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A progressive interactive learning strategy adapted for high voltage engineering courses

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ABSTRACT: This article presents a novel pedagogy - progressive interactive learning strategy (PILS). Experimental students design an animation applet illustrating elusive sections of the high voltage engineering course for undergraduates in electrical engineering progressively building on an applet made by the last class. These students indicate and modify the flaws of the animation made by the last class. Additionally, the applets are deployed in classroom instruction and generate critical thinking and discussion throughout the entire class, improving the learning environment for all. Visualisation enhances the students' ability to grasp fundamental concepts and to achieve a higher level of understanding. After the class, a questionnaire about what students have learned from the animation and what should be improved is collected. The students learn how to execute a research programme, understand course content better and increase their critical problem-solving skills. Feedback and assessment indicate that this approach is not only helpful in expanding the faculty's pedagogical research, but also benefits the students.

INTRODUCTION

Many theories taught in engineering courses are derived from experimentation; conclusions based on experimental data, therefore, are drawn without rigorous mathematical deduction. Fundamental concepts in the curriculum of high-voltage technology, like descriptions of the Townsend and Streamer Mechanisms and microstructures such as atoms, electrons and ions, cannot be demonstrated directly, especially, when these notions are manipulated using even more abstract vectors or differential operators [1]. Hence, some phenomena are not easy to comprehend from oral explanation in classroom settings. Pedagogical approaches to teaching these theories effectively and accurately are a pressing question of interest in engineering education.

In outdated teaching methods, instructors use a static scheme from a textbook and a one-size-fits-all approach to explain the concepts of the ionisation process. They extract the most crucial parts of the material and present it as a lecture. The key points and conclusions are typically chalked out on the blackboard and, then, students write them again and again as their homework [2].

However, students often lack the attention span, zeal, and discipline to sit through traditional conceptual lectures or critically review nonfigurative concepts, even though instructors work with great passion to explain and illustrate them [3]. The traditional method is a surface-level approach; students are able to recite what has been read but do not necessarily understand the material. A stiff and formal pedagogy focuses on unrelated parts of a task and has little to do with critical reasoning; students may confine themselves to memorising all the figures and facts, not underlying concepts. [4] Therefore, students have no idea how to apply theories to real life problems creatively.

There is no denying that students often rely on teachers for correct answers not in the real sense but in examinations. The unjustifiable imbalance between learning by acceptance and learning by discovery in the traditional educational system has deprived students of building up self-confidence in achieving learning goals autonomously [5]. As a result, many students rarely seem to absorb the skill set necessary to be critical enough of their own knowledge to discover systematically and proactively vulnerabilities, flaws or other weaknesses [6].

This article describes an interactive learning strategy applied to the high voltage engineering course in the School of Electrical Engineering, Wuhan University. About 200 students in the freshman classes of 2008 and 2009 joined this programme. In the programme, 15 students of each cohort had been chosen to make an animation applet, which would be shown in the class and discussed by other students. Then, that applet was also used in the next cohort, and so on. Feedback and assessment show this approach not only expands the faculty's pedagogical research, but benefits students regardless of their involvement in the projects.

The rest of the article is organised as follows. The second section presents related work on interactive learning methods and animation presently adapted in various educational settings. The third section describes PILS as applied in high voltage engineering instruction. The fourth section details the programme and presents example of part of a programme that a 2009 junior designed, based on the work of the previous 2008 class. The fifth section reports on the feedback from different groups after completing the applet design and an assessment comparing with test scores of students who were involved or not involved in the applet-making. The sixth section concludes the article.

RELATED WORK

After years of effort, a number of interactive pedagogical innovations have been put forward in engineering education. One active learning strategy is that of cooperative learning defined as instruction that involves students working in teams to accomplish a common goal, under conditions that involve both positive interdependence, and individual and group accountability [7]. This paradigm shift from a teacher-centred delivery approach to a learner-centred environment changes the focus of the learning environment. The Virtual Interactive Student-Oriented Learning Environment (VISOLE) uses a game-based learning approach encompassing the creation of a near real-life on-line interactive world modelled upon a set of multidisciplinary domains [8]. This interactive approach provides students with a better understanding of the theory and the development of problem-solving techniques. Most importantly, students have achieved better learning results than with traditional lecturing.

