Using active learning to teach Applied Natural Sciences to first year students

Gomez Puente, S.M.[1]
Education Development Policy & Quality Assurance Officer
Dept. of Applied Physics, Eindhoven University of Technology
Eindhoven, the Netherlands

Engeln, R.A.H.
Associate Professor, Group Plasma& Materials Processing
Dept. of Applied Physics, Eindhoven Univ. of Technology
Eindhoven University of Technology
Eindhoven, the Netherlands

Conference Topic: Active learning, Physics in Engineering Education, Technology in Education

INTRODUCTION

Teaching *Applied Natural Sciences* (ANS) would not have ever been so challenging as this subject was not the common course for up to 1,800 freshman students at the Eindhoven University of Technology (TU/e). The ANS course aims at teaching basic concepts on mechanics, fluid dynamics, harmonic motion, and thermodynamics with the application of active learning approaches, to involve actively students during weekly lectures and tutorials. Responding to the educational policy demands from the university educational management, innovation of education was to serve the new profile of the 'Engineer*S* of the Future' by emphasizing diversity in the study programs and by attracting students with different interests, among others. In addition, the curriculum transformation was aiming at increasing students' pass rate. Within this framework, the ANS course has been redesigned to meet curriculum requirements. The didactic underpinnings of the ANS course lie in the combination of active learning techniques, i.e. Peer Instruction method; in the use of ICT, i.e. electronic response devices; and in the integration of formative assessment through an electronic platform.

In this paper, we report on the results of students' perceptions regarding three consecutive academic years. Results show that students became more enthusiastic about the interactive setup of the lectures while pass rates do not show a clear trend. We explore, therefore, how active learning in combination with other methods has supported students to learn physics concepts. For the purpose of this paper we focus on the results of only one group combining physics, mathematics and chemistry students.

[1] Corresponding Author
Gomez Puente, S.M., s.m.gomez.puente@tue.nl

1 BACKGROUND

1.1 Educational Reform in Engineering Education: a detonator for curriculum transformation

In 2011 initiated the Eindhoven University of Technology (TU/e) a major educational reform in order to redesign the curricula and to accommodate it to the current challenges of the different types of engineers. Following an analysis of needs [1] it became evident that the profile of the Engineer*S* of the future holds specific characteristics, e.g. the work of the engineers is multidisciplinary in nature including knowledge of both technical and non-technical disciplines; it has an own 'unique selling point' or specialism; who possess strong analytical skills and is innovative and solution-oriented.

Furthermore, the new profile of the engineer plays a crucial role as a link between technology and society able to work in a globalizing world in which (s)he can communicate and cooperate together with other team members [2]. In order to prepare the students towards acquiring these profiles it became therefore essential to transform the curriculum into more attractive undergraduate tailored-made programs for the 'career scientists' and the 'people-oriented generalist scientists' too. The primary motto of the redesign of the curriculum was to change from a supply-driven university into a demand driven university. Within this motto the student becomes the focus rather than the curriculum.

Within this philosophy of change in educating engineering both generalist and specialist there were some basic considerations. One constant is the need for the students to acquire a sound basis in science, engineering principles and analytical capabilities. In addition, some other considerations played a role in this transformation process: the students' intake for the TU/e programs and the success rates decreased in the previous years.

To meet these demands, the study undergraduate programs were redesigned following some essential requirements:

- study programs need to include a broad variety of social and management subjects in order to focus on the engineers profiles of the future, but also to attract other categories of science students;
- study programs need to include more differentiation in the undergraduate programs: a general first-year program and a fast specialized program, providing more opportunities for students to choose a major;
- study programs need to have more flexibility in designing a personalized study program and coach students in the 'design of your own study'.

