A framework to generate learning objectives based on Vincenti's categorization of engineering knowledge

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Abstract: - Generation of learning objectives is one of the first steps in instruction design. Bloom's Taxonomy is widely used, from primary to higher education, to generate learning objectives. The cognitive domain competencies are categorized into six levels in Bloom's taxonomy. These levels do not take the categories of the knowledge specific to domain of concern. One categorization of engineering knowledge is due to Vincenti. This paper presents a framework to generate learning objectives for an engineering course based on Vincenti's categories of engineering knowledge, and Bloom's taxonomy of cognitive domain.

Key-Words: - Learning Objectives, Vincenti's Categorization, Engineering Knowledge, Bloom's Taxonomy

1 Introduction

Learning objectives, many times called behavior objectives or performance objectives, are statements of what students should be able to do to demonstrate their mastery of a course. Objectives guide the instruction designers and instructors in selecting/developing the content, developing an instructional strategy, and assessment instruments. Generation of learning objectives is not only necessary for instruction design but also to instructors, students, curriculum supervisors, and administrators. They help the students to know what they are supposed to learn. Curriculum supervisors and administrators will be able to develop quality assessment instruments based on these learning objectives and implement quality management systems.

Bloom's Taxonomy of cognitive domain and Robert Mager's methods to write learning objectives are widely used by educators. These methods help us in classifying the learning objectives, but do not provide any framework that would help in taking the categories of knowledge related to the subject of concern, and the objectives of the programme of which the course is one element. One categorization of engineering knowledge is provided by W. G. Vincenti. The course objectives are identified by the instructor in the context of programme objectives, which are chosen by the curriculum designer or in the context of an accreditation mechanism like ABET. This paper presents a framework to generate learning objectives for engineering courses in the context of Vincenti's categories of knowledge and Bloom's Taxonomy. The first course on Control Systems is chosen as a vehicle to exemplify the proposed process of generating the learning objectives.

2. Vincenti's Categorization of Engineering Knowledge

In the perception of many, modern engineering is seen as taking over its knowledge from scientists and, by some occasionally dramatic probably intellectually uninteresting process, using this knowledge to fashion material artifacts. From this standpoint of view, studying the epistemology of science should automatically subsume the knowledge content of engineering. In view of several historians, technology and engineering appear not as derivatives from science, but autonomous bodies of knowledge, identifiably different from the scientific knowledge with which they interact. Engineering has its own significant component of thought, though different in its specifics, resembles scientific thought in being creative and constructive; it is not simply routine and deductive as assumed in the applied-science model. In this view, engineering, though it may apply science, is not the same as or entirely applied science. Design, one of the core activities of engineering, involves tentative layout of the arrangement and dimensions of the artifice, checking of the candidate device by mathematical analysis or experimental test to see if it does not. Such procedure usually requires several iterations before finally dimensioned plans can be released for production. Numerous difficult tradeoffs may be

required, calling for decisions on the basis of incomplete or uncertain knowledge. W. G. Vincenti [1] identified six categories of engineering knowledge, as given below, after exploring several historical cases of engineering activities.

1. **Fundamental Design Concepts (FD)**: Operational principles of the devices. Operational principles also exist for the components within a device.
2. **Criteria and Specifications (CS)**: Quantitative goals and design criteria.
3. **Theoretical Tools (TT)**: Mathematical tools, physical principles, and theories based on scientific principles but motivated by and limited to a technologically important class of phenomena or even to a specific device.
4. **Quantitative Data (QD)**: Descriptive (physical constants) and prescriptive (how things should be) data.
5. **Practical Considerations (PC)**: An array of less sharply defined considerations derived from experience in practice, considerations that frequently do not lend themselves to theorizing, tabulation, or programming into a computer.
6. **Design Instrumentalities (DI)**: Procedural knowledge including the procedures, way of thinking and judgmental skills by which design is done. Standard practices used to solve design problems.

It is desirable to use this categorization to identify topics, concepts, criteria, quantitative data, the nature and complexity of problems that the students should be able to solve. This would ensure that learning by the student is compatible with the programme objectives and the industry needs. Such an exercise would also facilitate in identifying the learning resources that need to be generated.

3. Bloom's Taxonomy

In 1956, Benjamin Bloom [2] headed a group of educational psychologists who developed a classification of levels of behavior important in learning. This became a taxonomy including three domains; cognitive, psychomotor, and affective. Each of the learning domains has been categorized into levels known as 'taxonomies'. Bloom identified six levels within the cognitive domain, from the simple recall or recognition of facts, as the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation. The six levels are

1. **Knowledge (Recall)**: Recall, knowledge of specifics, ways and means of dealing with

specifics, and knowledge of universal facts, generalizations, theories and structures
2. **Comprehension**: The ability to grasp the meaning of materials, including interpretation and extrapolation (cause and effect, summarizing, etc.
3. **Application**: The ability to use learned material in a practical manner, or within a new situation, using rules, principles, etc.
4. **Analysis**: The ability to criticize, deconstruct, identify assumptions
5. **Synthesis**: Relating one theory to another, combining and re-constructing ideas, seeing relationships.
6. **Evaluation**: The ability to appraise, assign value, assesses arguments, etc.

