



Systems Perspective of Educational Technology

4

Chapter Outline

- Introduction to systems
- Education systems
- Educational technology systems
- Intelligent computer-assisted instruction
- Intelligent tutoring systems.

By the End of This Chapter, You Should Be Able To

- Describe the concept of a system, the conditions for the formation of a system, and three basic principles of systems
- Describe the general structure of an education system
- Describe the general components of an educational technology system
- Elaborate the four basic elements of educational technology system and how they interact.

Main Learning Activities

1. Discuss with your peers the conditions that form a system. What are the characteristics and components of that system? Use a specific example to illustrate your ideas.
2. Identify an education system with which you have interacted and list the elements of that system and typical interactions among those elements along with some inputs to and outputs from that system.
3. Think about how to view a classroom as a system? What are the typical elements? How do they typically interact and influence each other? Is the arrangement of desks and chairs a factor that affect interactions? What are the typical inputs to and outputs from a classroom system?

4. Create a concept map depicting an educational technology system that involves designing, developing, and deploying a system to support secondary school teachers in creating interactive games for specific learning goals in various science subjects. You can assume others are responsible for the design and development. Your task is to depict the larger context in which such a system is likely to be used. Be sure to indicate the major components of the system and the dynamic interactions likely to occur over time. The concept map should be contained on one page and include annotations to indicate the components and their interactions.

4.1 Introduction to Systems

Austrian biologist Ludwig Von Bertalanffy (1901–1972) is known as one of the founders of general system theory that was published in 1968. According to Bertalanffy, a system is defined as a set of elements standing in interrelation among themselves and within an environment (Bertalanffy, 1968). Peter Michael Senge (born 1947) is an American system scientist and the founder of the Society for Organizational Learning. Senge is known as the author of the book *The Fifth Discipline: The Art and Practice of the Learning Organization*, which focuses on group problem solving using the system-thinking methods in order to convert companies into learning organizations.

Systems are pervasive in the natural world (e.g., the solar system, the nervous system, various ecological systems, etc.) as well as in things created by people (e.g., a governmental system, a school system, a library system, etc.). In short, we live in and interact with systems every day in many different ways. The focus of this chapter is on systems involving education and technology, of which there are many and likely to be many more in the future.

A system is a combination of more than two interacting and interconnected elements which function as an organic or integrated or coordinated whole. There are three main aspects of a system (Huang, Sha, & Peng, 2006):

- (1) A system consists of two or more elements. Systems are pervasive. Many objects and processes involve systems.
- (2) A system is more than a collection of elements and includes how the elements are connected and how they interact over time. Systems change over time. Change and development of each system occurs in the exchange of material, energy, and information, which can benefit the dynamic stability and openness of these systems simultaneously.
- (3) A system is a kind of bounded whole that is situated in a particular environment or context, with input coming from the environment and outputs going back to the environment. Systems exist in an environment. Each system

accompanied by its surrounding can generate a larger/broader system, and those parts contained in the original system can be regarded as the subsystem of the new one.

Elements of a System

A system can be described in terms of five basic elements (Fig. 4.1): (1) the various components comprising a system (A, B, C, D in Fig. 4.1); (2) interactions among the components of a system; (3) the environment in which the system exists; (4) inputs from the environment to the system; (5) outputs from the system to the environment (Mangal & Mangal, 2009).

In general system theory, a system is any collection of interrelated parts that together constitute a larger whole. These component parts or elements of the system are intimately linked with one another, either directly or indirectly, and any change in one or more elements may affect the overall performance of the system, either beneficially or adversely.

Examples of a System

Solar system and the human body system are the typical examples of a system.

(1) The solar system is made up of the sun and eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune) along with smaller planetary objects; the solar system includes the mutual interactions among these elements (e.g., gravitational influence), their orbits, as well as influences from the milky way galaxy which is the environment in which the solar system exists.