Papadimitriou et al present an interactive problem-solving support system with adaptive educational hypermedia that assists students in solving electromagnetism problems individually and/or collaboratively [9]. Some Web-based laboratory exercises with remote access demonstrate how different disciplines make curricula more flexible and easier to learn [10-13]. Students sharpen their generic skills and develop a good command of various burgeoning techniques [14]. In general, it is difficult for a laboratory to arrange the extra time and curricular activities for interested students and offer them counselling help, but these systems can stretch spatial and temporal barriers. Dedicated simulation tools are not expensive, but can solve real life technical problems. Thus, time and funds saved by using these tools in curricula can be prioritised to solve other problems. Furthermore, no laboratory experiment is safer than operations performed on computers.

During the last decade, engineering education has improved significantly because of the advancement in technology and the increasing use of personal computers. By removing some of the syntactic absurdities of C++, JAVA has become the dominant language for undergraduate programming courses. Its simple model and libraries for networking, and graphical user interfaces have made it better suited to conveying object-oriented concepts and advanced computing topics, such as threads and distributed objects [15].

The interactive nature of animation, in which students input data and parameters, and immediately see their effects in the animation, support both active and constructivist theories of learning engineering [16]. Benefits include coherence with teaching and learning theory, which commonly indicates that multiple teaching modalities support the multiple learning styles of students in the classroom.

Murphey demonstrates the use of JAVA as a link to reinforce electrical engineering, physics, circuits, photonics and instrumentation laboratory experimentation. Students can create their own animation in a manner that reflects their talents and interests [17]. Several papers have reported the development of educational tools like JAVA in a virtual environment, where computer programs acting like the hardware replace the actual equipment [18-20]. They are well suited for self-paced, student directed study, student review, and classroom presentation and discussion. Other educators have noted the benefits of using a computer-aided educational animation to provide students with easy to use, easy to implement packages; and students must have an *immediate* response to their questions to understand electromagnetic scattering phenomena in real time [1].

The critical purpose of any teaching strategy is to help students comprehend the domain knowledge faster and more deeply, hence, that is the goal of the proposed interactive learning strategy. However, such approaches largely ignore one of the intrinsic benefits of JAVA - that students can create their own virtual animation in a manner that reflects their talents and comprehension. Furthermore, even though the animation is made by students under instruction, few of the learning strategies go along with the classes, let alone help students review courses in time. That is to say, the purpose in the present work is related but is not the same.

PROGRESSIVE INTERACTIVE LEARNING STRATEGY

In contrast to the traditional methods described in preceding sections, this article presents a novel pedagogical approach: a progressive interactive learning strategy (PILS). The purpose of this strategy is to challenge students to develop understanding on their own initiative as far as possible successively and progressively in an active, engaged way.

Explanation of Terms

Before the strategy is described, some terms and protocols should be clarified.

Experimental Groups: students are asked to volunteer to design the animation applet. All junior students learned Computer Fundamentals and Object-oriented Programming (C language) as a prerequisite for this course. Most students from urban areas in China learn about computing and software applications before they come to university. However, few of them continue to pursue interests in this area, especially, electrical engineering students. Computer programming and applications are not compulsory subjects for students in all programmes in a Chinese university. Thus, the experimental students must master the new software (Java-based Flash) as quickly as they can so they meet the design schedule for the course.

Control Group: all the students in class who are not in experimental groups are classified in this group. These students, along with the experimental group students, review the animation applet and contribute proposals to solve problems in the applet, according to their comprehension. After that, they are handed a questionnaire to collect feedback to aid the instructor, and the experimental students improve the applet design and methodology.

Description of PILS

In order to make the elusive parts clear and lucid, students simulate the processes described in textbook theories with software by themselves based on the previous class's work. The animation applet is presented in the class when the relative chapters are explained. The applet is demonstrated for the next incoming class. The schematic in Figure 1 describes procedures of PILS.