There are three main components of a learning objective [3].
1. Verb (Specify Action, Measurable)
2. Condition (Condition under which task to be performed)
3. Criterion (Accuracy, Criterion to meet)

Different techniques of writing objectives have been proposed by different educationists. Two of them are commonly used. One is proposed by Robert Mager (1975) and the other proposed by Norman Gronlund (1985). Mager [3] type objectives are very much precise and must have all three components which requires an unduly large number of objectives to be prepared, and makes objectives very lengthy. To overcome such difficulties Gronlund [4] suggested a system of writing objectives at two levels. He suggested that first level should define general objectives followed by sample specific behavioral objectives at the second level. The teaching should be directed towards achievement of general objectives where as sample specific objectives form the basis for evaluation.

4. A framework to prepare learning objectives

In most of the models for instruction design (Dick & Carey, Hannafin & Peck, Knirk & Gustafson, Gerlach & Ely, Rapid Prototyping, and Jerrold Kemp [5]) preparation of learning objectives follows the steps of need analysis and requirements of the target groups. This sequence, however, when applied to formal engineering courses brings in some limitations. Text books, many times, act as the frameworks for generating the learning objectives. Text books focus on design principles, theoretical tools and some times on quantitative data, and very rarely on the other three categories of

engineering knowledge, namely, criteria and specifications, practical considerations and design instrumentalities. These three categories of engineering knowledge represent the gaps between the competencies of graduating engineers and the needs of the industry. While some instructors create the learning objectives taking all the categories of engineering knowledge into account intuitively, majority do not. A framework that is based on Vincenti's categories ensures that some very important dimensions of a given course are not ignored by default. Therefore, an analysis of the subject with regard to the six categories of knowledge would enable the instruction designer in creating better learning objectives.

A framework that takes advantage of the Vincenti's categorization of engineering knowledge in generating the learning objectives is characterized by the following five steps.

Step - 1: Identify the aim of the course that is also indicative of the scope of learning.

Step - 2: Identify all the components that need to be considered under the six categories of knowledge, preferably exemplifying wherever required.

Step - 3: Write syllabus of the course and arrange it as Modules.

Step - 4: Identify one or two generic learning objectives for each cognitive level. Generate sample problems at all cognitive levels relevant to the course under consideration paying attention to the relevant categories of knowledge. Write the learning objectives of the course using Gronlund style.

Step - 5: Repeat this exercise for all the Modules of a course.

5 Learning Objectives of a first level course on Control System Design

Let us consider the process of generating learning objectives for a first course on Control System Design as per the five steps mentioned above.

1: Aim of the course: The aim of the course is to enable the student to acquire the ability to analyze, design and evaluate SISO electromechanical and chemical processes control systems using SCILAB tools.

2. Components of the course as per Vincenti's categorization: The components of the control systems course are identified in this step.

Fundamental Design Concepts: PID feedback control for specified performance requirements. Feed forward control for specified disturbance rejection, cascade control to improve performance.

Criteria and Specification: Transient response, stability criteria, disturbance rejection and robustness.

Theoretical Tools: State space models of SISO engineering systems with emphasis on electro-mechanical, and process systems, system responses in time domain, Liapunov stability, and tuning of controllers

Quantitative data: Transient and steady state performance requirements for electro-mechanical and process systems, physical and chemical constants associated with electro-mechanical and process systems, data sheets of sensors, actuators, and controllers.

Practical considerations: Available sensors, actuators, controllers and elements of the plants, disturbances to the system, cost of control, dependence on SCILAB, and industry practices.

Design Instrumentalities: Standards (diagrams, documentation, data exchange and transmission), procedure for designing controllers.

3. Syllabus of the course and Modules

Module 1: Introduction to Control Systems: Need of control, manual and automatic control, advantages of automatic control, open loop and closed loop control, components of the control loop.

Module 2: Modeling of dynamic systems: State space models, modeling electromechanical and process systems.

Module 3: Analysis of control systems: Step response of the system, response to ramp inputs, stability, response to disturbances, and sensitivity to parameter variations.

Module 4: Output feedback control system design: Regulator and tracking problems, analysis and design of PID controller, limitations of PID controllers, cascade, ratio, and feed-forward controllers.

Module 5: Controller implementation issues: Controllers and actuators, architecture of commercial controllers, selection of controllers, operation of controllers, tuning of controllers.

Module 6: Nonlinearities in control systems: Nonlinearities encountered in control systems, effects of nonlinearities on the performance of the system, some methods of handling effects of nonlinearities

4. Learning objectives of the course:

Generic objectives, sample problems that pay attention to categories of knowledge for a first level control system design course are shown in Table 1.

