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UNCONVENTIONAL APPROACHES TO TEACHING COLLEGE PHYSICS

Introduction

Teaching Physics at introductory and intermediate college levels for non-Physics majors, for whom it is a general prerequisite course, is always a big challenge. The main reason for that is that Physics is commonly taught at high school superficially and in a mixture of the Science class, where it is sequenced after Biology and Chemistry. Incidentally, instead of Physics students may choose earth/physical science which integrates geology, weather, astronomy, life processes and some parts of Physics. When college students majoring in biology, engineering, education, nursing and other areas face Physics, they feel scared and lost due to their inadequate preparation. The problem is exacerbated when working adult students take college classes after a long period after high school. This situation demands that instructors use innovative approaches to teaching and learning that go beyond the typical lecture-laboratory format and introduce effective practices in the college classroom. In addition, the instructor has to address various factors affecting learning, such as student attitudes and motivations; focus on active learning methods and use of technology, and also consider special challenges, such as teaching to culturally diverse or disabled students. In our research and teaching practice we focused on three major approaches, namely accelerated learning (AL), Iterative Instructional Model (IIM), and use of technology which helped make significant improvements in teaching General Physics classes, especially for adult learners.

Review of methodological innovations

The goal of college Physics is to construct a holistic knowledge of Physics as a science and its major concepts, understand and be able to interpret and apply its laws, develop research, experimental, and problem solving skills. Recent years have been remarkable in introducing a variety of effective strategies, techniques and technologies in teaching college Physics courses taking into account the 21st century requirements and a changing college environment. These can be divided into four groups:

Curriculum. Most of the curricula that have been developed over the past years in the United States based on research evolved using the cyclic model of curriculum development (see IIM below) [1].

Research-based teaching strategies. These include Inquiry-Based Learning (IBL) and Problem Solving Learning (PBL).
IBL uses questions, problems or scenarios in the teaching process rather than simply presenting established facts or outlining a smooth path to knowledge. The instructor in this type of learning acts as a facilitator.

PBL is a student-centered instructional strategy in which students collaboratively solve problems and reflect on their experiences. The main characteristics of PBL are:

- Learning is driven by challenging, open-ended problems.
- Students work in small collaborative groups.

- Teachers take on the role of "facilitators" of learning.

Merrill [2] suggests beginning with worked examples and then later introducing students to smaller less complex problems. But as the process progresses, the problems need to be changed by adding components to make them more realistic. Thus it is important to begin with simplified versions of real world problems to progressively add components (Compare to the IIT below).

Engagement techniques. These techniques are intended to actively engage students in interactions and collaboration through peer-to-peer or/and small group work, or whole class discussions, posing and answering questions (Socratic method), and making sense of Physics concepts [3]. For example, in one such technique called Peer Instruction the teacher poses challenging questions to students. Students discuss the question with their neighbors, use an electronic device called a "clicker" to vote on the answer, and then the instructor facilitates a whole-class discussion about the question using the real-time feedback from the students' electronic votes [4].

Although unguided or minimally guided instructional approaches are very popular and intuitively appealing, these approaches ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide “internal” guidance [5].

Extensive integration of modern educational technologies (ET). ET, such as computers, internet, visual tools, social media, mobile devices are used for research, modeling, simulation, visualization, information search, interaction, communication and sharing, making the learning more effective, rich, and convenient.

Students’ major concerns

To make improvements in teaching and learning college Physics, we first identified students’ needs and concerns. We conducted investigation of students’ expectations in two different Beginning Physics (one taught in a one-month format and the other taught in two one-month courses) at the start of the class, and then students’ assessment of their learning in these courses at and the end of the class using a specially designed questionnaire. As our research demonstrated, the main concerns of the newly enrolled students over the new Physics class were related primarily to math (32-36%), and then to the course content (25-35%). This observation points to students’ insufficient general math and science preparation before the classes. Subsequent query at the end of the class showed that students’ concerns over math and physics content, particularly the use of formulas and comprehending the problems, were substantiated during the class: 43-49% of students responded that math and the use of formulas were the most difficult in the course, while 29-36% stated that comprehending the problems was the second main confusing factor [6]. When students do not comprehend the problem, they are unable to identify and use the right formulas for solving the problem.

