# Building an Agent-Based System for *e*-Learning in Digital Design

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**ABSTRACT**

Because of the emergence of computer-aided design software and the internet technology, we witness a revolutionary change in architectural design education. An e-learning environment in architecture is required to be composed of (1) learning tools, (2) a learning management system, and (3) digital content and learning activities. Although it has been proved the convenience of accessibility and economics, yet it is lack of appropriate learning content, interaction and sense of participation. More importantly, learning problems are often difficult to be detected and solved.
Intelligent software agent is an AI research paradigm to enhance human intelligence by the reactive reasoning mechanism. Intelligent agents in e-learning should be a tutorial or learning interface for participants, and assist teaching and learning as different roles. The research is targeted to build an agent-based tutorial system for the online digital design education environment.
The research will be divided into six steps: (1) literature survey of e-Learning technology and agent theory, (2) building models for defining role-play in the learning activities and behaviors, (3) relationship definition of user interaction and cognition in e-learning, (4) system building (5) implementation, and (6) evaluation.

**Keywords:** e-learning, intelligent agent, artificial intelligence, digital design, design education

## 1. BACKGROUND AND GOALS

The development of computer-aided concept and application of network technology have brought about major changes in the architectural design education environment. In addition, the emergence of Electronic design studio, Networked design studio, Virtual design studio and Collaborate design studio have established a basis for digitized design learning methods. The creation of a "digital learning" or e-learning environment must include learning tool research and development, establishment of a teaching and learning platform, or called learning content management system (LCMS), the development of learning content, and the design of learning activities. Although design education is already taking full advantage of the just in time and economy of online information, online teaching materials suffer from scanty content, poor interactivity, and a sense of insufficient participation. These shortcomings will require further research, development and breakthroughs.

Computer-aided design courses in architecture-related departments and graduate schools must both convey computer technology while also integrating digital design thinking. And since there must be a high level of interactivity to compensate for limited classroom time, LCMS must therefore provide instruction in technical commands, so that learners can study on their own without restrictions of time or place. We discovered that there is still a tremendous need for reminders and interactive features in online teaching and learning when we conducted an experimental computer-aided course at National Cheng Kung University (NCKU). We therefore decided in accordance with our observations and records to use "online teaching assistants" based on the theory of "intelligent agents" as our fundamental construct.

One of the research areas of artificial intelligence, intelligent agents employs responsive reasoning mechanisms to increase human intelligence. E-learning intelligent agents may use a query or learning interface to provide users or participants with auxiliary knowledge and interactive mechanisms via different roles. The goal of this study is to establish a digital design learning system with an interface facilitating communication and cooperation, and use this system to ensure that all digital learning participants can learn interactively online at any time or place, and achieve the goal of teaching in accordance with learners' aptitudes via the expansibility of online resources.

## 2. THEORY AND METHOD

This study employed four steps to construct an intelligent agent-based digital learning system.

### 2.1 Investigation of Digital Learning, Computer-Aided Design Courses, and Agent Theory

*2.1.1 Digital Learning*

Digital learning, or e-learning, is defined by the American Society of Training and Education (ASTD) as: "E-learning is the application of digital media by the learner in the learning process, where digital media includes the Internet, corporate networks, computers, satellite broadcasts, audio tapes, videos, interactive television, and CD-ROMs, etc. The scope of e-learning applications includes online learning, computerized learning, virtual classrooms, and digital cooperation." While the ASTD definition emphasizes digital tools, the inflexible use of digital tools can by no means affect the sweeping reform of educational methods. For instance, the Computer Aided Learning (CAL) used in the 1960's emphasized only the use of computers in learning, and course content and learning activities were not significantly different from those of the age of pencil and paper. After the Internet emerged in 1995, online learning – which is also known as web-based learning (WBL) – used database and server technology to ensure that data transmission, access, and response were highly interactive and extensible. As a result, e-learning research is not just tool research and development (R&D), but instead must include the establishment of a teaching and learning platform, development of teaching material content, and design of learning activities.

