Challenges in creating online courses and establishing a measure of their efficacy with an example of MIT’s course in Sustainable Energy

By

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SUBMITTED TO THE DEPARTMENT OF SYSTEM DESIGN AND MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN SYSTEM DESIGN AND MANAGEMENT AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2016

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Director, System Design and Management Program
To my father who inspires me to never give up

Finite to fail, but infinite to venture.
- Emily Dickinson
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Submitted to the System Design and Management Program on June 2016 in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering and Management.

Abstract

Online education is changing traditional models of learning both in schools and the outside world. The developments of learning pedagogies and technology have also contributed to the adoption of online education. Some benefits of online education include the immense variety of content, lower costs, higher flexibility, increased interaction, and easy access. This is substantiated by the steady rise in student enrollment and the use of either Massive Open Online Courses (MOOCs) or Blended Courses in institutions. However there is a growing sense of skepticism for MOOCs owing to low retention, and less control over the learning process and educators prefer the adoption of a blended model for their courses.

The report details the research conducted leading to the selection of a blended learning approach for MIT's course in "Sustainable Energy" (1.818/2.65/10.391/11.371/22.811/ESD.166). The report outlines a design blueprint to create an online course. Some of the components of design are identifying the key tenets of learning that improve knowledge and skill, suitable learning pedagogies to transform the content for an online course, understanding the system behaviors, and our experimentation with the edX Platform. This end goal of this report is to create a template to help instructors and designers in creating an online course on the edX platform.

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Acknowledgements

I am very grateful to many people who played an instrumental role in the writing of my thesis and also in my two-year journey at MIT.

I would like to thank my thesis advisor Dr. Michael W. Golay for his continued support, guidance and encouragement with my research. I really enjoyed working as his research assistant and I am grateful for the opportunity.

A big thanks to Mr. Pat Hale and the entire SDM staff for making my SDM experience so valuable, rewarding and memorable.

Special thanks to my MIT friends for being there whenever I needed encouragement and guidance.

I would like to thank my parents for their love and support. Wherever I may be, you will always be my strength.

Lastly, I would like to thank my husband for his love, understanding, and encouragement. I could not have done this without your faith in me. I will only say to you - "It's a magical world, Hobbes, ol' buddy...Let's go exploring!".
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Chapter 1: Introduction

Educators are increasingly using digital learning tools in their classrooms to improve learning outcomes. The rapid growth in technology and evidence of improved student engagement, class efficiency, and long-term learning has contributed to their adoption. These tools range from online platforms for delivery of course material, communication tools, discussion forums, and online assessments. This large selection also leads to difficulty in striking a balance between technology and in-person interactions. A popular approach to apply these tools is by using blended learning models and combining face-to-face interactions with online course components in an effective manner. The idea is to “flip” the classroom with students using a Massive Open Online Course platform like edX to learn the course material at home and then to use the classroom time to deepen learning through discussions and worked examples [1]. Blended learning instructions organize course content, supporting information, and activities to enhance learning beyond rote memorization, and ability to transfer knowledge and skills to new settings [2]. It is also important to note that just the use of technology does not create or improve blended learning courses. A report by the Bok Center for Teaching and Learning states that blended learning also requires personalizing the learning process, instructional design pedagogies, opportunities to discuss and collaborate, flexibility over the pace and direction of learning, and in-person support [3].

Research Questions: What learning considerations improve blended learning? What tools and techniques are needed to implement blended learning for MIT’s course in Sustainable Energy?

Objectives: The objective of this report is to develop a blueprint for creating student centric blended courses having improved learning outcomes. This includes identifying gaps in student needs and in existing approaches for imparting instructions, and the importance of developing long-term knowledge and skills that can be applied to real-world problems. The report includes following tasks to fulfill our objectives to:
• Identify the performance gaps in the present state of education and their effect on transfer of learning. Research selected learning pedagogies and how they improve learning outcomes.

• Develop System Dynamics models for understanding the effects of identified learning consideration on learning outcomes for residential online courses.

• Apply learning pedagogies, as per the results of system modeling, to develop course in Sustainable Energy.

• Provide conclusions and next steps to instructors and designers who are in the process of creating online courses.

1.1 Motivation for Blended Course

In this section, we review the motivation behind selecting blended learning for our course. “Online Report Card”, a survey by the Babson Survey Research Group tracking online education in the U.S. Higher Education, states the most institutions have decided against creating Massive Open Online Courses, or remain undecided. However enrollment of students in online courses rises year-on-year and institutions are also inclined to use technology to facilitate learning [4]. The need for online education from both end of the spectrum is therefore driving its growth.

Student Enrollment: The survey mentioned earlier states that there has been a steady year-on-year rise of 3.9% in student enrollment for online course. In 2014, there were approximately 2.8 million students enrolled exclusively for online education, while 2.9 million students were taking some of their courses online. The Figure 1 below depicts the number of students in the US who are at least taking one online course. The survey also states that 53% of the students taking these courses reside in the same state as their present institution. These numbers conclude that students across different types of institutions are interested in using online courses to supplement their education and there is a lot of scope for growth.
Educator Attitudes: Institutions have included online education as part of their long term strategy. However affinity for MOOCs has declined to only 63.3% in 2015 in part due to the faculty's acceptance of the legitimacy of these courses for credit. Their acceptance for blended learning has increase to 42.3% in 2015 as the learning outcomes for these courses have surpassed those of the face-to-face courses. This is confirmed by Figure 2, as it highlights that institutions with higher number of student enrollments in online courses tend to express that the learning outcomes for online education is either same or superior to face-to-face education.
Blended Learning: The Babson survey also states that institutions tend to be more favorable towards blended learning with 42.3% of academic leaders supporting it as compared to 39.2% in 2003. In 2015, blended learning was rated to be 56.6% as effective as face-to-face learning and 35.6% superior to face-to-face learning as shown in Figure 3.

![Learning Outcomes in Blended/Hybrid Course Compared to Face-to-Face: 2012 - 2015](image)

Figure 3: Learning outcomes in blended courses [4]

In summary, the data about student enrollments, educator inclinations, and the favourable outcomes of blended courses highlight the need and opportunities in developing blended courses.

1.2 Challenges

In this section we explore the challenges experience by educators in developing blended courses. The effective transfer of learning requires long-term development of knowledge and skills in student and must overcome technical, organizational, and instructional design challenges. The challenges highlighted are divided into two parts, generic challenges for blended learning and specific challenges for MIT's course in Sustainable Energy.

Blended Learning: An important challenge for blended education is the appropriate use of technology that is easy to use by students, has trained
support, and resists the urge to include the latest tools. The effective use of blended learning requires overcoming mental biases that it is not as effective as face-to-face education. It also requires adapting to new methods of students engagement and new roles and responsibilities. It requires constant attention to how content the content is being presented and what is the best medium to represent the content [5].

**Sustainable Energy:** An important challenge in creating a residential blended course is establishing the desired learning outcomes and the gaps in achieving them with available resources. Some of the learning outcomes identified for our course are to foster critical thinking, develop uncertainty awareness, and understand the global energy context. We have identified the following challenges and opportunities in achieving these outcomes:

- Overhauling the course curriculum to align the learning outcomes to the course content and assessments. This includes trimming excess content and eliminating redundancies, implementing a suitable instructional design pedagogy that works for our course in Sustainable Energy. This step is challenging as it requires expertise in instructional design methodologies for achieving the desired outcomes [6].
- Developing critical thinking abilities in student through course content, assessments, discussions, and collaborative projects. This will help students in applying their knowledge to real-world problems. The challenge here is selecting the appropriate tools and technology to promote critical thinking.
- Developing new avenues of student engagement through student-student and student-instructor interactions and building a self sustained community of learners.
- Establishing a custom framework to structure all the lectures according to the defined learning outcomes.
1.3 Research Scope

This report details the steps in the development of a residential blended course exclusively for MIT. Our work identifies good practices in creating blended courses and focus areas such as learning pedagogies, tools needed, and the types of technologies to implement the course. This report is written from the perspective of the educator, with an understanding of the needs of students. The implementation is on the edX [7]. The research does not include Massive Open Online Courses or any financial model for the distribution of the online content.

1.4 Research Plan

The work for the project reported here is divided into five parts, namely performing literature review for the identified resources, data collection to understand user needs, model based evaluation to verify the relevance of the data, design and implementation of the course, and finally the conclusion and next steps. The different stages of the plan as represent by the Figure 4 are as follows:

- Establish the problem statement and scope for the research.
- Explore available literature resources to identify suitable learning pedagogies for our course.
- Survey student and instructors to understand gaps in needs.
- Develop system dynamics models to represent system behaviours for learning considerations like instructional design, critical thinking, assessments, feedback, and interaction.
- Conclude and list next steps based on findings from previous steps.
1.5 Report Organization

The rest of the report is organized as follows:

- In chapter 2, we review existing literature related to: Instructional Design, Critical Thinking, Assessments, Interactions, and Feedback. We also review a case study on MIT’s course in electrical circuits that used best practices in these areas to improve its learning outcomes.

- In chapter 3, we use systems dynamics causal loop diagrams to understand educational system behaviors with respect to: Instructional Design, Critical Thinking, Assessments, Interactions, and Feedback. These models helped us to understand ways in which we can influence learning by improving on these parameters.

- In chapter 4, we show the design and development of MIT’s course in Sustainable Energy based on our learning from chapter 2 and 3. This chapter also includes the new framework developed for structured learning in our course.

- In chapter 5, we discuss the conclusions drawn from the research and discuss potential next steps.

"E-Learning doesn't just "happen"! It requires careful planning and implementation." - Anonymous
Chapter 2: Literature Review

2.1 Instructional Design

Instructional design is the process of improving the quality of instructions by understanding learning needs and desired learning outcomes. John Keller, the creator of the Attention Relevance Confidence Satisfaction (ARCS) model for motivational design, stated that learning is improved by incorporation motivation for students to learn [8]. If the learning material represents value to the student then it is easier for them to get involved in the learning process. Therefore instructional design aids in highlighting the motivation behind the learning. There are many methods for implementing instructional design. In sections 2.1.1 to 2.1.3 we review three instructional design pedagogies that are being used to create our custom design framework.

2.1.1 Bloom's Taxonomy

The "Taxonomy of Educational Objectives" often referred to as Bloom's Taxonomy, was published in 1956 by Benjamin Bloom, in collaboration with Max Englehart, Edward Furst, Walter Hill, and David Krathwohl. The framework is a collection of three hierarchical models that are used to define learning objectives for varying levels of complexity [9]. These model are called the cognitive domain which deals with knowledge; the affective domain which deals with skill; and the sensory domain which deals with human behaviors and attitudes [10]. This implies that a unit of learning is successful if students attain knowledge, skills, and behavior. These domains are described below in detail.

Cognitive Domain involves development of knowledge through the learning activity. The depth of knowledge through given instructions is divided into six levels, starting with a superficial memorization of the concept, up to the level where student apply their learning to create new ideas. These six levels are: remember, understand, apply, analyze, evaluate, and create as shown in Figure 5.
The levels after remember are referred to as skills, and can be used only after necessary knowledge has been acquired. These levels are described below [11]:

- **Remember** refers to the ability to retrieve knowledge from long-term memory. This comprises of recognizing the long-term memory learning and retrieve the identified knowledge to answer the question at hand.

- **Understand** refers to the ability to comprehend the meaning behind the learning material. This requires creating a similar example related to the learning material, summarizing the value behind the learning material, comparing information, and building a cause and effect system model.

- **Apply** refers to the ability to use acquired knowledge to solve either a familiar task or an unfamiliar task.

- **Analyze** refers to the ability to divide information into constituent components and determine the purpose, relationships, and contribution of each component.

- **Evaluate** refers to the ability to make judgment on validity of the information based on evidences and specified criterion.

- **Create** refers to the ability to place elements together to form an alternative hypothesis, new design process, or a new process or product.

**Affective Domain** is related to the emotional reactions people exhibit when presented with any learning material. The reaction of the students is measure across how they receive the information, how they respond to the material and participate in the process, the manner in which students attach value to the material, how students organize the learning, and how they are able to apply the learning.

**Psychomotor Domain** is related to the relationship between acquiring new learning and its physical use in every day activities. It focuses on development of behavior and skills in using sensory stimulations to inform motor activity. This
could be the development of a person's response to a given situation, the ability to learn by following an example, ability to learn the intricacies of the material, simultaneously perform complex actions, and develop creative use of the newly acquired skills.

Our research concludes that Bloom's Taxonomy is a valuable tool for creating assessments. The six levels of learning can be easily rendered into rubrics for evaluation and grading. The three domains work well in ensuring long-term learning through the designed assessments.

