Excavation Game: Computer-Aided-Learning Tool for Teaching Construction Engineering Decision Making

Ahmed Sherif, M.ASCE[1]; and Hosnachah Mekkawi[2]

Abstract: This paper reports on an interactive computer-aided-learning (CAL) tool that was developed for the education of construction engineering students: the excavation game. It builds on the large potential of using CAL in education. CAL tools could offer a better learning environment for students, as they provide an excellent opportunity for applying and testing the management skills learned in classroom, but are difficult to implement in reality. In this research, the CAL tool focuses on improving students' decision-making skills in the aspects of excavation and related activities. These are excavation equipment, dewatering, and soil-support methods. It also covers mobilization, surveying, safety, overtime shifts, and reporting. Students compete with regard to time, cost, and quality of construction of a given project. The game flow is nonlinear as it depends on students' decisions. Wrong decisions deviate the construction flow to a path that costs money and time, while reducing quality. This must be corrected costing extra money and time. The game was tested by senior practicing engineering and university professors. Then, it was tested by senior undergraduate construction students. Both groups agreed that the game responds, to a great extent, to the characteristics of effective CAL software, and that the information provided could not be easily assimilated or practiced through the usual tutorial or demonstration educational format. 18% of the professionals and 72% of students indicated the usefulness of the game in applying management and decision-making skills. 60–70% of students believed that it improved their technical skills in dewatering, soil-support, and excavation activities. In addition, 80% of the professionals found the game presenting realistic soil-support and excavation situations, while 72% of students became more appreciative of the interdependencies between activities.

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Introduction

The success of future engineers is greatly influenced by the quality of their education. This education should not be limited to the solid technical background and basic "fundamental skills," such as the logical thought process and computer literacy; it should extend to the other "soft skills" (Hissey 2000). These are necessary for preparing students to the harsh competition of today's workplace. The education of construction engineers is specially related to acquiring a specific set of management skills. These management skills include directing the flow of work, adhering to commitments and deadlines, dealing with unexpected conditions, and coordinating between participants.

Practice of the operational and management skills before stepping to the professional world is fundamental to the success of future construction engineers. This is usually achieved through internships in construction projects. However, the internships are restricted in time and scope due to the special nature of construction operations, where any small mistake could result in serious technical, financial, or safety results. Computer-aided-learning (CAL) tools could prove very useful in this respect. They could effectively simulate realistic situations in the safety of the classroom environment, where students could freely make a wide array of management decisions.

Objectives

The objective of this paper is to report on the development of the "excavation game." It is an interactive CAL tool for training students on construction engineering decision making. The CAL tool takes the form of an educational game that concentrates on the excavation phase of building construction.

Methods of Learning and Teaching

In order to effectively integrate the "fundamental" and "soft" skills into engineering education, it is important to examine the different learning modes and available educational methods, as well as understand the learning process. There are several modes

[1]Associate Professor, Dept. of Construction and Architectural Engineering, The American Univ. in Cairo, P.O. Box 74, New Cairo 11835 Cairo, Egypt (corresponding author). E-mail: asherif@aucegypt.edu

[2]Technical Coordination Engineer, Dar-Handasah Consultants, 15 Amr St., Cairo 11511, Egypt. E-mail: hosnachah.mekkawi@dargroup.com

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for acquiring information (Wilson and Spears 1997). The first mode is the passive "transmission" mode, which utilizes traditional lectures. Although this mode is the easiest and most frequently applied, it does not enhance students' analytical and interpersonal skills. A more effective mode of learning is the "acquisition" mode, which is a conscious choice to learn. The material acquired in this case is based on the learner's initiative. Another mode of learning is the "accretion" mode, which is the gradual unaware acquisition of information. This usually applies to habits and social rules. Finally, the new information deducted and inspired by one's mind during reflection, interaction, and creative expression is the "emergence" mode of learning. It is based on one's ability to analyze, create, and innovate. This mode requires opportunity, time, and space to reflect and come up with new ideas and conclusions.

The educational methods can generally be divided into two main categories, the "instructor-centered" approach and the "learner-centered" one. In the instructor-centered approach, teachers play the major role in controlling and directing the learning process. On the other hand, in the learner-centered approach, teachers facilitate the learning process for students who have different learning styles. The approach focuses on the student himself, and the development of his self-learning skills, while adapting to individual differences between different students. A different categorization of the educational methods includes the following five approaches (Saskatchewan Education 1991): "Direct instruction," such as traditional lectures, questioning, and demonstrations, which suits the transfer of basic knowledge; "indirect instruction" includes inquiry, induction, problem solving, decision making, and discovery; in "interactive instruction," learning is achieved through discussions and sharing of opinions; this approach stimulates students, and enhances their argumentation and convincing skills; "experiential learning," which is an activity oriented approach that is based on students' induction, reasoning, and deductions while conducting an experiment; it emphasizes the learning process rather than the output; this method could be very beneficial to students but has resource, time, and safety limitations; "independent study" enhances students' initiative and ability to learn on their own.

