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Active Teaching and Learning as a Remedy for Engineering Education Problems

Abstract. *On examples of teaching introductory courses on digital design, the article summarizes four years of the author's experience in using active teaching and learning methods in engineering education. The results of a number of pedagogical experiments showed that: 1) active strategies lead to higher attendance in lectures and a noticeable improvement in student performance; 2) reducing course content and slide presentations in favor of more active teaching style is greatly welcomed by students and has positive influence on learning outcomes; 3) "Concept Inventories" standards allow for defining the minimum course content and identifying gaps in conceptual understanding; and 4) a significant improvement of learning outcomes can be obtained using dedicated video mini-lectures available to students online.*

Streszczenie. Na przykładzie dwóch przedmiotów podstawowych z dziedziny techniki cyfrowej artykuł podsumowuje cztery lata doświadczeń autora oraz stan obecnej wiedzy dotyczącej aktywnych metod nauczania inżynierskiego. Rezultaty przeprowadzonych eksperymentów wykazują, że: 1) strategie aktywne prowadzą do zwiększenia frekwencji wykładowej i polepszenia wyników egzaminacyjnych; 2) rezygnacja z prezentacji slajdów na rzecz form aktywnych spotyka się z bardzo dobrym przyjęciem studentów i wpływa korzystnie na osiągnięcie założonych efektów kształcenia; 3) wykorzystanie istniejących standardów „Concept Inventories" pozwala wykryć luki w zrozumieniu podstawowych koncepcji; 4) znaczną poprawę efektów uczenia się można uzyskać udostępniając studentom dedykowane przedmiotowi krótkie wykłady wideo. ***Aktywne formy nauczania jako remedium na problemy edukacji inżynierskiej***

Keywords: active teaching, active learning, online screencasts, digital systems
Słowa kluczowe: nauczanie aktywne, style uczenia się, nauczanie online, układy cyfrowe, screencasts, testy standaryzowane

Introduction

Rapid development of information technologies has changed the way people communicate and function. When it comes to students, they use smartphones not only as a basic communication and entertainment tool, but also as a main source of knowledge. This source is available at any place and time, providing almost immediately the information needed in a compact and attractive form. Unfortunately, smartphones are increasingly used to do the assignments quickly and superficially, without understanding the concepts or problem solutions. For instance, the instructional videos and ready-made solutions available on the Internet allow to quickly „learn" the topic, „do" the project, or „solve" the problem. This *surface learning* phenomenon is very common, and teachers, as a gatekeepers, are helpless in enforcing a deeper understanding of the course material [1]-[2]. On the other hand, academic curricula are overloaded and cognitive requirements for engineering students are too high in relation to their skills and background. This causes the high dropout rate among the freshmen and promotes memorizing and rote learning.

Another problem arises from a big change in student attitude toward lectures and lecturers. The todays' net generation of students are more daring in showing dissatisfaction during classes. If at some point they do not understand the presented topic, they start talking to each other, playing games, sending e-mails, or napping. This students' behavior is very annoying and stressful for teachers that devote a great amount of time and effort in preparation of classes. The author was experiencing this for a few years before he reviewed the scientific literature in search of a solution to the problem. An analysis of the research findings and own observations have changed his way of thinking about the role of teacher and student, and processes of teaching and learning. This in turn encouraged him to carry out experiments in teaching introductory digital design courses. The article presents a concise summary of the acquired knowledge, experience and results along with recommendations for educators that would like to implement a similar approach

Active pedagogy

In order to better understand how students learn, a lot of research in higher education has been done. For example, the research results in neuroscience [3] showed that teaching at school should be similar to the athlete's coaching. Although the strict implementation of this model in universities is unfeasible, approaching of it is possible through the use of *active learning* strategies, which effectiveness has been proven in many works, e.g., [4]. In the case of lectures, active learning can be realized by a series of several-minute knowledge transfers or problem solving instructions (mini-lectures) each followed by a several-minute „practice" during which students actively use this knowledge or skills, e.g., they complete the task started by the teacher, solve a similar problem or take a quiz. The students cooperate and discuss in small groups, and the teacher observes their work and provides additional hints and explanations if necessary. He also creates a positive relationship with students using humor and less formal language. The level of student understanding is regularly monitored with anonymous quizzes and *Audience Response System* (ARS) run on student smartphones [5]. Such a scenario was implemented by the author at Lodz University of Technology (TUL), Poland, in the three consecutive academic years 2015/16 – 2017/18 in teaching *Digital Systems* (*DS*) course using respectively 37, 33, and

39 sophomore students [6]. The result of the experiments was a noticeable increase in student engagement and, consequently, higher lecture attendance and better exam results compared to the traditional presentations held in 2013/14 and 2014/15 (see Fig. 1). The Welch's unequal variances t-test has confirmed statistical significance of these improvements yielding *p-values* < 0.05 for attendance and *p-values* < 0.01 for exam results. The results support the well-known finding of a close relationship between class attendance and student performance.