2.1.2 Understanding by Design

The "Understanding by Design" framework is based on the concept of backward design, where learning outcomes guide the process of designing instructions [12]. The focus is on identifying the knowledge and skills each student will benefit at the end of the instruction. The framework provides a guideline to enable teachers plan the curriculum based on learning outcomes and relevant assessments but does not restrict the method in which it is applied. The focus is on development of student's ability to apply their knowledge and skills to new problems. The indicators of learning across the six facets of learning namely the power to explain, interpret, apply, shift perspective, empathize, and self-assess can determine success of the instructions. The framework is usually organized into three stages: identifying the desired results, listing evidence of learning, and laying down a plan to accomplish them. This not only helps in identifying the purpose and priorities of the lecture but also eliminates parts that are already covered or no longer needed. The framework also eases the task of verifying that all learning objectives are met by the plan designed for the lecture. The framework employs continual improvement through reviews and feedback discussion to enhance quality and effectiveness. The benefits of this framework are bi-directional with respect to improving the teaching standards as well as student learning. The framework has been divided into three parts identifying desired results, the creating required evidence in the form of assessments, and then developing a learning plan to create a blueprint of what content and
activities will be included in the design. These three stages as shown in Figure 6 are discussed in detail below:

Stage 1 — Identify Desired Results
This stage of the framework helps instructors to identify the enduring knowledge that students will gain, and what they will be able to do with the skills developed as a result of this learning [13]. The realization of the “big ideas” helps the instructors to establish the learning outcomes at an early stage and it also serves as a checkpoint to measure the success of the design process. Some of the key questions to ask at this stage are:

- What are the long-term learning transfer goals and the “big ideas”?
- What knowledge and skills the students will acquire?
- What enduring understanding of the topic is desired for students?
- What essential questions will be explored to utilize the learning behind the big ideas?

This helps in measuring the goals against established content standards and existing course content. The course content is prioritized as well as tailored to fit the revised curriculum. An important aspect of this process is to review the length of the content and trim extra material that cannot be covered during the length of the course. This phase shifts the focus on what students need to know to apply these concepts in real life and engage in critical thinking of the topic being covered. The following template developed by Jay McTighe and Grant Wiggins [13] is used for capturing the stage one information:
Table 1: Identify Desired Results

<table>
<thead>
<tr>
<th>Stage 1: Identify Desired Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transfer</strong></td>
</tr>
<tr>
<td><strong>Established Goals:</strong></td>
</tr>
<tr>
<td>What are the learning goals that this unit of learning will address? These goals include:</td>
</tr>
<tr>
<td>- Content Standards</td>
</tr>
<tr>
<td>- Course or program objective</td>
</tr>
<tr>
<td>- Learning outcomes</td>
</tr>
<tr>
<td><strong>Meaning</strong></td>
</tr>
<tr>
<td><strong>Understandings:</strong></td>
</tr>
<tr>
<td>Includes information that students will understand as a result of this unit of learning. The main concepts captured here are:</td>
</tr>
<tr>
<td>- What are the big ideas?</td>
</tr>
<tr>
<td>- What specific understandings about them are desired?</td>
</tr>
<tr>
<td>- What misunderstandings are predictable?</td>
</tr>
<tr>
<td><strong>Essential Questions:</strong></td>
</tr>
<tr>
<td>Includes thought provoking questions that foster inquiry, understanding, and transfer of learning?</td>
</tr>
<tr>
<td><strong>Acquisition</strong></td>
</tr>
<tr>
<td>Includes information that students will know as a result of this unit of learning. What key knowledge and skills do students acquire as a result of this unit?</td>
</tr>
<tr>
<td>Includes information what students will be skilled at as a result of this unit of learning. What should they be able to do as a result of such knowledge and skills?</td>
</tr>
</tbody>
</table>

Stage 2—Determine Assessment Evidence
This stage of the framework deals with establishing reasonable evidence of students’ understanding and proficiency. This requires understanding what is an acceptable measure of learning, and how will students benefit from it. The challenge is to monitor if the students have achieved these goals. The designer/instructor have to always be careful in ensuring that the goals of step
one are followed as performance tasks and assessments in stage two. Some of the key questions to ask at this stage are:

- How will the instructor know that the students have achieved the desired learning?
- What evidences or assessments are needed to measure the transfer of learning?
- How will the students demonstrate the transfer of their learning to new situations?
- How will we evaluate the students in a fair and consistent manner?

This stage consists of two types of assessments: performance tasks and other evidence. The performance tasks require students to apply their recently acquired learning to new and unique situations in order to assess their knowledge and skills and measure the quality of the transfer of learning. It is not necessary to use all six facets of learning in a performance task but to select the most appropriate based on the learning outcome. Typically the performance tasks are not assessed on a daily basis, instead they are a culmination for a unit of learning in assignments. For example if the goal is to understand public perception to nuclear power then the important skills to assess will be to apply, shift perspective, and empathize. The daily lessons will build on each of these based on textual knowledge and practical skills for students to critically assess the problem at hand. In addition stage two also includes other evidences like quizzes, examinations, weekly assessments to measure their learning and how they can apply them. This helps in reiterating lessons students need to do to perform performance tasks and also ensure that we are able to assess all aspects of learning. The following template by Jay McTighe and Grant Wiggins [13] is used to capture stage two:
Stage 2 - Assessment Evidence

<table>
<thead>
<tr>
<th>Performance Tasks:</th>
<th>Other Evidence:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Through what authentic performance task(s) will students demonstrate the desired understandings?</td>
<td>• Through what other evidence (e.g. quizzes, tests, academic prompts, observations, homework, journals, etc.) will students demonstrate achievement of the desired results?</td>
</tr>
<tr>
<td>• By what criteria will “performances of understanding” be judged?</td>
<td>• How will students reflect upon and self-assess learning?</td>
</tr>
</tbody>
</table>

Stage 3—Plan Learning Experiences and Instruction

This stage of the framework deals with planning the course curriculum in order to meet the learning transfer goals and incorporating the relevant assessments to measure learning. The previous stages capture what needs to be captured in and outside the classroom and this stage captures how those objective will be translated and accomplished. Some of the key questions to ask at this stage are:

- What activities, experiences, and lessons will lead to achievement of the desired results and success at the assessments?
- How will the learning plan help students acquire the intended knowledge and skills. How will they apply them autonomously?
- How will the unit be sequenced and differentiated to optimize achievement for all learners?

It is important for teachers to focus on transfer of learning so that students can apply it to solve real-world problems. This requires careful presentation of lessons in a sequence that aligns with stage one and two, regular reiteration, hands-on activities, inter-class participation in discussions, and regular feedback to ensure that students are benefiting from the lessons. The following template by Jay McTighe and Grant Wiggins [13] is used to capture stage three:
2.1.3 First Principles of Instruction

The task-centered approach was developed by David Merrill to synthesize the key principles in his first principles of instruction. This principle describes a cyclic execution of instructional phases of activation, demonstration, application, and integration in the context of real-world tasks as shown in Figure 7. The components are described in detail as follows [14):

Demonstration Principle: Learning is facilitated when students observe a demonstration related to the topic and having the same learning outcome [15]. These demonstrations give students an opportunity to apply their skills to other tasks with varying level of support. Types of demonstrations include examples, procedure simulations, visualizations, and system modeling. These examples should be consistent with the topic content, must enhance the learning experience, and should employ guidance techniques to help students.

Application Principle: Learning is promoted when it is applied to tasks that are related to the topic and having the same learning outcome. Constant feedback and iteration are an important part of the application principle to reiterate the learning outcomes. The amount of guidance should be decreased as the skills of the students improve.

Activation Principle: The activation principle works on the concept of stimulating previous knowledge on which future knowledge is built. This requires careful selection of instances where prior learning aligns with the current topic and students can easily recall and apply it.

Integration Principle: Learning is enhanced when students integrate their
newly acquired knowledge and skills with the real world. The integration process requires adaptation of learning and collaboration often facilitates this.

![Diagram: Components of task-centered learning]

**Figure 7: Components of task-centered learning**

Conclusion: The first principle of learning is similar to Bloom's Taxonomy in identifying the different levels of learning and how it can be facilitated. We will not be using the first principle of instruction in our course because Bloom's taxonomy provides a more robust approach to defining rubrics.

2.1.4 A Task-Centered Instructional Strategy

The task-centered strategy is related to problem-based approach where instructions are given in the context of real-world tasks. Research shows that when students learn new skills in the context of real-world tasks that they are more motivated to learn, they can easily retrieve the information, and easily apply them to new settings. In a traditional classroom the lecture is organized into sequential topics, students are tested on this learning through assignments, quizzes, or application to a final project while in a task-centered approach the following activities are performed [14]:

1. Students are given a new real-world task
2. Instructions are given to solve each of the underlying component and the task as a whole. They are also taught how their learning is applied in this task.
3. Then they are presented with a second task.
4. They are now asked to use their new knowledge and skills to complete as
much of this task as they possibly can.
5. They are then taught additional instructions related to the missing information needed to solve the second task.
6. This sequence of steps is repeated for a third or forth task. For each task they are given additional instructions related to the missing information needed to solve that task.
7. The students are assessed on their ability to independently complete new tasks.

Task-centered instructional design can be achieved by using a four-component approach as stated by Prof. Sanjoy Mahajan, MIT's Director of Digital Residential Learning and Visiting Associate Professor of EECS [16]. The framework considers the selection of relevant tasks (i.e. problems, procedures, content etc.) that target the development of the same set of knowledge and skills abilities. The following are the various component of this design approach as shown in Figure 8.

**Task Class**: The task class is a collection of tasks represented as circles. The transfer of learning occurs by performing these tasks with varying levels of support from the instructor, as indicated by the blue shading in each circle. Usually the initial tasks require more guidance from the instructor. The guidance levels decrease as students acquire the necessary skills to solve this class of problems on their own or as a group. The end stage of any task class is to enable students to apply their skills to new problems.

**Supportive Information**: This related to information that helps student perform non-routine portion of the tasks. These include traditional lecture material, textbook, reference materials, articles, websites, discussion, and feedback. This set of information is introduced to the students before the first task and is available on demand.

**Procedural Information**: The information related to performing a specific procedure to develop specific skills fall in this category. These tasks are often
recurring and exactly the same in any context. This information is made available just in time when it is needed by students to reduce their cognitive load.

Part-Task Practice: These specific practice tasks are created in cases where the actual tasks do not provide enough learning on specific knowledge and skills that are imperative for that topic. The repeated practice sessions help automate these essential tasks and reduce the complexity of individual tasks.

Conclusion: Our research concludes that task-centered design is best suited to demonstrating solved examples in a lecture. A sample of the design is given in Appendix 6.3.

2.2 Critical Thinking

Critical thinking is the ability to gather information, interpret its value, and raise pertinent questions to establish its reliability and validity. The process focuses on evaluating the value behind the information presented. In more detail Michael Scriven and Richard Paul for the National Council for Excellence in Critical Thinking Instruction, define Critical thinking as: “Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or
communication, as a guide to belief and action. In its exemplary form, it is based on universal intellectual values that transcend subject matter divisions: clarity, accuracy, precision, consistency, relevance, sound evidence, good reasons, depth, breadth, and fairness” [17]. The rubric for measuring the skill in applying critical thinking is achieved by understanding the metrics to measure the quality of the analysis, with each metric including some specified element, as shown in Figure 9 below.

Figure 9: Critical Thinking [18]

Sections 2.2.1 to 2.2.3 discuss the components of critical thinking in detail.

2.2.1 The Metrics for Critical Thinking

The metrics of measurement of critical thinking are based on universal intellectual standards that are qualities needed by individuals to display critical thinking. Critical thinking can be activated through discussions and assessments, which require students to apply their knowledge and skill. The following are some of the skills needed to improve critical thinking [19]:

Clarity: Clarity of thought is a necessary ability for critical thinking because the gateway standard. If a statement is unclear, we cannot determine whether it is accurate or relevant. In fact, we cannot tell anything about it because we don’t yet know what it is saying.

Accuracy: A statement can be clear but not accurate, as in "Most dogs are over
300 pounds in weight."

**Precision:** A statement can be both clear and accurate, but not precise, as in "Jack is overweight." (We don't know how overweight Jack is, one pound or 500 pounds.)

**Relevance:** A statement can be clear, accurate, and precise, but not relevant to the question at issue. For example, students often think that the amount of effort they put into a course should be used in raising their grade in a course. Often, however, the "effort" does not measure the quality of student learning; and when this is so, effort is irrelevant to their appropriate grade.

**Depth:** A statement can be clear, accurate, precise, and relevant, but superficial (that is, lack depth). For example, the statement, "Just say No!" which is often used to discourage children and teens from using drugs, is clear, accurate, precise, and relevant. Nevertheless, it lacks depth because it treats an extremely complex issue, the pervasive problem of drug use among young people, superficially. It fails to deal with the complexities of the issue.