The direct instruction approach corresponds to the transmission mode of learning. It could be considered an instructor-centered approach. On the other hand, the other approaches fall into the category of student-centered learning. They mostly correspond to the "acquisition" and "emergence" modes of learning, as students participate in getting the information and are capable of generating their own thoughts. They also involve some degree of "accretion," since certain information will be transferred unconsciously to the student along the learning process.

CAL

CAL could be successfully used in integrating the learning methods identified above in a unified system. CAL is defined as "an integrated approach for teaching a subject, in which a learning technology forms a part, and which only comes about after reassessment of the current teaching methods" (Oliver 2001). The term "aided" implies that the computer is not the only tool used in the learning process; CAL became a part of an integrated learning approach.

CAL could be applied through different techniques. The most commonly used applications are the tutorials, demonstrations, and presentations, which introduce new information and act as a review tool. More interactive forms of CAL include the "drill and practice" format usually applied when mastering a new information or skill is needed. It is used as a second step after the material has already been introduced. There is also the "problem-solving" technique, capitalizing on the reasoning and analytical skills of students (Rist and Hewer 1996). Another interactive application of CAL is the "games" format, which provides a motivating learning environment, taking advantage of the competitive interests of learners.

Characteristics of Effective CAL Tools

CAL tools could offer a better learning environment for construction engineering students. They provide an excellent opportunity to apply and test the management skills learned in classrooms but are difficult to implement in reality. Furthermore, CAL could be more cost effective than giving additional classes or increasing class time or decreasing the number of students per class. It could also reduce operational costs, such as the cost of organizing field trips or acquiring expensive equipment (Masson 1997).

However, applying the latest innovations in CAL might not always be successful. The structure of the tool, the message it delivers to students, and the degree to which it responds to students' needs are among the factors that determine the success of the software. The main characteristics of an effective CAL tool could be summarized as follows (Sherif and Mekkawi 2006).

1. *Realism.* The project(s) selected for CAL implementation should be as realistic as possible by having some degree of complexity that provides a beneficial learning experience and a challenge to students. Yet, they should still be simple enough to be contained within a computer simulation that is accessible through widely available regular desktop computers (Al-Jibouri and Maudesley 2001). The speed of today's computers improves simulation capabilities and enhances interactivity with the system (Gibbons and Fairweather 1998).
2. *Self-learning.* CAL should ensure a degree of self-dependency during the learning process by creating a "learner-centered" system. The responsibility of understanding should be transferred from the instructor to students in order to create a feeling of urgency to acquire data, thus developing their sense of satisfaction, and increasing their self-esteem and need for further development (Issa et al. 1999). Moreover, CAL should allow students to set the pace of learning, thus giving time and chance for the "emergence" mode of learning (Cooper 2003).
3. *Nonlinearity and interactivity.* The flow of the CAL tool should be based on students' actions. Interactivity with the system could be provided at different levels. The first level is the stimulation of students' senses as hearing and viewing a simulation. The second level requires a small input from students in order to advance the learning process. In the following level, students control the sequence of learning. In the highest level, students select the content of the material to be learned. Selection of the most suitable level of interaction depends on the given material, target student group, and the degree of guidance required (Issa et al. 1999).
4. *Degree of guidance.* Together with nonlinearity, there should always be a degree of guidance concerning the branching of the program. This ensures that students will not greatly deviate from the correct path or feel lost within different branches.
5. *Uncertainty and novelty.* Integrating uncertainty in CAL

projects makes them realistic and teaches students how to respond to the unexpected occurrence of the professional world. Uncertainty could also be used to provide novelty by varying the nature of projects in different runs. This adds a challenging nonrepetitive aspect to the game and overcomes one of the defects of CAL, which is the onset of boredom after a few runs.
6. *Assessment of user's performance.* Computers could easily, and automatically, keep a record of students' actions (Gibbons and Fairweather 1998). This should be used to provide students with feedback in the form of assessment scores during, and at the end, of sessions. The record would also help teachers in evaluating students' performance.
7. *Interface.* The CAL tool should provide an attractive, user-friendly interface that utilizes efficient visualization techniques, without leading to ambiguity. An important aspect of the interface is dual coding of information by using more than one medium to provide information. People remember 20% of what is heard, 50% of what is seen, and 70% of what is seen and heard (Issa et al. 1999).
8. *Creativity.* The interactive learning medium, the stress relief, together with the enjoyment provided by CAL should be used to stimulate students' creativity.
9. *Enjoyment.* CAL applications should be attractive enough to rise to the expectations of today's students who are used to many types of entertaining computer packages.
10. *Safe learning environment.* Safety includes both the physical and moral meanings. The computer provides a virtual, nonthreatening simulated environment, where students can investigate activities, which may otherwise be difficult or unsafe to practice (Masson 1997), such as construction-site activities.

