Session 1630

Helen L. Plants and Charles E. Wales, A Retrospective

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Abstract

This paper describes the approach to the design of engineering education used by Helen Plants and Charles Wales at West Virginia University. Techniques used included behavioral objectives, generating correct responses, regular assessment, feedback and positive reinforcement, and programmed instruction, combined with regular class meetings. This method was shown to give measurable improvements in student achievement.

Introduction

The summer of 1999 brought the deaths of two pioneers in engineering education, Charles Wales and Helen Plants. Both served as ERM Chair, were in the first class of ASEE Fellows, and together they served West Virginia University for a total of about seventy years. As stars in the ERM firmament, both reached their zenith during the early 1970's. Their work stands out from most of the other leaders of that period for two reasons: they presented statistical evidence that their methods actually worked, [1, 2, 3, 4] and each of their innovative courses served students for over a decade in a stabile environment.

Both were strongly committed to the concepts that education is something which can be designed using engineering methods, that educational design itself is a discipline which can be taught, and that there are concepts in educational psychology which actually work. Both believed in the importance of underclass instruction, and in the serious commitment of resources to teaching of freshman and sophomores as preparation for professional course work. Both lead teams of instructors in their respective service courses.

West Virginia University (WVU) was a fertile place for their efforts. WVU has a traditional commitment to teaching, rather than selecting, for excellence. (WVU has achieved a good record in producing Rhodes Scholars and university administrators by helping students and faculty understand the qualifications, and the current institutional slogan is "Success - Expect It.") It was within this context that Helen established the doctoral program in engineering education,[5] to which Charlie made a major contribution.

Education By Design

Engineering design is based on the notion that design is a form of art in which scientific principles are used to improve our efficiency in selecting components and parameters for a product. It begins with careful specification of product performance requirements, and acceptance tests are designed before the product. It culminates with product testing and, more often than not, iterative product improvement before commercial distribution.

Like engineering design, educational design is based on product specifications. It is true that it is impossible to predict exactly which skills learned in a sophomore course an individual student will be called on to use during his career. But it is also impossible to predict whether an individual sport utility vehicle will ever be run at speeds in excess of 80 mph, be used off-road, or ever run on ice. Similarly we can not predict with any accuracy which features of an "office suite" software package will be used by a particular buyer. The variety of end use of a product means that we must be more thorough in developing design specifications, rather than more casual.

What is the product of an educational design? This is a subtle, but important issue. Many educators in the 60's yelled "Students are not widgets which can be banged out without regard to their feelings." At that time most of us in engineering viewed products primarily as physical objects. With our more recent experiences with computer software, it is easier for us to see processes, as well as objects, as products to be sold or licensed. Typically the target product an educational design is a program which a student uses to carry out some learning task. We design the process, not the student. The lexicological issue was complicated by other current notions of "programming" people as if they themselves were merely machines.

Psychology as a Scientific Basis for Education

No engineer would say that Kirchoff's Law tells you how to create a new circuit, or that Newton's laws tell you how to plan a bridge. Physical science helps a designer to understand and refine a design.

Plants and Wales approached psychology as they approached physical science. They looked for "laws" which seemed to explain relationships between design variables. They accepted that many common physical laws break down at "atomic" levels, and are therefor not "universal truths." They accepted current psychological principles primarily as empirical descriptions.

Most of their detailed design approach was based on behavioral principles, but not on behavior***ism*** as a philosophy. At the same time, they both used a lot of "cognitive" ideas in trying to establish the difficulties faced by students. During the 1960's, B.F. Skinner created a lot of hostility to behaviorism through his stand that all behavior is based on conditioning (seen by some as a denial of "the soul"), but most of what is taught in the behavioral theories seems to be almost unexceptional thinking when presented as rules-of-thumb. The core of principles on which Wales and Plants relied might be listed as follows:

* Focus on Behavior - As a practical matter, you never know what students are thinking, you can only observe what they do, or don't do.

* Use Behavioral Objectives - The formalized approach of Mager and Bloom helps structure design specifications.

* Use Positive Reinforcement - People tend to respond positively to rewards, and negative results tend to increase anxiety.

* Generate Correct Responses and Give Immediate Feedback - You don't want to teach students to screw things up, and you don't want them to spend their time practicing incorrect methods.

* Inform Students of Expectations - Give students a clear understanding of what skills they will be expected to demonstrate during a course.

* Plan Mastery-Based Outcomes - Assume that all students entering with the prerequisites can master all basic course objectives, and that the majority of all students will actually do so.

* Study Problem-Solving Methodologies - Understand how problems actually are solved, and work to convey this understanding to students.

* Examine Step Sizes and Step Counts - People can only make steps of limited size, and can make only a limited number of steps in a session.

* Evaluate Your Products - Test your students not only to evaluate individual performance, but also to measure the success of your educational system.

Because of the great importance of proper specifications in the design process, it turns out that a great deal of the designers' efforts are devoted to this part. As objectives become clear in detail, the preparation of appropriate activities, whether microscopic or macroscopic, often becomes a relatively simple, although lengthy, task.

There were two "gospels" for educational goal writing in the 1960's, *Preparing Instructional Objectives*, by Robert Mager,[6] and the *Taxonomy of Educational Objectives - Cognitive Domain*, by Benjamin Bloom.[7] Mager's work focused on "terminal objectives." Helen wrote terminal objectives of the following sort for mechanics courses.