**Breadth:** A line of reasoning may be clear accurate, precise, relevant, and deep, but lack breadth (as in an argument from either the conservative or liberal standpoint which gets deeply into an issue, but only recognizes the insights of one side of the question.)

**Logic:** When we think, we bring a variety of thoughts together into some order. When the combinations of thoughts are mutually supporting and make sense in combination, the thinking is "logical." When the combination is not mutually supporting, is contradictory in some sense or does not "make sense," the combination is not logical.

**Fairness:** Human think is often biased in the direction of the thinker - in what are the perceived interests of the thinker. Humans do not naturally consider the rights and needs of others on the same plane with their own rights and
needs. We therefore must actively work to make sure we are applying the intellectual standard of fairness to our thinking. Since we naturally see ourselves as fair even when we are unfair, this can be very difficult. A commitment to fair mindedness is a starting place.

2.2.2 Elements of Critical Thinking

Critical thinking abilities are improved by identifying the "parts" of thinking, and be able to assess use of these parts of thinking. The question can then be raised, "What appropriate intellectual standards do students need to assess the 'parts' of their thinking?" There are many standards appropriate to the assessment of thinking as it might occur in this or that context, but some standards are virtually universal (that is, applicable to all thinking): clarity, precision, accuracy, relevance, depth, breadth, and logic.

The elements of critical thinking as stated by Richard Paul and Linda Elder are guidelines for students as they work toward developing their reasoning abilities. They identify the following aspects of reasoning [20]:

- All reasoning has a purpose
- All reasoning is an attempt to solve some problem
- All reasoning is based on assumptions
- All reasoning is done from some point of view
- All reasoning is based on data, evidence, and information
- All reasoning is expressed through, and shaped by, concepts and ideas
- All reasoning contains inferences or interpretations by which we draw conclusions and give meaning to data
- All reasoning leads somewhere or has implications and consequences

2.3 Assessments

Assessments are an important part of instructional design because they represent what students should be able to do at the end of a lecture or course. They are an invaluable way to measure the extent of learning transfer, student
performance, and the effectiveness of the teaching practices as shown in Figure 10. The goal of assessments is to simplify measuring performance and grading [21].

**Figure 10: The Learning Cycle [21]**

Formative Assessments: These assessments reflect student’s progress and provide constant feedback to both the student and the instructor. These can be used by students to identify their areas of weakness and the instructors to identify portions of the curriculum that are difficult for individual students and collectively for the entire class. These usually carry less value with respect to the student’s overall performance grade.

Summative Assessments: These assessments are meant to test student learning at the end of a unit or course. These usually carry high value with respect to the student’s overall performance grade for example: examinations, final projects or paper. The formative assessments help build student learning and confidence for the subsequent summative assessments.

Rubrics: They are used to define the performance expectations that students must fulfill. This helps instructors to know exactly what they are looking for in student responses and students in knowing the weighted importance of each facet of learning. Rubrics are composed of four basic parts:
- Task description - Example: the assignment questions
- Scale of measurement - Example: levels of achievement, possibly in the form of grades. Scales typically range from 3 to 5 levels.
- Dimensions of the assignment (a breakdown of the skills/knowledge involved in the assignment)
- Descriptions of what constitutes each level of performance (specific feedback)

![Diagram of rubric layout](image)

Here are some of the benefits of using assessment expectations in the form of rubrics:

- Rubrics provide timely feedback because grading can be done more quickly. Since students often make similar mistakes on assignments, incorporating predictable notes into the “descriptions of dimensions” portion of a rubric can simplify grading into circling or checking off all comments that apply to each specific student.
- Rubrics prepare students to use detailed feedback. In the rubric, the highest level descriptions of the dimensions are the highest level of achievement possible, whereas the remaining levels, circled or checked off, are typed versions of the notes/comments an instructor regularly writes on student work explaining how and where the student failed to meet that highest level. Thus, in using a rubric the
student obtains details on how and where the assignment did or did not achieve its goal, and even suggestions (in the form of the higher level descriptions) as to how it might have been done better.

- Rubrics encourage critical thinking
  Because of the rubric format; students may notice for themselves the patterns of recurring problems or ongoing improvement in their work.
- Rubrics facilitate communication with others
  TAs, counselors/tutors, colleagues, etc. can benefit from the information contained in the rubric; i.e., it provides information to help all involved in a student's learning process.
- Rubrics help faculty refine their teaching skills
  Rubrics showing a student's continuing improvement or weaknesses over time, or rubrics showing student development over time, can provide a clearer view of teaching blind spots, omissions, and strengths.
- Rubrics help level the playing field
  To aid first-generation or non-native speakers of English, rubrics can act as a translation device to help students understand what teachers are talking about.

2.4 Interaction

The Classroom Assessment Scoring System (CLASS), developed at the University of Virginia's Center for Advanced Study of Teaching and Learning, helps educators view classrooms through a common lens and discuss them using a common language, providing support for improving the quality of teacher-student interactions and, ultimately, student learning. The CLASS describes ten dimensions of teaching that are linked to student achievement and social development. Each of the ten dimensions falls into one of three broad categories: emotional support, classroom organization, and instructional support as described below in detail [23].
Emotional support refers to the ways teachers help children develop warm, supportive relationships, experience enjoyment and excitement about learning, feel comfortable in the classroom, and experience appropriate levels of autonomy or independence. This includes:

- Positive climate — the enjoyment and emotional connection that teachers have with students, as well as the nature of peer interactions;
- Negative climate — the level of expressed negativity such as anger, hostility or aggression exhibited by teachers and/or students in the classroom;
- Teacher sensitivity — teachers' responsiveness to students' academic and emotional needs; and
- Regard for student perspectives — the degree to which teachers' interactions with students and classroom activities place an emphasis on students' interests, motivations, and points of view.

Classroom organization refers to the ways teachers help children develop skills to regulate their own behavior, get the most learning out of each school day, and maintain interest in learning activities. This includes:

- Behavior management — how well teachers monitor, prevent, and redirect misbehavior;
- Productivity — how well the classroom runs with respect to routines, how well students understand the routine, and the degree to which teachers provide activities and directions so that maximum time can be spent in learning activities; and
- Instructional learning formats — how teachers engage students in activities and facilitates activities so that learning opportunities are maximized.

Instructional support refers to the ways in which teachers effectively support students' cognitive development and language growth. This includes:

- Concept development — how teachers use instructional discussions and activities to promote students' higher-order thinking skills and cognition in contrast to a focus on rote instruction;
• Quality of feedback — how teachers expand participation and learning through feedback to students; and
• Language modeling — the extent to which teachers stimulate, facilitate, and encourage students’ language use.

2.5 Feedback
The feedback that students provide for the course content, teaching methods, and assessments on an ongoing basis and end-of-semester evaluations are valuable in improving learning effectiveness. Some of the benefits of collecting feedback are related to increasing student engagement [24]. By finding out what learning activities students like the most and least about your class, will make you better at designing lessons that really engage them. Learning more about each student’s experience in your class can go a long way toward improving the relationship you have with them. And that can go a long way toward improving classroom management. Grades and test scores don’t tell the whole story. A student who is getting excellent grades might be accomplishing that only with tremendous effort and hours of work at home. Conversely, a student who consistently turns in mediocre work might actually want more of a challenge. By asking students how well the work fits their abilities, you can adjust your instruction to better meet their needs. When students are given an opportunity to share their feelings about your class, they might also include information about students who harass them. If a student says he hates coming to your class every day, the reason might have more to do with his peers than with anything you’re doing. Gathering student feedback is the first step toward discovering the things you don’t know about your own classroom [25]. Many school systems are implementing teacher evaluation programs that include student feedback. And at the college level, student evaluations can significantly impact a professor’s promotion and tenure. Instead of waiting for the “official” forms to be distributed to students, get ahead of the curve by asking for similar feedback early, while there’s still time to correct the problem.
2.6 Residential MITx Platform

The residential MITx platform is a learning management system based on open edX to create online content for undergraduate and graduate courses at MIT. The platform offers tools for creating videos, text, assessments, interactive elements, and sophisticated automatic grading. The platform also provides rapid feedback, adaptive hinting, simulations and visualizations, active reading/discussions, and flexibility in course delivery [26]. Some of the important features of the platform are discussed below:

2.6.1 Screen Layout

The layout of any unit of learning in edX is arranged as per Figure 12. The course outline is the container for your entire course content. The outline contains may contain one or more sections. Each course sections are at the top level of your course and typically represent a time period. A section contains one or more subsections. These course subsections usually represent a topic or other organizing principle. A subsection may contain one or more units. The course units are lessons in a subsection that students view as single pages. A unit contains one or more components. Course components are objects within units that contain your actual course content [27].

![Figure 12: edX Layout](image-url)
2.6.2 Assessments

The edX platform provides the following tools to create common types of graded and ungraded assessments in the online course [28].

### Table 4: edX Image-based Exercises and Tools

<table>
<thead>
<tr>
<th>Problem Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annotation Problem</td>
<td>Annotation problems ask learners to respond to questions about a specific block of text. The question appears above the text when the learner moves the cursor to the highlighted text so that learners can think about the question as they read.</td>
</tr>
<tr>
<td>Calculator Tool</td>
<td>The calculator tool is available for every course through the course advance settings. When the calculator tool is enabled, it appears on every unit page. Learners can enter input that includes Greek letters, trigonometric functions, and scientific or e notation in addition to common operators.</td>
</tr>
<tr>
<td>Completion Tool</td>
<td>This tool allows learners to mark sections of course content as completed. It helps learners to track their progress through sections of the course (including for ungraded activities such as reading text, watching video, or participating in course discussions), and gives them a way to indicate to both themselves and course staff that they completed the required activities.</td>
</tr>
<tr>
<td>Conditional Module</td>
<td>You can create a conditional module to control versions of content that groups of learners see. For example, learners who answer “Yes” to a poll question then see a different block of text from the learners who answer “No” to that question.</td>
</tr>
<tr>
<td>Custom JavaScript Problem</td>
<td>Custom JavaScript display and grading problems (also called custom JavaScript problems or JS input problems) allow you to create a custom problem or tool that uses JavaScript and then add the problem or tool directly into Studio.</td>
</tr>
<tr>
<td>External Grader</td>
<td>An external grader is a service that receives learner responses</td>
</tr>
</tbody>
</table>
to a problem, processes those responses, and returns feedback and a problem grade to the edX platform. You build and deploy an external grader separately from the edX platform. An external grader is particularly useful for software programming courses where learners are asked to submit complex code.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Calendar Tool</td>
<td>You can embed a Google calendar in your course so that learners see the calendar in the course body. You can use a Google calendar to share quiz dates, office hours, or other schedules of interest to learners.</td>
</tr>
<tr>
<td>Google Drive Files Tool</td>
<td>You can embed a Google Drive file, such as a document, spreadsheet, or image, in your course so that learners see the file in the course body.</td>
</tr>
<tr>
<td>Google Instant Hangout Tool</td>
<td>You can add the ability for learners to participate in instant hangouts directly from your course. With instant hangouts, learners can interact through live video and voice, share screens and watch videos together, and collaborate on documents.</td>
</tr>
<tr>
<td>Iframe Tool</td>
<td>With the iframe tool, you can integrate ungraded exercises and tools from any Internet site into an HTML component in your course.</td>
</tr>
<tr>
<td>LTI Component</td>
<td>LTI components allow you to add an external learning application or non-PDF textbook to Studio.</td>
</tr>
<tr>
<td>Office Mix Tool</td>
<td>You can embed interactive lessons created from PowerPoint files so that learners can experience them directly in the course body.</td>
</tr>
<tr>
<td>Open Response Assessments</td>
<td>In open response assessments, learners receive feedback on written responses of varying lengths as well as image files that the learners upload. Open response assessments include self-assessment and peer assessment.</td>
</tr>
<tr>
<td>Oppia</td>
<td>You can embed Oppia explorations in your course so that</td>
</tr>
<tr>
<td>Tool</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Exploration Tool</td>
<td>Learners can interact with them directly in the course body.</td>
</tr>
<tr>
<td>Peer Instruction Tool</td>
<td>This tool offers the experience of the Peer Instruction learning system within your online course.</td>
</tr>
<tr>
<td>Poll Tool</td>
<td>You can include polls in your course to gather learners' opinions on various questions. You can use the Poll Tool in Studio.</td>
</tr>
<tr>
<td>Poll Tool for OLX</td>
<td>You can run polls in your course so that your learners can share opinions on different questions. You can only add this type of poll to a course by using OLX. Support for this tool in Studio is not available. For more information, see the edX Open Learning XML Guide.</td>
</tr>
<tr>
<td>Problem with Adaptive Hint</td>
<td>A problem with an adaptive hint evaluates a learner's response, and then gives the learner feedback or a hint based on that response so that the learner is more likely to answer correctly on the next attempt. These problems can be text input or multiple-choice problems.</td>
</tr>
<tr>
<td>Problem Written in LaTeX</td>
<td>If you have a problem that is already written in LaTeX, you can use this problem type to easily convert your code into XML.</td>
</tr>
<tr>
<td>Qualtrics Survey Tool</td>
<td>You can import surveys that you have created in Qualtrics. The survey appears inside an iframe in your course.</td>
</tr>
<tr>
<td>Recommender Tool</td>
<td>RecommenderXBlock can hold a list of resources for misconception remediation, additional reading, and so on. This tool allows the course team and learners to work together to maintain the list of resources. For example, team members and learners can suggest new resources, vote for useful ones, or flag abuse and spam.</td>
</tr>
<tr>
<td>Survey Tool</td>
<td>You can include surveys in your course to collect learner responses to multiple questions. You can use the survey tool in Studio.</td>
</tr>
<tr>
<td>Text Input Problem</td>
<td>In text input problems, learners enter text into a response field. The response can include numbers, letters, and special</td>
</tr>
</tbody>
</table>
characters such as punctuation marks.

