AC 2011-575: INSTRUCTIONAL VIDEOS WITH PURPOSE: COMPENSATE, SUPPORT, AND CHALLENGE CHEMICAL ENGINEERING STUDENTS IN AN INTRODUCTORY THERMODYNAMICS COURSE

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Instructional Videos with Purpose: Compensate, Support and Challenge Chemical Engineering Students in an Introductory Thermodynamics Course

Introduction

Instructors typically address the relatively large spectrum of students’ needs in a classroom by tailoring their instructional interventions toward the average of this needs spectrum. The main challenge that instructors are facing when employing this strategy is how to make sure they are not losing those students that lag behind the estimated class average, and respectively are keeping excited the high achievers. Technology-driven instructional tools were proved useful in addressing this challenge, but novelty of these tools as well as the contextual character of the instructional process place additional burdens on the instructor. The availability of easy-to-use video capture and video editing technology combined with increased capability to make these videos available online made small educational videos (often called “courselets”) useful tools for instructors interested in expanding their classroom activities beyond the lecture time \(^4,^{11}\). In addition, instructors interested to integrate technology in their classroom are likely to get more institutional support. That is, instructional designers and instructional technologists are available to work with these instructors.

This paper presents some strategies related to the introduction of some custom short instructional videos developed created through a synergic collaboration between the instructor of the course and an instructional designer.

Instructional Context

Thermodynamics for chemical engineers is considered by students one of the driest topics in the curriculum. Sophomores enrolling in this course typically undergo a cultural shock as they move away from their freshman engineering experience. Chemical engineers know that elements of thermodynamics are needed to understand how units such as distillation towers, condensers, boilers, mixers, pumps, crystallizers, and so on function. In addition, the chemical engineers use the Laws of Thermodynamics for the analysis of processes. The complexity of these topics needs then to be nurtured in the introductory thermodynamics courses.

At our institution, the chemical engineering thermodynamics course is offered in a two-semester sequence. In the first semester the instructor introduces the principles of the science and limits the discussions to single components. At this level, students are mainly sophomores in their second semester of courses. The emphasis during this first semester is on phase equilibrium, but some time power generation and refrigeration cycles might be included. In the second semester (mainly first semester juniors enrolled in the course) the instructor extends the principles to mixtures and focuses our discussion on phase equilibrium. In addition, this second course covers chemical reaction equilibrium and mixing processes. The combination of a very abstract topic and very young students makes therefore the teaching of thermodynamics a challenging experience.
To be effective learners in this course, students need some thermodynamics background beyond their high school experience and that, unfortunately, very often is not the case. Along with the subjective factors that create this situation, some local instructional factors often play a role in sustaining a lower-than-expected level of prior knowledge. For example, one such local factor is the sequence of prerequisite courses students can take. For examples students learn elements of thermodynamics in their physics class and then enroll in a Physical Chemistry course whose main topic is thermodynamics. They are expected to complete this sequence before they enroll in our second Thermodynamics course. Unfortunately some students take the Physical Chemistry course during the same semester with our second semester Thermodynamics course.

In addition, students’ experience is limited to the use of “off-the-shelf” equations. In other words, their ability to set up a problem from scratch is quite limited. This weakness is often compounded by some limitations in students’ mathematical skills as most of their courses in this area are offered in large courses with a rather de-contextualized context.

When adding these deficiencies to a per-se abstract and conceptually challenging topic, this course is at the verge of disaster. To address the complexity of this context, an instructional designer engaged teamed-up with the instructor to identify, develop and implement instructional strategies that mitigate this course’s complexity.

**Instructional Model**

After about one semester of instructional designer’s classroom visits and follow-up meetings with the instructor it was clear that an instructional model is needed to make the efforts toward enhance students’ learning experiences more effective. The high complexity of the topic combined with the wide range of issues related to students’ readiness to tackle the course challenges pointed toward the Cognitive Apprenticeship as grounding model. Research shows that instructional strategies grounded in the cognitive apprenticeship model can be effective learning tools in various domains such as performance system analysis, clinical training or leadership development.

The redesign of learning materials and strategies was informed by the four stages of the cognitive apprenticeship:

1) **modeling** that enable students to emulate expert in action;
2) **scaffolding** (task complexity reduction) as cognitive support for students in emulating expert performance;
3) **coaching** through deliberate and planned feedback to guide students performance as they move from novice to expert level, and
4) **fading of support**, by removing the existing scaffolds as students become more competent;

This redesign activity focused on both classroom activities and the development of supporting materials that students could use outside the classroom. The process started with identifying classroom activities that match various stages of the cognitive apprenticeship and, when needed redesign them to better address the goals of each stage.
For some of these activities, we developed supporting materials to address needs that could not fit in the available classroom time. Table 1 summarizes the major changes for classroom activities for each stage and the resulted supporting materials and activities.

