Pedagogical And Structural Considerations
In The Design Of
A Set Of Control System Lessons

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Abstract

This paper discusses design considerations for a set of electronically delivered lessons on control systems. The design of these lessons is based upon pedagogical principles initially discovered by Kolb, and which have have come into wide use in engineering education. The design of the lesson set is also influenced by certain structural considerations related to the platform on which they are delivered and the authoring system in which they are written. The paper discusses how all of the design considerations influence the actual structure and implementation of the lesson set.

Introduction

This paper discusses the design of a set of electronically delivered control system lessons. Classical control systems is a discipline taught by electrical engineering, mechanical engineering (sometimes emphasizing system dynamics) and chemical engineering (emphasizing process control), and there are numerous texts in the area. It is a discipline that is rich in visual tools and graphical design procedures including at least frequency response plots and methods (Nyquist and Bode’ plot based) and the root locus. As such it gives ample opportunity for pictorial presentation of information and has a large number of opportunities for simulation and graphics animation, all making it attractive for electronic delivery. In addition, students are more oriented to electronic delivery of material, web based and others, and often find printed texts to be less useful than we, the instructors, believe.

We have experimented with electronic delivery of other course material in the linear stem of our curriculum, with apparent good results, and, in the early part of 1998, decided to embark upon development of an integrated set of material for the course(s) in classical control systems. Our engineering background predisposed us to design these courses using what we knew of what was available about how students learn and their
various learning styles. In other words, as engineers we wanted to base the design of the lessons on the best available design principles in this area.

There is a large amount of pedagogical research that supports different approaches to course organization and presentation of material. We were particularly familiar with the Kolb cycle (1,2,3,4), and decided to base the design of the electronic modules on that work. The Kolb cycle concept has substantial evidence for its effectiveness. It is a concept that seems particularly attractive for engineering faculty and students, and its implementation is straight-forward and relatively easy in our context.

While the Kolb cycle is the foundation for the pedagogical aspects of the lessons, there are other aspects that we had to consider. The general esthetics of the design are important. Also, the structure of the lessons has a great effect on the accessibilty of material. In particular, most engineering material is not really as sequential as the numerical order of pages in a text would imply. Control systems, in particular, is really a web of interconnected knowledge, and it seemed especially desirable to give different ways of accessing the information in the course modules, especially with hyperlinks between and within modules. Students who work in the context of the world wide web are used to that sort of navigation. However, there is a challenge in providing hyperlinked navigation and still keeping a consistent navigation scheme that students can become familiar with.

Thus, we were led to at least three strong design considerations in these lessons - pedagogical, structural and esthetic considerations. In the following sections we will discuss how those considerations influenced the eventual design of the lessons.

Pedagogical Considerations

When we design a circuit or a structure like a bridge, as engineers we invent the circuit or bridge out of our imagination, but we then use various tools – based on physical laws – to predict the performance of our design. In a circuit we might use a tool like Spice – a tool based on Kirchoff’s laws, for example – to predict the performance of our circuit design. When designing electronically deliverable lessons we take somewhat the same approach. We will invent a course for delivery of material to be learned, we use our imagination to produce a structure to accomplish our purpose. This structure should be based upon available knowledge of pedagogical principles – what is known presently about how people learn and how to deliver material in the way that maximizes learning and retention of the material.

One important concept is based upon work done by Kolb with engineering students at MIT. He found that learners work through two processes as they learn material. First, they perceive new material, then they process it to incorporate it into their store of knowledge. Kolb found evidence that how learners initially perceive material and how they process it could both be thought of in terms of bi-polar situations.
In other words, there are essentially two different ways that learners initially perceive material, and two different ways that they process it. Thus, there are four different combinations that learners can use to learn new material – four different learning styles.

Kolb found that the ways learners perceive new material was either by feeling (sensing) or by thinking (symbolically, conceptually). Kolb found that the ways learners processed new material was either by watching and observing or by becoming actively involved (doing). The modes of perception have now been named Concrete Experience (CE, for feeling/sensing) and Abstract Conceptualization (AC, for thinking). Similarly, modes of processing have been labelled Reflective Observation (RO, for watching) and Active Experimentation (AE, for doing). Additionally, looking at the four different combinations of perception and processing, names have been given to the four kinds of learners thus defined.

Concrete Experience/Reflective Observation Divergers
Abstract Conceptualization/Reflective Observation Assimilators
Abstract Conceptualization /Active Experimentation Convergers
Concrete Experience / Active Experimentation Accomodators

Each of these learning types has a preferred way of learning, each has a preferred set of learning activities and – most importantly – each has a particular question that s/he likes to have answered in the course of learning new material.