<table>
<thead>
<tr>
<th>Word Cloud Tool</th>
<th>Word clouds arrange text that learners enter - for example, in response to a question - into a colorful graphic that learners can see.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Write-Your-Own-Grader Problem</td>
<td>In custom Python-evaluated input (also called “write-your-own-grader”) problems, the grader uses a Python script that you create and embed in the problem to evaluates a learner’s response or provide hints. These problems can be any type.</td>
</tr>
</tbody>
</table>

2.6.3 Open Response Assessment

Open Response Assessments allow the course team to assign questions that might not have definite answers, such as text responses or short essays. Learners submit responses to questions, and then each learner and the learner’s peers compare the responses to a rubric that you create. You can also allow learners to upload an image, a pdf file, or another file of a type that you specify, to accompany their text responses [29]. Open response assessments can include self-assessments, peer assessments, and staff assessments. In self-assessments, learners compare their own responses to a rubric that you create. In peer assessments, learners compare their peers’ responses to the rubric. In staff assessments, a member of the course team evaluates the learner’s responses using the rubric. In open response assessments, learners usually only see their own responses and any peer responses they assess. You can also allow learners to see the top scoring responses that their peers have submitted.

The following elements are included to create an open response assessment assignment:

**Prompt/Question:** One or more prompts that you want your learners to answer, appears near the top of the page, followed by a field where the learner enters a response. You can require your learners to enter text as a response, or
you can allow your learners to both enter text and upload another file, such as an image or document.

Figure 13: The Question Prompt

Rubric: Assessment rubric to grade all the prompts in the assessment. The same rubric is used for all the types of assessments (self, peer, or staff). The person performing the assessment sees the rubric when she begins grading, and compares the submitted response to the rubric.
Videos are one of the most important assets of an online course. Making course videos available to learners who might be located all over the world, and who are accessing course content with different devices and Internet connectivity constraints, can be a complex undertaking.

- Videos need to be available from more than one host site and be able to be played in locations around the world.
- Videos need to be available in several different formats to play on both desktop computers and smartphones.
- Videos need to be available for both download and streaming to be watchable by learners with slow or intermittent Internet connections.

To help course teams at partner institutions meet the challenge of delivering high quality video experiences to as many learners as possible for edx.org courses, edX offers media encoding and hosting services to partners to address multiple playback and download needs.

Figure 14: Sample Rubric for Assessment
Chapter 3: System Dynamics Modeling

The system model developed for this analysis examines the effect of good educational practices on learning effectiveness. The idea is to identify the external parameters that impact transfer of learning and then understand the network effects that encourage strengthening of these parameters. We will be referring to these parameters as the core model variables. The two-fold approach is used to highlight what practices instructors can employ in creating online courses and how they can improve these practices by understanding their learning environment. The below Figure 15 depicts the overall positive affect of instructional design, critical thinking, assessments, interaction, and feedback on the rate of transfer of learning for students.

- **Instructional Design Paradigms** is an aggregation of all the best practices related to instructional strategies and activities that can be incorporated in and outside the classroom to facilitate learning.

- **Critical Thinking** is related to the development of critical thinking abilities in students and how they are able to apply this skill to the learning process.

- **Assessments** are important in judging the performance of the students and the quality of the instructions by the instructor. They are also a great motivator for the educational institutions, instructors, and students as they provide a quick and easy result of the learning process.

- **Interaction** in the form of content consumption, discussions, and group activities for the following relationships: student-content, instructor-student, and student-student.
• **Feedback** collected from students and instructors at various points of the course regarding the learning material, teaching practices, assessments, and course management.

The scope of this analysis includes creation of a causal loop diagram to represent the system behavior. The model establishes the feedback loops for the core model variables, but it does not perform the sensitivity analysis, as it is very difficult to quantify some of these parameters. For each of the core model variables the following activities have been performed:

• Establishing a metric for measurement of the intrinsic value of these variables
• A system dynamics causal loop diagram depicting the feedback loops. The models capture the effect of the core model variables on learning outcomes and the effects of the learning environment on the core model variables.
• Critical analysis of the model and the implications for online courses.

Sections 3.1 - 3.5 use System Dynamics causal loop diagrams to represent the variables in the system and their affect on the overall system behavior. A positive link between variables implies a positive relation. In this analysis we have considered the reinforcing affect of instructional design, critical thinking, assessments, interaction, and feedback of learning effectiveness.

**3.1 Instructional Design**

The metrics to measure the effectiveness of instructional design are based upon its ability to enhance the learning experience. The process of creating the instructional design is improved by setting expectations for instructors and students right at the beginning of the planning phase [30]. Some of the areas to consider setting expectations for are timelines, participation, assessment rubrics, and code of conduct. This helps in setting personal goals and boosts motivation and participation. It is also important to remove distractions in the content in the form of irrelevant and redundant information and in the classroom by setting up
a clear plan of implementing the instructional design. The careful planning and scoping of the design helps in accomplishing the learning outcomes. Another consideration is to pace the content to allow for self-exploration and discussions [31]. Developing a collaborative culture in the classroom to improve learning and communication. This creates a community of learners who are able to leverage the benefits beyond the classroom. These metrics along with the steps in the Analysis Design Development Implementation Evaluation (ADDIE) approach help in defining the parameters that affect instructional design. This part of the analysis concludes that if we are able to manage these steps then we can create good design.

System Dynamics Model:
This part of our analysis consists of a system dynamics model represented in Figure 16. It depicts the impact of instructional design on learning effectiveness.
Conclusion:
The system behavior of the above model is explained by understanding that using effective instructional design in the course directly affects the alignment of goals to assessments and the quality of instructions. These in turn influence student participation, performance grades, and instructor enthusiasm. Therefore we can conclude that the use of instructional design has a positive influence on learning effectiveness.

3.2 Critical Thinking

Expectations: The main purpose behind development of critical thinking abilities is to be able to identify the goals and purposes of the information presented. This requires gathering relevant information and determining the assumptions behind the information. Disciplined critical thinkers are able to think through the implications of the decisions with accurate inferences and interpretations. They also have the ability to consider alternate ways of looking at problems and situations. These skills help us to quantify critical analysis elements.

System Dynamics Model:
This part of our analysis consists of a system dynamics model represented in Figure 17. It depicts the impact of critical thinking on learning effectiveness.
Conclusion:
The system behavior of the above model is explained by understanding that the development of critical thinking abilities in the course directly affects the development of new ideas, discussions, and formulation of questions. These in turn influence student and instructor motivation, achievement of learning outcomes, and performance grades. Therefore we can conclude that the development of critical thinking abilities has a positive influence on learning effectiveness.

3.3 Assessments

The measure of quality for assessments is based on reliability and validity. Reliability refers to the extent to which trial tests of a method with representative student populations fairly and consistently assess the expected traits or dimensions of student learning within the construct of that method. Validity refers to the extent to which a method prompts students to represent the dimensions of learning desired. A valid method enables direct and accurate assessment of the learning described in outcome statements. It is also important
to note that the process of writing relevant assessments requires focusing on student behavior, appropriate assessments methods, and relevant performance criteria. If these three parameters are reliable and valid then it ensures quality assessments.

System Dynamics Model:
This part of our analysis consists of a system dynamics model represented in Figure 18. It depicts the impact of relevant assessments on learning effectiveness.

![Figure 18: System Behavior for Assessments](image)

Conclusion:
The system behavior of the above model is explained by understanding that using effective and relevant assessments in the course directly affects the alignment of learning objectives and assessments and improves the quality of instructions. These in turn influence student participation, performance grades,
and increased enthusiasm. Therefore we can conclude that the uses of relevant assessments have a positive influence on learning effectiveness.

3.4 Interaction

The Classroom Assessment Scoring System (CLASS), developed at the University of Virginia's Center for Advanced Study of Teaching and Learning, helps educators view classrooms through a common lens and discuss them using a common language, providing support for improving the quality of teacher-student interactions and, ultimately, student learning [23]. The ten dimension of CLASS framework discussed in section 2.4 are important student achievement and social development. In this section we will use emotional support, classroom organization, and instructional support to improve the overall interaction in and outside the classroom.

System Dynamics Model:
This part of our analysis consists of a system dynamics model represented in Figure 19. It depicts the impact of interaction on learning effectiveness.
Conclusion:
The system behavior of the above model is explained by understanding that using effective interaction mechanism in the course directly affects the transfer of learning through feedback, student participation, discussions, and achievement of learning outcomes. These in turn influence performance grades, and instructor enthusiasm. Therefore we can conclude that the use of improved interaction has a positive influence on learning effectiveness.

3.5 Feedback

Effective feedback collects information about student engagement, class discipline, personalization based on preferences, achievement of learning outcomes, and the quality/difficulty of the course material. It measures the set learning objectives with the actions taken to achieve them and determine if
students and instructors are on track. Feedback should be tangible, actionable, user-friendly, timely, continuous, and consistent.

System Dynamics Model:
This part of our analysis consists of a system dynamics model represented in Figure 20. It depicts the impact of feedback on learning effectiveness.

![System Dynamics Model Diagram](image)

Figure 20: System Behavior of Feedback

Conclusion:
The system behavior of the above model is explained by understanding that by using effective feedback in the course directly affects the achievement of learning outcomes and student participation. These in turn influence performance grades and instructor enthusiasm. Therefore we can conclude that the use of feedback has a positive influence on transfer of learning.
Chapter 4: MIT's course in Sustainable Energy

The report documents the activities performed in creating the online course for MIT's Sustainable Energy (1.818/2.65/10.391/11.371/22.811/ESD.166) in the MITX platform. The scope of this course is limited for use within MIT and is not aimed for the MOOCs market.

4.1 Student Survey

We started our research for this project by interviewing the students for Fall 2015. The objective of the survey was to understand their expectations and the gaps in fulfilling them. We also wanted to identify the most appealing and least appealing aspects of the course. In appendix 6.1 I have listed down the survey questions and responses. Some of the important findings from the survey were as follows:

- We observed that most of the students had similar expectations where they wanted to learn about evaluating the various global energy options and 87.5% of them stated that the course met their expectations.
- Most students stated that the idea of having guest lecturers was very interactive but this made it difficult for the course to have more structure and often overlapped in content.
- The course was successful in achieving its objective of making students think critically about the global energy option, as one student remarked: “Incorporating nuclear into Renewables Mix by Prof. Golay I never seriously thought about nuclear energy contributing to renewables and energy security. Prof. Golay’s explanations make a good case for why it has to be taken into consideration”.
- The survey also helped us to establish some clear favorite lectures and some that that needed attention. The best thing about the feedback was that the students had told us exactly why they liked or disliked the lecture and it makes our job very easy.
• The most important feedback was regarding the mismatch in the lectures, reading material, and assessments. As a result of this we have used instructional design pedagogies to design effective assessments.

4.2 Approach

The approach for developing an online version of MIT's course in Sustainable Energy is divided into two models. The first model is based on a blended learning format where students complete few tasks before class and engage in a participatory format in the classroom. The second model learns from the first model and moves towards having most learning in the online world with minimal in-person support, as indicated below:

![Diagram of Model 1 and Model 2](image)

**Figure 21: Model for Sustainable Energy**

4.3 Stakeholder Analysis

This section discusses the roles and responsibilities of the stakeholders involved in the process of design and development for this course.

**Instructor:** The main responsibility of the instructor is to identify the learning outcomes, essential questions, and performance tasks for that lecture. They are also responsible for teaching the lecture both through recorded videos and in the classroom. They participate in discussions and office hours and collect feedback and improve course content accordingly to ensure the course goals are met.
Designer: The main responsibility of the designer is to create the design approach, learning plans using information from the instructors and students. They are also responsible to implement the course with all its content on the online platform. Create assignments along with relevant rubrics to measure performance and maintain and update content.