Table 1. Redesign Results using Cognitive Apprenticeship Model

<table>
<thead>
<tr>
<th>Stage</th>
<th>Classroom activities redesign</th>
<th>Supporting Materials &amp; Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling</td>
<td>Balanced and complemented content information presented on slides with detailed information presented on the board to support active note taking. Developed outline slides to guide students through the exemplary problems worked by the instructor on the board during the lecture.</td>
<td>Compensate for lack of prior knowledge with videos that model the thinking process for complementary areas in the context of thermodynamics problems or contexts (e.g. Calculus video; Mathcad videos)</td>
</tr>
<tr>
<td>Scaffold &amp; Coaching</td>
<td>Transfer problems worked in classroom by the students with instructor’s assistance. Extra classroom worked examples to prepare students for the term project.</td>
<td>Supporting video of major examples worked into the classroom to allow students review the thinking process at their convenience (e.g. Steam Accumulator video). Student peer-teaching sessions: top students trained by the instructor helped their peers with homework issues.</td>
</tr>
<tr>
<td>Fading Support</td>
<td>Homework transfer problems presented to the students at the end of the supporting video. Students’ answers and instructor’s feedback managed online through the course LMS.</td>
<td>A challenging video-driven activity intended to engage high-achievers in a far-transfer problem that extrapolates classroom-based knowledge to new domains (Thermodynamics of elastomers - video under development).</td>
</tr>
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</table>

Small educational videos are the supporting materials that are object of this paper.

Video Production Strategy and Implementation

The main advantage of instructional videos is that fact that they offer a multimodal instructional environment that covers text, audio and images in a seamless and complementary manner. When carefully crafted, instructional videos are able to convey instructor’s perspective in a focused manner helping therefore students to quickly understanding the main ideas conveyed through these instructional environments. Finally, current Web2.0 flexibility and power allows streaming of videos anywhere and anytime making then videos a convenience for today’s digital learners.

Selection of Production Strategy

There are several options to create videos, each offering various strength and weaknesses. The most obvious strategy is to create live-taped videos in classroom settings and then edit and repackage the content in smaller modules.
The clear strength of this strategy is the use of an existing context for the videotaping process. However, the major disadvantages range from relatively poor quality of these videos due to the constraints of a typical classroom (light, position of camera, background noises) to the need to edit the video, as the classroom activity not necessarily follow a “script”. An alternative strategy is to use specialized video recording studios, but its main weaknesses are first the cost of producing these videos and second the need for the instructor to prepare for the recordings in one or more sessions.

A second type of strategy, often called screen casting, involves the use of screen-capture software to generate short videos that unfold a specific topic or the use of a given software application. Compared to live taping strategies previously mentioned, the major strength of this approach is its flexibility, relative low cost and simplicity. However, the task of using the screen capture software and producing the video is still instructor’s full responsibility. The instructor is required to make the time investment needed to learn and use the software, and very often time is a very valuable commodity for faculty members.

Finally, another strategy involves creating videos by combining animated slides and pictures on an audio narrative that serve as the “spine” of the video production. In addition video clip can be included in this structure. We found this strategy as effective due to its two major strengths:
   a) The faculty was able to fully control the instructional materials that were the focus of the produced video;
   b) This strategy facilitated a better division of labor. The faculty member focused mainly on the instructional materials while the instructional designer focused on the production and deployment of the video.

Video Development and Implementation

A short description of the major video development steps and the insights resulted from their implementation will be described in this section.

Scope of the Video

We found that three of the four stages of the Cognitive Apprenticeship model, modeling, scaffolding and fading of support could benefit of supporting instructional materials in form of online short videos and, so far developed short videos for the modeling and fading stages (see Table 1).

First, for the modeling stage we identified the need for three compensatory movies: (a) two to enhance the computational skills related to the use of advanced mathematical software - Mathcad, (b) one to address lapses in the prior knowledge in calculus. The need for compensatory movies resides in that very often students do not meet the expected levels of prior knowledge and skills to successfully engaging in the topic of the thermodynamics course. Research on prior knowledge and their associated instructional strategies indicated two rather contradictory issues. On one hand, the lack of prior knowledge has a significant negative impact on the learning process.
On the other hand, inclusion of pedagogical interventions that proved effective for low prior knowledge students can sometimes be deleterious for high prior knowledge students. In addition addressing these issues during the classroom significantly decreases the time available to tackle challenging thermodynamics topics. Moving this type of intervention outside the classroom by using short videos helped to address these issues and therefore to increase the effectiveness of the overall instructional process.

