Application of ADDIE Model in Instructional Design of Structural Mechanics Course

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Abstract. ADDIE is one of the most widely used instructional design (ID) models in educational technology, which stands for five phases contained in the ID process, i.e. analyze, design, develop, implement, and evaluate. Based on the study of instructional technology, ADDIE model was applied into the instruction of Structural Mechanics, which is a core curriculum of civil engineering and hydraulic engineering. Taking the lesson “free vibration of multi-degree-of-freedom systems” as the illustrative sample, the five phases of ADDIE model were investigated and established. Both the instructional theory and the practical circumstance in the engineering education were presented in this paper. Superior learning outcomes have been achieved in the course designed with this ADDIE model, which is expected to give inspiration and reference to the engineering education.

Introduction

As defined by the Association for Educational Communications and Technology (AECT), instructional design (ID) is “the theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning” [1]. Further to say, ID is a technology for the development of learning experiences and environments which promote the acquisition of specific knowledge and skill by students, and it incorporates known and verified learning strategies into instructional experiences which make the acquisition of knowledge and skill more efficient, effective, and appealing [2]. This has also presented the end goal of ID, which should be widely applied and practiced in all the activities concerning with learning or education.

Throughout the whole research history of ID, Benjamin Bloom and Robert Gagné have done greatly influential work for the deep study of cognitive and behavioral process in learning and teaching. The Bloom’s taxonomy was published in 1965 [3], in which the learning objectives were classified into three specific domains, i.e. affective, cognitive and psychomotor. Based on this classificatory model, Gagné defined five learning outcomes, i.e. verbal information, intellectual skills, cognitive strategy, attitude, and motor skills, and proposed nine learning events as well [4,5], each of which is a condition for learning and should be mirrored by an instructional event correspondingly. Gagné’s work is widely used and cited in the design of instruction and it should be believed that instructional designers can obtain tightly focused and efficient instruction when following Gagné’s theory. Since then many present-day ID models have been proposed by theorists [6], such as Dick and Carey systems approach model, Jerold Kemp’s model, Merrill’s first principle of instruction, etc., while most of these models can be classified under the ADDIE process or ADDIE model.

ADDIE stands for the five phases contained in this model, i.e. Analyze, Design, Develop, Implement, and Evaluate (shown in Fig.1). It was initially proposed by Florida State University to explain “the processes involved in the formulation of an instructional systems development (ISD) program for military interservice training that will adequately train individuals to do a particular job and which can also be applied to any interservice curriculum development activity” [7]. Over the years, the steps taken in the five phases were revised. Until the middle of 1980s, the most popular version appeared. Commonly to say, the ADDIE model emphasizes on the design of essential stages in instruction and is feasible and valid in implementation, thus it has been widely used in various instructional activities and occasions, from primary schools to universities.
Structural Mechanics is a traditional and fundamental knowledge of civil engineering. The corresponding course has been offered for almost seventy years in colleges and universities in China. Under the situation that the development level of higher education has been greatly concerned over the country, instructions of such foundational knowledge play more and more important roles in engineering education. The present phenomenon is that, since many difficulties in the mechanical theories and methods exist in this course, instruction designers or teachers may pay most of their attentions to the knowledge itself rather than the instruction process, failing to notice the learning events of learners. As a long-term teacher and researcher of Structural Mechanics in the university, the author did a brief study on the ID technology and has used the ID ideas and methods during the whole instruction process. The constructed Structural Mechanics curriculum is a main part of the national top courses in China. Taking the lesson “free vibration of multi-degree-of-freedom (multi-DOF) systems” of the chapter “structural dynamics” as the sample, this paper gives brief introductions of the five designed phases in ADDIE model in teaching of Structural Mechanics, with both the instructional theory and the implementation method being demonstrated.

ADDIE Model in Structural Mechanics Course

Analysis Phase

This is the first phase of the ADDIE process and play an essential role, in which the information about instructional problems and objectives, learning environment and learners’ existing knowledge and skills are gathered. There are several questions for designers to answer and the process of answering these questions is a part of a needs analysis, during which constraints and resources will be determined. Considering the characteristics of Structural Mechanics course, the questions are designed to be as follows. At the view of learning-centered education, the questions are all learners-oriented.