Online e-learning employs three kinds of transmission models: asynchronous, synchronous, and blended. The two former models overcome the spatial restrictions of conventional classroom learning, while the blended model proposes improvements to overcome some of the disadvantages of the first two models. Asynchronous teaching models employ a transmission method that can be divided into two parts: "Teaching content" is transmitted via a webpage or CD-ROM, while "teaching interaction" is transmitted via e-mail or discussion area. The synchronous model employs "virtual classroom" hardware and software, and uses the Internet to conduct videoconferencing and chat room activities to transmit "teaching content" and "teaching interaction." The intent of this model is to achieve teaching as synchronous as in a real classroom. If we compare the two, we see that the former offers the advantages of in-depth learning at any time or place, but has the disadvantages of inconvenient communication and lack of real-time response capability. Nevertheless, although the latter enables real-time interaction and a sense of participation, it has the disadvantages of time restrictions, high cost, and need for high-tech supporting equipment. As a consequence, in order to cut costs while offering good interactivity, most contemporary e-learning systems adopt the highly feasible blended model. In a typical blended model, learners can read teaching materials asynchronously from a teaching website, while providing for necessary face-to-face explanation, discussion, and physical operation in the classroom.

*2.1.2 Design-oriented Computer-aided Courses (DOCC)*

The Architecture Department's computer-aided design courses must convey computer hardware and software technology as well as integrating training in digital design thinking and methods (Shang-Yuan Chen, 2004). We consequently divided the computer-aided design course's teaching material content into two parts in line with the course objectives: One part consisted of the technical issue of well-defined computer instructions, and the other consisted of problem-oriented design activities emphasizing the flexible application of instructions to achieve design goals. The former items were compiled into online teaching materials placed on a teaching website, and we used the limited classroom instruction to conduct design activities with high need for interactivity. This kind of design-oriented computer-aided course is a form of blended mode. Our observations show that although students already habitually used instructional websites outside of class to learn about technical instructions, the students frequently needed a teaching assistant's pointers when they encountered the design task (which usually consisted of production of a design by interactively using a set of instructions with prescribed scopes), and thus instinctively returned to the teaching website so that they could search for and review tips. Nevertheless, it proved hard to complete design activities within a limited time because too many students needed or were waiting for teaching assistants' instructions. It therefore became necessary to provide a real-time online interaction mechanism. Along other lines, the innovativeness of the design inevitably caused the need for instructions to exceed the preset scope, which implied a possible need for expanded teaching resources.

*2.1.3 From Agents to Intelligent Agents*

Marvin Minsky – the father of artificial intelligence – defined "agents" as "constituent elements of a 'society of mind': Each mind can be broken down into smaller processes known as agents. In other words, when these agents come together to form an interactive community, this is intelligence" (Minsky, 1988).

At the application level, "agents" are computer systems located in specific environments. These systems are able to behave autonomously in accordance with design objectives, and are also able to sense and respond to changes in environmental circumstances. In other words, the agents are a type of goal-oriented object. Basic agents possess "autonomy," and complex agents possess "learning." So-called "intelligent agents" can respond to different environments and generate adaptive autonomous behavior to meet design goals. Here "adaptive" implies reactive, proactive, and social abilities (Wooldridge, 2002).

### 2.2 Determination of Agents' Digital Design Learning Characteristics, Functions, and Behavior

The next step was to construct a teaching and learning platform possessing "online teaching assistants." We had to first analyze the work attributes of teaching assistants and decompose their work attributes into even smaller work procedures. These attributes or procedures had relationships of "level" and "enclosing," and can be regarded as "teaching assistant agents" possessing specific intentions. The community in which teaching assistant agents function and interact constitutes an intelligent online teaching assistant.