In redesigning the programs the curriculum took a different structure. The major developments in this regard included three parallel courses of 5 ECTS, in which each student can follow their own unique path as they will be guided by a coach who will provide academic counselling and supervision. Regarding the didactical challenges some innovations were also initiated. In order to make the study programs more feasible opportunities for self-study, less contract hours and more assignments per subject, facilitated by providing more on-campus workspaces were created. In addition, formative assessment and innovative teaching methods and ICT teaching support to activate the students were also introduced.

1.2 Active learning methods to teach physics courses

The implementation of active learning methods in science and physic classrooms has brought about evidences on improved students' gains in comparison to traditional lecture-based methods [3]. Research in this regard has focused on devising and testing pedagogies to improve students understanding of physics by tackling misconceptions [4, 5, 6, 7].

The increased interest in the engagement of students during classroom lectures has led to use a variety of methods that encourage students to apply the material not only during the lecture time but also before class. Active learning techniques such as Peer Instruction [8, 9], demonstrations, real-time computerized data collection and display, Socratic "guided inquiry" [10], interactive computer simulations, and structured problem-solving, among others, report significantly improvements in students' development. The combination of methods ranging from Peer Instruction (that enhances students to discuss about concept questions and think and interact with their peers to come up to a solution), together with more technology-advanced tools (i.e. Just-in-time-teaching, that support students to grasp core elements of the lecture through readings and exercises before class), has reinforced the pedagogy of teaching. Moreover, the notion of 'talking physics' using electronic audience response system (ARSs) has mushroomed in higher education proving benefits. Studies on *Classtalks* experiences [11, 12], show evidences on how audience response systems have influenced students' improvements and has increased level in attendance, attention levels, participation and engagement, and finally, in learning physics concepts through interaction and discussion following multiple choice questions [13].

1.3 Applied Natural Sciences course

The Applied Natural Science course has been taught at both physics and mathematics students in the past 10 years. In this course, topics such as Newton's laws, energy conservation, energy-work theorem, momentum, impulse, and collisions were taught.

Following a curriculum transformation to accommodate the course to the current trends in Engineering Education and to serve the needs of the Engineer*S* of the future, the course has been redesigned and includes now also subjects such as waves/acoustics, and heat transfer. Moreover, the relevance that this topic has gained in the last years has placed this course as one of the basic compulsory courses in the curriculum of all engineering study programs for all freshman students at the Eindhoven University of Technology.

2 INSTRUCTIONAL DESIGN OF THE APPLIED NATURAL SCIENCES COURSE

2.1 From traditional teaching to a studio classroom approach

The organisation of the Applied Natural Sciences course has experienced several alternations in the last four years. From a traditional teaching approach consisting of a series of weekly lectures (to teach main theoretical insights and physic concepts illustrated by demonstrations on free fall, momentum conservation during collisions, and the pendulum), supported by small-size group tutorials supervised by an instructor (where students work on solving problems individually or in pairs supervised) to a more inductive and experiential system to teach. With the introduction of Peer Instruction in 2010/2011 some changes were made in the didactics of learning physics concepts. Coloured flash cards were introduced as a method to activate students to participate and provide answers to multiple-choice concept questions. This method was meant to give feedback to the students about their gaps regarding misconceptions but it was also used as a feedback instrument for the teacher to get acquainted with the students' learning process. The ultimate goal was to optimize the following lectures. Despite the positive response of the students about this method, there were still suggestions for improvement i.e. monitoring individually students' progress regularly.

Later in 2012 and due to the university educational policy to introduce active learning methods, the Peer Instruction method with coloured flash cards was replaced by audience response devises, i.e. clickers. These devices were consistently used for classroom exercises during the lectures to not only activate the students and provide individual weekly feedback, but also to asses formatively the students. In addition, during the redesign of the Applied Natural Sciences course an online learning platform, Mastering Physics, was introduced by which students are able to electronically work on interactive exercises upon which they also get feedback. Furthermore, the organizational format of the lectures was readjusted following the studio classrooms structure method. By this method, the traditional organization of the lectures and tutorials was *flipped out* [14] encouraging a more inductive and experiential approach to learn. The classroom arrangement of Applied Natural Science resembled therefore the studio classroom [14] structure consisting of an integrated block of interactive lectures with clicker quiz questions, tutorials and self-study time (see Figure 1.). Although this integrated setup was meant to be given in a four-hour block combining activating methods, it was changed after the first lectures due to the students' request. It was turned therefore into sessions of a two-hour lecture and a two-hour instruction every week.