Teaching Assistant: The main responsibility of the teaching assistants is to manage student led discussions, grade essay assignments and manage grades and grading policies and manage office hours, recitation, and other administrative activities.

Students: The main responsibility of the students is to remain engaged in and outside classroom activities and provide meaningful feedback wherever necessary.

4.4 Instructional Design Approach

The main activities involved in the creating the instructional design for the course are defined as follows:

1. Identification of learning outcomes for the course and individual lectures and the "big-ideas" for lectures and discussions. Create opportunities for student to analyze, reflect on, relate to, and question the course content to improve their critical learning experiences
2. Develop a structured approach to create content and assignment with the help of a customized instructional design approach.
3. Identify and divide tasks to all stakeholders early in the development process.
4. Research the process associated with video production having videos for lectures, expert interviews, and feedback discussions etc. Use of illustrative and analytical educational tools and content visibility control
for students - monitor and stagger access to content ensuring sequential and timely completion.

5. Design an online grading rubric that clearly communicates expectations and motivate student participation - quality, quantity, performance etc.

6. The number of hours required for course design and development varies in a wide range from 70 – 600 hours. Multiple uncertainties could see us leaning closer to high end and needs careful planning. The duration of the project from start to finish is a period of 6-9 months period in which the online course will be designed/developed from the existing classroom-based offering. The cost of project would include compensation for the technology and design services, the faculty involved in the course, graduate students (Teaching Assistants and Research Assistants). The cost of repeated offering includes the sustained budget to run and manage the online course offering every year.

7. Update the syllabus for Sustainable Energy (1.818/2.65/10.391/11.371/22.811/ESD.166) as list in Appendix 6.5.

The instructional design approach for this course is a combination of the following approaches discussed in chapter 2:

- Understanding by Design
- Bloom’s Taxonomy
- Task-Centered Strategy

The design approach is based on a backward approach with the following stages:

4.5.1 Stage 1: Plan

Identify the lecture learning goals and outcomes at the beginning of the design phase. The goals identified for the course are listed below:

- Students must understand the complexity climate change response problem. The factors are:
  - Political
  - Scientific
  - Economic
  - Technological (main focus of course)
• Students must develop the mental habits to ask critical thinking questions such as:
  o How can this (tech, solution, etc.) be wrong?
  o What is weak about this proposal?
  o What should we do if the solution does not meet its promises?
• Students must think about what would a low-carbon future look like, and ask:
  o What do we do about transportation fuels?
  o What should we do about the nuclear-renewable balance?
  o How do we get to this low-carbon future, assuming we have 60 years to change course before climate change becomes inevitable?
• Students must learn how to work with uncertainty, that is, to ask what are the factors that contribute to it?
• Students must be able to identify complexity and interdependencies.

Identify “big-ideas” that students will be that will contribute to building their knowledge and skills. The step also ensures that these ideas are aligned with the course goals. The stage also lists down the prerequisites for the course in the form of readings and activities.

4.5.2 Stage 2

This is a crucial stage where we identify the assessments needed to evaluate if the students have been successful in achieving the learning outcomes. For example creating assessment like: “In 2014, the United Nations Intergovernmental Panel on Climate Change found that nuclear power has the lowest lifecycle emissions of any electric generating technology, except for wind energy. Discuss the nuclear lifecycle emissions compared to renewables”, helps students in exploring the uncertainties and complexities in the nuclear lifecycle.

4.5.3 Stage 3

This stage is responsible for developing the planned activities for the course constitutes dividing each lecture unit into three parts: pre-class, in-class, and
post-class segments. Each segment has defined goals, learning outcomes, and assessments to ensure maximum transfer of learning.

The pre-class stage is a foundational phase where students develop their concepts and basic understanding of the topic. It is also a great place to understand student’s misunderstandings related to the topic and how they can be eliminated. Selected activities in this segment include:

- Readings: Case studies, Papers, Textbook,
- Video - Targeted concepts, Solved examples, Panel discussions, Demonstrations
- Assessment: Embedded short questions in videos. Annotation of textual matter to reflect understanding before class. Assessment: Short reflections essay to reflect understanding
- Posting on discussion forums

The in-class activities are devoted to discussion and reinforcing the concept in the form of following activities:

- Quizzes - Individual / Group
- Discussion - On before class material, Panel, Student led, Student guest
- Worked example (application, country specific, case study etc)
- Standard lecture (aligned to our framework)
- Group activities

The post-class activities are used to test student learning and for feedback as follows:

- Assessments - Faded example, Performance tasks,
- Assessment: Short reflections essay to reflect understanding after class
- Journal - Notes to oneself on the lecture
- Lecture feedback and open questions to the lecturer

4.5 Technology Evaluation Framework
The diversity of the course content makes it difficult to maintain a uniform structure in content layout and representation. This has led to confusion among students in the past as they found it difficult to compare the course units based on some commonly defined parameters. Therefore we have built a framework to evaluate an energy system through four lenses, namely:

- Technology
- Society
- Environment
- Economy

Each lens is measured against the expected outcomes and the associated uncertainty for the following factors:

- Critical material limitation and resource availability
- The energy economics related to the competitiveness of energy source in different contexts and geographic locations.
- Impact to different sections of society in the energy market:
  - Established energy players (incumbent utility companies)
  - Electricity consumers of different income groups
- Risk associated with a technology wrt relative risk reduction and risks during deployment (throughout the lifecycle of the technology).
- Interdependencies within technical, social, environmental, and economic factors
• A comparison between expected outcomes and associated uncertainties enable us to identify areas of concern. The uncertainty that remains after the best possible analysis has been undertaken is called residual uncertainty.

Technology Impact:
This section identifies the following factors that affect technology development and deployment. The factors are evaluated on the basis of four indicators: effectiveness, readiness, implementability, and reliability. The primary goal of studying these factors is to establish if the energy technology is ready for placement in society.

![Factors](image)

**Figure 23: Factors affecting Technology Development**

**Societal Impact:**
This section identifies the following factors that affect societal response to a technology and its impact on the present and future use of the technology. The factors help in stakeholder analysis is to discuss the roles, interdependencies, feasibility, concerns and the sensitive groups for that technology. These are often the most important factors in deciding the fate of any technology.
Environmental Impact:
This section identifies the following factors that are associated with the environment impact of a technology solution. The considerations for evaluating the impact are the resources needed and consumed, damage done to the environment, process residual created, and the future consequence in using the technology. This segment usually has a resource damage mitigation plan.

Economic Impact:
This section identifies the following factors that affect the economic feasibility of an energy technology solution. This includes life-cycle costs such as management
and integration (M&I) costs, capital costs, and operations and maintenance (O&M) costs and country specific issues that contribute towards the ability/need of a country to invest in a particular technology.

![Factors affecting Economic Concerns](image)

The overall framework to evaluate an energy technology solution can be represented as:

![Technology Evaluation Framework](image)
Chapter 5: Conclusion and Next Steps

The objective of the work reported here is to develop a blueprint for creating student centered residential blended course with improved learning outcomes. This included identifying the gaps in student needs and existing educational standards. It also emphasizes on establishes learning considerations to improve development of long-term knowledge and skills that be applied to real-world problems. The end goal has been to deliver an approach for the implementation of MIT's course in Sustainable Energy with these considerations. In this chapter, we discuss the conclusions that are drawn from this work and the limitations and potential next steps in this area of research.

5.1 Key Findings

This report provides several valuable insights into the challenges and opportunities in the present online education system. The findings have been synthesized into an overall plan for successful implementation of the course. Educators that are considering building such blended courses will significantly benefit from using this research in their adoption and development plan. The key implications for educators to implement blended learning are discussed below.

5.1.1 Implications for educators

The research findings reveal the following implication for educators:

- There is no “one size fits all” approach for instructional design, and the course design and content has to be customized for student needs educator strengths. In our research we selected segments from various learning pedagogies to develop a blueprint for the course in Sustainable Energy to achieve desired learning outcomes.

- The most important step in creating any course is identifying the goals and learning outcomes because they inform subsequent design and implementation decisions. In our observations it is a good practice to establish them right in the beginning of the planning process because delay in setting these expectations will impact the progress of the course design and development.
- The process of writing measurable learning outcomes requires focusing on student needs and abilities, selecting relevant assessments methods, and setting performance criteria [32]. We have utilized the staged approach in the "Understanding by Design" framework to create meaningful learning outcomes.

- The selection of learning considerations like what kind of skills do you wish to build in students has to be done at the beginning of the course. In are focused on building critical thinking skills and uncertainty analysis in student, therefore our design includes activities that build these skills.

- The edX platform provides a range of options to implement the course content and assessments. The appropriate use of tools and technology is imperative in making the course effective. An example from sustainable energy is that we chose to use visualizations instead of video to explain the technology evaluation framework in the course, based on feedback.

- Collecting feedback and iterating through the design and development decision is vital. Feedback while the course is live and after its completion is more important.

- Lastly, the most challenging portion of our research has been adapting existing course content to an online format. Our findings have been that in order to digitize the content we should incorporate instructional design pedagogies to make the course more engaging and effective. This is due to the following factors:
  
  - Learning in an online course is mostly dependent on the student's interest and participation and as designers we need to be able to retain their engagement in the course through meaningful design and deep learning.
  
  - It is difficult to measure a student's level of engagement in an online course, hence we need to build checkpoints to ensure they are completing the assigned units and are able to retain and recall the information.
5.2 Limitations

This report delivers an approach for creating a residential online course. There were certain constraints on the time and resources available for this research combined with decisions related as scope, existing course expectations, research design and methodology resulted in a few limitations as discussed below [33]:

- Online learning allows students to work at their own pace, in areas where they need more practice, and be able to master skills with repeated exercises. This benefit for the student makes the educator's roles and responsibilities complex. The instructor needs to adapt to provide more personalized instruction and intervention to help each student. This scope of this research limits the exploration of the additional responsibilities that teachers play in online education and how their actions be made more effective and less strenuous.

- The instructions delivered online are beneficial but it is important to capture the data of each student’s progress at a granular level. This report does not explore the ways in which data is being collected and analyzed in present online courses.

5.3 Next Steps

This report provides a design foundation for creating an online course including the learning pedagogies needed to aid the development process. The research findings and limitations stimulate several potential future directions this research could take. A few suggestions are discussed below [33]:

- One of the objectives of blended learning is to personalize instruction to meet the student needs. However, if the school chooses an approach to building the course, which is not adaptive to student, needs and the resources available student learning will not be as personalized. Therefore there is scope for educators and designers to create meaningful content that is linked with the needs of their students. The future steps in the design field would be to collect these approaches and develop templates for adaptive learning.

- The present online courses allow instructors to view student progress
data showing with respect to skill area, the obstacles in learning and the individual or small group instructions needed to solve them. The process of collecting and analyzing this information is still in its fledgling state and its improvement should be an important next step.
Chapter 6: Appendices

6.1 Student Survey

We conducted a survey with the graduating class of Fall 2015 to collect feedback on the course content and design. The questions and responses are listed in the following sections.

6.1.1 Questions

2.650 Student Feedback Survey
Student feedback form for development of online course

- Required

Are you a graduate student or undergraduate at MIT? ·
- Undergrad
- Grad
- Other: [ ]

What were your initial expectations from the course? ·
What you wanted to learn when you enrolled for this class?

Were your initial expectations met by the course? ·
- Yes
- No
Did you like the structure of the course? What are your reasons? -
Your thoughts on the structure of the course content:

What were your most favorite lectures and why? -
Top 3 lectures/topics covered in class and reasons why they were able to add to your learning:

What were your least favorite lectures and why? -
Bottom 3 lectures/topics covered in class and reasons why they were not able to add to your learning:

Did the textbook and reference material compliment the learning in class and assignments? -

What difficulties, if any, did you have with any/all of the assignments? -

What were your key learnings from this course? -
What energy related courses have you taken?

How often did you meet with guest lecturers after class?
- 0
- <= 5
- > 5

Any other feedback for the course?

Would you be interested in testing out some of the online modules?
If so, please fill out your email address And Thanks!

6.1.2 Student Responses

Are you a graduate student or undergraduate at MIT?

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergrad</td>
<td>4</td>
<td>23.5%</td>
</tr>
<tr>
<td>Grad</td>
<td>12</td>
<td>70.6%</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>5.9%</td>
</tr>
</tbody>
</table>

1. What were your initial expectations from the course?

- Mechanisms for financing sustainable energy in developing countries. Sustainable energy options Climate change
- My expectations of this course was to obtain a full, complete scenario of the current global energy spectrum and what efforts can be done to mitigate the climate change impact being caused from the Energy
Industry.

