Integrated Interactive Algorithmic Approach in Physics Education

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***Abstract*—The various approaches to use of computer technology in educational process and especially in teaching of Physics are reviewed and analyzed. First among them is a business-centered approach which considers the computers as the means to implement the business-effective (maximum profit) model of education, by increasing the number of students and reducing the role of faculty or totally eliminating them. In the second "old-school approach" computers are considered at best as the auxiliary methods of widening the lecturer's spectrum of teaching tools. In the third - integrated interactive algorithmic approach (I^2A^2), computer technology is integrated in the educational process, and promotes the student-centered learning model. The structure, features and components of I^2A^2 are considered in details. While the elements of I^2A^2 are partially developed for entry-level physics education, they are almost non-existent for specialized undergraduate courses and are totally missing at graduate and post-graduate levels. The authors consider the ways of developing such elements and implementing them in Physics education.**

***Анотація*—Розглянуто та проаналізовано різні підходи до використання комп'ютерних технологій у навчально-виховному процесі та, зокрема, в навчанні фізики. Перший з них - бізнес-центроваий підхід, який розглядає комп'ютери як засіб реалізації бізнес-ефективної (максимальної вигоди) моделі навчання шляхом збільшення кількості студентів та зменшення ролі та кількості викладачів аж до повного їх усуненя. У другому підході властивому переважно представникам "старої школи" комп'ютери в кращому випадку розглядаються як розширення спектру навчальних засобів викладача. У третьому - інтегрований інтерактивний алгоритмічний підхід (I^2A^2), комп'ютерні технології інтегровані в навчальний процес та базованій на моделі навчання орієнтованій на потреби студента. Детально розглянута структура, особливості та компоненти I^2A^2. Хоча елементи I^2A^2 частково розроблені для викладання фізичних дисциплін початкового рівня, вони практично не існують для спеціалізованих курсів з бакалаврату та повністю відсутні на рівні магістратури та докторантури. Автори розглядають шляхи розробки таких елементів та їх впровадження в галузі прикладної фізики**

Keywords— Education, physics, computer technology, web-based home assignment, applets, interactive approach

Ключові слова— Освіта, фізика, комп'ютерні технології, домашнє завдання на веб-сайті, аплети, інтерактивний підхід

VI. Introduction

From the early years of computers, the educators have recognized their powerful potential for improving the quality and effectiveness of teaching. Computers were pretty expensive those days and its acquirement by educational institutions often required persuasion of the state officials as well as luring donors from private business describing to them the benefits of such purchase. Sometimes such persuasions were making the impression that introduction of computers can make the educational process more financially sustainable or even more profitable. According to such anticipations, the introduction of computers could make courses remotely accessible to larger number of students, thus making savings on teacher's salary by cutting the number of faculty. . The number of remote classrooms with network connection to base campuses were build across the US. Unfortunately the initial expectations failed pretty soon. One of the authors[1] taught at such a class in Iowa, US about 22 years ago. From about 20 initial students in each of the remote network classes at average only two completed the course. Later such centers were converted into on-line courses but there are still a lot of reservations about such system among students, faculties and future employers. First of all, from author's experience, only about 10-20% of the student population can master the material in a self-paced mode and this number didn't change significantly since the times when knowledge and skills could be extracted from books in the silence of library. The rest of the students prefer the live interaction with the instructor. There are also problems with cheating that can't be addressed effectively in a remote location. In Physics there is also a very specific problem of getting hands-on experience in Physics labs. Such experience is crucial for a student's future employment. Initial expectations of substituting lab classes with computer-simulated experiment failed in providing such experience and skills. It could be compared to learning how to ride a bicycle by playing video games. The other approach was in designing small affordable lab kits that were sent to student's homes so they can do some experimental work in their kitchens or garages. Their costs were about 1000 times less compared to the cost of real lab equipment, and as a result they were too oversimplified and didn't develop the necessary hands-on skills for students. The on-line courses still exist and are highly marketed, but the employers, if having a choice, prefer to hire graduates educated in traditional classroom setting.

VII. THE CONTENTS AND RESEARCH RESULTS

The initial failure of high expectations to computerizing the educational process led to skepticism and even opposition of some faculty to widening the use of computers in classrooms. They considered their role only as one of the teaching illustration tools with little better features than slide, video, or document camera projectors.

The situation changed quickly with the development of worldwide network. Pretty soon the solutions to almost every problem, from almost every undergraduate and graduate Physics textbook became available to students on the web through free search or as a paid-on service. The traditional role of homework as a part of the educational process and student's assessment become compromised due to widely-spread cheating. To address the situation, the instructors had to redesign the role of homework and significantly reduce its contribution to the course grade. The other choice was development of instructor's own set of problems that were modified or changed every year or two. The publishers of most popular Physics textbooks tried to solve this issue by developing the on-line algorithmic home assignment systems, such as WileyPlus, Mastering Physics and WebAssign [1-3]. In such a system the students are assigned a set of the same problems with different data values. It requires the development of algorithmic solution for each problem in order to enable the automatized computer grading. Such development of algorithms for thousands of problems is a time and money consuming process and became affordable mainly to the publishers of most popular Introductory Physics textbooks. The adoption of web based homework assignment systems resulted in some reduction of cheating (unfortunately not in its total elimination) and substantial time saving for lecturers on grading the student's work. Pretty soon the developers and publishers started to offer more sophisticated systems so students could be given feedback based on the results of grading and reference to the textbook materials that should be re-mastered. At the same time publishers began supplementing the described system with enhanced tools for teaching, such as prepared Power Point presentations for each covered topic as well as various physics applets that visualized the solutions to the example problems with interactive animations.

