CAAD: THE INTERACTIVE EFFECT IN TECHNICAL EDUCATION

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Abstract

The factors that determine the value of CAAD tools in technical education are investigated. Pedagogical theory on problem solving is reviewed, and its relationship to the design process as described by Mitchell is discussed. The goals of design practice and design education are compared. Consideration of the nature of the architectural design process and the impact of CAAD leads to the conclusion that cognitive skills, as defined by Gagne, are of increasing importance.

Pre-CAAD approaches to technical instruction are discussed. The opportunities represented by CAAD in terms of more relevant, effective, and rewarding learning experiences are noted. Features that make CAAD tools effective for instruction are considered, and the need for specialized instructional software is pointed out. Additional benefits of CAAD usage, including greater effectiveness of instructional staff and substitution for laboratory hardware are noted.

Introduction

The call for use of CAAD in architectural education and practice has been international [1], and increasingly we do see the use of CAAD in both areas. Reasons for introducing a computer-aid are:

a) increasing the speed at which an existing operation is performed to make the user more efficient;

b) enabling the user to perform new operations, increasing the scope of activity;

c) fashion.

Of course, the last is not a very sound justification. One wonders how much equipment and software sits idle because it was acquired to "keep up" with perceived trends rather than to meet carefully defined needs. This paper will consider the factors that determine the value of CAAD tools in education. The questions that will be examined are:

a) What are the pedagogical bases for the use of CAAD tools in architectural education?

b) How do the goals of education compare with the goals of practice?

c) What are the appropriate applications of CAAD tools in architectural education?

d) Should CAAD tools used in education differ from those used in practice?

CAAD applications to performance, as opposed to formal, aspects of design will be emphasized. This bias reflects my primary involvement with CAAD in education. These two aspects of design are also worth differentiating because they involve different bases of judgement and different modes of representing problems [2].

Pedagogical Theory: Learning Outcomes

Design has been recognized as a type of problem-solving activity [2]. Selection of instructional techniques in design education can benefit from pedagogical theory on problem-solving skills [3]. Gagne notes that human capabilities used in problem-solving differ fundamentally according to the problem type [4]. He calls these capabilities learning outcomes, and has identified five types:

a) intellectual skills;

b) verbal information;

c) cognitive strategies;

d) attitudes; and

e) motor skills.

The first four are of particular interest in considering CAAD in practice and in education. They are defined as follows.

Intellectual skills enable the learner carry out tasks through the use of symbols and rules or relationships. An example would be calculating heat flow through a wall. Special features of intellectual skills are the recall of previously learned capabilities and the application of a general procedure to a specific situation [5].

Verbal information forms the largest part of most instruction. Learners acquire organized knowledge, and the expected performance is restatement of the knowledge in such a way as to convey its essential meaning. This implies the retention of terms and general ideas, but not the recall of specific facts in verbatim form. While intellectual skills are precise (e.g. a heat flow calculation is carried out correctly or incorrectly), verbal information is more general (e.g. the factors affecting building energy efficiency).

Cognitive strategies are capabilities used in guiding one's own learning and thinking. The learner is faced with a situation where known methods and knowledge cannot be applied directly; they must be modified or new methods devised. In other words, a strategy must be devised to solve the problem. Becoming a self-learner and an independent thinker requires the cultivation of competence in using cognitive strategies. We shall also see, shortly, that cognitive strategies are crucial in architectural design.

Attitudes are learned internal states that influence personal action (e.g. choosing to use a computer-based method to solve a problem instead of a manual method). Favourable attitudes are fostered by either internal or external reward when a behaviour is exercised [5]. The quality of student experience with CAAD is important because the first exposure is a particularly sensitive point in the formation of attitudes.

The Nature of The Architectural Design Process

As William Mitchell notes in his book, Computer-Aided Architectural Design, architectural design involves the solution of "ill-defined" problems - those problems for which a clear test to indicate a "correct" solution does not exist. To solve such problems it is necessary to work

> "on the basis of incomplete criteria, to subject the resultant proposals to critical analysis, then to use the resulting clarified and more complete criteria as the basis for another design cycle. Criteria and solutions emerge concurrently, and the problem only begins to seem well-defined as the final solution approaches." [2]

Verbal information and intellectual skills alone are inadequate for such a task - cognitive strategies must be employed.