We can infer that, at the application level, online teaching assistants possessing the characteristics of intelligent agents are not only able to satisfy the need for simple sensory stimulation and reflexive response on a webpage, but can also actively detect circumstances and judge the state of learning. The online teaching assistants can respond to different communication by providing students with necessary learning pointers and teaching content meeting individual needs. In addition, online teaching assistants must also possess social abilities such as the ability to communicate with other online teaching assistants and interact with human users, while using the Internet's boundless resources to provide access to expanded teaching materials. Furthermore, relatively intelligent online teaching assistants also possess the ability to learn: They can acquire usage models from teachers or well-performing students, and thereby give other students even better learning suggestions.

### 2.3 Exploring the Relationships Between e-Learning Users: Investigating the Interaction and Cognitive Communication Models of Users and Agents

Our observations of the experimental course in the university section of the NCKU Architecture Department showed that guidance teachers, teaching assistants, and learners had the following interactive relationship in the teaching platform environment:

(a) Guidance teachers towards teaching assistants: Authorized applications, authorized use, designed teaching materials, designed tasks, set evaluation standards, and performed troubleshooting.
(b) Guidance teachers towards students: Teaching in the classroom, designing learning activities, troubleshooting, and evaluation and grading.
(c) Teaching assistants towards guidance teachers: Accepting applications, authorizing permission, accepting teaching material design, organizing teaching materials, accepting homework design, organizing homework, performing progress management, asking for crisis instructions.
(d) Teaching assistants towards learners: Accepting applications, authorizing permission, providing teaching materials, providing additional resources, detecting problems, recording learning progress, preserving background information, answering questions, providing examples, providing homework, evaluating homework, assessment and grading, and crisis warning and troubleshooting.
(e) Students towards guidance teachers: Providing problems and performing design activities.
(f) Students towards teaching assistants: Authorizing applications, authorizing use, providing background information, turning in homework, providing problems, and performing learning exercises.

The work of teaching assistants was analyzed as consisting eight attributes in accordance with the items in (a), (c), (d) and (f), and these attributes can be subdivided into the following procedures:
Authorization: Accepting applications, authorizing permissions, and authorizing use.
Teaching materials: Accepting teaching material designs, organizing teaching materials, providing teaching materials, and providing additional teaching materials.
Homework: Accepting homework designs, organizing homework, providing homework, and turning in homework.

Learning: Recording learning progress and preserving background information.
Evaluation: Setting evaluation standards, performing assessment and grading, and evaluating homework.
Problems: Detecting problems, searching for solutions, and providing examples.
Progress: Scheduling progress, tracking progress, and adjusting progress.
Difficulties: Giving crisis warnings, asking for instructions in the case of difficulties, and troubleshooting.

### 2.4 Constructing a Digital Design Learning System

The work of teaching assistants can be separated by attributes into authorization, teaching materials, homework, learning, evaluation, problems, progress, and difficulties agents. Independent agents can be further subdivided into smaller working procedures (see Fig. 1). Nevertheless, the relationship between agents and procedures does not merely involve the principle of order; from the point of view of agent communities, the relationship between different procedures can typically be represented as a complex network. The various factors shown in Fig. 2, including response to users and use motivation, cause design tasks to change in order that the agents exhibit adaptive autonomous behavior meeting the design objectives. At the application level, online teaching assistants thus possess adaptive interaction, and are able to provide instruction tailored to individual students:

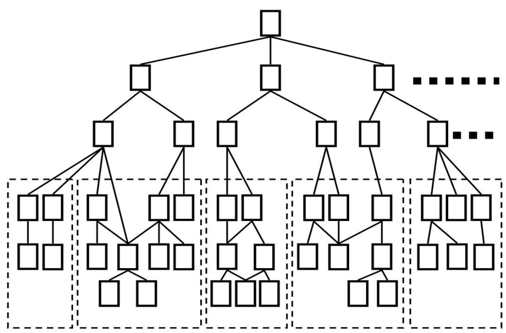

Fig. 1. Agents and procedures can be classified and layered according to attributes and applications