Implementation of CAL should also consider some of its limitations. Some students might not be at ease with the excessive use of technology. CAL tools might become ambiguous or overloaded, thus hindering the learning process (Masson 1997). Some learners might become disoriented because of the nonlinear nature of CAL that lacks a system of cues or maps that could enable them to navigate easily, i.e., "discourse cues" (Gygi 1990). In addition, CAL applications will never be able to fully duplicate reality, no matter how good they are. Many parameters are usually omitted for practical reasons. Thus, CAL tools should resemble reality as much as possible, while focusing on core activities. This could be considered an advantage because it allows students to concentrate and comprehend basic principles (Masson 1997). Furthermore, computers should complement the normal methods of teaching, as CAL deprives students of the personal contact and gestures of their instructors (Harasim 1989; Moore 1991; Feenburg 1998). Finally, development of the learning tool and investigation of the technical data could turn out to be costly and time-consuming if not planned properly.

Earlier CAL Packages for Construction Engineering Education

Several CAL packages were developed for the education of construction engineering students. Earlier attempts at the development of CAL games for construction were as old as 35 years ago, where "the construction management game" and "constructo" were developed by Au et al. (1969) and Halpin and Woodhead (1973), respectively. Since that date, many applications were introduced. Some were developed for teaching mechanics of materials such as M.D. solids (MDSolids 2009). Others, like "DEFLECT," aimed at teaching structural design (MacCallum and Hanna 1997). Many other games teach surveying. These include Survey, Isis (Mika 1996), and SurCAL, AshCAL, and TrimCAL (Smith and Roberts 1997). The financial aspects of construction were also addressed by some packages such as the "equipment replacement game" and "a simulation game aiming at pricing construction contracts in a competitive market" (Nassar 2002).

A limited number of CAL games addressed the operational and managerial aspects of construction projects. This section concentrates on these educational packages. Seven CAL games were selected representing the range of CAL types that are available in this area. A unique name was assigned to each game in order to facilitate identification. These are the following.

1. The Hong Kong game was developed by the Department of Real Estate at Hong Kong University. It teaches planning of on-site construction activities. A task is presented to students, together with alternative methods and activities. Students are required to make a sequenced list of selected activities and method statements, describing the rationale for their selection (Marsh and Rowlinson 1999).
2. Contract and construct (C&C) models contract management. It teaches trade-offs between cost, quality, time, and safety, as well as decision making and people management. The program simulates the construction of a chemical plant, where students act as project managers aiming at the successful completion of their projects. Students select contractors. Then, construction activities advance automatically. Unexpected events and problems occur, challenging students to select appropriate decisions (Martin 2000).
3. Virtual construction (VIRCON) teaches the basics of construction planning. The game is played by groups of students (contractors) bidding for a given project. The VIRCON system—provided online—is used for project planning, scheduling, cost estimation, and documentation activities. Prebid reports are submitted to a "board of review," which selects the winning team (Jaafari et al. 2001).
4. The building industry game (B.I.G.) aims at the development of students' ability to analyze situations, gather data, and make strategic decisions while balancing time, cost, and quality. B.I.G. is played by groups of students (contractors) submitting bids for given projects. To increase the challenge, the game generates an additional computer contractor X who also bids. Players start with the same financial position, which changes during the game due to overhead costs, bidding expenses, and lack of work. B.I.G. produces dynamic balance sheets, which add profit and subtract costs and losses (Johnston et al. 2003).
5. The management game teaches project planning and control. It models the construction of a rock and clay fill dam. Students act as the contractor's project manager who is responsible for the performance of earthworks. Students report to the head office that can vary game parameters such as weather, site layout, and other random events in order to give different levels of difficulty. Overheads and liquidated damages are accounted for (Al-Jibouri and Maudesley 2001).
6. COMMITTED links between the technical and management studies through presentation of the tendering stage. The first stage of the game involves tender preparation by students. The second stage handles project implementation, which includes selecting subcontractors and solving technical issues,

while monitoring cost. The game also covers ethical issues and claims (Hornibrook 1996).

7. Superbid aims at teaching the different factors that should be considered during the bidding process. Students, assuming the role of a general contractor, submit bids for projects. Financial transactions such as loans and deposits can be made (AbouRizk 1992).

Analysis of Selected Earlier CAL Packages

Now, it is important to investigate the above games in relation to the main characteristics of an effective CAL tool, which were identified above (Sherif and Mekkawi 2006). The analysis is based on the information published about these games in the references cited above.

Present realistic situations. Most of the applications present rather realistic projects. These were designed for game purposes, having variables controlled by instructors, as in the case of C&C, B.I.G., the management game, COMMITTED, and SuperBid. A realistic project is even used as a case study in one of the applications (VIRCON). Some other applications concentrate on specific construction activities such as piling as in the case of Hong Kong game. These activities are also realistic in nature.