The heart of architectural design is form-making. New disciplines have originated as mastery of particular design tasks has become increasingly demanding. The past century has seen the emergence of structural, mechanical, electrical, lighting, cost, and a host of other consultants. In some cases, project managers have assumed the coordinating role in the design team. What the architect has not surrendered is pre-eminence in the creation of forms, the organization of spaces and systems, and the selection of materials. This does not mean that the architect's work is beyond rational or quantitative enquiry. Particularly in practice, the architect must know the consequences of decisions about form, space, and materials - consequences such as cost and energy requirements. Frequently, these consequences are now determined by other professionals in response to proposals by the designer.

The Impact of CAAD on Practice

Automation will change architectural practice by freeing humans from tedious and time-consuming document production activities. The following diagram from Mitchell illustrates this shift [2].

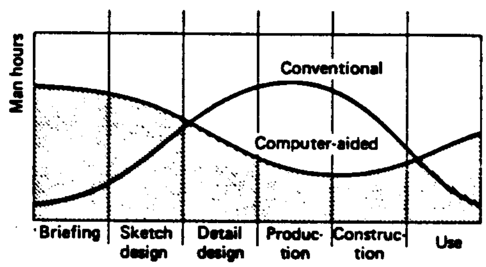

Figure 1. Redistribution of design effort with use of computer-aided design methods.

One of the projected consequences of CAAD usage is an increased emphasis on problem definition and conceptual design. It is argued that by speeding up the steps from concept to working drawings, CAAD will allow greater consideration of alternatives in the early stages [2].

These stages are the most critical in design. For instance, cost consultants point out that at this point in the design process, the designer still has 100% discretion over the budget. As design and construction progress, that discretion diminishes [6] (see Figure 2, below). The same is true of designing for energy efficiency.

Computer tools also make it possible to be more accurate about the performance consequences of early design decisions. For instance, queries about building energy performance that can now be quickly addressed used to be unthinkably time-consuming. Thus, CAAD tools encourage approaching design as a process of discovery, and are in tune with the "ill-defined" nature of design problems.

The shift in emphasis from finding an acceptable solution to

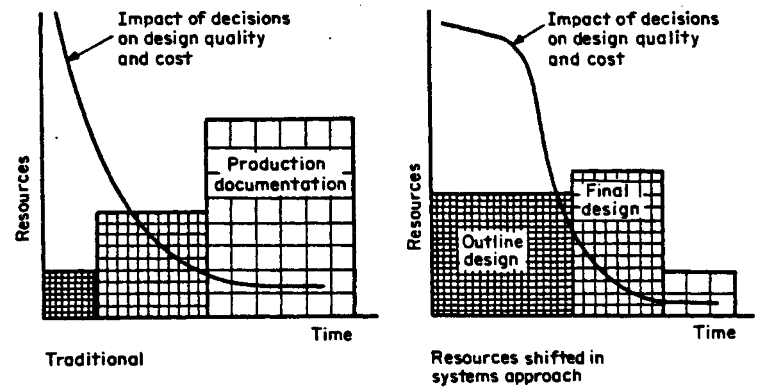

Figure 2. Decision impacts in the traditional and CAAD design processes.

weighing alternatives represents a change in approach from "how to?" to "what if?". Cognitive strategies become increasingly important to students as the scope of enquiry possible widens. Achieving competence in the use of cognitive strategies, then, is not only sound educationally, but will become increasingly important in preparing students for employment in CAAD environments.

Instructional Techniques

In a rational teaching process, instructional techniques would be selected after desired learning outcomes have been identified; the choice of technique would depend on effectiveness in developing the desired skills, knowledge, or attitudes. Dickinson enumerates a dozen instructional techniques, and it is easy to add to his list [7].

In university settings, the lecture is a widely used technique but it is not appropriate when

a) the instructional objective involves any form of learning other than acquiring information; or

b) the instructional objective involves the application of skills or knowledge.

One alternative to lecturing is the "simulation" which is characterized by placing the learners in a setting as close to reality as possible. Dickinson notes that simulations are effective when teaching students to:

a) evaluate or analyze an existing system; or

b) develop and evaluate a new model or system;

Item b) is especially relevant to cognitive learning. Design studios are classic simulations long recognized for their value in architectural education. The teaching technique of simulation also has great possibilities for teaching about performance of designs.

Past Approaches to Technical Education

In architectural practice, the objective of the design process is to work from a set of requirements to a completed building. In architectural education, the design process is used to make students aware of the foundations of architectural design and to give them skill in form-making. The design studio sequence is normally the core of any program; generation and criticism of schemes shows students how knowledge and skills are applied to the making of designs. The conceptual and schematic stages of design are given prominence. The emphasis is on making judgements about what is worth building rather than on how to build.