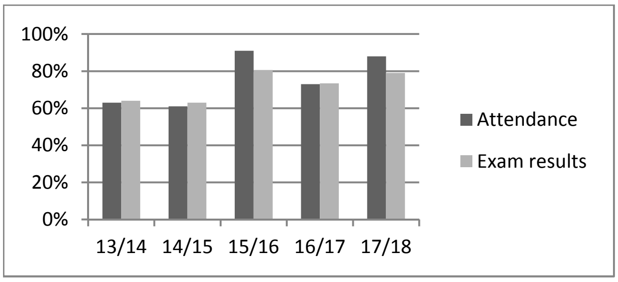
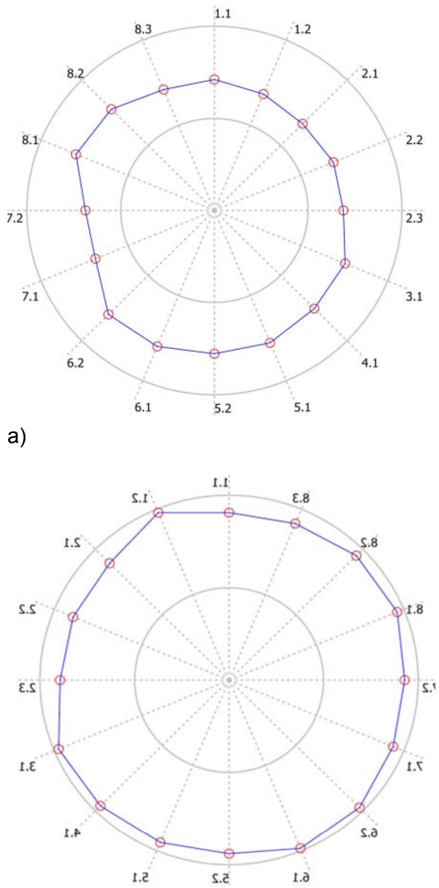


Fig.1. Average attendance rates and average exam results as percent of maximum score for traditional approach (years 2013/14 - 2014/15) and active learning approach (years 2015/16 - 2017/18)



a)

b)

Fig.2. Average student ratings for 16 questions testing the teaching quality of two approaches to Programmable Devices course: (a) broad content taught using slide presentation and (b) a narrow content taught using active real-time „programming" in VHDL. The outside labels denote the question numbers. The small circles show the averages of student answers; the further from the center the higher the score

Content reduction

The transition from passive to active pedagogy requires a reduction in course content because less time is available for knowledge transfer. Despite the resistance of a group of educators, many universities are implementing this idea by moving from „covering" the content toward „using" it for deep teaching in the discipline, e.g., [1]-[2]. This in turn leads to the question how to determine the minimum scope of content for introductory courses. The proposed first-line strategy is to remove concepts and problems that are not included in exams. Such an approach was used by the author in Programmable Devices (PD) course consisting of 10 lecture hours and 20 lab hours. In 2016/17 the lecture was held in the traditional format using PowerPoint slides, and the topics discussed included: parallel and serial buses, data synchronization, memories, classification and architectures of programmable logic devices (PLD), structure of an example PLD, syntax and semantics of VHDL using simple examples, and description of selected peripherals. In 2017/18 the lecture content was reduced exclusively to teaching VHDL by demonstrating the of design, compilation, and simulation processes in real time using the same software that was used in the lab [7]. Some students worked on their laptops, others wrote the code on the pages. Pre-prepared slides were not used and the systems' block diagrams were drawn by the lecturer with a pen tablet. Such a lecture format was enthusiastically welcomed by students, who assessed this "active" course offering much better than students of the previous "passive" offering (see Fig. 2). Moreover, the average grade for student projects increased by 0,12 on the scale of 2.0 to 5.0.

Concept inventories standards

The selection of the course content can also be done using standards named Concept Inventories (CI). They have been developed by experienced teachers from American universities for the purpose of evaluating the quality of teaching in various engineering areas. For digital systems the Digital Logic Concept Inventory (DLCI) standard defines a list of 12 learning outcomes that should be achieved for introductory courses [8]-[9]. The two most important are to understand the difference between the current state and the next state of the finite state machine (FSM) and to draw a state transition diagram of the FSM given its specification. A number of "traditional" topics such as look-ahead carry generators, asynchronous systems, or hazards have not been included in the standard, which in this case recommends discussing them if the time allows. The relatively small number of CI learning outcomes allows the use of active teaching techniques to deepen the knowledge of fundamental issues. The standards provide universities with an important tool to assess the quality of teaching. Multiple-choice tests developed as a part of the standard assess the level of students' conceptual understanding and mastery of skills.