-- When a student has completed Unit J, he will be able to determine the force in any designated member of a pin-jointed truss using the method of joints, and tell whether the force is tension or compression. The student will do this in a examination setting, finding forces in three members within 15 minutes, and using only pencil, paper, and either a slide rule or pocket calculator.

Bloom's work focused on differentiating between final and intermediate requirements. In the automotive world, a design team might include "turn a lap at the Datona Speedway at 125 mph" as one terminal requirement. Along the way to a finalized design, other requirements such as "must have an effective tire outer diameter of 28 inches and a maximum tread width of 10 inches." Bloom also helped us understand the power of learning to specify extremely complex outcomes and involving students in high level skills such as synthesis and evaluation.

One of Charlie's papers details objectives on the Second Law of Thermodynamics for an introductory thermodynamics course. [8] He lists skills such as "state and write the Second Law from memory," and "solve for any one variable in terms of the others using algebra," as well as "analyze a story problem, choose the known variables from the problem statement, and solve for the unknown variable." If the student can do the latter, a considerable degree of mastery may be inferred, but if failure occurs in our program at this level, we need to establish whether we need to devote more attention to basic knowledge, mathematics, or some other specific skill.

Of course writing objectives for a basic "content driven" course, or even a "freshman design" course, is easier than doing the same for a "capstone design" course. At the basic level, it may only be necessary to translate existing exams and texts. When I became involved in senior design, I found it necessary to flounder through the imprecisely stated objectives of the design area, [9] and my experiences with that were of great help when I became involved in a freshman course revision.

Writing Behavioral Objectives and giving students a clear understanding of expectations are not synonymous. The instructor must see the complexity of such things as choosing between alternate methods or dealing with excess information from the beginning. The student is happier, and therefore probably more successful, if these are only revealed toward the end of a program. Sophisticated designs motivate students by providing various "need to know" clues based on both "real world" and "to ace this course" scenarios.

Detractors of the systems approach often say "Of course if you tell students exactly what you want them to learn, they'll do it." We were committed to the operation of our degree programs as a training scheme rather than as a filtration plant. The real power is learning to specify extremely complex outcomes which involve students in high level skills such as synthesis and evaluation. When that level of performance is required, you deliver precision education, not cheap results.

Programmed Instruction

Both Helen and Charlie stopped "lecturing." That is, they stopped using the traditional lecture coverage of basic information and problem solving routines. Both continued to use significant amounts of instructor led classroom time, but programmed instruction textbooks were used for most "content transmission."

As noted above, in programmed instruction it is the instruction, not the student, which is programmed. When engineering students are drilled, it is not to make them automatons, but rather to help them respond rapidly to situations. Programmed instruction, as it was used in the 1960's, can still work effectively, but it is unlikely that anyone will ever successfully market it. It was, basically, a paper application of the principles described above. If we were starting anew with the same goals, we would probably use the same techniques in the design of Computer Based Instruction (CBI).

Little of the current CBI is sufficiently sophisticated in design to warrant the title of Programmed Instruction. Much of it consists simply of linked readings. Exercises are often simply quizzes on terminal behaviors, which test, but don't shape, student abilities. And last but not least, few current CBI authors appear to be following a path of rigorous self-assessment of program performance.

What do you do in class if there is no need to transmit content? Helen's team usually taught mechanics classes by beginning with a "post test" (quiz), and devoting the remainder of time devoted to feedback, discussion, and group problem solving exercises. [10] Charlie's team members were to focus on design problems, with quizzes to assure students had adequate content knowledge. [10]

Changing Students' Attitudes

Affective behavior, or behavior indicating attitudes, can also be prescribed and measured. Robert Mager noted in a 1969 article in Engineering Education that no one accuses a developer of spoonfeeding or mollycoddling a physical device, nor do we say that such a device lacks motivation. Engineers know that such systems operate according to rules of behavior, and that the probability that a system will function in the desired manner can be increased by changes in design and production parameters. Many of the same engineers declare that human beings should never be manipulated, but should be motivated through preaching.

Plants and Wales both considered affective change to be part of their brief. They worked on constructing facets of their courses which would help students to modify their attitudes if they wished to become engineers. It was the more efficient handling of the routine portions of the courses which allowed them time to act as mentors and role models.

It is, in fact, sometimes not particularly important that we "teach," if we provide students with proper objectives, resources, and tests – and rewards. You have only to watch students involved in national contests such as the SAE automotive designs and ASCE structural designs to see this. At the same time, it is important to study how carefully rules are structured to ensure that students master skills in such diverse areas as manufacturing processes, analysis, and communications. At the institutional level, it is always critical that students are monitored, and supported in a way consistent with local curricular objectives.

Dead Authors - Living Concepts

Given the limited attention which the principles described in this paper receive today, you might think they have been forgotten, but that is far from the case. In fact, ABET 2000 is based on many of these principles, and it owes a great intellectual debt to the many ERM pioneers of the 1960's. If you teach in an ABET accredited program, you will be doing much of the work required for education by design, you might as well harvest the benefits which can be drawn from it.

Bibliography

The papers by Plants, Wales, and Venable listed below are now available on line at http://www.cemr.wvu.edu/~wwwenged/

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