Non-design courses support the design studio by providing information on the historical, aesthetic, behavioural, and technical bases for design decisions, and by developing analytical skills. In technical education, one is attempting to create an awareness of opportunities, constraints, and consequences. Schematic and detailed stages of design are emphasized, as students learn how to translate design concepts into buildings.

Historically, learning outcomes in technical courses have fallen into the categories of verbal information and intellectual skills. The student is typically a passive receptor of information developed by someone else. The information is framed in general terms - that is, not particular to a specific project and certainly not particular to the student's work. Exceptions are so-called "integration" studios run by some schools, involving detailed development of certain aspects of design projects, or course projects that draw on studio work for problem content. Due to time constraints, the technical design process has not been iterative. That is, it does not lead to redevelopment of schemes, just to their working out.

Technical learning tasks have been chosen as much for the feasibility of completing the tasks as for their relevance to the architectural designer. Before the advent of programs for simulating building energy use, it was popular in mechanical services courses to have students calculate the maximum heating load for a house, most likely because it was a manageable task rather than because it gave students much insight as architectural designers.

I have also noted a tendency for technical faculty to set problems that replicate the work of their disciplines rather than to pursue problems of a more architectural nature. Furnace sizing and dimensioning of structural members are examples. This is understandable when faculty have no background in architectural design, but it is not the most effective education of design students. The result of introducing CAAD in such contexts may simply be the automation of less relevant tasks such as furnace sizing.

POSSIBILITIES OFFERED BY CAAD IN TECHNICAL EDUCATION

The real opportunity in CAAD is to make technical learning reflect architectural issues and the cognitive processes used in design. The speed of the computer allows the student designer to answer more relevant questions that were formerly too time-consuming to be considered in an educational setting. For instance, the energy use and cost consequences of different decisions about building massing and envelope design can be investigated. The student becomes an active participant in the process of discovery and generates information pertinent to a specific situation (e.g. analysis of energy use of a building designed by the student). The speed of computer analysis also allows emulation of the CAAD process of practitioners - the iterative process of hypothesis and test.

This can have dramatic effects on learning effectiveness. One example is understanding of energy flows in buildings. I have found that most students' and many practitioners' knowledge of energy flows in buildings is influenced by the experience of living in single family dwellings. Very few residences in Canada require any type of cooling system, while heating systems may be used 12 months of the year, if on a sporadic basis in the summer months.

Commercial and institutional buildings, on the other hand, experience large internal heat gains and have relatively small surface area to volume ratios. Even in Canada, these buildings must have year-round cooling. In fact, some buildings in Calgary experience peak cooling loads in the winter due to the low sun angle. Intuitively basing design decisions for large buildings on experience of small buildings can lead to very inappropriate results. This information can be communicated to students in lecture mode. That it is not absorbed, or is greeted with skepticism, is evidenced by the surprise of students when they conduct simulations of their own designs and find that heating is indeed not the major load in large buildings in a cold climate.

Through education we are attempting to instil attitudes as well as skills and knowledge. This includes the willingness to use the most effective tools, computer-based or otherwise. If students are to be prepared for practice in a CAAD environment, it is desirable for them to acquire a view of the design process as a weighing of alternatives rather than the development of a single solution. Use of CAAD tools in instruction is needed to make students aware of the rewards of this type of process, including the possibility of investigating intuitive notions that may prove to be wrong.

Choice of CAAD Tools for Instruction

An increasing stock of CAAD tools is being developed for practice. There is a great temptation to simply apply these programs in the classroom; they have the authority and legitimacy of professional acceptance. Transfer to the classroom may be appropriate in cases where the aim is to develop a specialist's level of competence. An example is training architectural-engineering students in the use of STRUDL for structural work.

There are disadvantages to using such powerful tools in the classroom. Learning to use the package can require a substantial investment of time. Frustrations with the complexity of the package can obscure the learning goal. For practitioners such as engineers who specialize in a particular area and use programs regularly over long periods, these difficulties are not nearly as significant. However, instructors in schools of architecture should weigh them carefully in reckoning the utility of a CAAD package.

The typical architect is more concerned with the general behaviour of structural systems than with sizing structural elements within three significant figures. The structural analysis programs with graphical output developed by SOM are good models for programs that would assist students in understanding the behaviour of structural systems [8]. The visual display of loading effects emphasizes system behaviour over precision dimensioning.