Content	Timespan
Demonstration (introduction to a core concept)	25
Break	
Refreshment on the core concept through click quiz questions including feedback to the students	15
Introduction to a new concept Demonstration Quiz	25
Introduction to a new concept Demonstration Quiz (peer discussions)	25
Break	15
Introduction new concept Demonstration Quiz (peer discussions)	25
Introduction new concept Demonstration Quiz (peer discussions)	25
Break (to start up notebooks)	15
Digital test Answer to concept test questions through the digital platform Mastering Physics including feedback to the students	30

Figure 1. Example of a block of interactive studio classroom lecture. This set up was afterwards adjusted in two-hour interactive lectures.

Despite the positive results in students' gains in pass rates in comparison with previous years as indicated in Table 1. there was still a need to fine tune the method. Students' observations regarding the setup of the course are that the four-hour block became a discouraging factor to attend the whole lecture schedule as planned. The readjustments of the organisation of the lecture include therefore two times two hours of interactive lectures and two hours of tutorials. Furthermore, in optimizing this model in 2013, some additional didactical elements came in. Inspired by Walter Levin's demonstrations at the Massachusetts Institute of Technology (MIT) [15], live demonstrations were included to teach topics such as free fall, momentum conservation during collisions, the pendulum and the 'sun set'.

3 RESEARCH METHOD

3.1 Selection of research methods

To gain an overview on how the variation in didactical methods and adjustments has influenced students' pass rates in consecutive years we researched the students' rates in consecutive years. The research methods consisted of the Applied Physics department quality assurance questionnaires that students fill out at the end of each course. This evaluation questionnaire collects both quantitative data through a 5-point Likert scale structured questionnaires, as well as through a series of structured open questions that helps to gather students' perceptions from a qualitative research perspective.

3.2 Selection of participants

For the purpose of this study we have taken into account the last three cohort years of the Physics freshman course including the academic years 2011/2012, 2012/2013 and 2013/2014. The students' cohort of 2011/2012 focuses only on physics and maths students, while in 2012/2013 and 2013/2014 includes also the students of the chemistry department. In total N= 92 physics and maths students followed the traditional Mechanics 1 course in 2011/2012; N= 186 physics, maths and chemistry students in 2012/2013; and finally, N= 273 physics, maths and chemistry students in 2013/2014.

4 RESULTS

The results in Table 1. show an increase in the pass rates (%) regarding 2011/2012 and 2012/2013. Furthermore, the breakdown analysis of the % students' with >5 as a final score has increased in the cohort of 2012/2013while the % of students' with <=5 has decreased. The data confirms consequently a positive impact on students pass rates as a consequence of the introduction of new educational approaches to teach physics such as the combined structure of educational methods, i.e. studio classrooms, the IT clicker approach to test conceptual understanding through multiple choice questions, and finally through the support of the online Mastering Physics platform.

With respect to the cohort 2013/2014, we compare this cohort with previous years. Although we observe a constant increase in the >5 as a final score with regards to the physics and the maths individual groups, and less in the chemistry group in the last year, we perceived however a decrease in the total pass rates regarding the last cohort year. We are not able to easily find an explanation with regards to this matter, except that the examinations with Mastering Physics probably were not at the expected conceptual level. It becomes relevant to mention however that the integration of active learning methods indicate an improvement in students pass rates as % of students gaining higher scores is larger in the year cohort 2013/2014 than in previous years. These results must be seen in perspective and within the context of the university policy first time pass rates which is typically 70%.