(2) The human body is comprised of several systems, including the nervous system, the skeletal system, the endocrine system, the exocrine system, the blood circulatory system, the respiratory system, the digestive system, the urinary system, and the reproductive system. These systems coordinate with each other to carry out their different physiological functions. The human body exists in an environment

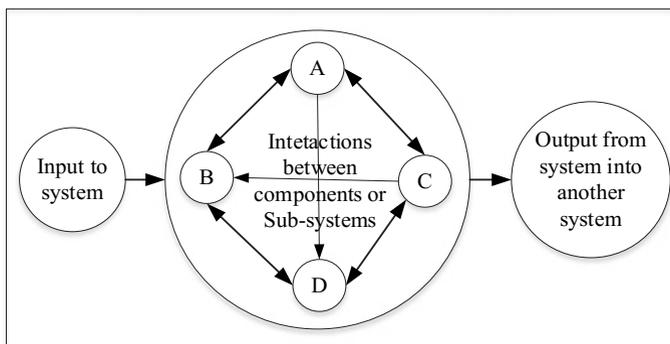


Fig. 4.1 A typical system. Adapted from the Robert Gordon University curriculum; see <http://www2.rgu.ac.uk/celt/pgcerttlt/systems/sys3.htm>

that provides oxygen, water, and nourishment (inputs necessary for life), and there are outputs from the human body to the environment as well.

4.2 Education Systems

Roger Kaufman (1972) was one of the first to apply a systems approach to education. An education system is a man-made system and can be considered as a subsystem of the society in which it exists. One might think of an education system as taking inputs from the society (e.g., students) and providing outputs to society (e.g., graduates). Moreover, an education system could be conceptualized as a collection of subsystems, such as a school system, a curricular system, a grading system, and so on.

Elements of an Education System

According to the characteristics of the system, the education system can be categorized to different levels: (1) macro-level: state, social education system; (2) meso-level: community and school education system; (3) micro-level: teaching process, learning process, media development, and other education system. The school system may be treated as a subsystem of the education system or a system complete in itself (Mangal & Mangal, 2009). In this chapter, we mainly focus on the school education system at the meso-level, and the structure of the education system is shown in Fig. 4.2.

An education system includes four kinds of elements: (1) inputs: pupils, administration, teachers, material for formal or informal education; (2) processes: formal or informal education process; (3) outputs: people who have attained educational objectives, such as grades and abilities; (4) and an environment: formal learning venues (e.g., schools) and informal learning venues (e.g., home, café, etc.). In addition, the system consists of interactions among these elements.

An instructional system is a subsystem within an education system, although one can describe elements and interactions relevant to an instructional system (e.g., resources, assessments, instructors, students, scaffolding, etc.). One can also

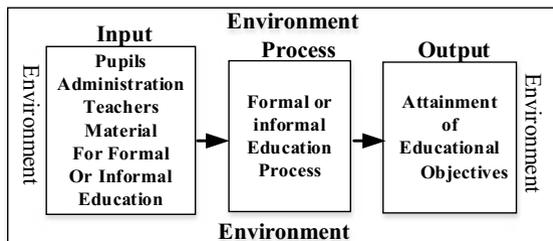


Fig. 4.2 Structure of an education system. Adapted from Mangal and Mangal (2009)

consider a curriculum as a subsystem within the larger instructional system. In short, one can elaborate an education system in terms of subsystems.

Principles for an Education System

(1) Overall principle

A system should be effective in fulfilling its purpose. An instructional system should have integrity, in the sense of being reliably effective; this is the essential characteristic of a system and the core of system theory. A system is composed of elements within an environment and should interact in a way that fulfills the purpose of the system. The overall principle of an education system requires coordinating the relationships among teachers, learners, and resources.

(2) Feedback principle

A system should be stable. From a system dynamics point of view, there are two kinds of feedback mechanisms within a system—positive or reinforcing feedback and negative or balancing feedback (Spector, 2015). As an example, the moon is orbiting the earth at a speed of more than 3600 km an hour. At that speed, it would keep going into outer space and not return each day; in this case, one can say that gravitational attraction of the earth on the moon serves as a balancing mechanism or a kind of negative feedback control that keeps the system stable and the moon in orbit around the earth.

The feedback principle tells us that an instructional system also has feedback mechanisms. One can think of assessments as a kind of balancing mechanism that helps to keep an instructional system stable. If all students simply attended and then left without any kind of assessment (neither formative nor summative), the system would become unstable and unable to attain its intended purpose of helping students develop knowledge and master skills. If all that matter in an instructional system are the number of participants without any consideration of learning, then the system is unlikely to fulfill its instructional purpose. Some have criticized early massive open online courses (MOOCs) for this very reason.

(3) Order principle

Order refers to the nature and structural functions of a system. Systems can be categorized along a simple-to-complex scale. Systems can also be categorized along a disordered-to-ordered scale. Given the prior mention of thinking about an education system as a collection of subsystems, one can then categorize the subsystems as progressing along these two scales (simple-to-complex, and disordered-to-ordered).

Typically, an education system will have complex but ordered subsystems. One might argue that if one thinks in terms of grade-level educational subsystems, they do progress from simple and relatively disordered at an elementary level to a more complex and more ordered level as one proceeds to a secondary and tertiary level.