Based on the findings, the following suggestions for the modifications to the courses and improvement of the learning outcomes are recommended:

- To remediate the situation with insufficient math preparation, the college has to make college algebra and trigonometry courses prerequisites, not co-requisites.
- Instructors need to carefully select and organize the learning materials adapting the course content to the students’ preparedness in Physics, and use a variety of instructional methods and techniques.
- Instructor’s advising, consulting and mentoring students before, during, after and between classes is critical for alleviating individual and common issues associated with their competence level.
- It is imperative that math and Physics education in high school is significantly improved, and colleges and high schools match their entrance and exit requirements to ensure smooth transition of school graduates to the university classes.

Accelerated learning

One of the ways to improve the learning outcomes is Accelerated Learning (AL), which is a growing trend in today’s adult higher education {7, 8]. Working adults who need higher degrees, new specializations and continuous professional development are looking for accessible, flexible, customized, convenient and, especially, fast educational opportunities. The major problem for adult learners is the limited time they can allocate for learning due to their hectic lifestyles and numerous job, family and other responsibilities [9]. Universities and colleges competing for students thus have to provide a variety of programs in new, short-term formats, including accelerated, compressed, short-term and intensive ones. Without effective teaching models for serving adult learners, colleges and universities may face educational quality and, consequently, enrollment and retention problems. The development of new paradigms of learning is pursued with the most important goal in mind: teaching for long-term retention and transfer [10].

The accelerated learning model used at National University is distinguished from traditional educational systems by its 1x1 format: one-month-long course delivery in a one-course-at-a-time learning process. Compressing semester-long courses in the one-month format is a complicated task, especially when the courses, such as General Physics, require substantial knowledge base, specific learning skills and extensive cognitive and physical efforts on the part of the students [11]. Clearly, effective instructional design and non-conventional methodological, psychological, and organizational solutions are needed.

The challenges in teaching General Physics in an accelerated course were identified through surveying students. They are as follows:

- Considerable temporal interval between students' taking this class and their previous learning (high school or college).
- Insufficient level of preparation in Physics and sciences in general as well as in math obtained at high school.
- Lack of specific skills, such as conceptualization, research, problem solving, and other cognitive skills required in a science class.
- Short, accelerated format of instruction that compresses all major parts of physics into sequence of two one-month courses, the first being a theoretical part and the second a lab, which aim at developing theoretical knowledge and practical skills necessary for their further work [11].

A compressed, accelerated course means shorter duration but also longer classes with shorter time intervals between them, which may affect retention of the new information. In view of these challenges, it became evident that an accelerated General Physics course cannot be delivered in one month using traditional methodology and necessitates an innovative approach to course and learning process design, planning and organization, as well as more effective instructional strategies and techniques. The goal of these courses remains to provide learning outcomes comparable to the traditional semester-long course offered in the same 45-hour classes.

Two critical issues in achieving quality learning outcomes are understanding and retention of knowledge, which are in fact major goals of learning.

Repetition, Iteration and Retention

Accelerated learning approaches require effective instructional methodology to ensure the necessary quality of the learning outcomes. Educational and psychological research determined there should be a sufficient number of repetitions of the same material in the learning process to provide for understanding and retention. Simple repetition, however, is insufficient; it takes several spaced cycles to achieve the desired result. An Iterative Instructional Model (IIM) was developed to explain the process of effective learning based on spaced repetitions and implemented in teaching an accelerated General Physics unit [11, 12].

Instruction starts with an elementary acknowledgment of the fact that repeated practice or iteration is a universal method of learning. "Repetitioest mater studiorum," says the old Latin proverb. One learning experience (exposure to knowledge) is not sufficient for full understanding and retention. It has to be reinforced and extended by re-use in identical or similar situations. Students should be offered the opportunity to master content and develop skills through repeated iteration [13].

According to Schoenfeld, Smith and Arcavi [14], the growth of understanding is highly non-linear with starts and stops; the student in the learning process develops partial understandings, repeatedly returns to the same piece of knowledge, and periodically summarizes and ties related ideas together. This leads to the conclusion that understanding can be reached if we accept the need for multiple iterations toward a solution [15]. The same repetition procedure applies to retention as will be shown below.

Among the many instructional strategies, repetition, or rehearsal and recall remain the primary ones that can lead to effective learning outcomes. The amount of repetitions is a primary factor involved in the learning process. "The more repetition, the greater the depth of the learning and the slower the rate of decay" [16]."An opportunity to review previously presented material may affect not only the quantity of what is learned but also the quality" [17].