Self-learning. All the games promote self-learning, because of their open-ended game format. They allow students to practice and learn various management concepts on their own. Some of these applications, such as the Hong Kong and the management games, provide help tools allowing self-study of technical information.

Nonlinearity and interactivity. The studied packages offer a limited degree of nonlinearity. The game structure or role playing assumed by these games implied that students are the ones making decisions with regard to selection of their paths. However, the programs do not present enough path options. Some games offer interactivity with other applications, such as the Hong Kong game, which gives access to a note pad that enables students to write method statements while remaining within the game mode.

Degree of guidance. One of the games providing a notable degree of guidance is the Hong Kong game. It includes a corrective feedback mechanism that allows students to modify their answers accordingly. It also offers a theoretical overview in the form of diagrams and illustrations describing the activities that are not familiar to students. In addition, the optimum solution is also offered at a late stage of the program. Other forms of guidance are provided by some of the applications, such as the management game, through assistance screens or right clicking on relevant screen parts.

Uncertainty and novelty. The occurrence of unexpected events is common in many games. For example, the second stage of C&C application focuses on uncertainty and unexpected events. In both B.I.G. and the management game, the administrator controls several variables such as weather and material cost during the game and also creates change orders. However, the majority of these games are limited in terms of novelty. They do not provide means for changing game parameters during different runs.

Assessment of user's performance. Counters are used by some applications to assess performance. The C&C game includes different counters for cost, time, quality, morale, and safety. These change according to students' decisions. Superbid and B.I.G. use financial results, such as return on investment and profit for assessment. Reports are also used for assessment in as in VIRCON, where groups submit reports on their bid costs and durations. They could also take the form of work programs and financial plans, which are submitted, before and at the end of the game, in the management game. A simpler approach is adopted by COMMITTED and the Hong Kong game, where students describe and comment on their performance in a final report.

Interface. All the games provide simple user-friendly interfaces. Most games use consecutive windows and forms with navigation buttons, as in the case of C&C. They may also depend on pressing parts of the screen as in the case of the management game. The same is for the first module of VIRCON, which provides a user-friendly interface for data entry and analysis, and a databank for each project. No graphical illustration of activities is used in B.I.G. The Hong Kong game and the management game use dual coding of information by including explanatory diagrams and video clips. This is expanded in VIRCON, which includes a "schedule simulator" that illustrates the duration of the activities in a three-dimensional (3D) presentation, and 3D "walk-through" tool.

Creativity. The level of student creativity promoted by these games is closely related to the amount of nonlinearity and guidance offered. It also relates to uncertainty provisions. These vary between the different games as discussed before.

Enjoyment. According to the authors, most of the games provide a joyful nontraditional learning experience.

Safe learning environment. All the games provide a kind of safe learning environment. The VIRCON's 3D walkthrough, and the videos of the construction operations presented by the Hong Kong game and the management game, expose students to the on-site techniques while remaining in the safety of their classrooms.

Introduction to the Excavation Game

The excavation game developed in this research focuses on the project management aspects of building construction. It stresses the importance of monitoring cost, time, and quality of any project. The game covers excavation related activities, namely, excavation equipment, dewatering, and soil-support methods, together with other important concepts such as mobilization, surveying, safety, overtime shifts, and reporting. When playing the game, students should satisfy a target cost budget and adhere to a given project time duration (Sherif and Mekkawi 2008).

Logic and Flow of the Game

In the excavation game, students act as construction managers. The flow of the game is nonlinear, as it depends on students' decisions. Students are allowed to make mistakes and are given options for rectification. For example, students should select from a set of alternative methods and equipment of dewatering, soil support, and excavation. Students should also make sure to adopt appropriate corresponding steps and quality actions. Incorrect selections result in unexpected site problems, such as soil failure or water flooding, that appear at later stages of construction. Corrective actions must be taken in these cases, costing money and time, and some construction works might need to be repaired or repeated. Moreover, ignoring important preparatory steps such as soil investigation and surveying, and allocation of site facilities, fences, and other safety precautions entail consequent problems that should be rectified. For example, construction might stop due to the settlement or misallocation of foundations. This could be a result of an earlier mistake of ignoring soil investigation reports,