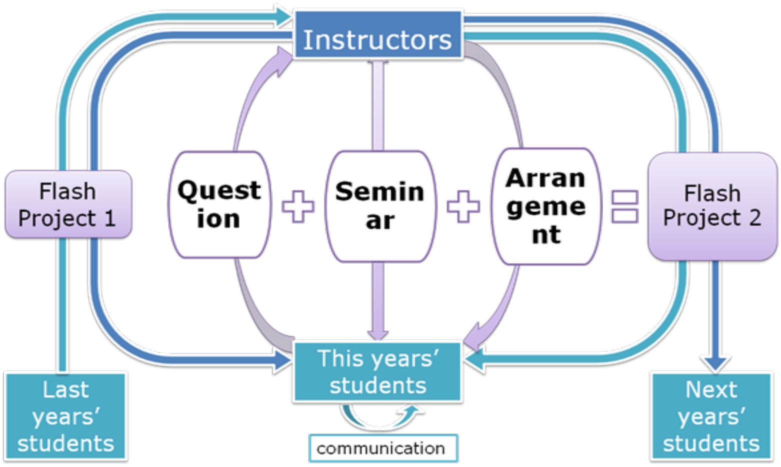

Figure 1: Schematic of progressive interactive learning strategy.

During the first lecture, the PILS procedure is described in detail so that students gain a concrete understanding of the principles. Teams of programme-solving students are selected, each team contains 4-5 students; the instructor arranges various tasks for each team to update and revise the applets. Since the programming work is divided into several components, the work load is reduced, so that students are able to concentrate on their own section. Questions and feedback are sent between the instructor and students by e-mail and QQ (an instant messaging computer program like ICQ) in real time. Seminars are held once a week, so that every team can show details of their work and discuss challenging or interesting sections. Instructors communicate with each other to evaluate the effect of specific teaching methods.

Applet demonstrations performed by the experimental students for the entire class are arranged in two formats: 1) 15 minutes before the end of normal lecture times; 2) A demonstration without lecture combining them for a full class period. The new applets are shown in class and all students' evaluations are accepted. The questionnaire is eventually sent to the students.

This approach not only helps learners with developing understanding when they read, programme and discuss, but also improves instructors' teaching methods iteratively. Building on the programmes made by previous students, later students make the most of the existing animation applets. As a result, the more students are involved in this project, the more members benefit from it.

PROCESS OF THE PROGRAMME

Construction of the Programme

To deal with the teaching difficulties that high voltage engineering presents, an array of methods have been proposed and tested to make the contents more comprehensive [21-23]. This course is a two-credit compulsory course for students specialising in electrical engineering and automation in Wuhan University. The lectures are two hours per session, twice a week, for a total of 36 hours.

Being an auxiliary to traditional classroom instruction, the programme does not necessarily include all of the contents of the curriculum. Some regulation and standardisation are required. There are two main regulations which will be included in this programme.

1) Some fundamental but obscure concepts are virtualised just for the theoretical lecture course, such as the Townsend Criterion for breakdown, Paschen's Law, Streamer Mechanism, and gas gap breakdown.
2) Some schemes illustrated directly, enable students to grasp the meaning of what the textbook describes.

The construction of the scheme is shown in Table 1.

Table 1: Construction and elusive sections of the course.

Topics	Sessions	Elusive sections
Introduction of high voltage engineering	1	
Gas insulation	6	Avalanche Townsend Mechanism (Paschen's Law) Streamer Mechanism Polarity effect Volt-time characteristics
Liquid and solid insulation	1	
High voltage experiment	4	
Over-voltage by lightning	6	Generation of lightning Arrester rod and line Transmission line

Two classes joined in this programme from the 2008 and 2009 freshman cohort, two years into their programme as juniors in the years 2011 and 2012, respectively. During the first lecture, 15 students from a class of 71 volunteered to be experimental students. Three groups were set up, each group had five students and three applet projects *Avalanche*, *Paschen's Law* and *Streamer Mechanism* was assigned to three groups respectively. Most of the experimental students were not familiar with Flash and Java programming when they begin with this course. The first task for them was to learn the relevant software. When classroom lectures reached elusive and difficult sections, the animation applet designed by the previous classroom cohort was presented. The strengths and weaknesses of the applet design were pointed out along with the content which the applet described. The group of students assigned to design this part of a new applet began their task by referring to the old version. The full demonstration of the new version of animation applets occurs in seventh week of the term after all the elusive topics have been taught in the traditional lecture format.