The Diverger asks “Why?” (Why learn this material?)
The Assimilator asks “What?” (What is it I have to learn?)
The Converger asks “How?” (How can I use this material?)
The Accomodator asks “What If?” (What if this one thing were different?)

There has been a significant amount of work done that shows that answering these questions sequentially, cycling through a satisfaction of each learning style in sequence, will produce better overall learning for all types of learners. More importantly, that approach reduces the tendency to eliminate (e.g. through transferring out) different types of learners, especially when the difference is a difference between the learning style of the student and the learning/teaching style of the instructor.

The lessons described in this paper were designed so that – as much as possible – they cycle through answers to the four Kolb questions. In that way, each sub-topic may warrant its own set of Kolb question/answers. In particular, each lesson opens to a page that has hot words that take the student to different sections within the lesson. Figure 1 shows such a page. There are five sections in this lesson on Nyquist plots. The first two sections answer questions about why the student needs to learn about them. The second section discusses what they are. The next two sections talk about how some particular plots are used, and the last section discusses what happens when things are different, the "What If?" question from the Kolb cycle. This scheme does not guarantee that each
student cycles through the Kolb cycle, but it strongly encourages that approach, and our experience is that most students will work through each lesson more or less sequentially.  

There are other pedagogical aspects to the lessons. As we noted earlier, this material is rich in pictorial and graphical content. That presents many opportunities to get the students involved in ways that increase the number of senses they use. There is a body of research that indicates that a lecture that involves only lecturing (hearing) is not as effective – in the sense that material is not as well retained – as a lecture that involves use of lecturing (hearing) and any sort of visual aids (seeing). For maximum retention, having the students use their hands (pencils?) to calculate answers or to sketch a part or a graphical example, etc., will greatly improve learning retention.

In these lessons, there are numerous ways that students get more involved. It is easy to design a set of lessons that works out to be a glorified “page-turner” for text. However, there are numerous other things that are incorporated into these lessons.

♦ Asking questions – with numerical answers – which can lead to contingent navigation to different parts of the lesson or different lessons, depending upon the answer given,

♦ Auditory feedback for correct and incorrect answers,

♦ Graphical movies that illustrate system performance change with change in system parameters. In classical control systems, there are numerous opportunities for some interesting visual effects as, for example, root loci change form dramatically as a compensator singularity changes position. Note that typical movies are “one-dimensional”, but these lessons include some two-dimensional changes. For example, there is a page that lets students move a dot around the s-plane to show changes in step response for different damping ratios and natural frequencies.
Finally, the lessons incorporate some explicit objectives. These have only been incorporated recently, but they follow a specific format like this one:

*Given* a root locus for a system with an arbitrary set of open loop poles and zeroes.  
*Determine* the gain for a given closed loop pole location.

There are two important effects of incorporation of these objective statements. First, students have a very clear idea of what they are to learn, and are subsequently able to focus on accomplishing the objective. Our experience testing the lessons indicates that this is an effective aid to learning. Secondly, given ABET 2000, instructors are often anxious to determine effective objectives and goals they can document, and the objectives incorporated in the lessons are intended to help in that regard. In general, we have embedded the objectives in the "Why?" sections of each module so that students encounter them early in their work on any given module.

**Structural Considerations In The Design**

There are some obvious structural considerations in the design of any lesson set. Here are some of those.

♦ There should be a consistent way to navigate through lessons.
♦ There should be an obvious way to work through the lessons.

Each page of a lesson - except for the opening page in each lesson - has a navigation bar at the lower right - in the corner. That navigation bar has a pop-up text field that tells what action each button performs - return to the starting page, go to the previous page, go to the next page, or exit the lesson. That navigation scheme is absolutely consistent throughout the entire set of lessons.

![Figure 2](image_url)

Besides navigation within lessons, there is an issue of navigation throughout the set of lessons. The lessons are written in an authoring system called ToolBook (from
This authoring system is based on a page metaphor, much like world wide web pages. The authoring system permits customization of menus, so, initially, the approach taken was to permit access to the lessons by using a customized menu. Each menu item in the customized menu corresponds to a lesson on a particular sub-topic. This approach works well, and the first author was satisfied with that design. However, the second author (Hoyt) noted that the menu design was especially appropriate for a global thinker, but not well suited to a sequential thinker, who may wish to proceed through the lessons sequentially. A sequential thinker may find it hard to keep track of where s/he has gone in a multi-layered menu structure.