Table – 1 Learning Objective for first level course on Control System Design

Bloom's Cognitive domain level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed
Recall	Define the terms related to system, controller and control loop.	1. What is negative feedback? 2. What is "system" and define the state of a system? 3. List all the features of a step response? 4. List all the commonly encountered nonlinearities in control systems?	TT

Bloom's Cognitive domain level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed
Compreh-ension	Explain in depth the design consideration for a control system.	1. How does the negative feedback influence the behavior of a dynamic system? 2. When do you opt for cascade control? 3. Explain how does the accuracy of a model play a role in application of feed forward control? 4. When do you say that system is in steady state? 5. Explain how does saturation of one state variable affect the performance of a feedback control system?	TT
		1. What is the most attractive point of linearization for control purpose, and why? 2. What are the desired values of performance measures of a drill positioning system?	PC

Bloom's Cognitive domain level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed
Application	Develop a mathematical model of a system.	A reactor tank is designed well, with baffling and impeller size, shape and speed such that the concentration should be uniform in the liquid. Develop a state space model of a system. The data given are as- Input flow = 0.085 m^3/min, Volume of tank = 2.1 m^3, Input stream concentration (C_{AO})= 0.925 mole/m^3. Make necessary assumptions.	TT, QD, PC

Bloom's Cognitive domain level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed
Analysis	Analyze performance of a given SISO control system.	A cylindrical level tank has diameter of 2m and height of 1m. At steady state the inlet flow of liquid is 0.5m^3/min and level in a tank is 0.8m. If the inlet flow is decreased to 0.4m^3/min, when will the level in the tank reach the steady state? What will be the new level in a tank? What is the steady state gain? Prepare the state space model of a system. Find out the Eigen values and comment on stability of the system.	CS, TT, QD

Bloom's Cognitive level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed
Synthesis	Design a controller for a given system to meet a set of specified performance requirements.	**1.** Design a position controller for a PCB drilling machine. Identify the performance criteria for a control system considering the accuracy needed in drill positioning. Select a suitable control scheme. Model the plant taking the mechanical and electrical parameters of the devices constituting the plant. Identify all the limitations of the devices. Consider the PCB drill file format e.g. EXCELLON or S & M while designing the controller. Follow the standard control system design practice.	FD, CS, TT, QD, PC, DI
		2. Chemical reactors are widely used in industries like pharmaceutical, fertilizers, petrochemicals etc. Chemical reactor needs different types of controls like concentration of output product in spite of the concentration change in input feed. Many reactors need control of operating conditions for safe operation and quality output product. Operating temperature and pressure control is very crucial in many chemical reactors for safety and quality output. In an isothermal CSTR in a pharmaceutical plant a A First order reaction takes place as A → B. A plant manager wants to sell a reactor exit stream with a concentration of C_b = 9 g/L. A steady state concentration of A, in feed is 10g/L, but it experiences disturbances. In spite of disturbance in concentration of A in feed it is required to maintain the concentration of B constant. (Concentration in B must not deviate from its desired value for a long time to minimize the waste and eventually the financial loss). Design Controller to maintain concentration of B	FD, CS, TT, QD, PC, DI

Bloom's Cognitive domain level	Learning Objective - Gronlund First Level	Learning Objectives -Gronlund Second Level (Sample behavioral objectives)	Vincenti's categories addressed e
Evaluation	Evaluate performance of a given set of controllers.	The parameters of a permanent magnet DC motor used in a speed control system are: moment of inertia of the rotor (J) = 0.01 $kg.m^2/s$, damping ratio of the mechanical system (b) = 0.1 Nms, electromotive force constant (K=Ke=Kt) = 0.01 Nm/Amp, electric resistance (R) = 1 ohm , electric inductance (L) = 0.5 H Required performance criteria are: Settling time less than 2 sec, Overshoot less than 5% Steady-stage error less than 1% Two solutions are presented. One group has used PID controller with the controller parameters set at Kp = 100, Ki = 200 Sec, and Kd = 10 sec^{-1}. Another group has proposed cascade control with outer loop having PI controller with parameter set at Kp = 5, Ki = 200Sec and inner loop having PD controller with Kp = 20, Kd = 5. Both the controllers meet the required performance criteria. Which controller would you prefer and why?	FD, CS, TT, QD, PC

5. Learning objectives at module level

A same method can be used to prepare learning objectives at module level.

6 Conclusions

Generation of learning objectives, while appears to be simple post facto, is a frustrating process even for the experienced teachers. An analysis of the proposed course in the context of Vincenti's categories of knowledge greatly helps in ensuring that all relevant aspects of the course are adequately addressed in the learning objectives. The framework proposed here identifies all the steps involved in preparing the learning objectives at the course level and Module level. It also provides a platform for an effective interaction among all the stakeholders.

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[5] http://www.umich.edu/~ed626/dc.html