To produce these compensatory videos while modeling the expert in action, we decided to use examples from thermodynamics to ground the demonstrations of the target prior knowledge. For example for the first supporting Mathcad video the instructor demonstrated how to use this software to calculate the sensitive heat (a constant) of a fluid upon a change in temperature from $T_0$ to $T$ using a set of constants available in students’ textbook. The focus of this first Mathcad video was to introduce students to the basic mechanics of this software (toolbar functions for writing constants, variables and equations, using Greek symbols, using programming functions to run the program, etc.). The context of the second supporting Mathcad video was similar but its focus was to help students learn how to use this software to find and represent the roots of a polynomial equation similar to those they will face in homework problems.

For the compensatory video focusing on multivariable calculus, the application was set in the context of a cylinder and piston system filled with gas. This system was set first for a constant volume experiment and second for a constant pressure experiment. The focus was on helping students to build and solve multivariable functions (e.g., rules of differentiation, properties of exact differentials, state and path functions). By grounding these knowledge and skills in the topic of the course, we intended to help students bridging the generic format of their earlier mathematics experience with the specifics of applying them into the current topic.

Second, for the scaffolding phase we found instructional videos useful because in science and engineering instructors introduce major topics through classroom worked examples to be used by students later on for homework or projects. However, even the good note takers often miss to record important parts of thinking process that the instructor exemplifies while solving those problems. A video of a major worked example available to the students will certainly compensate for this weakness of classroom worked example. In time also several such videos can became a valuable online support for those students that need extra support on difficult topics. For this second phase, the instructor decided to create a short video based on a major worked example used during the first semester of this thermodynamics course, open systems exemplified with a steam accumulator.

Finally, for the fading of support stage we decided to develop a challenge video to engage the high-achieving students in a far-transfer, open-ended tasks. The topic of chosen for this video was the thermodynamics of elastomers and the video for this stage is yet in production. The core element of this material is the recording of a laboratory experiment that produces a “counterintuitive” output. For the first task, the video of the experiment stops short of showing the result and students have to predict that result and provide an explanation associated with their prediction. Then the video shows the actual results and students move to an application of the described phenomenon and asked to solve it with a minimal support from the instructor.
**Instructional Materials for the Raw Video**

With the purpose of the video established, the instructor moved on and collected the readily available instructional materials or generated additional instructional materials as needed. During this stage, the instructor closely consulted with the instructional designer on alternative solutions that: (1) could better serve the identified instructional purpose and, at the same time, (2) help streamline the video production process.

The quickest path for the overall video production is to use only materials that are digital native. However, often production of videos has to adapt to constraints such as availability of adequate hardware and software tools, the need to learn new tools and skills in a short time, or the nature of the readily available materials. Therefore, we used a combination of instructional materials that included handwritten information, PowerPoint slides, computer-generated text and graphics, screen-captures. For example, Figure 1 shows a summary slide used in the calculus compensatory-video that includes a combination of handwritten notes, computer-generated text and graphic.

*Figure 1. Sample material that included handwritten material*

Figure 2 exemplifies the use of a screen-capture used in the Mathcad compensatory video to introduce the basic toolbars of this software. We decided to use screen-shots instead of desktop video captures of this navigation because they allowed the instructor to better focus students’ attention to each of the major tools in these toolbars. In addition, this strategy significantly reduced the demand on the instructor’s time to produce these materials.

*Figure 2. Instructional material using screen capture*

Once the instructional materials selected, the instructor recorded the audio narration for batches or individual parts of these materials.
An alternative strategy used to get the audio narrative, involved a live recording of instructor’s presentation using a lapel microphone to ensure the needed audio quality. This alternative proved effective in the beginning phases of creating these videos when the instructor found a critical topic and decided to create a quick audio “on-the-fly” based on actual classroom activity. One such example is the first Mathcad compensatory video that was initially as classroom activity. Once the set of two compensatory Mathcad videos were completed, this activity changed in an out-of-the-classroom activity that used the video as support for a Mathcad homework task.

While using the video streams recorded during the lectures looks more attractive, we found that giving the instructor the ability to record the audio at own pacing produces a more focalized and therefore a more effective narrative for the video. We used a mid-way solution for generating the scaffolding videos for worked examples introduced in the classroom. We recorded instructor’s audio presentation during the classroom and then the instructor used it as a guide for generating the final narrative for the supporting audio narrative. While the instructor generated the audio narrative, the instructional designer digitized and refined the handwritten materials to make sure that factors such as size of the text or color schemes are optimal for the desired quality of the final video.