The DLCI test containing 25 questions was administered in 2018/19 academic year to assess the quality of teaching the DS course. The test was attended by 28 students, and one point was assigned for each correct answer. The cumulative test results are presented in Fig. 3 as percentage distribution of the correct answers. The analysis of the answers for specific questions allowed not only to identify concepts not understood by students, but also to reveal false beliefs and misconceptions. The most common problems in learning DS were concerned with modular design (Question 11), the concept of overflow in two's complement arithmetic (Question 14), and the analysis of a simple 3-bit arithmetic-logic unit (Question 22). While in the first and third cases students selected different wrong answers, in the case of Question 14 most students gave the same wrong answer, confusing overflow with carry. An interesting experience was that during the test the instructor reminded students when overflow occurs, and they confirmed they understood the concept. The conclusion is that the processing of corrective information can strongly be affected by student misconceptions.

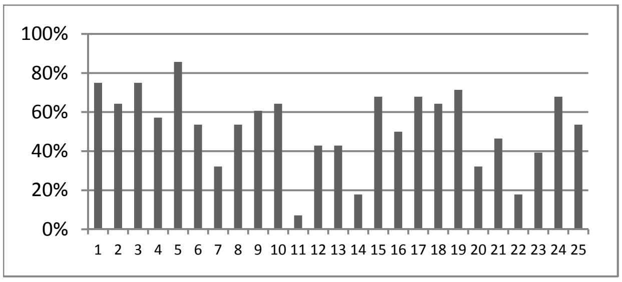


Fig.3. Distribution of correct answers to the DLCI test questions obtained in 2018/19 for "Digital Systems" course

The average percentage of correct answers for the DLCI test was equal to 52% and was only lower by 9% than the average score obtained for about 1000 students from seven American universities *(data obtained by e-mail from one of the test authors*).

Teaching and learning styles

Another problem in engineering education is incompatibility between teaching and learning styles. The learning style is considered in five dimensions [10]: 1) preferred source of information (*sensory* vs. *intuitive*); 2) sense by which external information is perceived most effectively (*visual* vs. *verbal*); 3) preferred order of information (*inductive* vs. *deductive*); 4) way in which information is processed (*active* vs. *reflective*); and 5) way in which the understanding progresses (*sequential* vs. *global*). The results of the standardized test of learning styles [14] carried out in 2015/16 for *Computer Science* (*CS*) and *Telecommunications and Computer Science* (*TCS*) students are presented in Fig. 4. Over 65% of these students are sensory learners, who like facts and experiments, pay attention to details, but require more time for learning. Only 35% are intuitive learners, who use imagination, like theories, general principles and innovations, but do not care about details. Research results showed that most professors use intuitive approach and give lower grades to "sensory" students [11].

Similarly, the commonly used teaching style in education is deduction, although induction is a natural way of how people learn – the actual situation or problem to be solved appears first, followed by general conclusions, principles or theories. And although the students' preferences are evenly balanced between induction and deduction (as in Fig. 3), the research experiments proved much higher effectiveness of inductive teaching in most students [12].

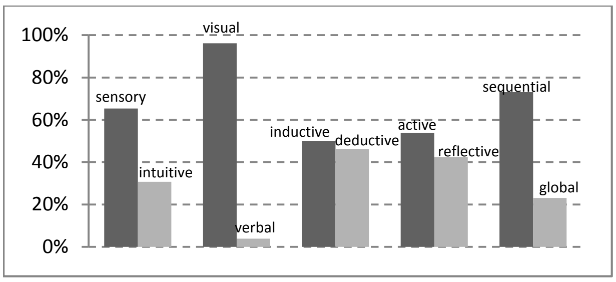


Fig.4. Diversity of learning styles of TCS and CS sophomore students

Another dimension of learning style classifies students to active experimenters and reflective observers. On the other hand, majority of lectures are given in slide presentation format which is considered passive and not suitable for the both groups. Such lectures do not give students occasion to actively participate in classes or time for reflection. In order to engage students, multiple active teaching sessions should be included in lectures, such as peer instruction, anonymous self-assessment quizzes, think-pair-share or think aloud pair problem solving strategies, as well as short breaks for reflection on the concepts just discussed [1].

The last dimension characterizes the learning curve in a general way, distinguishing sequential and global learners. The former group master the course material step by step at a similar pace as it is presented during classes. The global learners cannot solve the simplest problem for days or weeks, before they experience the „eureka" moment of understanding the course material to the extend allowing them to solve difficult problems, often by making intuitive "jumps" that they cannot explain [10]. Unfortunately, many global students are frustrated and often do not graduate. On the other hand, they are creative, see relationships that others cannot see, and can become outstanding interdisciplinary engineers. The author of the article experienced a few cases of students who, after several unsuccessful attempts, showed knowledge at a surprisingly high level during the next exam.