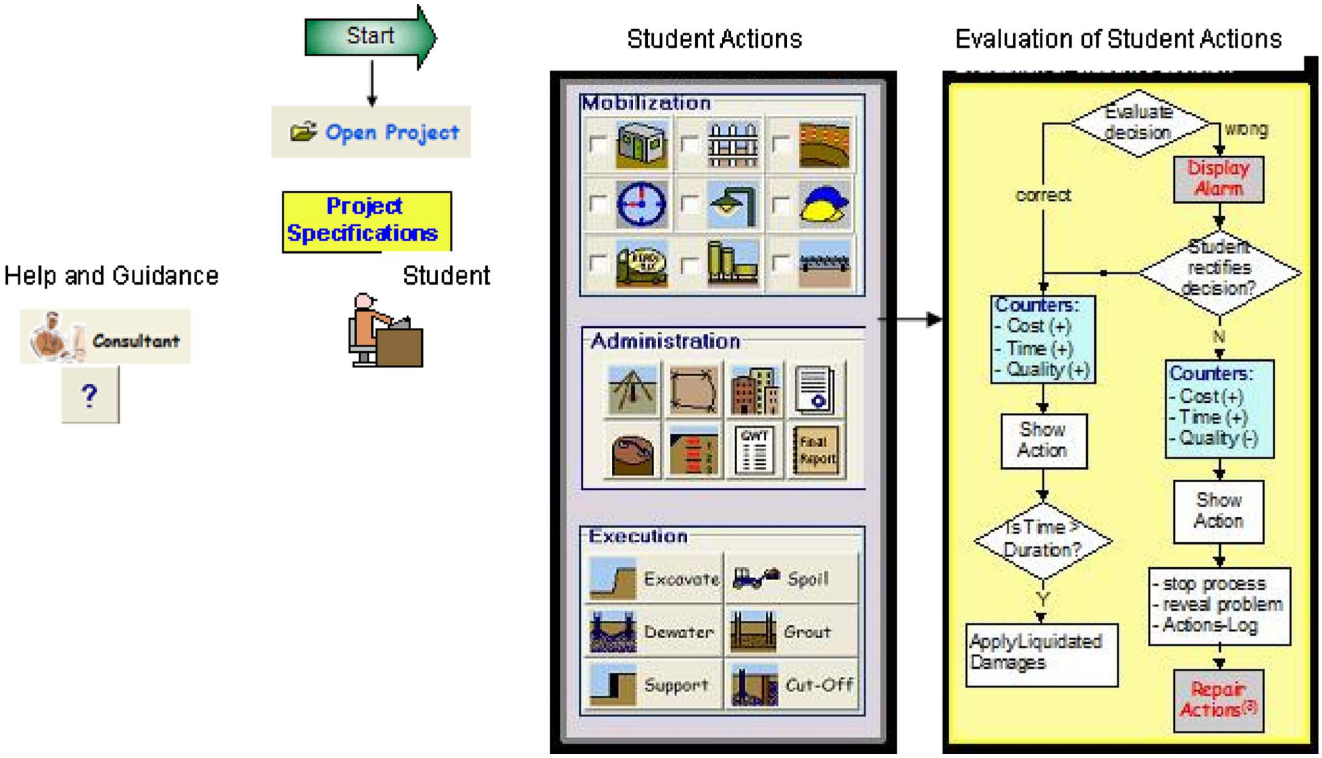

Fig. 1. Logic and flow of the excavation game

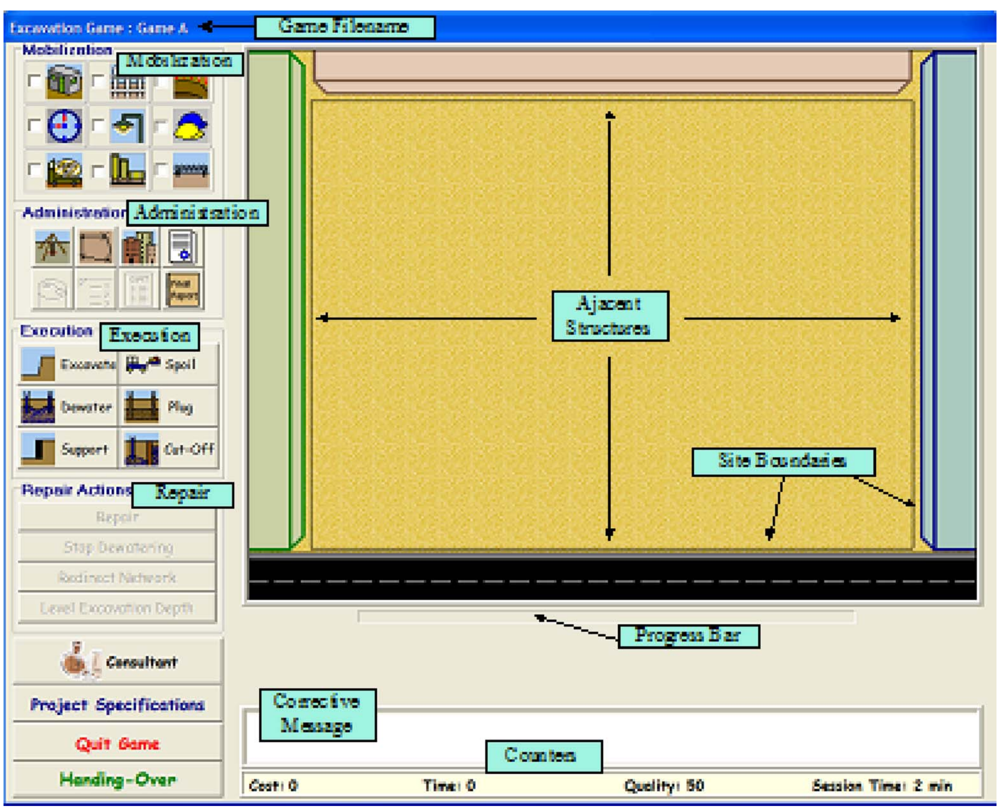

Fig. 2. Main screen of the excavation game

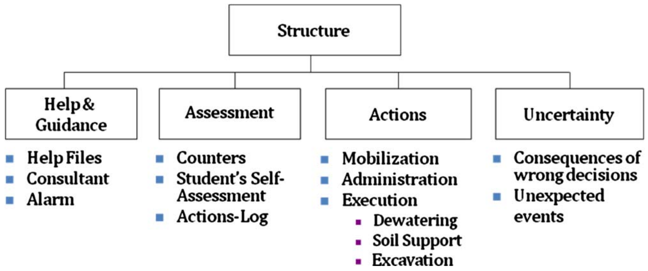

Fig. 3. Structure of the excavation game

or forgetting to make site surveying. The foundations will have to be either removed or corrected in this case, costing extra money and time. Fig. 1 illustrates the logic and structure of the game.

The main screen of the excavation game is initialized based on the data loaded from the game file (Fig. 2). Different game files could be designed by the instructor through another application called "project designer" that was also developed in this research. There is a two-dimensional presentation of the project site and adjacent structures. During the excavation game, student's selections are drawn on site. Main actions and alternatives that are available for accomplishment of the given task are also presented in the main screen in the form of buttons and check boxes. These actions are categorized as mobilization, administration, or execution actions. Buttons related to each category are grouped in one panel for clarity and guidance. An error message is available for alarming students. A progress bar is used to illustrate the progress of activities. Cost, time, quality, and session time counters change concurrently with the implementation of different actions.

Structure of the Game

The excavation game is composed of four main components: main actions, help and guidance tools, assessment tools, and uncertainty (Fig. 3). It was developed using Borland C++ Builder programming environment.

Main Actions

Mobilization Actions

The excavation game starts with "mobilization." Some of the offered mobilization actions aim at teaching students about site organization, such as "site office," "batch plant," and "steel workshop." Others stress security and safety procedures; these include "site fence," "safety barricades," and "personal protective equipment." Site illumination and working extra night shifts to expedite work are offered. Once one of these items is selected, it is recorded by the excavation game and drawn on site while the cost and time counters increase. The student can still remove the selected item if unnecessary or wrong, but this entails extra cost and time and decreases the quality counter. On the other hand, not selecting appropriate mobilization items in due time causes later consequences.

Administrative Actions