When the new version was shown in class, a representative of the group presented the main idea expressed in the design, pointed out what they had improved and the shortcomings of the old version they inherited. The entire class could then ask questions about all areas including the content or the software design, etc. A questionnaire was sent out at the end of the class by USB, e-mail and QQ, to be returned one week later.
An Example of Animation Applet Design

One group of students in the 2009 freshman cohort was assigned to design and modify a part of an animation of Paschen's curve after referring to the applet built by the 2008 freshman cohort. Through comparative analysis, students improved their familiarity with textbook knowledge of Paschen's Law. Paschen's Law is the fundamental theory of high-voltage apparatus insulation [24]. The equation of the curve is shown as below:

$$V = f(pd) \tag{1}$$

Where V is breakdown voltage, p is the pressure of gas and d is the distance between the electrodes. In Figure 2, the Paschen's Law can be illustrated as a curve with the breakdown voltage relating to pressure of gas and distance between the electrodes.

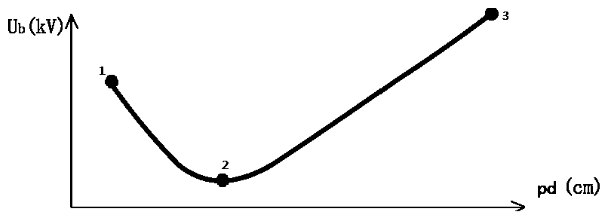

Figure 2: The scheme of Paschen's curve.

Reviewing the original animations designed by the students from the freshman cohort of 2008, some basic principles and amendments were made and mentioned by students from the freshman cohort 2009 as shown in Figure 3 [25].