This observation is also supported by the Atkinson-Shiffrin Multi-memory model, which explains that the rehearsal loop (repetition) helps transfer information into long-term memory from the short-term memory: "rehearsal serves the purpose of increasing the strength built up upon in a long-term store both by increasing the length of stay in short-term store...and by giving coding and other strategies time to operate" [18]. This notion is further reiterated explaining that learning process is gradual and cumulative – the more review, the better retention [19]. These repetitions can be introduced during the same class, in the course sections or in extended work in the lab which follows the theoretical course.

Presenting the same information in different formats or modalities can have a more profound effect on retention than repeating it in the same form. Improvements in learning can be achieved by proper organization of learning, effective use of time in the classroom, iterative process, distribution of time between learning events, spacing effect and multimodal learning process combining textual, oral, visual and multimedial presentation of material [20].

Immediate application of the learned material in some kind of practice enhances retention.

Solving problems and doing labs are examples of such applications. Repetition coupled with effective techniques, such as the generation effect [21] enhances retention. The generation effect is based on students' better remembering the items they have generated rather than items they have just read and memorized explains some of the activities in the Physics class that involve students in explaining Physics concepts, in continuous problem solving and in experimentations in the lab. So, both the nature of the repeating event and the number of repetitions determine the time course of learning [22].

It is evident, therefore, that repetition remains one of the major strategies for understanding and retaining new information. Even more important than repetition itself is the time interval between repetitions. It has been proven that better retention is achieved when there is a sufficient interval between repetitions. Frequent repetitions may provide for better understanding and retention; however, the number of repetitions should be reasonably limited due to restrictions of the planned learning process. Research warns there can be a threshold after which the number of repetitions may not have a considerable impact on the retention.

Simple repetition, however, does not adequately describe the learning process based on recall. It is a two-dimensional model that takes into account only the fact of occurrence and the number of repetitions. Iteration as a higher level concept brings the necessary clarification in this process allowing to describe the learning process in its complexity.

Iteration as a process presupposes a gradually expanding set of information added to each preceding cycle to increase the initial knowledge and bring learning at each cycle closer to the desired outcome. This process is essentially an approximation of the current state of the learner and learning to the desired outcomes. Thus, IIM becomes a 3D model of learning.

In teaching and learning, iteration is a repeated procedure carried out during a particular course, topic or lesson that provides knowledge presentation, activation and application through a set of interconnected iterations or cycles. IIM is applied at the presentation cycle where the content is iterated several times in different modalities (lecture, instructor demonstration, text, visuals, audio-visual or multimedia show and simulations). It is important at this cycle that the topic is presented as a whole, in its entirety, through several increasing levels of approximation. Thus, students perceive and process information a number of times in multiple formats, which improves understanding and retention.

Iterative instructional model describes learning in the following way:

- Learning is usually taking place in cycles based on the repetition effect.
- The learning material of each course can be repeated and recalled in a number of cycles determined by the course content, goals, structure, and conditions of study.
- Learning process based on iteration develops as an expanding spiral consisting of a measured number of interconnected cycles separated in the course by intervals.
- Student knowledge is gradually expanding at each cycle by adding new information to each preceding cycle thus approximating the results at each cycle to the desired outcome.
- Each cycle is based on all the previous ones and adds to them new details, increasing its complexity and coverage, until the topic is exhausted, thus developing a deeper understanding.

Learning built on the IIM is an effective cumulative process. The IIM, like spiral and other sequencing strategies (progressive differentiation, hierarchical and short-path) offers a way to develop knowledge and skills in a particular content area from the simple to the complex.

A major factor in ensuring retention is the nature of the instructional approach. Instructional strategies and activities that reduce the effect of forgetting and improving long-term retention should be organized in learning cyclic course structure. This structure may consist of the following four cycles: presentation of the new material coupled with a demonstration; class analysis and discussion; group and individual applications (problem solving and/or lab experiments); and review and assessment. Each cycle should include iterations in the quantity (at least 6) sufficient to ensure understanding and retention. These iterations should be distanced in one lesson (up to 30 minutes), in the course section concentrated on the same topic (1-3 days), and in the unit (four weeks).

Integration of IIM in General Physics classes at National demonstrated that iteration can take place at various levels of the course: its parts, topics and individual units and assignments. In the accelerated course there are five general course iterations: introduction, midterm and final reviews, midterm and final exams. Each of the topics has the same cyclic structure that includes introduction, presentation, student activities, predominantly in the form of problem solving, homework (reading textbook and solving problems), and review.