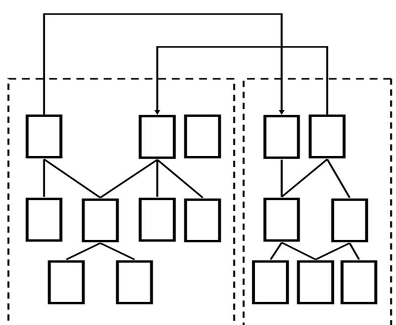

Fig. 2. Interactive behaviors in response to design tasks and procedures, and between procedures

*2.4.1 Interaction*

- Reactive:

Simple agents are able to sense changes in the environment, and can generate real-time responses. For instance, a problem agent can sense when the learner's instructions and operations are incorrect, and immediately give an "error" reminder. Or a homework agent can accept homework within then given deadline and immediately give a "received" response.

- Proactive:

Because agents can perform goal-directed behavior, they are able to proactively and spontaneously complete design objectives. Here goal-directed behavior refers to making progress towards a goal; this action occurs when (if) changes in the external environment satisfy present assumptions, and the system (then) activates subsequent processes. Taking an authorizing agent as an example, if the agent receives an authorization application from the user end, it then identifies the user in accordance with the background information. If the user's identity is correct, it then grants permission and proceeds to perform analysis, assessment, and grading in accordance with the background information, provides a learning plan at an appropriate level, and activates other agent mechanisms. In this example, as soon as the authorization agent finishes confirming conditions, it then autonomously completes design objectives: It activates service mechanisms after completing authorization of the user. On the other hand, if the conditions are not correct, and identification cannot be made, then the application will be invalid.

- Social ability:

Agents possess the ability to converse with other agents and with human users. The receipt and transmission of messages enables agents to complete their common goals in a coordinated fashion. Social behavior includes both division of labor and cooperation, and also includes conflict and harmonization. Taking "harmonization" as an example, a difficulty agent must elicit progress tracking and comparison with the scheduled progress from a progress agent; if there is a pronounced gap, then the difficulty agent must submit a difficult request for instruction to the guidance teacher, and complete progress adjustment and difficulty troubleshooting. But if the progress agent's progress tracking relies on information from a different source or reflecting different views, such as when homework evaluation results from the evaluation agent indicate that learning performance is poor, it may be felt that teaching progress is too fast. But if the message from comparison with scheduled progress indicates a significant gap, then the "conflict" will need to be "harmonized." Judgment is ordinarily performed in accordance with level, where the higher-level agent usually possesses superiority. If the two levels are the same, a logical function and Boolean values (true and false) are employed to perform deduction, up until the crisis has been confirmed. In addition, when the difficulty agent submits a difficulty request for instruction to the guidance teacher, the guidance teacher may instruct the evaluation agent to lower its evaluation standards or may instruct the teaching materials agent to assemble teaching materials and homework appropriate for a different learning grade, until the time that evaluation results meet scheduled progress and preset standards, which will cause the warning to disappear.

*2.4.2 Instruction Tailored to Individual Students*

To achieve the goal of teaching the student, the evaluation agent must first establish evaluation and grading standards before the teaching materials agent can propose a set of teaching materials in accordance with grading results. Evaluation standards include different items and standards for the beginning, middle, and end of the semester. We found from experiment results and comparison of homework grades that "computer ability" prior to the start of university had the biggest influence on the students' initial learning performance. In contrast, mid-semester learning performance was directly proportional to "degree of participation" in course activities and "accessibility" of computer equipment. For its part, learning performance at the end of the semester reflected the "grading gap" between initial evaluation and final evaluation: The bigger the gap, the better learning performance.

Initial evaluation and grading was therefore performed on the basis of the computer ability survey included in the students' background information. Mid-term decisions to raise students' grades were based on their homework grades. Moreover, since the learning agent recorded the students' computer time and course attendance rate, degree of participation statistics were also available. Accordingly, the problem agent either encouraged the learner to make progress or warned the learner of falling behind in accordance with the learner's degree of participation. The problem agent also actively helped learners to find solutions or provided them with examples when they encountered a possible difficulty.