Production of Raw and Final Video

We used Camtasia Studio v6 © to generate the video because it offers the power and flexibility needed to generate a good quality video while the learning curve to use this software is acceptable. The production of the raw started with the mixing and editing of the narrative segment by segment followed by the addition of the images that are referred in the narrative. Once the raw video was generated by the instructional designer, the instructor reviewed it and, when necessary changes or additions were made. The final “touch” included the inclusion of the animations in form of highlights, arrows or pop-up text, features allowed by Camtasia (see Figure 1 and Figure 2 above).

Implementation of Videos

The videos run on a web server and students were able to access the video through a link posted in Blackboard for exclusive use of the students enrolled in the class. Following suggestion from the literature, we increased the effectiveness of the video by including a task that required the students to use the video. The task was either the form of a homework included at the end of the video (Figure 3) or, as a separate transfer task when a supporting video was the target of this task.

Figure 3. Homework included at the end of the video
To summarize, the major “how-to” steps we found useful for increasing the effectiveness of generating short instructional videos were:

- Define the purpose of the video by analyzing the critical instructional needs to address. If the cognitive apprenticeship model is used to define these needs, keep in mind the following issues:
  - For compensatory prior-knowledge videos carefully select the context to introduce them;
  - For supporting worked examples select those problems that typically produced the lowest results when introduced only during the classroom;
  - Don’t forget to also find some challenging tasks for high-achievers in the classroom through some more open-ended tasks as this group is typically eager to get extra credit for such tasks;
- Identify or generate the instructional materials that are pertinent for the defined purpose;
- Do an initial selection of the identified materials for an estimated length of the video from 8 to 15 minutes;
- Record the audio related to the selected instructional materials and, if needed, digitize those materials that was generated as hard copies;
- Generate the raw video by matching the visual materials to the audio stream;
- Review and adjust the raw video if needed, and add pointers and animations that will guide learner’s focus on the presented material;
- Implement these videos through tasks that are part of the instructional process of the course.

Exploratory Results of the Impact of Instructional Videos

As the process of generating and implementing these videos required full commitment for both the instructor and the instructional designer, there were not too many resources left to structure a formal research process. However, we implemented a series of monitoring tools that explored students’ perception reflected in both the formal course evaluations and an open-ended survey administered online at the end of the semester. Since this study reports on the activity of one instructor, one first analysis of the impact of introducing these videos into the classroom was the analysis of three questions from the students’ final course evaluations:

1. Rate the instructor’s concern for your understanding of the material
2. Rate the instructor’s preparation for class, and
3. Rate the overall teaching effectiveness of this instructor.

We compared students’ ratings for two fall semesters, first being the one prior to the full implementation of the compensatory and supporting videos. We found a statistically significant increase in ratings for the first two questions ($t_1(22) = -2.26, p < .05; t_2(22) = -3.27, p < .01$) and a statistical marginal increase for the third one, $t_3(22) = -1.97, p < .10$.

A series of open-ended reflective questions were developed and administered to the 15 students enrolled in the fall semester when both compensating and supporting videos were implemented. Analysis of students’ answers indicated an overall positive perception with some of their answers being exemplified below:
I found the videos somewhat useful, especially the Calculus one…I definitely think that the Calculus video is a useful reference for partial derivatives. (Student 1)

Before I looked at the videos, I was stuck in the homework, they helped guide me along to the right answer, and they are very helpful… (Student 3)

The videos were useful refreshers to recall some of the math skills required. (Student 10)

Yes. I am currently in calc 3 so I had no idea how to do the partial derivatives. I found it very helpful. Sometimes I zone out in class and miss something so I think it is good to have the videos to refer back to and make sure that what I heard in class was right. (Student 11)

I do find the videos useful, they are a refresher needed and by posting them you don't waste the time in class. (Student 14)

Some students also provided valuable suggestions both for future improvements of current videos and for topics of interest for future similar instructional videos, as exemplified in the sample answers below:

…videos over some chem.E 120 might be helpful. (Student 3)

A video discussing the types of systems and how and why certain equations apply or don’t apply would be helpful. (Student 7)

I think the videos were helpful, but I would like videos of more worked out examples. Practicing the same thing over and over again helps us build skills, and if we had a video to practice with you could make it in the form of a lecture. That way we could pause the video and try to answer the question on our paper. Ask questions during the video and set up a time to pause so that way we can think and come up with an answer just like we do during the lecture. [italics added] (Student 8)

**Future developments**

Regarding the development of new videos, we intend to finish and test the impact of the challenging video. In addition, the instructor already identified the need for some compensatory videos on information literacy. This video is intended help students improve their performance in the term project that requires them to find, select and analyze scientific articles published in research thermodynamics journal as base for their project.

As for educational research, we intend to set a more formal research process that will include pre and post survey to compare students’ expectations and perceptions related to these videos. In addition to the perception analysis, we intend to analyze the impact of students’ performance on the tasks related to these videos on similar homework and test problems as well as on the overall students’ performance.

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