- I wanted to learn how to have an intelligent discussion about energy options, and how to evaluate feasibility and compare fuel sources.
- Learn about ways society can use energy sustainably how can the world function in a more environmentally-friendly way what will be the best energy options in the future
- I wanted to learn about the various types of energy as well as considerations when we say "sustainable."
- Sustainable sounded more unrealistic for me because renewables are less powerful to change the world. But listening many facts for example PV getting much less expensive than before etc. convinced me to accept and understand its usefulness in near future.
- To increase my general knowledge on the current state of energy around the world, particularly the areas not related to my research.
- To give me the knowledge necessary to study sustainable energy options
- I wanted to learn more about the different types of alternative/sustainable energy systems and technologies.
- I was interested in learning more about the potential effects of an increased amount of renewable energy generation on the electrical grid.
- Understand Climate Change Learn renewable energy options and challenges
- I wanted to gain a broad overview of sustainable energy technologies and the factors that impact their implementation- political, economic, cultural, etc.
- I expected to have a survey of sustainable energy-related issues
- I was interested in learning about various forms of energy other than my research (nuclear).
- Learn various technology field related to low-carbon or efficient energy.
- To get broad knowledge and wide view of energy, mainly focused on renewable
- Approaches to generating sustainable energy
- I really didn't come in with much for expectations. This was a course I
needed for the energy minor and my last energy minor class was very different from all the other classes I had taken.

- Relevant technologies for energy; energy economics and infrastructure; political considerations, related to current developments
- Get an understanding of the overall energy market, with its links to climate change mitigation and adaptation.
- I was expecting more structure to the lectures, and while I did really enjoy the variety, it would have been nice to have a bit more continuity.
- More about the role of renewables with nuclear - and the realistic capacity that renewables have.
- I had expected a more technical class analyzing current technologies.
- Just wanted a broader view of everything. As a grad student it's easy to live life with blinders regarding your particular project.

### Were your initial expectations met by the course?

<table>
<thead>
<tr>
<th>Yes</th>
<th>21</th>
<th>87.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>3</td>
<td>12.5%</td>
</tr>
</tbody>
</table>

### Did you like the structure of the course? What are your reasons?

- The idea of having guest lecturers was very interactive but made the course tough to follow because the guest lecturers sometimes repeated some things already talked about.
- I thoroughly enjoyed the structure of the course. It really can't be much better in my opinion. Having 4 one-hour lectures every week from an expert in various fields of the energy industry has been very special.
- I disliked it, because the lectures were hit or miss and often overlapped highly.
- Yes. I enjoyed hearing from such a variety of speakers. Many different mindsets and opinions were brought to the table
- Yes, I wanted a broad range of information, and this seminar style with so many guest speakers was perfect for doing so.
• Yes. Because you can study all kind of topics related to energy.
• Yes and no. The different guest speakers made it very interesting but also broke the continuity of the course.
• Yes! The fact that different guest lecturers come every week was extremely positive.
• I really liked the guest lecture format, which made the course effectively like a seminar course with different material each day.
• I did like the structure of the course but I did not find the toolbox lectures particularly helpful given my background in mechanical engineering.
• I enjoyed the lectures. Homework wasn't helpful.
• I really like the structure of the course. I think having a different lecturer for each hour keeps the class dynamic and interesting, and also gives us insight into the perspectives of different industries on sustainable energy.
• Yes I liked the structure of the course. It was neat to be able to hear from and meet the experts in each area. The lectures complimented each other well and helped paint a complex picture in an understandable way. This was a very timely class with the occurrence of the Paris Conference.
• Yes, especially the wide range of lectures by different people. It was really awesome to hear from experts in each field, and I thought this was much better than the alternative of one person trying to cover everything.
• Yes. I like to have lectures both from prof. Golay and guest lecturers.
• I didn't like the structure, cos it felt like different pieces falling over the head. I think it's better to make some logical path without changing focus to different things all the time. But a mostly lecture was very useful and interesting.
• No -- I thought that the different lectures were not very well connected because people would repeat things that had already been taught and fail to build off of previous lectures in general.
• Yes. It is nice to get to hear from many lecturers with different backgrounds on a large variety of topics.
• Very wide range, but not too superficial - great as an introductory course to gain an overview Interesting perspectives from guest lecturers - this
was the best part of the course The tours were also good

- Yes, I liked having various speaker sessions by different individuals. Also, all the sessions were well organized and followed the schedule well. Coming from a chemical engineering background though, some lectures were more beneficial to me than others. For example, the nuclear fusion lecture was a bit difficult to follow. The same comment can be applied to the DC/AC lecture.
- I enjoyed the guest lecturers, but it made psets and exams very difficult since the graded assignments did not correspond with the lectures at all.
- Yes - the break between the lectures was very important I think
- The lectures were interesting however the order of lectures sometimes did not follow a line of logic. It is understandable that certain lecturers cannot be fit into a perfect schedule.
- It jumped around a lot, but I can imagine that it is difficult to coordinate so many professors. A more organized structure has its own downsides as well.

What were your most favorite lectures and why?

- Battery technologies by Prof. Shadowy Clear presentation of ideas and the underlying science Sustainable energy in India and Africa by Prof. Robert Stoner Very important lecture covering development studies and how it relates to power. I enjoyed the first hand experience that Prof. Stoner brought to talking about the topic. Incorporating nuclear into Renewables Mix by Prof. Golay I never seriously thought about nuclear energy contributing to renewables and energy security. Prof. Golay's explanations makes a good case for why it has to be taken into consideration
- It's hard to choose 3 favorite lectures. So many lectures were incredible. I'm going to cheat and mention 6 that really stood out to me: - Prof. Prinn's initial lecture on climate change was a great way to start the semester - Susan Solomon's lecture on climate change probably had the biggest impact on me. - Shell's deep water drilling projects were jaw dropping - Both of Professor White's presentations were pretty incredible

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- Ralph Izzo’s lecture on Electricity Generation - Donald Sadoway’s lecture on Energy Storage

- Prof. Stephanopolous lecture--very new material Prof. White because she’s an excellent lecturer Prof. Roman’s biofuel lecture they all covered new material here!

- I liked the climate ones from EAPS (Prinn and Soloman) Frank O’Sullivan was a good speaker and gave important information

- Prinn - again, he gave an excellent overview of climate change and the problems associated with it Roman - I wasn’t very interested in fossil fuels until this lecture, and felt he gave a compelling case for their use

- Sadoway - one of the best lectures I’ve heard on any topic at MIT, great lecturer, outlined problems with batteries and why they would never (or would be unlikely to) replace fossil fuels

- Sadoway’s Solomon’s

- -Fossil fuels with Prof Roman -Fusion with Anne White -Sustainable buildings

- Batteries with Sadoway, Climate change, grid issues

- The lectures about climate change, economics, biofuels

- My three favorite lectures were: Cape Wind - Provided insight on regulatory and legal challenges related to public opinion for controversial projects. Anne White on Fusion - Very interesting description and discussion on the promise and challenges of the technology Susan Solomon - I enjoyed her comprehensive discussion of the current state and future of the climate change problems.

- Batteries Prof. Forsbeg Ann White They rocked.

- My favorite topics covered were the automotive lecture on electric cars, Professor Solomon’s lecture on climate change and the lecture on green buildings. All of these talks were multi-dimensional in nature, focusing on the technical aspect of the given topic but also introducing political, economic and social factors, and all of the lecturers were very engaging.

- Susan Solomon - climate change; she was clear, was an authority on the subject, and had practical, memorable facts and advice Anne White - grid circuits; a dynamic and clear and interesting lecture. Ross Collins - system
dynamics; clear, interactive, interesting

- Sadoway (batteries) -- Really good speaker and was interesting to hear about what I consider to be one of the key technologies in making renewable energy practical. 2.) Prinn and Solomon (tie) (climate change) - Extremely good introduction to climate change for someone who wasn't from EAPS 3.) Izzo (electric utilities) -- Very interesting to hear from someone who sees things "from the top" of the utility

- Energy Storage International collaboration Economic Feasibility Assessment

- My favorite lecture was about batteries (Pr. Sadoway). What is more - it was best lecture in my life - the way he lead the lecture, how he spoke and gave the information - piece of art! Professor Golay (all topics he covered) was great too, the way he gives the information is very clear. Pr. Roman was great in terms of giving very active and fascinating lecture, so you wouldn't be bored and would focus on the lecture 100 % your attention

- I liked Susan Solomon's lecture on the persistence of climate change, which was really interesting and well taught.

- Paris lectures because it was very relevant to events happening today. Sadoway lecture because he's a wonderful lecturer and energy storage is a very interesting topic. The energy in Brazil lectures because it was amount sustainable energy succeeding in a developing country.

- Global Change Issues and Responses (Prof. Prinn) - atmospheric science and historical data giving proof of man-made climate change, forecast model to limit global warming Fusion Energy (Prof. White) - prospects for an abundant and clean energy source, at the same time practical difficulties with its development A combined future renewable and nuclear energy economy (Prof. Forsberg) - interesting, cheap heat storage in FIRES, prospects of finding an economically viable solution Susan Solomon's talk - Fracking - Energy Economics Easy to follow through, had a clear structure and a clear conclusion. The speakers were also very engaging and clear in their explanations.

- Fossil Fuels I&II Sadoway Electricity in japan

- Energy Economics (Knittel) - he was able to answer a lot of questions
about economics, which is not what I study so it was an interesting addition to the energy debate. 2. Global Warming (Prinn) - he was able to lay out the facts clearly which helps when I explain to others why people should be concerned about climate change. 3. PSEG (Izzo) - He offered good insight into how utilities make decisions, which is one of the primary ways to change the energy mix we have.

- Forsberg Electricity in Japan: Rather than explaining a problem and demonstrating an ideal solution. The Japanese situation is an open-ended problem that provided a foundation for a lot of thought rather than just an open shut case. Biomass: Did not know much about biomass at all prior to this course. Was a good opener. System Dynamics: A much more participation heavy lecture and established basic concepts that were very useful even outside of the course.

- Most lectures were good. I think I liked the ones that came from perspectives outside of academia the most. Not necessarily because they were more informative or better presentation, but because they were different. If most of the presentation were industry, then I probably would have enjoyed the academic ones.

**What were your least favorite lectures and why?**

- I enjoyed all the lectures.
- Though there were no weak lectures, I believe the 3 I found the least engaging were: - The Energy Resource Assessment lecture - The Carbon Sequestration Lecture (but I was tired that day) - Finally, though not a specific lecture in itself, I believe one less lecture could be dedicated to Nuclear Energy (it was by far the technology that was given the most focus), and use that 1 hour lecture for a different topic that wasn't looked into.
- All of the lectures that explained global warming was a problem yet again. Lectures that repeated content (ex/ "intermittency is a problem")—really cool the first time. The lecture that explained supply/demand--redundant for people who have taken intro econ.
• Shell techworks was badly presented and only covered a small amount of what they do. I didn't learn much in cape wind a lot of white's electricity stuff went over my head

• These still added to my learning, but I felt the lectures could have been more condensed, as they tended to drag on. Collins - system dynamics Izzo - electric utility Olmstead - Cape Wind

• About wind power

• Mostly the wind energy and battery lectures.

• Don't remember.

• Case studies about regions or countries.

• My three least favorite lectures were: Economic Feasibility Assessment Methods - I did not feel that this was taught well and caused some confusion with students. Alex Kalmikov - I did not feel that this lecture added much information on wind power. System Dynamics - I did not believe that this system dynamics industry really contributed to the overall messages in the class.

• N/A

• My least favorite lectures were the deep-water oil drilling lecture by Shell representatives, the wind power lecture and Professor White's lecture on electrical system dynamics. In the first case, the lecturer was not engaging and spent a great deal of time showing videos rather than actually presenting material. In the second case, the content introduced was very preliminary to the point that I learned very little new information. In the third case, the lecturer was engaging, but the structure of the presentation was weak.