The management of the construction project not only involves technical issues, but also many administrative issues. The administrative actions presented by the game are mainly categorized as regulatory issues such as obtaining required permits, reporting aspects such as topographic, geotechnical surveys and adjacent foundations surveys. It also involves technical aspects such as checking excavation depth and conducting ultrasonic tests of piles, if needed. Missing the selection appropriate administrative actions cause later consequences.

Execution Actions

Dewatering Methods

The main goal of the dewatering section is to train students on the integration of dewatering systems with the whole construction process. The subscreen on dewatering is presented in three main sections. These are selection of appropriate method, identification of the steps needed to carry out the selected method, and quality control. Other activities related to dewatering such as construction of cutoff wall, horizontal plug, permits, and GWT report appear in the main screen of the game. Upon closing the subscreen, a simple illustration of the dewatering system is drawn on site. The dewatering progress bar, as well as the cost and time counters, increases. As the progress bar advances, many checks are performed by the game with regard to the selected quality control measures. They are also related to selection of a water-tight system and suitability of the selected dewatering method. In case of a wrong decision, the game will stop the dewatering process and alerts the student to rectify the problem. Cost and time and quality counters are affected in this case.

Soil-Support Methods

This part aims at teaching students about different soil-support techniques, as well as the selection of the appropriate method with respect to the site parameters, soil conditions, and GWT. The soil-support subscreen is divided into four panels. These are alternative methods (diaphragm wall, secant piles, sheet piles, and Berlin wall), the corresponding equipment, the implementation steps, and quality control measures. If a problem arises as a result of lack of quality control, the quality counter decreases. In addition, the repair button and the missing quality action become red for guidance. As the student exits the subscreen, alarm warns if some quality actions are missing. On exit of the soil-support subscreen, a progress bar and representative lines are drawn on site representing progress of the soil-support works on the main screen. Cost and time counters increase accordingly. Different support methods are presented together with an explanatory legend. The student can modify his selection of soil-support methods at any time with added cost charges.