In response to this concern, a second method of accessing the lesson material was added. That addition was a complete outline that gave exactly the same access to the material as the menu structure. In that way, both types of thinkers could navigate through the lessons. After addition of the outline then students could access any given lesson through either of two methods. For example to get to the lesson on Nyquist plots, the student could do either of the following.

- Using the menu follow the menu-path **Basic Concepts -> Frequency Response -> Nyquist Plots**
- Using the outline, pick the hot word Nyquist plots from the outline (hot words are underlined:

  Frequency Response
  Introduction
  Nyquist Plots
  Bode' Plots

These two navigation schemes are one-to-one. Each menu item corresponds to an item in the outline, and vice-versa. However, as students use the lessons, they often need to revisit particular pages for particular points on a topic. An overall index - much like a conventional book index, but with hot-words instead of page numbers - permits students to access particular points in most lessons. Thus, if a student need to revisit material on how to calculate damping ratio for a pole location, it is possible to get to that particular page, even though that page is buried within a more general lesson on second order system response. However, once within the lesson, the student can navigate to any point in that lesson using the navigation bar described earlier. Within lessons, students normally navigate from page to page with the navigation bar described earlier. Within a lesson there are hyperlinks that may start another lesson, move to a different page within the lesson, or show other pages. There are also some contingent navigational decisions, where a user will move to one of several locations dependent upon an answer to a question.

Another structural aspect of the design is the requirement that the lesson set play on as many platforms as possible, staying within the "wintel" world. With an extensive number of avi-files, we initially used the ToolBook stage object to play avi files. However, changing monitor resolution and font size (e. g. large fonts vs. small fonts as a display option) can cause conflict between object and text positioning on a page in this particular authoring system. To eliminate that possibility of conflict, the entire lesson set
has been modified to play all video ("avi") files in floating/movable windows, for example, when the option would be to play avi files in a ToolBook stage object.

**Other Design Considerations**

In addition to the material, pedagogical and structural considerations in the design there are clearly other considerations. In particular, there is a need to pay attention to the aesthetics of the design.

Initially, as we started writing lessons in this general format, our initial efforts resulted in color schemes that can best be described as garish. Although it is tempting to blame that on a limited color palette in early versions of the software, the fact is that the primary lesson author was relatively inexperienced in this regard. The present set of lessons has matured considerably, at least in our opinion.

The present lesson design has several esthetic characteristics that are worth noting.

♦ The opening page, from which the learner navigates using the menu system, has a natural photo background - trees against a sunset. The set of control lessons is titled "Exploring Classical Control Systems", and is part of an "Exploring - - " series. To take the edge off a purely technical "feel", and to emphasize the "Exploring..." theme, we chose to show photo backgrounds from various areas. That choice of background gives an entrance into the lessons that is interesting, albeit non-technical, and seems to attract the students’ attention. It also clearly identifies the set of material on which the student is working since it is distinctly different from splash pages for any other software.

♦ The background is a textured, neutral color. It allows good contrast with the different colors we have chosen to emphasize various "word uses". For example, important words, especially words introduced for the first time, are in dark blue and bolded. Hot words are light blue, and titles are dark green. The background color and texture permits those colors to stand out so that the importance and function of a particular word or phrase can be coded into the color and style of the text.

♦ The background is generated from a small bitmap used repetitively as a ToolBook resource. That permits one small bitmap to generate a larger background, and keeps the file size smaller when the book is stored.

**Summary**

At this point the control systems lessons have been used in the fall of 1998 for the course taught within electrical engineering. Other lesson packages are planned or being produced for courses in Introductory EE, Basic Circuits and Linear Systems. The Introductory EE package has been used in several courses with good results.
This design approach is being followed in the development of three sets of lessons, the control systems lessons described here, a set of lessons on introductory material in electrical engineering, and a set of lessons on laboratory equipment within the electrical engineering department. As we gain experience with lesson design we find that previous work that does not fully incorporate these principles often is not judged to be of high quality, both by the authors and faculty, and by the students. In those cases, we find that we need to go back and re-work previous lessons to bring them up to these standards, incorporating the design features and principles presented in this paper. The evolution of the design standard is an on-going process, and as we learn, we try to enforce a uniform standard throughout the lessons.

Student reaction to this approach is good. We note that students use the lessons extensively. When the lessons are not accessible, for any reason, complaints arise, and that is the best indication that students rely upon them. That’s especially true in the case of final exams where students were given access to the lessons, and demand permission to move when the electronic lessons are not available.

Bibliography


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