Models for research-based teaching in engineering courses: a case-study at the University of Aveiro (PT) and San José State University (USA)

Isabel Huet[1], Nikos J. Mourtos[2], Nilza Costa[3], Osvaldo Pacheco[4], José Tavares[5]

Abstract - **There is considerable educational literature to suggest that the way universities conceive and manage the relationship between research and teaching, impacts negatively or positively teaching practices and student learning in Higher Education. Although the relevance of linking research and teaching is perceived as of central importance by many authors and university leaders, empirical findings suggest that research does not always influence the teaching quality and vice versa. The purpose of this communication is to analyse how institutional policies and practices can help or hinder engineering faculty members to link their teaching and research and how academics perceive the teaching/research nexus with the broader objective to enhance quality teaching and learning in Higher Education. More specifically the objective of this research is to investigate a range of institutional policies and practices at the Universities of Aveiro (PT) and San José State (USA) aiming at understanding how engineering faculty use research-based teaching in their classes. Empirical findings suggest that a research-based teaching model engages more actively the students in the daily tasks and develops deeper critical thinking.**

Index Terms – engineering education, informed-based teaching, research-based teaching.

INTRODUCTION (NATIONAL POILICIES IN PORTUGAL AND USA)

Under the Bologna reform, still in progress in Portugal, major changes are being introduced in the organisation of higher education, concerning both the degree structure and the organisation of teaching, with effects that started in the academic year 2006/07. The most visible change is the 3-year undergraduate degree, which replaced the 5- year degree in most fields except some engineering courses which have an ‘integrated masters’. This new structure promotes the mobility of students, researchers and teachers around higher education institutions in Europe. But other changes will affect the higher education institutions. Indeed, Bologna has been a political motive to speed the need of a profound reform in the Portuguese higher education system. One of the Bologna guidelines refers to the student-centred approach to teaching and learning and the design of the curricula based on competences and learning outcomes.

In order to achieve a student-centred approach, teaching and learning strategies need to change. Until recently we faced a traditional teaching model, centred on the teacher with the predominance of information passing style in lectures and where assessment did not have a visible effect on the system. Now, academia is discussing best strategies to effectively design the curriculum and evaluate learning outcomes. The importance of teaching best practices, the promotion of inquiry-based learning, research-led-teaching and teaching-led-research are issues strongly discussed for the first time, mainly at engineering and science schools. The need to actively engage students in the process of learning will highlight the importance of a research-based teaching approach.

In United States, several factors have played a key role in shaping engineering education, such as:

(a) Increased pressure from parents, taxpayers, and legislators, who are dissatisfied with the de-emphasis of undergraduate education at major universities.

(b) Employer complaints about the lack of professional awareness, communication and teamwork skills in engineering graduates.

(c) Challenges posed by the changing needs of our student populations and in particular the diversity of native ability, background, motivation, attitudes, and learning styles. These challenges seem to escalate as one considers the shrinking pool of applicants for engineering schools.

The need to change the way we prepare engineering students, was first emphasized in the famous Green Report [1]. In their own words, ‘*…engineering education programs must not only teach the fundamentals of engineering theory, experimentation and practice, but be relevant (to the lives and careers of students), attractive (to highly talented students with a wider variety of backgrounds), and connected (to the needs and issues of the broader community)’*.

These new realities are also reflected in the ABET Engineering Criteria 2000 [2], which introduced new concepts for engineering educators, such as ‘outcomes assessment’ and ‘continuous program improvement’.

[1] University of Aveiro, PT, iza@dce.ua.pt
[2] San José State University, USA, njmourtos@sjsu.edu
[3] University of Aveiro, PT, nilza@dte.ua.pt
[4] University of Aveiro, PT, osvaldo@det.ua.pt
[5] University of Aveiro, PT, tavares@dce.ua.pt

Outcomes assessment shifts the emphasis from what we teach (old criteria) to what engineering students can actually do (new criteria). Moreover, the burden is now on engineering educators to find convincing ways to document the various student abilities specified in Criterion 3 (Outcomes Assessment). Continuous improvement requires a process for using the results of assessment to guide programmatic and / or course changes in a manner that improves the quality of each program.