*2.4.3 Open Framework Teaching Material Modules*

The teaching materials possessed an open framework able to respond to different learning needs. The content of teaching materials was divided into different modules on the basis of topic or section. The form of the modules endowed them with the flexibility to handle changes: Each module was composed of a relatively invariable "structural" portion and a readily variable "filler" portion, and the relationship between these two portions is influenced by the "level" and "envelopes." A high level can enclose a lower level. When the controlling level is higher, then the lower level is variable. What is enclosed by each level can be seen as a module, and modules are thus considered to be relative envelopes, and not absolute packets. The smallest and indivisible part of the teaching materials level is termed assets, and this is followed by learning objects and then aggregation; an aggregation usually represents one class session. The level above aggregation consists of different subjects or departments. The use of open-framework teaching materials modules allows online teaching assistants to compile different teaching materials employing the controlled structural level and variable filler content in response to learning gaps and learning goals. Nevertheless, in actual applications, when there are learning objects that can be shared, methods and standards for communication between different elements must be determined before the teaching materials agent can assemble teaching materials.

## 3. RESEARCH PROCESS AND RESULTS

### 3.1 Computer-Aided Design Course at NCKU

*3.1.1 Course Positioning*

This course was given to two classes of first-year students from the NCKU Architecture Department. Students were expected to attend one hour of class and two hours of laboratory time each week. The course was intended to teach students: (1) how to use online learning resources, (2) how to establish a website, and (3) basic aesthetics and design theory. Research issues included (1) instruction in application of computer technology and digital design thinking, (2) evaluation of grades and application of teaching materials modules, (3) application of digital teaching platform, and (4) research on the deployment of intelligent agents. Participating personnel included one instructing professor, one guidance teacher, two teaching assistants, 28 students in class A, and 23 students in class B.

*3.1.2 Course Framework*

Instruction encompassed the two different aspects of application of software technology and training in design methods. In order, the course content included (1) design methods: copying of cases, case analysis case reasoning, design creativity, and cooperative design; (2) software technology: Photoshop, Flash, and Dreamweaver.

Teaching materials concerning technical instructions were posted on the NCKU online LCMS according to modular principles. Fig. 3 shows the website providing students with resources for after-class self-study. When in the classroom, students listened to the guidance teacher lecture on the application of software instructions in design. In the laboratory, the teaching assistants helped students engage in design activities. In the online learning platform environment, interaction among the guidance teacher, teaching assistants and students was observed and recorded to provide basic research data concerning the deployment of intelligent agents.


Fig. 3. National Cheng Kung University Online LCMS; 2005, (Interfaces, left for teachers and right for students)

*3.1.3 Operating Environment*

NCKU"s online LCMS runs on a Unix operating system employing the PHP+ MySQL mechanism. It uses PHP, ASP, and JSP scripting languages, and even allows Flash. Design options are dictated by security and convenience of system maintenance, etc. Different configurations can be used to meet the needs of individual environments.

### 3.2 Teaching Results and Assessment

Course instruction achieved the three main goals. The following observations were made with regard to research issues:

(1) Learning mode: Students displayed both passive and active attitudes: Observations showed that passive students hoped to get by without working hard, and take advantage of the course's readily obtained teaching

materials and information, casual homework, and easy grade points. Active students had self-expectations and expectations of the course; they made suggestions concerning the course as a whole, looked forward to even better learning equipment, and proposed ways of overcoming operating obstacles.

(2) Learning problems: Learning problems included both technical problems and design problems: Technical problems consisted of "routine" maintenance or equipment updating problems. Most hardware problems consisted of poor or inadequate equipment, insufficient computer time or excessively slow network transmission. Software problems typically consisted of problems with instructions and different software versions, etc. Although design problems are commonly poorly defined, we considered operating standards issues to be "routine" problems. We considered students' unexpected perspectives on design to be "non-routine" problems, however. For instance, while students used the same software and performed case analysis using the textbook "Architectural Examples," they sometimes submitted design problems that exceeded the design knowledge originally provided to them.