4.3 Educational Technology from a System's Perspective

Educational technology is an area that uses systematic methods to analyze educational problems, design and develop instructional systems to support learning. A system's perspective views the various elements and interactions in a systemic manner, functioning in a well-ordered manner just as a healthy human body with its various subsystems functioning in a well-ordered manner. In addition to that systemic perspective, instructional designers and educational technologists typically employ systematic methods and processes to ensure that stable instructional systems result. This systemic view and the associated systematic methods and processes have evolved over time, as indicated in the brief overview of recent educational technology history (see Spector & Ren, 2015, for a more comprehensive treatment).

4.3.1 Five Stages of Educational Technology

Educational technologies have evolved from simple texts to highly complex and interactive digital systems. Table 4.1 depicts a simplified view of that development. The important point here is that education systems have become very complex, which results in the increasing challenges in designing, developing, implementing, and supporting these systems.

4.3.2 Typical Educational Technology Systems

With the use of technology in education system, the educational technology systems are changing rapidly. The typical educational technology systems developed

Table 4.1 Historical stages of educational technology development

Development phase	Components	Examples
Intuitive instruction (seventeenth and eighteenth centuries)	teachers, students, textbooks	textbooks with text and pictures, along with physical objects and models
Visual instruction (nineteenth and twentieth centuries)	the previous components plus visual artifacts	slides, silent movies
Audiovisual instruction (1920s–1950s)	more complex media enter into consideration	educational television
Audiovisual communication (1950s–1970s)	early networked system begin to appear	PLATO
Information and communication technologies (1970s to present)	digital media, large media repositories, changing technologies	interactive computing systems, augmented and virtual realities, social networking, etc.

from CAI, ICAI to ITS, with personalized and adaptive learning are more and more emphasized.

4.3.2.1 Computer-Assisted Instruction (CAI)

The formation of CAI is influenced by machine teaching and program teaching. It was first used in education and training during the 1950s, such as PLATO (Programmed Logic for Automated Teaching Operations; see <https://chip.web.ischool.illinois.edu/people/projects/timeline/1960won.html>). Early work was done at IBM and other mainframe computer companies and by Gordon Pask, O.M. Moore, and others, but CAI grew rapidly in the 1960s when federal funding for research and development in education and industrial laboratories was implemented. (See <http://cehdclass.gmu.edu/ndabbagh/Resources/IDKB/models.htm>)

CAI is a method of instruction in which there is a purposeful interaction between a learner and the computer device (having useful instructional material as software) for helping the individual learner achieve the desired instructional objectives with his own pace and abilities at his command (Mangal & Mangal, 2009). It stands for the type of instruction aided or carried out with the help of a computer as a teaching machine.

CAI is characterized as one-to-one interaction between a computer system and a student; the system elicits responses from a student and provides feedback, and allowing students to proceed at their own pace. (See <https://www.britannica.com/topic/computer-assisted-instruction>). Yet, CAI also has some limitations and drawbacks: (1) simple man-machine conversation; (2) passive acceptance of knowledge; (3) single learning style; (4) the stable studying procedure.

Extended Reading

TICCIT (Time-Shared Interactive Computer Controlled Information Television) is another major CAI system developed at the University of Texas and Brigham Young University and funded by a grant from the National Science Foundation in 1977.

In December, 1971, the National Science Foundation (NSF) Technological Innovations Group granted a contract to MITRE to further develop the TICCIT system as a computer-assisted instruction (CAI) system for community colleges. MITRE subcontracted with the CAI Laboratory at the University of Texas at Austin and also with the Department of Instructional Research, Development, and Evaluation of Brigham Young University to refine the user interface and create the massive amounts of courseware needed to teach a complete college-level English and algebra course. A trial implementation of the English and algebra courseware took place through the 1975–77 school years, and was evaluated by the Educational Testing Service (ETS).

See <https://en.wikipedia.org/wiki/TICCIT>

4.3.2.2 Intelligent Computer-Assisted Instruction

In the traditional CAI, the computer is only used as the disseminator of knowledge, but it does not understand the knowledge that it teaches; moreover, it does not understand the students beyond a simple parsing of text-based responses. With the development and maturation of artificial intelligence, AI technology is used in more sophisticated CAI system so that the CAI system can understand what to teach, how to teach, and how a student is progressing, which leads to the emergence of the intelligent computer-assisted instruction (ICAI). ICAI is a kind of application mode of CAI, which is based on artificial intelligence, cognitive science, and thinking sciences. ICAI constructs a simple cognitive model of learners using established characteristics and processes of human thinking. Through an ICAI system, students can acquire knowledge through individualized adaptive learning.