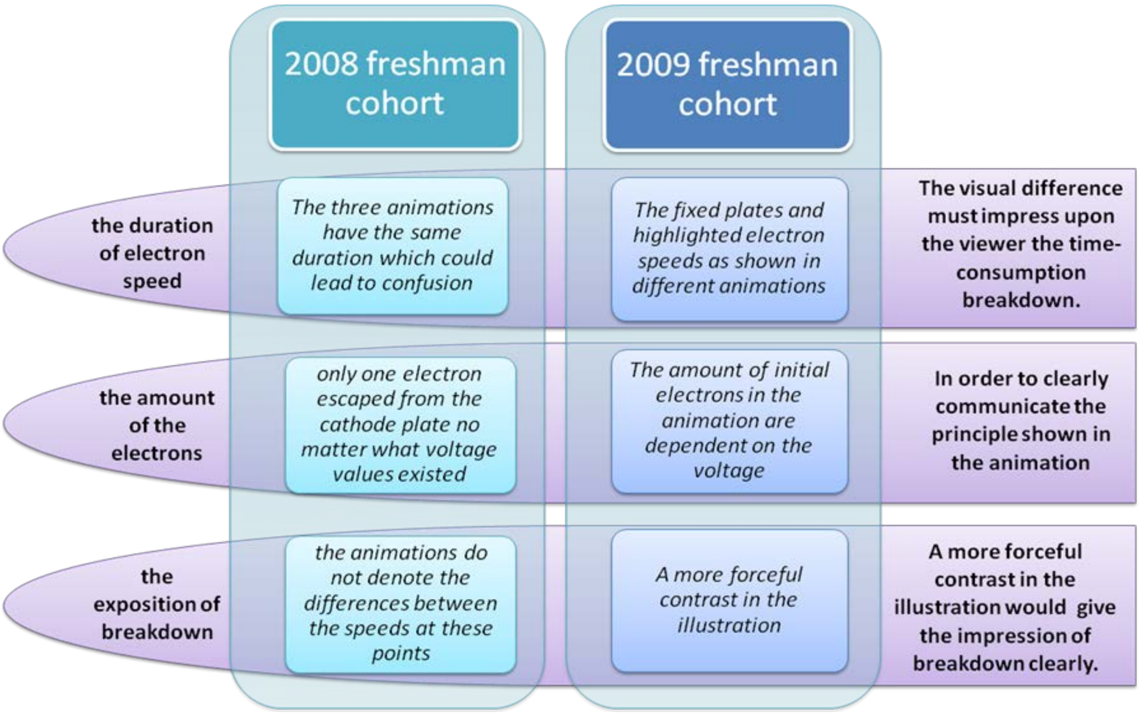

Figure 3: The animation improvement made by the 2009 students in comparison with the 2008 freshman cohort.

However, the animated visualisations designed by the 2009 freshman cohort still have shortcomings; in this visualisation the electrons have the same velocity in the gap. However, the electrons will accelerate in the electric field. This defect in the visualisation can be supplemented and corrected by the next class.

FEEDBACK AND ASSESSMENT

In the 2009 freshman cohort in the second term in the third undergraduate year, volunteers from the class were divided into three groups of five. Each group undertook a different project. Experimental groups were invited to submit feedback on the design process as shown in Table 2.

Table 2: Feedback of experimental group.

Group	Project Name	Feedback
1	Avalanche	Comprehend the electron avalanche, both the forming process and the intrinsic mechanism Use the software Adobe CS4 Offered an opportunity to read reference correlative to theory
2	Paschen's Law	The learning process benefits more Reading lots of the literature Make the process virtually to exposure the essence Contribute to future professional life greatly
3	Streamer Mechanism	Familiar with software Deepen understanding of the Streamer Mechanism Learn how to make other people understand the process

Table 2 shows three advantages that students reported they gained by making animations of fundamental concepts. The first and most important thing is that they understood the theory better when they designed their own animated visualisations. Second, by using new software they gradually grasped how to study and operate unfamiliar software. Finally, they learned how to search references.

The feedback from control students are shown in Figure 4. The overwhelming majority of control students (95% and 93%) agreed that the animation applet benefited them and helped them to understand the corresponding concepts even though they did not design the animation. Most students liked this kind of methodology and wanted to join the design team after watching the applet. This result was surprising because at the beginning of the course, only a few students

(15) were willing to join the project. For the multiple choice question: *What is the most difficult part of the design process?,* most control students considered the coincidence of content and animation, and these were also a cause of concern for the instructor.