Who Are the Learners and What Have They Learnt Before? The course of Structural Mechanics is set for students of the third grade in departments of civil engineering and hydraulic engineering of the university. The students are studying the courses of Elasticity, Steel Structures and Concrete Structures at the meanwhile, and are going to participate in some practice curricula of structural design in the next term. Before this course, they have learnt Material Mechanics which lays the groundwork for mechanical analysis of structures including the basic concepts and methods. Before this lesson “free vibration of multi-DOF systems”, they have learnt free vibration of one-DOF system, including the concept of vibration frequency, the dynamic equation and displacement solution, and the whole idea as well.

What Are the Desired New Knowledge and Behaviors for Learners? Even in the instruction of such a short lesson, there may be lots of new knowledge and capabilities that teachers want to deliver to students. However, the main goal of this question is to let the designer or teacher think clearly about the emphases of his instruction. In the present lesson, these emphases can be summarized into
two concepts and one method. The two concepts are frequency and vibration mode, while the method is dynamic-static method based on D'alembert's principle. What is the most important is that all these emphases have appeared in the one-DOF system analysis, and for multi-DOF system, it is an expansion. Thus the desired new knowledge of this lesson is the differences of concepts between one-DOF system and multi-DOF system, and the desired behavior for learners is to know how to expand these concepts from simple problems to complicated problems.

What Types of Learning Constraints Exist? The two learning constraints exist in this lesson are also the two existing in this course. Since students are mostly facing mechanically simplified sketches and mathematical equations, one of the learning constraints is the lack of perceptual knowledge, and the other one is that they know nothing about applications of these sketches and equations in practical engineering. These constraints make students often be puzzled by the purpose of study and then even lose the purpose.

Design Phase

The design phase is the main process in ADDIE model and will achieve the final implementation strategies and evaluation results. Based on the information gathered from the analysis phase, tasks of instruction are divided into small ones which should be more manageable for the designer or teacher. Especially the activities required for learners to overcome the learning constraints should be determined. The design phase is systematic and specific, and generally a design document/design proposal will be written to aid the final implementation. Besides of the learning goal, three key activities to help students overcome the learning constraints are designed for the illustrative sample in this paper. Some brief introductions are given in this section.

Learning Objectives. Learning objectives are known by many other names, such as learning outcomes, terminal objectives, etc. As we talked about, Gagné has stated five learning outcomes, i.e. verbal information, intellectual skills, cognitive strategy, attitude, and motor skills. In China, the three-dimension objectives have been adopted in the recent decades, i.e. knowledge, skills and attitudes. In this case, the learning objectives in the lesson of free vibration of multi-DOF system are set to be as follows:

(1) Knowledge. Students will know both the physical meaning and mathematical meaning for frequency and vibration mode, and will know the solution process used in free vibration analysis of multi-DOF system.

(2) Skills. Students will be able to implement the concepts of frequency and vibration mode to analyze the intrinsic characteristics of skeletal structures in practice. Students will be able to derive the governing equations for more complicated system by themselves, e.g. a simply supported beam, solve them with appropriate mathematical approaches and then analyze the dynamic features of the system.

(3) Attitudes. Students should be convinced of the responsibility they are undertaking to create safer structures under normal situation and severe situation.

Three Sample Activities Designed to Meet the Learning Objectives. Three sample activities which have been designed to overcome the learning constraints and difficulties are introduced here.

(1) The Usage of Famous Aphorism. In order to meet the learning objective of skills, the famous aphorism from an ancient philosopher of China was used throughout the whole instruction process of this lesson, that is,

Out of Tao, One is born,
Out of One, Two,
Out of Two, Three,
Out of Three, the created universe.

which was written by Laozi in his famous book Tao Te Jing. It has vividly described and summarized the deriving and solution process of free vibration analysis, from one-DOF system to two-DOF system and then to a multi-DOF system. At the beginning of instruction, the governing equation and dynamic displacement solution of one-DOF system was reviewed with the definition of frequency being given. And then following the similar idea and strategy, governing equations and displacement
solutions of two-DOF system was derived by expanding the variables and quantities in one-DOF system to matrix and vectors, which yielded two frequencies and vibration modes. At last the results of two-DOF system were expanded again in dimensions of matrix and vectors to obtain those of multi-DOF system.