Table 1. Overview of pass rates (%) of different cohort years

Year Cohort	Study program	N= students >5	N= students <=5	Total % ANS** pass rate	N=students participating in final exam
2011-2012	Physics	36 (54.5%)	30 (45.5%)		66
2011-2012	Maths	8 (30.8%)	18 (69.2%)	47.8	26
2012-2013	Physics	63 (86.3%)	10 (13.7%)		73
2012-2013	Maths	36 (81.8%)	8 (18.2%)	81.7	44
2012-2013	Chemistry	53 (76.8%)	16 (23.2%)		69
2013-2014	Physics	97 (71.9 %)	38 (28.1%)		135
2013-2014	Maths	57 (67.9 %)	27 (32.1%)	66.7%	84
2013-2014	Chemistry	28 (51.9 %)	26 (48.1%)		54

** ANS - Applied Natural Sciences

Regarding the 5-point Likert scale questionnaire we compared the results of the students' perceptions in the three consecutive years (see Table 2). Due to the changes in the format and setup of the quantitative questionnaires we are not able to provide an overview of students' perceptions regarding all questions as these are not always the same.

Table 2. Overview of students' perceptions in different cohort years

Questions	2010-2011**			2012-2013			2013-2014		
	Mean	SD	N= st.	Mean	SD	N= st.	Mean	SD	N= st.
Are you satisfied with the content of this module?			32	3.4	1.1	317			219
Are you satisfied with the organization of this module?				3.2	1.1		2.9	1.1	
Are you satisfied with the lectures?	4.47	0.56		2.9	1.2		2.7	1.2	
Are you satisfied with the instructions?	4.35	0.73		3.5	1.1		2.8	1.1	
Are you satisfied with the interim test?	3.53	1.35		3.2	1.2		2.2	1.3	
Are you satisfied with the examination/final test?	4.16	0.83		3.5	1.1		3.2	1.1	
Have you enjoyed taking this module?				3.1	1.2		2.9	1.1	
Please, rate this course in a scale of 1 to 10				6.2			5.8		

** There are no data available of the cohort year 2011/2012. However, since no changes were introduced in the design and setup of the course, we take the cohort 2010/2011 as a representation of students' perceptions.

With respect to the qualitative research, open questions were asked in order to get the students' perceptions. The questions were geared to collect perceptions on the positive aspects that the students observed during the course but also on the less positive elements in the course that still are in need to improve. By collecting this information, we were able to gain an insight, in general terms, about the students' opinions along the years according to the different didactical changes included in the course.

Regarding students' observations in the cohort year 2010/2011, the introduction of the coloured flash cards was found to be instructive. As a new element during the lectures, the voting system with cards was perceived as an added value to support conceptual understanding.

With the introduction of the electronic devise systems, i.e. clickers, in 2012/2013 the appreciation for this didactical approach was valued as students recognized an incentive to prepare lectures in which the main concepts were recalled. This system of testing knowledge weekly basis did not only increase the interaction and participation during the lecture time but also influenced the pass rates in comparison with previous years. Furthermore, as the response system included immediate feedback the quality of the content provided during the lectures was enhanced. In addition, the fact that the feedback was anonymous was geared to provide direct and individual overview of progress. Moreover, the demonstrations before the lectures upon which the conceptual questions were based were highly appreciated by the majority of the students. In contrast, the integrated block of four-hour interactive methods had no the expected positive effects. Instead of motivating the students during the lecture time the four-hour intensive block was considered to be a discouraging element for the students to be present throughout the requested time. Despite the fact that there are positive experiences in the literature with four-hour blocks [16] with small groups, this doesn't appear to work with large groups and/or with groups from different disciplines.