A simple response to different learning styles is diversification of teaching styles, in order *each* student experience learning progress in understanding the course topics. During lectures the instructor should present the concrete examples as well as principles, give students time for problem solving as well as for reflection, accept alternative methods and lack of detailed explanations. Because engineering students are visual learners who prefer graphics, demonstrations, animations and videos, the amount of text and formulas should be limited to the minimum necessary. Returning to „chalk and blackboard" lecturing method is recommended by the author, who currently all his lectures using a graphics tablet. In this way, the pace of knowledge transfer becomes compatible to the students' perceptual abilities

Dedicated online mini-lectures

Another Adjusting the pace of teaching to individual preferences can also be obtained by providing students with full video recordings of lectures. An even better solution is to record mini-lectures lasting from a few to several minutes. For the video creation simple tools available on the Internet can be used, such as Screencast'O'Matic capturing screencasts, i.e., images from the computer screen along with the lecturer's commentary [13]. In 2017/18, an experiment was conducted at TUL with a series of 28 screencast mini-lectures dedicated for an introductory digital systems course taught to 71 *Electronics and Telecommunications (EIT)* students. The screencasts lasting from 6 to 15 minutes and 6 hours in total were posted on YouTube and the links to the videos were published on the website dedicated to the course. An example video is available at: http://youtu.be/iiIkOWP9MXM?hd=1.

The main research question of the experiment was how the mini-lectures affected students' learning and achievements. The YouTube statistics confirmed that students watched the mini-lectures before the lab tests, exam and exam retakes, which was expected. A less obvious result was that they watched the videos just before or just after the corresponding face-to-face lecture was hold, and in the following semester, probably during learning more advanced courses on digital design such as *Microelectronics*. During the semester the total number of „hits" amounted almost 7000, which gives on average 100 "hits" per student, and the actual watching time was equal to 530 hours, which gives on average 8 hours per student. The number of clicks on "*Like*" amounted 96, and no student selected „*Dislike*" for any mini-lecture. The objective evidence of the screencasts effectiveness was the improvement of the average final exam grade from 2.86 in 2016/17 to 3.44 in 2017/18 on a scale from 2.0 to 5.0. It should be emphasized that the number of not passing grades has significantly decreased. Effectiveness of the approach was also confirmed by the results of the survey, in which students rated the screencasts as the most useful (4.86 points on a scale from 0 to 5) in the group of 11 different methods of learning the course (Fig. 5). Analysis of individual answers revealed that almost 80% of students assigned the screencasts rank 5 - extremely useful and no student assigned the lowest two scores, 0 and 1, to them. One-to-one teacher assistance received a similar score, while tutorials, quizzes, peer instruction, and face-to-face lectures were ranked noticeably lower. Books (including e-books) and lecture materials, which were available and recommended to students, received the least scores. The assessment of the usefulness of books featured the highest variability (standard deviation = 2.4).

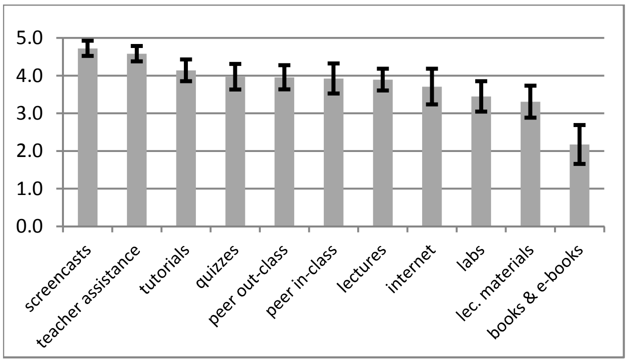


Fig.5. Averages and standard deviations of the usefulness of various learning methods declared by students in 2017/18, scaled from 0 to 5 (lowest to highest)

Conclusion

The literature review and the presented results and observations demonstrate that active teaching and learning strategies lead to better learning outcomes and satisfaction for both students and teachers. In order to promote deep learning, the content of courses should be reduced and educators should set high standards for students in terms of the remaining fundamental concepts and skills. Online mini-lectures are suitable for different learning styles and improve students' achievements.

Educators must see their role as committed trainers who actively monitor the work of students giving them appropriate guidance if needed. They should transfer to students a big part of responsibility for their learning, for example by being open to their requests or suggestions. The adoption of such an attitude by the author caused that the previously annoying lectures have become a very pleasant experience providing great satisfaction.

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