ICAI changes the traditional teaching mode. The students get feedback information in real time through human-computer interaction, adjusting the learning pace actively. The whole teaching process is shifted from teacher-centered to student-centered. In 1970, the first influential ICAI system was the scholar system that taught South American geography, creating a precedent for ICAI research.

An ICAI system has a computer program that uses artificial intelligence techniques (e.g., a production model, backward chaining, and other means) for representing knowledge and performing an interaction with a student to stimulate and control his learning in a given field. In an intelligent instructional system, the student is actively engaged with the educational environment and his interests and misunderstandings drive the tutorial dialogue (Bottino & Molfino, 1985).

It must be pointed out, however, that from an educational point of view, ICAI systems are not only expert systems, but they must also embody suitable models both for the student's behavior and for the teaching methodology (Bottino & Molfino, 1985).

Extended Reading

One of the earliest ICAI systems was SCHOLAR, which is a system designed to teach South American geography. The program uses a network of faces and concepts as well as an extensive data base. The original system allowed the student to conduct a "mixed initiative" dialogue. Allowing SCHOLAR to ask the student questions and then, with a limited natural language interface. Permitting the student to ask questions of the system. This kind of interaction highlights SCHOLAR's most advanced qualities: the tutoring component and a limited communication module. These two features enable the student to interact with SCHOLAR.

See Woodward, J. P., & Carnine, D. W. (1988). Antecedent knowledge and intelligent computer assisted instruction. *Journal of Learning Disabilities*, 21(3), 131.

4.3.2.3 Intelligent Tutoring System

The innovative feature of ICAI was to support individualized learning for students. Intelligent tutoring system (ITS) is a typical instance of an ICAI system. ICAI and ITS are often used interchangeably.

An ITS is a computer system that aims to provide immediate and customized instruction or feedback to learners (Psocka, Massey, & Mutter, 1988), usually without requiring intervention from a human teacher. It can assist students in studying a variety of subjects by posing questions, parsing responses, and offering customized instruction and feedback. During the rapid expansion of the web boom, new computer-aided instruction paradigms, such as e-learning and distributed learning, provided an excellent platform for ITS ideas.

The ITS is the typical educational technology system, including four technology components: (1) domain model, (2) learner model, (3) pedagogical model, and (4) interaction model. Figure 4.3 presents a typical ITS architecture.

(1) Domain Model

The term “domain” means a specific field or scope of knowledge, such as algebra, critical thinking, and psychology. People who have a deep understanding of a domain are called *domain experts*. A domain model represents domain experts’ ideas, skills, and the way that they solve domain problems. A good domain model provides a structure to minimize domain experts’ authoring time and maximize the quality of the content (Robert et al., 2013).

The domain model contains the set of skills, knowledge, and strategies of the topic being tutored. It normally contains the ideal expert knowledge and also the bugs, mal-rules, and misconceptions that students periodically exhibit (Robert et al., 2013). The domain model consists of the concepts, facts, rules, and problem-solving strategies of the domain in context. It serves as a source of expert knowledge, a standard for evaluation of the student’s performance and diagnosis of errors (Ahuja & Sille, 2013).

(2) Learner Model

We simply need to record, represent, and track characteristics of the learner before, during, and after learning. The practical problem is that it is expensive to identify, track, store, update, and later retrieve the ever-growing universal set of variables.

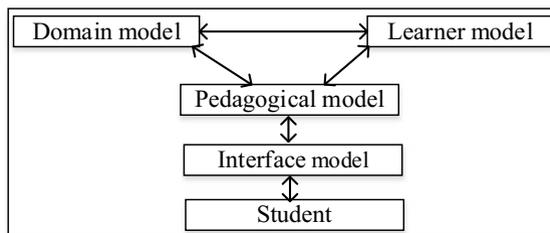


Fig. 4.3 Typical architecture of an ITS. Adapted from Ahuja and Sille (2013)

The mapping problem is that the alignment between the theoretical variables and computer code is often vague, incomplete, or incompatible.

Learner modeling is the cornerstone of personalized learning. The learner model is a representation of the system's assessment of an individual learner's current knowledge, including misconceptions, learning styles, personality traits, and affective states. The system infers this information from interactions between the system and the learner (Spector, 2015).