The most desirable types of packages for instruction are those which allow students to focus on the subject matter rather than the program. Program characteristics are of interest in technical education only to the extent that they increase the students' knowledge of what computers can do and of what is involved in getting them to do it. Batch programs, such as STRUDL and DOE2, typically require very careful formatting of input and/or the learning of a special language. Interactive programs can lead students through problems step by step, and with very little prior instruction and practice. Interactive programs normally have the further virtue of requiring less knowledge of operating system instructions.

Steps of Instruction

Recognizing the steps of instruction is useful in developing CAAD tools for teaching. Gagne [9] has outlined them as:

a) gaining attention;

b) informing the learner of the objective;

c) stimulating recall of prerequisite learning;

d) presenting the stimulus material;

e) providing "learning guidance"

f) eliciting the performance;

d) providing corrective feedback;

e) assessing the performance; and

f) enhancing retention and transfer.

Some of these steps are irrelevant to CAAD tools designed for practice. The professional user presumably knows the objective, does not require "learning guidance", and needs little corrective feedback. However, this is not true of the student user. Instructor intervention can supplement program capabilities, but CAAD tools could be made more effective for teaching by including such capabilities. This necessitates the development of custom CAAD instructional software, or the adaptation of existing packages. I am currently developing, and testing in the classroom, programs for instruction in acoustics and lighting. I'm sure that others are also developing "courseware". An example of the latter route is SAS, or Simulation Apprenticeship System, an interactive front end processor for TRNSYS developed by the Faculty of Architecture of the University of Montreal [10]. There is a great deal of development work to be done both on creation of packages and on methodologies for the design of educational software.

Until "ideal" CAAD instructional packages are available, the value of existing packages can be enhanced through the intervention of instructors. For instance, the DOE2 program was created to carry out sophisticated simulations of building energy performance. Unlike many such programs, it allows extensive exploration of features of the building shell including, in the most recent version, use of daylight. While this package requires substantial instruction in the use of a batch system, our school decided a few years ago to introduce it as a teaching tool because of our strong interest in energy efficient design.

In order to generate more than tertiary heating and cooling information for designs, it is necessary to specify mechanical systems. This work is not considered appropriate for architecture students, so the instructor sets up these components of the simulation. The instructional process is organized to promote early rewards from use of the system, and to minimize student frustration. This is achieved through an empirical approach that emphasizes working immediately with simple simulation examples, introducing additional simulation features over time, and ready access to instructional assistance. For the past three years, all second year students have applied the program to a design after learning how to generate simulations. In the following winter term studio, they have worked in teams to simulate schemes selected to represent a variety of approaches to form. This gives a good indication of the sensitivity of energy use to a range of form decisions. By this point, the students are quite competent at developing code for the architectural components of the project, but still rely on an instructor to code the mechanical components. Perhaps a processor like SAS could reduce the effort involved in this process.

We more typically make use of programs like HOTCAN, an interactive program developed in Canada for assessing the energy requirements of designs for single family dwellings. Programs like this meet more of the requirements of the ideal CAAD instructional system. The entire description of a residence is entered through a question and answer sequence. Little instruction is required to use the program and obtain results.

Another point worth noting with respect to CAAD tools is their capacity for provoking the interest of students. It might be feared that students would remain ignorant of the processes by which solutions are generated if they use CAAD tools. My experience has been that CAAD tools can enhance students' learning of procedures. Their curiosity is aroused as to the reasons for systems behaving in particular ways, and they turn to principles and formulae to understand system behaviour.

Additional Benefits of CAAD in Technical Education

Laboratory equipment may be used to set up demonstrations of building system performance. In many cases the cost of equipment can preclude the teaching technique of simulation, which would require that every student have the opportunity to participate in experiments. The multipurpose computer and terminal can allow greater participation by students, and substitute for expensive lab equipment, with the appropriate development of software. An example of a substitution might be a demonstration of deflections induced by loading of a structural frame.

Financial pressures on universities are also reducing the availability of professional and technical teaching staff. CAAD teaching software with pedagogical capabilities could also make it possible for instructors to teach more effectively and get more out of students in the face of these constraints.

Conclusion

Returning to the four questions posed at the beginning of this paper, we see that:

a) pedagogical theory indicates that cognitive skills are of increased importance in CAAD environments, whether in education or practice;

b) the goal of practice is producing buildings, the goal of education is producing architects;

c) appropriate applications of CAAD tools in architectural education are those which enhance the student's understanding of the architectural aspects of design, especially the hypothesis and test nature of the CAAD design process; and, finally,

d) CAAD tools for education should differ from those used in practice: educational software should have features that are not important to practitioners and likewise features that are important to practitioners are not important to educators.

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