(3) Teaching problems: Teaching problems involved experience and evaluation standards. Generally speaking, the experienced teaching assistant was quicker at spotting students' learning obstacles and lending a helping hand than the newcomers. As a consequence, the class taught by the experienced teaching assistants performed better than the other class. As far as teaching evaluation standards were concerned, homework evaluation was broken down into clear-cut items such as "quantifiable" guidelines, completed homework, "can be looked up" answers, and "principle-based" design elements includes balanced composition, controlled color fill, fineness of lines, and layering, etc. While the two teaching assistants did not have many disputes concerning the quantifiable and can be looked up answers, they held divergent views concerning the grading of principle-based design aspects.

## 4. CONCLUSIONS AND RECOMMENDATIONS

This study discovered and assessed online teaching problems, and analyzed agent conditions based on the literature and a teaching experiment. Online teaching assistants could split into different attribute-based agents in accordance with need, and agents could generate adaptive autonomous behavior meeting design objectives in response to changes in users, use motivation or the design task. This yielded process interaction and the ability to tailor instruction to individual needs. As far as the organization of teaching materials was conducted, modularity enabled an open framework. Nevertheless, in actual applications, when there are learning objects that can be shared, methods and standards for communication between different elements must be determined before the teaching materials agent perform different degrees of assembly.

Apart from the grading of teaching materials, agents should be able to determine use modes from learning attitude. Learning attitude can be classified as either passive or active, where passive students need active online teaching assistants and actively provided pointers and reference materials. In contrast, active students can select passive online teaching assistants providing search engines and more example cases. This model can encourage students to perform research, while providing fewer intrusive active pointers. With regard to eliminating learning obstacles, agents can be preprogrammed to recognize and handle routine problems. Experienced teaching assistants will still needed to deal with non-routine problems, however. Furthermore, the grading of homework should set aside principle-based design items for judgment by the guidance teacher.

It is expected that online teaching assistants will be deployed on online teaching and learning platforms, during the next stage (see Fig. 4). Looking ahead, communities composed of online teaching assistants of different types in dispersed learning environments will undoubtedly display more complex behavior than single-platform online teaching assistants. Future theoretical and experimental efforts may explore how these online teaching assistants generate interaction, communication, and coordination, expand teaching materials, and increase their intelligence.

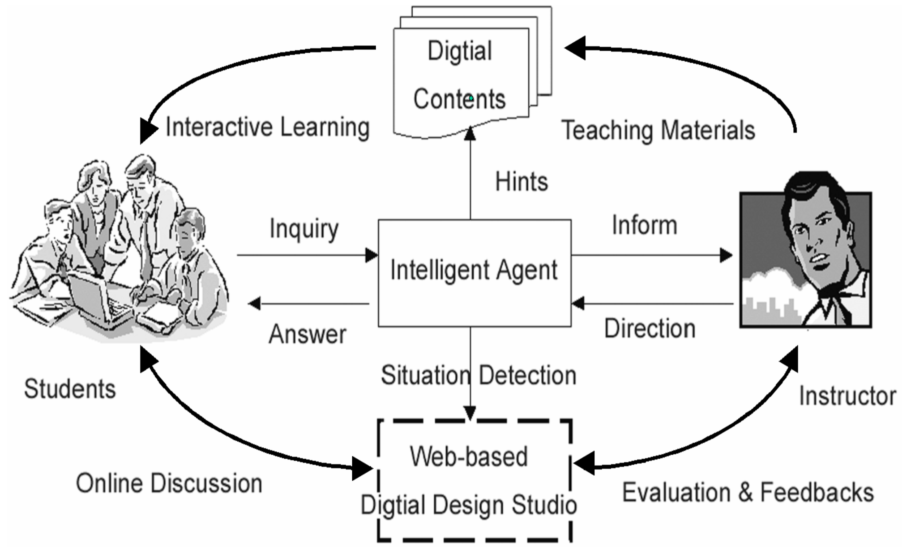


Fig. 4. Future Design Studio Model

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