The learner model consists of the cognitive, affective, motivational, and other psychological states that evolves during the course of learning. The learner model is often viewed as an overlay of the domain model, which changes over the course of tutoring. For example, *knowledge tracing* tracks the learner's progress from problem to problem and builds a profile of strengths and weaknesses relative to the domain model (Robert et al., 2013).

(3) Pedagogical Model

The pedagogical model selects appropriate strategies and activities to promote successful learning given the progress of a particular learner and the associated information stored in the learner model (Spector, 2015).

The pedagogical model accepts information from the domain models and student models and devices tutoring strategies with actions. This model regulates instructional interactions with students. Pedagogical model is closely linked to the student model, which makes use of knowledge about the student and its own tutorial goal structure, to devise the pedagogic activity to be presented. It tracks the learner's progress, builds a profile of strengths and weaknesses relative to the production rules (Ahuja & Sille, 2013).

The pedagogical model takes the domain models and learner models as input and select tutoring strategies, steps, and actions on what the tutor should do next in the exchange, in mixed-initiative systems, the learners may also take actions, ask questions, or request help (Aleven et al., 2006). The pedagogical model always needs to be ready to decide "what to do next" at any point and this is determined by a pedagogical model that captures the researcher's pedagogical theories.

(4) Interface Model

The interface model decides how to interpret user input and then how to give appropriate responses. This requires both specific domain knowledge and some commonsense knowledge about the world. The learner and system interaction is traditionally expressed by typed or spoken texts, and recently by multimodal interactions through mouse clicks, screen touches, facial expressions, eye movements, and gestures (Spector, 2015).

User interface model is the interacting front end of the ITS. It integrates all types of information needed to interact with learner, through graphics, text, multimedia, keyboard, mouse-driven menus, etc. Prime factors for user acceptance are user-friendliness and presentation (Ahuja & Sille, 2013).

The user interface interprets the learner's contribution through various input media (speech, typing, clicking) and produces output in different media (text, diagrams, animations, agents). In addition to the conventional human-computer

interface features, some recent systems have incorporated natural language interaction, speech recognition, and the sensing of learner emotions (Robert et al., 2013).

Extended Reading

Here is an example of an interaction model involving Microsoft products that most have probably used. In Microsoft Word, the interaction model supports the conceptual model of users' putting a piece of paper into a typewriter and typing. It also happens to have a lot of features that enable users to format a page and content in almost any way they can imagine. But that interaction model sits at its core. With Microsoft Excel, the interaction model reflects the conceptual model of accountants' working with accounts in ledgers that contain rows of entries and columns of numbers and show a balance. Excel has additional features that make it a much richer experience than creating a spreadsheet on paper. But at its core is an interaction model that all users can internalize quickly. The interaction model for Microsoft PowerPoint reflects the conceptual model of users' writing on a sheet of transparent plastic, then placing it on an overhead projector—for those of us who are old enough to have actually seen this! The interaction model for each of these products is very different, yet each, in itself, is very clear.

The Typical Example of ITS

AutoTutor is an intelligent tutoring system developed by researchers at the Institute for Intelligent Systems at the University of Memphis in 1997. The goal was to help students learn physics, computer literacy, and critical thinking using an intelligent tutorial (Graesser, Chipman, Haynes, & Olney, 2005).

AutoTutor is a computer tutor that helps students learn by holding a conversation in natural language (AutoTutor, 2018). It has produced learning gains across multiple domains (e.g., computer literacy, physics, critical thinking). Three main research areas of AutoTutor are: human-inspired tutoring strategies, pedagogical agents, and technology that supports natural language tutoring.

Key Points in This Chapter

- (1) A system is defined as a set of elements standing in interrelation among themselves and within an environment.
- (2) A system can be described in terms of five basic elements: the various components comprising a system; interactions among the components of a system; the environment in which the system exists; inputs from the environment to the system; outputs from the system to the environment.
- (3) An education system includes four elements of inputs, process, output, and environment.

- (4) The educational technology has gone through five stages: intuitive instruction, visual instruction, audiovisual instruction, audiovisual communication, and information and communication technologies.
- (5) The typical educational technology systems include CAI, ICAI, and ITS.

Learning Resources

- System Dynamics and K-12 Teachers, see <https://ocw.mit.edu/courses/sloan-school-of-management/15-988-system-dynamics-self-study-fall-1998-spring-1999/readings/teachers.pdf>
- Using System Dynamics to Model and Analyze a Distance Education Program, see <http://www.it.itb.ac.in/~sri/papers/sysdyn-cdeep-ictd10.pdf>.

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