• Wilfredo Rosa - poor presentation style with lots of jargon, but interesting, cool videos showing offshore drilling Howard Herzog - not a very interesting presentation; very text heavy Charles Forsberg - good information, and dynamic presenter, but a rather authoritative, salesperson-type attitude/ tone

• Shell -- not very informative 2.) Very first toolkit lecture -- information did not seem very useful 3.) Electrical systems dynamics -- I personally enjoyed the lecture with a background as EE, but probably way too
technical for people without EE background

- Electric Utility Decision-Making Electricity in Africa
- I liked everything, some topics more, some less, but there isn't any very bad ones, which I can remember.
- System dynamics -- seemed totally devoid of content Anything on biofuels -- was not helpful for people without a chemical engineering background Anything on electric grid -- was not able to learn from the few equations that they put on the slides as I have limited electrical engineering background. Didn't learn anything past the general sense of the electric grid that I already had.
- Fukushima, because it teach me very much new information and hearing the specifics about this instance doesn't tie in the well to sustainable. Energy use in buildings lectures because I personally don't find the topic as it was presented that interesting. An energy grid lecture. While I find the topic interesting, I feel like it was discussed too much considering the limited number of different lectures we can have.
- Deep-water oil drilling (rather like a commercial for Shell) Nuclear Energy II/III (seems a little biased, underestimating the danger of nuclear and neglecting the long-term consequences e.g. in Fukushima, unsolved problem of nuclear waste disposal)
- Nuclear fusion - Electrical Systems Dynamics - Carbon taxes For the nuclear fusion and electrical systems dynamics lecture, I lacked the background knowledge on the topic and therefore, wasn't able to follow through the entire scope of the lecture. For the Carbon taxes lecture, it was very hard to feel engaged in the lecture, as the lecturer wasn't very engaging.
- Hydropower - presented only one side of the argument
- Energy Storage and Conversion - I already knew the material covered 2. Shell - it was interesting - but very dry 3. Nuclear - good lecture, but I already knew the material
- Risk Assessment: This class could have been covered rather than in power point but on the chalkboard and had every student taken notes it would have been much more helpful for students to just have time to
work out examples. Energy Conversion and storage: Repeated lecture for course 10 students Liquid Metal Battery: Repeated lecture for course 3 students

- As a grad student the toolbox lectures are not very useful.

**Did the textbook and reference material compliment the learning in class and assignments?**

- Yes
- No
- Very little--I found the textbook much more about technical calculations, the lectures more abstract concepts, and the problem sets were unit calculations mostly, and they were hard to relate to one and other in terms of applying my learning.

- I didn’t find the book helpful for homework assignments. Additional reading was interesting. The textbook was not necessary as a grad student.

- Yes, although I felt the textbook readings were far too long, especially having to read for 4 lectures a week. It’s very difficult reading to absorb

- Yes. I expect next version of this book will be published including shale revolution and its implications.

- Not for the grad students. It was a waste of money.

- The readings from the textbook were helpful in providing background material before the lectures they were assigned for but I often felt that the speaker never discussed much of the material in the readings.

- Not at all.

- Yes, the textbook and reference material complimented the learning in class.

- To some degree; usually, the reading was an impractical amount of material given only 24 hours ahead of time. Short papers of up to 5 pages are practical if the expectation is that we will read the material ahead of the lectures. Posting the slides ahead of time is helpful so we can review ahead of time and come up with some questions.

- Reference material was helpful but textbook was not.
- yes
- The textbook was very helpful.
- No, the textbook was unreadable. It didn't provide any analysis, but just listed information. I did not find it helpful.
- The textbook readings assigned on the syllabus often did not match the lectures for that day and I think the lectures were sufficient without the readings in most cases (for the textbook). The reading by lecturers were useful for the discussions but thy should be posted before the weekend so we can read while we have more time.
- Current reference material (e.g. from newspaper, papers) are good as a resource Good, extensive textbook, but often readings not really related to topic Mandatory assignments as a basis for the lecture are not read by most students
- It depended on the lectures. I personally found the specific articles assigned by the readers helpful (Charles Forsberg readings and Susan Solomon readings). However, the textbook was just way too much content and it was challenging to follow. I think it's more beneficial to assign more specific readings that are shorter so it's easier to make sure that readings are actually completed on time.
- not at all
- not as much during - it's good for referencing back after the class though
- Yes
- Yes.

What difficulties, if any, did you have with any/all of the assignments?
- None
- The assignments are well designed. Some questions were a bit confusing to understand, but overall I think the problem sets are fine.
- Vague wording was the prime one--especially on the take home.
- I didn't hear back what I had gotten on any of the assignments until after I had turned them all in. So if I had been doing them incorrectly I wouldn't have known.
• I felt there was little to no guidance on the term paper aside from the rare deadlines.
• I am auditor who has no homeworks.
• No difficulties.
• Not too many, but you needed to have a pretty substantial basis of learning in order to complete assignments.
• None, I found them all straightforward.
• They didn't grade them until we were complete with almost all of them. Very delayed feedback.
• The assignments were reasonable and educational.
• No specific difficulties. It would have been preferable to have them graded in a timely manner so that we can have feedback about the expectations/quality of our solutions.
• Ended up spending an inordinate amount of time looking up reference material as opposed to actually working on the problems. Textbook was not helpful at all.
• Instruction for term paper prospectus was not clear. I confused of what is required for prospectus and what is not required for prospectus.
• It was very clear how to do the assignments, as I got the results, and still not agree about the grades. From my point of view, it was correct, and the way you solve it is very relative, and there isn't one clear obvious answer.
• I really didn’t like having to use new programs/applications for assignments because sometimes it was difficult and stressful to get them to work.
• Writing a paper is awful. The research portion of the assignment was very interesting but writing papers should be a punishment reserved for HASS classes. I would prefer more psets and exams. As this class is offered through engineering departments, reports that are not in research paper format would have been appropriate and less awful.
• Not enough guidance and responsiveness from term paper advisor
• The Monte Carlo question was difficult to solve because I didn’t have past experience in solving that sort of questions. Also, the electrical systems
dynamics question was really difficult for individuals without an electrical engineering or physics backgrounds.

• I did not like having to download applications to complete the psets. The psets were completely unrelated to the lectures and did not help me learn.

Exams were completely unrelated to the lectures and not cumulative at all. They did not help me learn whatsoever.

• none

• The term paper assignment feels a bit vague and underdeveloped.

What were your key learnings from this course?

• We have to focus on the developing world if we are serious about mitigating the impacts of climate change. The developed world has to finance some of the actions to be taken by the developing world in solving energy problems - Prof Golay 2. China and India are very important to any global strategy towards a 2 degree world. 3. System dynamics and tools.

• This was my favorite class of the semester. It's really really great. Helps provide a full sense of the challenge that we're facing. I guess my key learning is just fully understanding our situation in terms of climate change and the energy sector. The course does a great job of tying multiple variables together.

• I learned at least a surface level amount about most of the lecture topics, I'd say.

• We can be hopeful that society will move to function in a more environmentally friendly way. Developing countries are pretty far behind in terms of energy.

• The strongest impact the course had on me was educating me about climate change (further than knowing it's happening and it's bad), the role of CO2, and how complicated the problem is with developing countries becoming more industrialized.

• New technologies challenging CO2 reduction. i.e. Prof. Sadoway, Prof Solomon, etc. and also, future world requires zero emission even if fossil fuels remain.

• That the solution to our energy needs will be a combination and balance
between many technologies and a collaborative effort.

- There is no silver bullet solution, but several small solution.
- Exposure to different technologies.
- The importance of international cooperation in the fight against climate change. Additionally, the scope of the problem of the climate change and how much electrical generation is needed.
- Energy is hard.
- Aside from the exposure to an array of technologies, the key learning was the fact that every problem must be approached from multiple angles and optimize the balance between competing interests.
- I work on PV technology. I especially gained a better understanding of the role of nuclear power and the economics and policy challenges and solutions associated with incorporating large amounts of renewables on the grid. I also solidified my understanding of the realities of climate change.
- Climate change effects were way worse than I thought 2.) Energy storage is *the* key issue for making renewables work
- Big picture over energy technology and sense of energy economy
- Just as I expected, wide vision of energy - in general.
- I didn't really learn anything.
- Difficulties with adding solar or wind into the grid. Politicians are not very helpful future energy solutions ultimately depend on cost-competitiveness - economic and political considerations are as important as technical ones - the energy sector is highly complicated and it required clear and unideological thinking to find the best solutions
- How to optimize the usage of various energy systems including fossil fuels, solar, wind, and others - How to account for various technical, social, and economic factors when planning an energy systems plan - How to account for inefficiencies in various energy systems
- I learned that I wouldn't recommend this class to anyone
- Solar may actually be useful
- -Electrical issues with grid -Possibility of nuclear -Growth of Solar -
Carbon taxation - The Japanese energy situation
- Economics and policy can drive technologies more than the research we do. Understanding all sides of the problem is necessary.

What energy related courses have you taken?
- None
- 0
- Henry Lee's course at Harvard
- I am in course 22
- 15.657
- N/A
- 2.626, 3.42
- 15.933 Strategic Opportunity in Energy
- before this
- 12.021
- Thermodynamics
- Thermodynamics, heat and mass transfer
- energy policy classes in undergrad
- 10.26
- Idk. Turbines, thermodynamics, etc.

How often did you meet with guest lecturers after class?

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12</td>
<td>50%</td>
</tr>
<tr>
<td>&lt;= 5</td>
<td>11</td>
<td>45.8%</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>1</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

Any other feedback for the course?
- I would've liked to learn about geothermal energy and looked further into transportation. I believe these two issues are key when addressing energy sustainability. Also, I would've liked to look further into the economics
and overall value of the oil and gas industry, in terms of numbers. Have a "dollars and cents" approach to that industry. Then again, I'm not sure what lectures I would take out of the program. The semester needs to have 6 more hours of lectures ;)

- *Office hours would have been great *the grading situation, where we had to take a test before getting any feedback, was not great.

- overall great!

- Home page of old version still remains. It makes image of this course too old.

- N/A

- I would strongly suggest having a quick survey after each lecture on the quality of the information, slides, presentation, feedback for the presenter, and whether we would want to invite them back (yes or no). It is difficult to recall and formulate opinions about a whole semester of lectures. This can also help ensure high quality presentations are invited back the next time.

- No, was great course, would recommend it for coming students

- Please end at 4:55. As an athlete, I had to leave right at 4:55 to get to practice on time and I always felt bad dipping out while the class was still going on. Also please get a warmer room. Please! Please! Please! I regularly brought a ridiculous amount of warm clothing to the class so I didn't feel terrible during the 2 hours in the cold. I wish we would have discussed means of limiting population growth to reduce energy consumption.

- Interesting topic hardly considered so far: energy storage and alternatives

- Need to communicate expectations with the students more. Psets and exams should correspond more with the lectures or should just not exist. Change the format of the class; 2 hours twice per week is too long. would strongly prefer 2 1-hour lectures, MAYBE 2 1.5 lectures.

- Put lectures online! It's good to go back after.
6.2 Example of First Principle of Instruction

How-to Strategy

• How-to is often the primary goal of the instruction.

Goal:

• Perform a series of actions that lead to some desired consequence.

Presentation

• Tell steps in the procedure and sequence

Demonstration - Show:

• Show a specific instance of the task.
• Demonstrate each of the steps required to complete the task.
• Show the consequence of each step and the complete procedure.
  o Provide opportunity for learners to “play with” the situation (try to do the procedure in an actual or simulated situation.)
  o The play should enable learners to clearly see the consequence of their actions.

Application - Do:

• Require learners to do the task by executing each step in a real or simulated situation.
  o Provide intrinsic feedback (observing the consequence of one’s actions) and extrinsic feedback (informing the student about the appropriateness of a given operation or action.)
  o For complex tasks early practice should be with simple problems or tasks and each succeeding problem or task should be more complex.
  o Early problems or tasks should be heavily prompted while the amount of help is gradually withdrawn with each succeeding problem or task.
### 6.3 Sample Activities Structures

<table>
<thead>
<tr>
<th>Precursor reading method</th>
<th>Before-Class</th>
<th>In-Class</th>
<th>After-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursor reading for class.</td>
<td>Discussion - On before class material</td>
<td>Assessments: 1. PT - Open ended 2. Toolbox application</td>
<td></td>
</tr>
<tr>
<td>1. Case study 2. Paper</td>
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<tr>
<td>Study guide questions</td>
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<tr>
<td>Short quiz</td>
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<tr>
<td>Group discussion</td>
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<table>
<thead>
<tr>
<th>Tech Review Method</th>
<th>Before-Class</th>
<th>In-Class</th>
<th>After-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursor reading for class.</td>
<td>Solve faded example Discussion - On before class material</td>
<td>Assessments: 1. PT - Less scaffold example 2. Idea or example of contributions</td>
<td></td>
</tr>
<tr>
<td>Video - Concepts, Solved example</td>
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<tr>
<td>Short quiz</td>
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<tr>
<td>Reflections essay</td>
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</table>

<table>
<thead>
<tr>
<th>Application Example Method</th>
<th>Before-Class</th>
<th>In-Class</th>
<th>After-Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading: Relevant paper Video - Demonstration, Solved example</td>
<td>Discussion - On before class material, Panel, Student led, Student guest</td>
<td>Assessments: 1. PT - Less scaffold example 2. Idea or example of contributions</td>
<td></td>
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<tr>
<td>Short quiz</td>
<td></td>
<td></td>
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<tr>
<td>Annotation of textual matter to reflect understanding before class</td>
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### 6.4 Nuclear Power Basics: Backward Design

#### Stage 1 - Desired Results

<table>
<thead>
<tr>
<th>Goals</th>
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<tbody>
<tr>
<td>(Hint: Content Standards, Course or Program Objectives, Learning Outcomes etc.)</td>
</tr>
</tbody>
</table>
1. Students will know the basics of nuclear reactions to inform students’ opinions on nuclear power safety concerns.
2. Students will be able to understand the role of nuclear power in the following context:
   - Fulfilling domestic and international energy needs.
   - In climate change mitigation efforts
3. Critically evaluate the challenges facing nuclear power from societal, technological and environmental

**Essential Questions**

(Hint:  
1. What are the Big Ideas that students will be learning?  
2. What questions will foster inquiry, understanding, and transfer of learning?)