The introduction of feedback for students and faculty in such systems can be considered as the beginning of the Interactive Algorithmic Method. In our opinion such approach could be extended to cover the Physics education in more systematic and structured way. In brief, it should be Integrated, multilevel, algorithmic, interactive and self-learning approach. For brevity, we will name it I^2A^2 - Integrated Interactive Algorithmic Approach. Such method can be embedded in almost all stages of the educational process:

- The first component of I^2A^2, as mentioned before, is the development of individual data problems in student's homework. The results are automatically analyzed and graded by the algorithm that should be provided for each problem.
- The web assigned homework program could be extended to enable interactive guidance of students through retraining process in the areas where their skills in Mathematics or Physics need improvements.
- The other extension of such program could analyze data and supply faculty with a recommendation on adjusting the pace of teaching and volume of material covered. It can also identify students who need additional help before they fail the course. It could also keep track of students with disabilities who are eligible for extended examination time and remind the lecturer about the necessity of special arrangements for them.
- The very similar algorithmic set of problems can be used for testing the students during exams and quizzes. It has the potential of reducing cheating and solution copying especially in large classes (100-350 students), but the number of precaution measures should be undertaken. It should secure the access to test to only students in the particular room at a particular time through the local network, and limit the ability of students to search for help during the exam.
- The additional connected algorithmic program can address the student's preparations for lab experiments. The online interactive simulation program could be accessed by students at home to provide the necessary training before using the actual lab equipment. During the lab experiments that employ data collecting interface, students can supplement them with analysis and conclusions allowing the computer to grade their work.
- In the combined complex approach the student's success in homework, tests, labs and other components

of the course can be evaluated and graded according to the algorithm provided by faculty [4].

- On the completion of the course the algorithmic program can estimate whether the goals and outcomes for the given course that are set by faculty in the syllabus, or by educational authorities at the institutional, or even national levels as accreditation requirements are reached.
- The further development of algorithmic programming can enable institutional administration to monitor and compare faculty teaching based on the data automatically collected by the program in previously described activities. The data can also be used by state and national educational boards in order to rank the institutions. Of course the criteria for evaluating the faculty and ranking the institutions should be set very carefully in order not to promote the grade inflation, and subjective assessment.

Currently some elements, of such system (homework assignment with automatic grading, reference service) are more or less developed for Introductory Physics course of 100-200 levels[1-4]. Above such level the homework assignment system is totally absent even just for grading student's work.

There is a great need for the development of algorithmic approach for higher level Physics courses(Mechanics, Electrodynamics, Quantum Mechanics, etc.). Unfortunately, there are few substantial obstacles in such a work. First of all, the sets of problems available in traditional format for such courses are very limited and contain about 50 to 100 times less problems than for introductory physics courses. Secondary, the writing of such algorithms involves substantial amount of work and time [5, 6]. The third reason is the number of students in higher level courses (about 20-50 times less) compared to introductory ones, so creation of such web based assignments and tests doesn't bring much profit to developers. Anyway such programs can be developed through student involvement in a course or diploma thesis projects [6].

As an example, we consider in more details the above mentioned project [6]. It addresses the problem of calculating quantum-mechanical commutators of secondary quantization operators in the course of Advanced Quantum Mechanics (graduate or postgraduate level). In order to develop the algorithm of such procedure, the quantum physics operators were mapped to their computer representation by using object-oriented programming (OOP). Such approach could be considered as the form of application design and not as of feature of specific programming language. The software application may be seen as composed of a collection of individual units, which are called objects. They interact one with another through methods or events. The set of functions or procedures were combined into modules. To represent the quantum physics models and their mathematical expressions in terms of OOP the binary tree technique was used. The set of rules for commutators, combination of operators and order of evaluation were presented in the form of binary tree expressions. To evaluate a tree the C++ preorder recursive algorithm was used. Developed such a way program is flexible and could be extended by other programmers to meet not only educational needs, but to serve also as a powerful tool in increasing the speed of research calculations in theoretical physics.

CONCLUSIONS

Summarizing, the development and implementation of the whole complex of integrated interactive algorithmic approach can result in extension of available educational tools, time saving on homework and test grading for faculty; increased availability of help and tutoring for students during work on homework problems and preparation for lab classes, class adaptive design of the courses, and generally in increased quality of computer-assisted teaching.

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