Accelerated theoretical General Physics classes call for a specific instructional design involving more frequent change of instructional activities to maintain student alertness and attention and increase their productivity of learning. Thus, based on iterative approach, during one 4.5-hour class students have 3-4 short 15-minute lectures followed by the 5-10 minute lecture demonstrations, and 3-4 problem-solving sessions lasting up to 30 minutes. Typically used strategies include interactive lectures, lecture demonstrations, video and inquiry, analysis and discussion of the problem-solving techniques, question and answer (Q&A), and problem solving (on the board before the class and individual). Lab classes, due to their specificity, cannot provide this variety of activities and frequency of iterations. Nevertheless, lab works themselves are modified iterations of the material learned in the theoretical course, which thus provide another level of spaced repetition separated by 30 days.

As follows from this research, the number of A's is practically the same in both models; however, when using IIM in the accelerated courses there are more B's and C's than in the traditional courses. Overall, students in the accelerated classes using IIM learned more positive grades than in the traditional ones: 100% versus 87.9% [11]. It is even more remarkable that no students failed the classes. These data demonstrate a notable improvement in learning outcomes of the students using iterative learning.

An experiment we conducted in 2011-2013 using a new, combined approach in teaching General Physics courses was based on the Vygotsky's concepts of the Zone of Proximate Development (ZPD) [23] and Iterative Instructional Model, and evaluated with fuzzy logic method [24]. Students in the class that integrated all three approaches achieved significantly better outcomes than in the control group, which suggests that a combined, systemic use of advanced educational approaches produces the best results.

Technology applications and online learning

Teaching and learning Physics is boosted by integration of educational technology in the class [25, 26, 27]. Some of the applications include the use of powerpoints, video demonstrations, and multimedia at the presentation stage; computers at the research and problem solving stage; and lab equipment and computer simulations at the practice stage.

Students who are unable to attend the classroom take online courses which offer theoretical material on the course topics, illustrations, simulations, problems, tests, and supporting materials. Students also participate in regular discussion fora and videoconferences,collaborate in small groups, and interact via various communication and collaboration options, e.g. threaded discussions,chats, email and social media. Most of the work in an online class is performed by students independently; the instructor's role is to facilitate their learning, provide continuous support, advice and control, and engage students in interactions, communication and collaboration [28].

Online courses are often used in the onsite classes as an additional resource for the enhancement of students'independent work; it is called eCompanion - there they can find a variety of learning materials, illustrations, problems, reference materials, etc.

Conclusions

Innovative approaches described in this article proved to be effective instructional models helping improve student's understanding and retention of the new material by enhancing their learning through more active engagement with the content, instructor and peers. Physics classes taught on the basis of accelerated learning model, which integrates IIM and educational technology, demonstrate a marked increase in productivity of learning and improvement of recall.

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Анотація. Сердюкова Н.В. Нетрадиційні підходи до викладання фізикі у вищому навчальному закладі.

Автор розглядає деякі методичні підходи з викладання курсу фізикі в американськом університеті для студентів з непрофільною підготовкою з цього предмету. Особлива увага приділяється використанню таких підходів: прискорене навчання в одномісячном та двомісячном курсових форматах, Ітеративна Навчальна Модель, та впровадження іноваційних технологій. У статті представлено порівняння успішності студентів та приведені докази ефективності навчання в кожному з цих підходів.

***Ключові слова**: Викладання фізики, прискорене навчання, Ітеративна Навчальна Модель, технологія навчання.*

Аннотация. Сердюкова Н.В. Нетрадиционные подходы к преподаванию физики в вузе.

Автор рассматривает некоторые методические подходы к преподаванию курса физики в американском вузе для студентов с непрофильной подготовкой по этому предмету. Особое внимание уделено использованию следующих подходов: усконенное обучение в одномесячном и двухмесячном курсовых форматах, Итеративная Обучающая Модель, и применение инновационных технологий. В статье представлено сравнение успеваемости студентов и приведены доказательства эффективности обучения в каждом из этих подходов.

***Ключевые слова**: преподавание физики, ускоренное обучение, Итеративная Обучающая Модель, технологии обучения.*

Abstract. Serdyukova N.V. Unconventional approaches to teaching college physics.

The author discusses some methodological approaches for teaching Physics in the US university for non-majoring students. Specific consideration is given to the following approaches: accelerated learning in one and two-month course formats, Iterative Instructional Model, and integration of innovative educational technologies. The article offers a comparison of students' achievements and demonstration of instructional effectiveness of each of these approaches.

***Key words**: Teaching Physics, accelerated learning, Iterative Instructional Model, educational technology.*