1. What are the chemical and physical properties of nuclear energy that make it a feasible energy option?  
2. What are the social biases associated with nuclear power and how do they impact the development of nuclear power?  
3. Which countries are going to be the leaders in nuclear power in future?

**Key Takeaways**

(Hint:  
1. What key knowledge and skills will students acquire as a result of this unit?  
2. What should they eventually be able to do as a result of such knowledge and skill?)

1. Understand that role of nuclear energy in future energy portfolios alongside renewables.  
2. Understand the basics of nuclear physics and apply it to questions related to safety, waste management, cost, and proliferation.
Basics
- Explain the nuclear fission reaction and recall the fission products
- Recall the structure and function of a light-water reactor power plant
- Appreciate the role of nuclear power production today in some developed countries and possible future role in developing countries

Economics/Cost
- Compare the life cycle costs of nuclear power plants to coal power plants
- Recall the cost drivers of nuclear power plants (capital vs operation vs ..)

Safety
- Describe/recall what measures are needed to protect against hazards from the different fission reaction products.
- Critically evaluate the societal concerns with nuclear power

Prerequisites
(Hint: What are the prerequisites for this lecture: knowledge and readings)?

Readings:
5.
<table>
<thead>
<tr>
<th>Stage 2 - Evidence</th>
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<tbody>
<tr>
<td>Performance Task</td>
</tr>
<tr>
<td><strong>PERFORMANCE TASK(S):</strong></td>
</tr>
<tr>
<td>(Hint: Through what authentic performance task(s) will students demonstrate the desired understandings? By what criteria will “performances of understanding” be judged? GRASPS framework)</td>
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</table>

- **GOAL:** Provide a statement of the task. Establish the goal, problem, challenge, or obstacle in the task.
- **ROLE:** Define the role of the students in the task. State the job of the students for the task.
- **AUDIENCE:** Identify the target audience within the context of the scenario. Example audiences might include a client or committee.
- **SITUATION:** Set the context of the scenario. Explain the situation.
- **PRODUCT:** Clarify what the students will create and why they will create it.
- **STANDARDS and CRITERIA [INDICATORS]:** Provide students with a clear picture of success. Identify specific standards for success. Issue rubrics to the students or develop them with the students.

1. In 2014, the United Nations Intergovernmental Panel on Climate Change found that nuclear power has the lowest lifecycle emissions of any electric generating technology, except for wind energy. Discuss the nuclear lifecycle emissions compared to renewables.

2. Discuss California's future plan on nuclear energy considering the following vulnerabilities:
   a. Seismic
   b. Aging
   c. Policy

<table>
<thead>
<tr>
<th>Other Assessments</th>
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</table>
| (Hint: Through what other evidence (e.g. quizzes, tests, academic prompts, etc.) will students demonstrate achievement of the desired results? How will students reflect
Stage 3 – Learning Plan

Learning Activities

Learning Activities:
(Hint: Summary of Key Learning Events and Instruction. WHERE TO framework)

| W | Help the students know where the unit is going and what is expected? Help the teacher know where the students are coming from (prior knowledge, interests)? |
| H | hook all students and hold their interest? |
| E | equip students, help them experience the key ideas, and explore the issues? |
| R | provide opportunities to rethink and revise their understandings and work? |
| E | allow students to evaluate their work and its implications? |
| T | be tailored (personalized) to the different needs, interests, abilities of learners |
| O | be organized to maximize initial and sustained engagement as well as effective learning? |

Pre-Class Activities

Video:

Renewable Energy: Is the Future in Nuclear?: Gordon Aubrecht at TEDxColumbus - [https://www.youtube.com/watch?v=nRXDYC3TnG4](https://www.youtube.com/watch?v=nRXDYC3TnG4)

The Basics of Nuclear Reactors (MIT’s example) - [https://www.youtube.com/watch?v=K_5x-hc14tU](https://www.youtube.com/watch?v=K_5x-hc14tU)

Essay:

What is your reaction to the video about the use of nuclear power in our society?
Readings:

In-Class Activities

1. Recap: Message from the video through lecture slides (similar to content already available in the presentation)
2. Discussion: What are the concerns of the students regarding nuclear power having watched the Ted talk and the lecture?
3. Explain: How social, environmental, and economic factors govern the future of nuclear technology. Introduce the study on California's assessment of Nuclear Power Plant.

Post-Class Activities

Assessment:

1. Performance Task 1: You represent a citizen's group either for or against the proposed nuclear power plant. You need to research the topic from the perspective of your assigned role and find evidence to support your position. Give at least three reasons for your position and support each reason with three facts. You also need to address at least one argument that the opposite viewpoint might bring up. Write a persuasive letter based on your viewpoint to be presented to the ASLB (Atomic Safety and Licensing Board), which will determine, based on the evidence before it, whether the COL (Combined Licence) should be issued.
   a. Roles:
      i. Local Electric Utility - Obligated to provide its consumers their electric needs with the most cost effective energy it
can obtain. Utilities are subject to state legislative and regulatory requirements.

ii. **Residential Consumer** - Wants cheap electricity, does not want to pay higher rates.

iii. **Global warming activist** - Proponent of nuclear energy as a non-C02 emission energy source

iv. **Nuclear Scientist** - Enthusiast for advancing nuclear energy technology

v. **Representative of Financial Organization** - Determines if financing for the construction of the plant is feasible for the company

2. **Performance Task 2**: Essay - What is your opinion changed about nuclear energy after this lecture. In your opinion what will be the role of nuclear power in the coming future?

3. **Performance Task 3**: Do the licensing procedures differ between countries and do they allow different levels of safety?

4. **Performance Task 4**: What kind of hazards to nuclear power plants occur that originate outside the plants? What protection is there against the effects of external hazards?

### Video Description

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<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td><strong>Part 1: Recap</strong> - Video with instructor and lecture slides</td>
</tr>
<tr>
<td>2.</td>
<td><strong>Part 2: Discussion</strong> - Video with instructor and students exchanging ideas</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Part 3: Explain example</strong> - Video with instructor and lecture slides</td>
</tr>
</tbody>
</table>

6.5 Syllabus for Introduction to Sustainable Energy

**Overview:**
Discussion of global energy systems and their association to climate change mitigation. Assessment of current and potential future energy systems, covering resources, extraction, conversion, and end-use, with emphasis on meeting regional and global energy needs in the 21st century in a sustainable manner. Different renewable and conventional energy
technologies will be presented and their attributes described within a framework that aids in evaluation and analysis of energy technology systems in the context of technical, political, social, economic, and environmental goals.

**Learning Objectives:**

- Understand the tradeoffs, difficulties, and opportunities involved in the development and deployment of the energy systems;
- Understand the methodology for assessing and selecting technologies and policies for energy supply;
- Understand lessons learnt from technologies and policies deployed on local scales, so that unanticipated problems can be remedied before large scale mistakes are made;
- Identify and quantify the technical, environmental, and geopolitical time scales essential to implementing the sustainable stewardship of energy and other natural resources;
- Practice the principles of sustainable energy and communicate to others the importance of choosing more sustainable energy options in our lives, homes, workplaces and communities;

**Textbook:**

*Sustainable Energy – Choosing Among Options.* 2nd ed. J.W. Tester, E.M. Drake, M.W. Golay, M.J.


**Web Sites:**

https://stellar.mit.edu/S/course/22/fa5/22.811j/

http://ocw.mit.edu/courses/nuclear-engineering/22-081j-introduction-to-sustainable-energy-fall-2010/
Other References:

- The Future of the Electric Grid, See http://mitei.mit.edu/publications/reports-studies/future-electric-grid
- Transitions in Alternative Vehicles and Fuels, National Academies Press,
Lecture/Recitation Format:
Two 2-hour lecture sessions per week occasional replacement with a recitation or discussion. Many guest lecturers are featured in the course, and therefore the schedule is subject to change.

Recitations led by the TAs will be scheduled weekly at the start of the term. Then, depending upon the level of student participation, the schedule of sessions will be readjusted to match student interests.

Additional Activities:
We are arranging tours to energy-related MIT facilities/labs. These will be conducted on Fridays (when possible) in place of TA-led recitations. Exact times and details will be determined over the course of the semester. These activities are not mandatory, but we encourage you to attend to glimpse the real life working of facilities.

Classroom Rules:
1. Place your name card where the lecturer can read it. This helps the discussion in class and aids in taking attendance.
2. Be sure to have done the reading before the current lecture and be prepared to discuss it. Contribute valuably to the discussions during class.
3. Please do not use wireless devices or computers during class. If you need to respond to a message go outside of the classroom to do so. For note taking use something other than a computer. Chronic violations of this rule will be noted and reflected in the class participation grade.
Undergraduate Student Requirements

Homework:
One problem set per 4 class meeting days on average. The first four problem sets focus on analytical skills; later problem sets are more comprehensive and integrating. Seven problem sets in total, choose 2 of 4 questions per problem set for the first 5 problem sets, answer each of the questions in the remaining problem sets.

Exams:
There will be two take-home mid-term exams administered to students enrolled in the undergraduate offering.

Undergraduate Grading:
- Homework: 30%
- In-class participation: 10%
- Take-home mid-term exam 1: 20%
- Take-home mid-term exam 2: 20%
- Term paper: 20%
- Student-led discussion, extra credit: 5% (max)

Graduate Student Requirements:

Homework:
One problem set per 4 class meeting days on average. Four problem sets in total, focusing on analytical skills; choose 3 of 4 questions per problem set. The problem sets are the first four problem sets (shared with undergraduate offering).

Term Project:
Graduate students will be required to turn in one written term paper (20-30 pages) with an interim progress report.

Grading:
- Homework: 25%
In-class participation 15%
Term project 60%
Student-led discussion, extra credit 5% (max)

Course Organizational Structure
The course is divided into four parts: Toolbox lectures, Energy in Context, Specific Energy Technologies, and Energy End Use, Option Assessment, and Tradeoff Analysis as shown in Figure 28.

![Course Organizational Structure](image)

The lectures within each of the four segments is detailed below:

**Toolbox Lectures**
1. Energy Resource Assessment
2. Economic Feasibility Assessment Methods
3. Energy Storage and Conversion
4. Electrical Systems Dynamics
5. Energy Supply, Demand, and Storage Planning Methods
6. System Dynamics
7. Risk Assessment Methods

**Part I: Energy in Context**
1. Introduction
2. Sustainability, Energy, and Clean Technologies in Context
3. Global Change Issues and Responses I
4. Global Change Issues and Responses II
5. Electrochemical Energy Storage
6. Historical Factors and Prospects for Change in the Electrical Power Grid
Part II: Specific Energy Technologies

7. Wind Power
9. Fossil Energy II: Types and Characteristics
10. Biomass Conversion to Liquid Fuels
11. Biomass Energy
12. Hydro Electricity
13. Cape Wind Energy and Offshore Wind Projects
14. Nuclear Energy I: Current Technologies
15. Nuclear Energy II: Nuclear Safety
16. Nuclear Energy III: Nuclear Proliferation and Waste Disposal
17. Fusion Energy
18. Solar PV Technologies
19. Solar Thermal Technologies
20. Low Carbon Fuels

Part III: Energy End Use, Option Assessment, and Tradeoff Analysis

21. Economics of Energy
22. Hydraulic Fracturing
23. The Future of Solar Energy
25. Electric Utility Decision-Making II
26. Carbon Capture Sequestrations and Recycle
27. Carbon Reduction Energy Policies
28. Factors of International Energy Cooperation
29. Sustainable Buildings
30. Energy in Vietnam
31. Deepwater Oil Drilling
32. Persistence of Climate Change and Its Implications I
33. Persistence of Climate Change and Its Implications II
34. Electricity in Africa
35. Energy in India
36. Electricity in Japan
37. The MIT Climate Change Response
38. Transportation Technologies
39. A Combined Future Renewable and Nuclear Energy Economy
40. Energy Overview and Prospects

**Recitations:**

- Requirements for a Low-Carbon Energy Economy, I and II
- Course Wrap-Up and Critique
References