(2) The Demonstrations of Famous Buildings and Practical Examples. In order to meet the learning objective of attitudes, the very famous building called *Chines Zun* which is under construction in Beijing was shown to introduce the necessity and importance of multi-DOF analysis, and after the formula solutions of two-DOF systems had been obtained, the vibration analysis of a two-story house in practical engineering was raised, as shown in Fig. 2(a).

In the dynamic analysis of *Chines Zun*, the building was discretized into about 30 million DOFs in finite element analysis. It gave students a quite strong sensor impact and inspired them to both the strong learning interests and social responsibilities. For the two-story house, when given different ratios of mass and stiffness of the two stories, two special engineering circumstances will be obtained. For one of them, the second story vibrates like an entire rigid body (Fig.2(b)), which is used as the fundamental theory and original model of isolation mountings. For the other one, the second story undertakes serious vibration while the first story barely moves (Fig.2(c)), which is viewed as the simplest model of whiplash effect in civil engineering. Pictures of serious damages caused by whiplash effect under earthquakes were shown and engineering responsibility was inspired again.

(3) The Self-experiences with Special Teaching Aids. In order to overcome the learning difficulty in lack of perceptual knowledge, some specific teaching aids were developed and applied in the instruction of this lesson. For example, a teaching aid with a thread going through two toy balls was made to let students experience the two different vibration modes of the two-DOF system themselves. To experience the vibration modes of systems with more DOFs, students can construct their own systems and get the animation demonstrations of all the modes using the teaching-aided software called Structural Mechanics Solver (SM Solver) as shown in Fig. 3, which is detailed in the next section.
Development Phase

In the development phase, instruction activities and content assets described in the design phase are created and assembled. For example, in the illustrative lesson of this paper, pictures of Chinese Zun and damages caused by whiplash effect were gathered, the two-story house were designed and the teaching aid with two balls were made. What is the most worthy of mention among all is the development of the teaching-aided software, SM Solver, which we used through the Structural Mechanics course.

SM solver is an original software for CAI (Computer Aided Instruction) of structural mechanics which was developed by the author’s institute. It was specialized for mechanical computation of plane skeletal structures. Each one of its various functions is corresponding to one chapter of the structural mechanics course. In this case, SM Solver can give students intuitive image impacts, sufficient chances of practice and facilitate their learning a lot.

Implementation Phase

After the contents and tools are developed, it is time for implementation. In practice, it may contain procedures for training facilitators and learners, e.g. training students how to use software. It also includes evaluation of the design. The designer or teacher tests all materials to determine whether they are functional and appropriate for the intended learners and desired objectives. Actually the implementation phase has close relationship with the design phase and the evaluation phase. P.L. Smith and T.J. Regan showed that instructional strategy is the key of instructional implementation [8], i.e. the method chosen for content delivery is very important. The instructional delivery method contains the choices of media and learning manners, such as lecturing or group discussion, slides or blackboard, oral exercises or paper tests. According to the author’s comprehension and experience, the delivery method has always been designed before implementation, however, it should be changed under the practical situation when closely observing the learners’ reaction or gathering the formative evaluation as the instruction goes on. Therefore the implementation phase is a challenge for instructional designers or teachers.

Evaluation Phase

The evaluation phase is involved in another subject of instructional research, i.e. instructional evaluation, which consists of two aspects: formative evaluation and summative evaluation. Formative evaluation can present in each phase of the ADDIE process, while summative evaluation is achieved when the course is all finished. Evaluation can ensure that all the materials, activities and designs have achieved the desired goals. In the illustrative sample, the final examination and a question whether the designed lesson is better or not were given to the 103 students in autumn term of 2017.
More than 90% of these students considered the designed lesson to be better than usual ones. The data gathered in this stage will be used to alter and enhance the instructional design.

Summary
Based on the study of instructional technology, the author applied the widely-used ADDIE model of ID into the Structural Mechanics course, which is a core curriculum in the majors of civil engineering and hydraulic engineering. Taking the lesson “free vibration of multi-DOF systems” in the chapter of dynamics as the illustrative sample, the five phases in ADDIE model, i.e. analysis, design, development, implementation and evaluation, were investigated and established. Both the instructional theory and the practical circumstance in the engineering education are presented in the paper. The course designed with ADDIE model has achieved superior outcomes and the corresponding research and practice will be continued by the author.

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