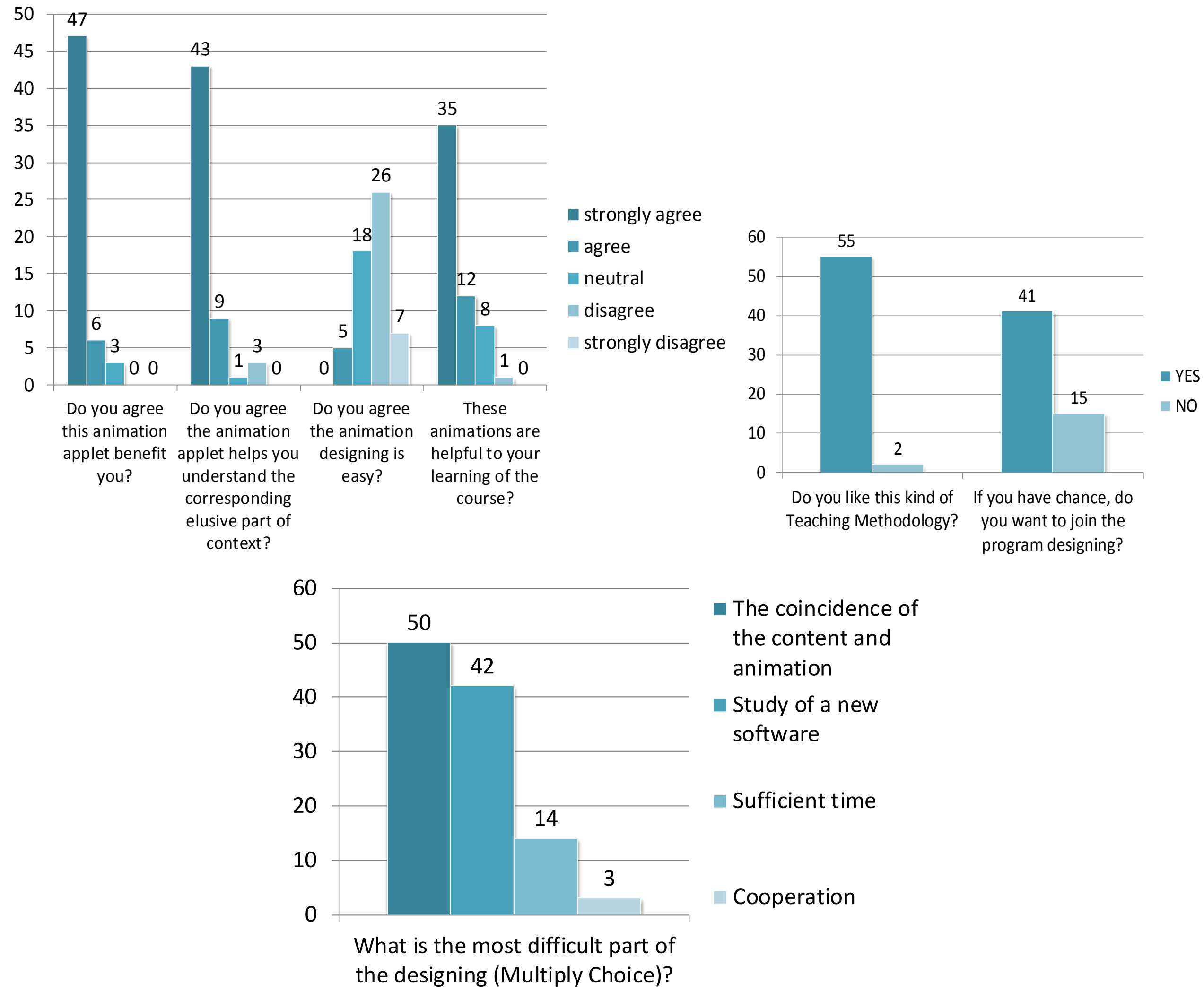

Figure 4: Feedback of the control group.

CONCLUSIONS

As is demonstrated in this article, PILS using animation applets visually describes the physical phenomena in elusive sections of a high voltage engineering course. Animations simplify procedures and clarify concepts, and are helpful to students when they learning how to analyse and explain phenomena scientifically, as well as to identify problems. Even control students, who did not design programs, were able to benefit from finished animation applets. It is becoming widely accepted that PILS is an effective means for bridging the gap between the instructor and students, as well as among the students themselves. In PILS, instructors realise what their own effect on classroom instruction is and monitor how much the students have grasped from the textbook. PILS also imbued students with team spirit by talking in specifics.

Through the interactive action between instructor and students in the 2008 and 2009 cohorts, the students gained many benefits. They came to understand the theories not described clearly in narratives and static pictures in textbooks; they are challenged to master new software; and they are required to search for references to support their research. Assessment shows that students evidently improve their scores, and gain both the theoretical knowledge and skills to meet the needs of their future profession.

Some improvements should be made for the sake of measuring how cogent and effective this study method is. The first step is to let the students volunteer for applet construction to evaluate the method of teaching. The second step is to test the effectiveness with randomised experimental design: namely, all students must be provided with equal opportunities in subsequent years. If the conclusion is still supported by them, the programme could be implemented for all students, thus, more and more learners would be able to get the most from an alternative learning strategy.

Given the dramatic improvement of students' test performance, PILS must be used extensively and improved, especially as applied to engineering education since the theories are not easy to transmit in the traditional lecture approach.

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