Excavation

This section relates to the excavation process where student's selections in terms of dewatering, soil support, and excavation equipment get integrated and evaluated by the game. The excavation equipment subscreen presents the available tools (bulldozer, backhoe, and loader) and their respective production rates. The rates are entered by the instructor through the project designer application. As the excavation progresses, different checks are done by the game. Such checks cover the suitability of the selected equipment, soil investigation, safety precautions, soil-support and dewatering methods, and similar issues. Checking results may result in problems that entail student's need to revisit other sections such as dewatering and soil support, which results in increase in cost, time, and quality counters.

Help and Guidance

Help files can be designed by the instructor as html files that are linked to the game. Such files may cover any related information.

At any point of the game, the student can ask the "consultant." The consultant will advise him on how to rectify a wrong action or on which step to do next. This consultancy service adds to the cost and time. It is recorded in the actions log. The instructor can set the maximum number of times the consultant is used. Alarm can be set on/off by the designer. If it is set to "on," the alarm notifies the student if he/she attempts to start some activities without satisfying their prerequisites. Being an indirect guidance tool, the alarm simply hints about the anticipated problem.

Assessment of Student's Performance

Actions Log

It provides feedback to students and assists the instructor in evaluating students' performance. Any student error is recorded, together with an explanation of the reason and indication of the proper action. Any missing task is also recorded, such as "checking excavation depth" and installation of a "site office." The actions log ends with comments regarding student's performance and scores. The actions log appears to students after "handing over" and is saved as an output file for use by the instructor.

Counters

There are four counters that appear on the main screen. These are the cost, time, and quality counters. Cost and time counters increase with the implementation of any task. In case of removing an installed item or correcting a wrong action, the cost of removal would be added to the cost counter. Liquidated damages are added to the cost counter when the given project duration is exceeded, while a bonus is awarded in case of early completion. The quality counter increases/decreases depending on students' decisions and their effect on project quality. An actual session time counter is also available.

Final Report

Another form of evaluation is the "final report." It is a self-assessment report done by students at the game end, where students describe their performance, the problems they encountered, and suggest improvements.

Uncertainty

In order for the game to be realistic and to increase the degree of nonlinearity, the game incorporates the occurrence of unexpected events, which are common in the professional world and typically result from making wrong on-site decisions. These include, for example, failure of the excavation sides or/and damage to neighbor's foundations.

Testing and Evaluation of the Game

Testing Process

The excavation game was tested by professionals as well as students. Fourteen professionals, mainly senior practicing engineers and university professors, were selected for this purpose. They were selected based on their experience in the fields addressed by the excavation game. In addition, 45 senior level undergraduate construction engineering students from the American University in Cairo played the game as part of their "construction methods and equipment" course requirements. Student evaluation was conducted in three sessions, lasting 50 min each. All attending students were asked to play the game during a formal session organized at the last quarter of the semester, where an appropriate level of technical knowledge was acquired.

The evaluators were asked to play the game on sample projects, and feedback was sought in the form of questionnaires addressing conformity of the game with the characteristics of effective CAL tools that were identified earlier in this paper. Two game files were developed for testing. These were randomly distributed on students. The "consultant" and "alarm" functions were enabled in both files. A handout was distributed outlining game instructions before game play.

Two questionnaires were designed for the purpose of testing the excavation game. The first one was addressed to professionals, while the other was addressed to students. The professionals' questions address the realism of the technical aspects of the game and their suitability to students' knowledge level. They addressed the degree of freedom given to the instructor in designing different project parameters at various levels of difficulty, and the degree of uncertainty facilitated by the unexpected events. The questions investigated the effectiveness of the help and informative tools. In addition, questions addressed the effectiveness of performance measurements and self-evaluation tools in assessing student work. The questionnaire also asked about clearness of the game interface, level of interactivity, challenge, creativity, and the suitability of time allowed. Other general aspects were sought, such as comparing the time required for gaining the same training through traditional forms, the background level required before using the game, and also the general opinion about the usefulness of the game, and suggestions for improvement.

The students' questionnaire included questions addressing most of the above aspects, but was formatted in a different manner that suits students' background and attitudes. In addition, it included questions about the friendliness of the game, the information included, and knowledge acquired. It also addressed issues such as whether the grading system was fair and the usefulness of the comments provided in the actions log.

Game participants were requested to answer the questionnaires after completion of game play. A five point scoring system was used (strongly disagree, disagree, neutral, agree, and strongly agree). Responses were tabulated and grouped where the percentage of all those who "strongly agree" and "agree" to any question was calculated in relation to the number of total answers to the question. This percentage was used as an indicator of those who are in agreement with the question. Thus, the results of the game testing present the informed opinion of the professionals and students who played the game.

Evaluation Results

Presenting realistic situations. The presentation of dewatering, soil support, and excavation process was well appreciated by professionals who agree that the methods offered are the main ones actually used. 65% of the professionals view that the evaluation of methods with respect to the given site conditions was realistic. 70% of professionals agree that mobilization and safety measures were well covered. They recommended allowing students to select the location of these items in order to teach students about site organization.