With respect to the cohort year of 2013/2014, we still observe a constant appreciation by the students regarding the clicker system for the conceptual test and the live demonstrations before the lecture time were again a core motivating factor for teaching physics. On the contrary, and against expectations, the Mastering Physics electronic platform that works to practice content given during lectures but also to test students' knowledge was perceived less positive than in the previous year, and especially when it comes to the judge this system as an assessment instrument

5 CONCLUSIONS

From this experience we arrived to several conclusions. First of all, the integration of active learning methods to teach physic concepts has proved once more to be a successful factor for learning according to students' appreciation. This experience supports therefore the broad body of empirical research on the positive impact of using active learning in physic courses. The progression in students' confident and perceptions along the years shows motivation when it comes to learning with the enclosure of coloured flash cards and later with the electronic devices. Secondly, the fact that the integration of active learning methods depends also of the setup of the lecture structure, the organization needs to be carefully selected to support students' learning.

REFERENCES

[1] Toekomstbestendig en Studentgericht Bacheloronderwijs van de TU/e: Eindrapportage van de taskforce Redesign Ba-curriculum en Standpunt College van Bestuur, (2011), Eindhoven University of Technology, the Netherlands.

[2] Clough, G.W., (2004), The Engineer of 2020: Visions of Engineering in the New Century, National Academy of Engineering, Washington, DC: National Press, USA.

[3] Meltzer, D.E., Thornton, E.K., (2011), Resource Letter ALIP-1: Active-Learning Instruction in Physics, *American Journal of Physics*, Vol. 80(6), pp. 478-496

[4] Crouch, C.H., Mazur, E, (2001), Peer Instruction: Ten years of experience and results, *American Association of Physics Teachers*, Vol. 69 (9), pp. 970-838.

[5] Smith, M.K., Wood, W.B., Krauter, K., Knight, J.K., (201 1), Combining Peer Discussion with Instructor Explanation Increases Student Learning from In-Class Concept Questions, *Life Science Education*, Vol. 10, pp. 55-63.

[6] Ding, L., Reay, N.W., Lee, A.m Bao, L., (2008), Effects of testing conditions on conceptual survey results, *The American Physical Society*, Vol. 4, pp. 010112-6.

[7] Savelsbergh, E.R., de Jong, T., Ferguson-Hessler, M.G.M., (2011), Choosing the right solution approach: The crucial role of situational knowledge in electricity and magnetism, *American Physical Society*, Vol. 7(1), pp. 010103-12.

[8] Crouch, C., Fagen, A., Callan, J.P., (2004), Classroom demonstrations: Learning tools or entertainment?, *American Journal of Physics*, Vol. 72, pp. 835.

[9] Watkins, J., Mazur, E., (2013), Retaining Students in Science, Technology, Engineering, and Mathematics Majors (STEM) Majors, *Journal of College Science Teaching*, Vol.42(5) pp-36-41.

[10] Hake, R.R., (1992), Socratic pedagogy in the introductory physics lab., *The Physics Teacher,* Vol. 30, pp. 546.

[11] Henriksen, E.K., Angell, C., (2010), The role of 'talking physics' in an undergraduate physics class using an electronic audience response system, *Physics Education,* Vol. 45(3), pp. 278-284.

[12] Mollborn, S., Hoekstra, A. (2010), "A meeting of minds": Using clickers for critical thinking and discussion in large sociology classes, *Teaching Sociology*, Vol. 38(1), pp. 18-27.

[13] Kay, R.H., LeSage, A., (2009), Examining the benefits and challenges of using audience response systems: A review of the literature, *Computers & Education*, Elsevier, Vol. 53, pp. 819-827.

[14] Drake, E., (2014), Teaching and Learning in Active Classrooms, The Faculty Center for Innovative Teaching, Central Michigan University, USA.

[15] Lewin, W., (2011), For the love of physics: from the end of the rainbow to the edge of time – A journey through the wonders of physics, Simon & Schurster, New York, USA.

[16] Gomez Puente, S.M., Swagten, H.J.M. (2012), Designing Learning Environments to teach interactive quantum physics classrooms, European Journal of Engineering Education, 37(5), pp. 448-457.