Providing a degree of guidance. Professionals agree that the consultant tool provides useful comments and represents a confident source for advice. On the other hand, students were cautious in using the consultant, because it charged cost and time. As for the alarm, 80% of professionals find it very effective as it does not present direct guidance. As for students, 45% of them reported that they needed more helping tools. This contradicts professionals' opinion, as 80% of professionals believe that the educational game offers enough help.

Assessing student's performance. 85% of professionals and students reported that counters provided a good incentive. 80% of professionals and 84% of students found that the comments of the actions log were very useful. Also, they believed that the comments on each of the student's actions give an intimacy feeling as if the game is addressing each student individually.

Combining uncertainty and novelty. 70% of the professionals, who practiced the excavation game several times, indicated that the rationale for solving the project was different in each time. However, 55% of professionals suggested adding more unexpected events such as weather conditions or detection of a rock layer along excavation. Students who selected the correct actions did not face much uncertainty; this was due to the fact that uncertainty in this game is based more on the consequences of "wrong" decisions rather than events that are independent of students' actions.

Promoting self-learning. Students reported that their knowledge in excavation related activities was enhanced through the game. 80% of professionals found the game useful in applying and testing management and decision-making skills.

Ensuring nonlinearity and interactivity. 80% of the students, who played a more complicated project, believed that the educational game provides a good degree of interactivity and that the flow of the game depends on students' decisions. 65% of professionals appreciated the degree of nonlinearity offered by the game and suggest increasing the topics and alternatives offered to students, such as weather detection of a rock layer during excavation.

Providing an attractive interface. Both professionals and students indicated that the interface is generally simple and user-friendly. However, 80% of students believe that the interface needs some 3D presentation. Professionals suggested illustration of equipment operation and illustration of ramps and access roads, as well as the dewatering and support methods. On the other hand, 85% of professionals and 65% of students agreed that different helping tools ensure double coding of information, especially those related to corrective feedback.

Providing enjoyment. 80% of students reported that the educational game was interesting and enjoyable and would recommend it to other students.

Providing a safe learning environment. 80% of professionals and 72% of students found the game useful as a safe practice environment for training engineers on project management within before joining the practical life.

Promoting creativity. Both students and professionals agree that there is not much space for students to make creative decisions because students were limited by available options.

Conclusions

This research aimed at developing a CAL tool that could assist in the training of construction engineering students on the technical and management aspects of the excavation stage of construction. The tool developed in this study was based on the game format that provides a challenging learning environment.

The excavation game was built to satisfy the criteria of effective CAL tools that were identified in this paper. These are presenting realistic situations, providing a degree of guidance, assessing student's performance, combining uncertainty and novelty, promoting self-learning, ensuring nonlinearity and interactivity, providing an attractive interface, providing enjoyment, providing a safe learning environment, and promoting creativity. The game was developed after analyzing similar available CAL tools with regard to these criteria. Other future CAL tools could be developed taking into account the identified criteria.

The game focuses on the project management aspects of building construction. It covers excavation related activities: excavation equipment, dewatering, and soil-support methods, together with other important concepts such as mobilization, surveying, safety, overtime shifts, and reporting. Students act as construction managers who are allowed to make mistakes and are given options for rectification within a nonlinear game flow. Student actions and their associated cost, time, and quality consequences are recorded for assessment. The game, which was developed using Borland C++ Builder programming environment, is composed of four main components: main actions, help and guidance tools, assessment tools, and uncertainty.

The game was tested by seeking the informed opinion of the professionals and students who were selected to play the game. They indicated that it responds to a great extent to the characteristics of effective CAL. 80% of the professionals and 72% of students found the game to be useful. 65–70% of the professionals reported that the game includes aspects of realistic situations, while 65% of the professionals and students appreciate the degree of nonlinearity of the game. In addition, 80% of the professionals believe that the game includes enough guidance helping tools. The use of time, cost, and quality counters was well received by professionals and students, where 85% reported that the counters provide good incentive. Moreover, 80% of the students reported that the educational game was interesting and enjoyable and would recommend it to other students. Although 70% of the professionals felt that the game provides the needed level of uncertainty and novelty between one session and the other, 55% suggested adding more unexpected events within the game itself. Furthermore, although the game interface was perceived as simple and user-friendly by both professionals and students, 80% of the students believe that the interface needs addition of some 3D features. However, both students and professionals agree that there is not much space for students to make creative decisions. These aspects would be addressed in further research.

A series of CAL tools could be developed in the future along the same format of this excavation game. They would cover major construction engineering topics such as the construction of various structural, mechanical, and finishing works. They would allow students to make mistakes and learn from those mistakes in the safety of their classrooms. These tools should not be considered as substitutes to the traditional educational methods. They should act as complementary learning mechanisms. Integrating these modern educational tools with traditional learning methods would definitely improve the quality of future engineers' skills.

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