To meet these new demands, engineering educators must change the way they approach teaching and learning [3]. For example, it is now well established that traditional instructional methods are not adequate to equip engineering graduates with the knowledge, skills, and attitudes they need to meet the demands of the 21st century workplace [4]. Moreover, focusing engineering courses entirely on technical content and expecting students to develop critical process skills automatically is not realistic [5]. The design of engineering courses must be approached like any other engineering product, i.e., they must have specifications (instructional objectives), made using proper manufacturing methods (learning activities), and tested (assessment) [6] – [5]. For engineering products, if the specifications are not met during testing, the engineer(s) goes back to the drawing board for modifications and re-design as needed. Similarly, for a course, if the assessment shows that the instructional objectives are not met, the instructor needs to go back and re-evaluate the content as well as the delivery methods.

Critical instructional objectives for 21st century engineering students include problem-solving, design, communication, teamwork, self-assessment, ethics, lifelong learning, and other process skills [2], [5]. Research shows that alternative teaching methods, such as active, cooperative, and problem-based learning (PBL), offer good prospects for meeting such objectives [6]. On the other hand, engineering educators, like most university educators, do not have formal training in pedagogy and course design. Hence, there is a need to provide such training in institutions of higher education or other venues [3] and provide incentives to engineering faculty for engaging in the scholarship of teaching [7].

In spite of this 'demand' to change, the discussion of the effectiveness of such strategies is questionable. It will take time until we are able to evaluate the impact of those changes in the student's learning. This paper intends to discuss some strategies used by engineering faculty members at the Universities of Aveiro and San Jose State and the work that still needs to be done to achieve higher rates of engineering students' academic success.

TEACHING AND LEARNING IN ENGINEERING

Effective teachers will face a climate of continual change in which distance learning and other teaching media are more prevalent. Teachers as social scientists 'have a plurality of methods from which to choose when they research a subject, and it is their responsibility to select the one method that best fits the ontological contours of the problem they are studying' [8]. Furthermore, there is no single method that can 'fully appropriate the manifold complexity of social life' [8] and the same is applied to the teaching methods. Academics have to adjust each method according to the student needs and the complexity of the subject.

Some teaching strategies in the area of engineering were explored by Felder & Silverman [9] aiming to motivate and develop deep learning approaches in students and to turn them into reflective and active learners [10]. Nevertheless, different types of learners are more motivated by one strategy than another. The success of the implementation of any strategy lies in the lecturer's ability to combine activities that accommodate different types of students and different moments of the class as expressed by Felder & Silverman [9]: '*The idea, however, is not to use all the techniques in every class but rather to pick several that look feasible and try them; keep the ones that work; drop the others; and try a few more in the next course. In this way a teaching style that is both effective for students and comfortable for the professor will evolve naturally and relatively painlessly, with a potentially dramatic effect on the quality of learning that subsequently occurs'*.

The same authors [9] support the view that engineering education is usually auditory, abstract (intuitive), deductive, passive, and sequential; while many engineering students are visual, sensing, inductive, and active. These mismatches can 'lead to poor student performance, professorial frustration, and a loss to society of many potentially excellent engineers'.

The balance between concrete information (facts, observations, experimental data and applications) and abstract information (concepts, theories, mathematical formulas and models) should be balanced in delivering the courses. Academics often refer to the difficulty of introducing abstraction. When abstraction is introduced in a class without considering the cognitive structures of the individuals, it is unlikely that that the new material will be transferred to long term memory [11], [12].

Indeed, the findings suggest that academics should provide effective concrete material in class for students with more difficulties to engage in the learning process. Visual illustrations and demonstrations are perceived as more effective than verbal information by the students (sensor learners). Sensors are more comfortable with concrete information than with abstraction and the converse is true of intuitors.

Essentially, effective teachers should offer students cognitive apprenticeships by working with students and modelling key aspects of learning until the students are able to work unassisted and become responsible for their own learning and the learning of others. The lecturer is responsible for passing on knowledge of the process rather than simply focusing on content. Ideally, the faculty member serves as a facilitator or coach. The ability to combine different methods and teaching techniques requires from the lecturer a deep knowledge of the students' learning styles [13].

There are numerous approaches to teaching engineering courses [14]. Each of these approaches has benefits and drawbacks [15]. In spite of the time allocated for labs, the traditional style of lecturing is still the most common method for teaching engineering. A study developed by Huet, Pacheco, Tavares & Weir [16] concludes that a significant number of engineering students express a preference for fewer lectures and more practical sessions. In this study students suggested that lectures should be held in labs, so everyone could program during lectures, and see the program running rather than that of the lecturer.

With such student behaviour and student requests for more labs or lectures with a strong practical component, we may wonder at the long term future of lectures.

The students' suggestion revealed that academics should present 'real-world problems, in which future engineers are expected to not only understand the phenomena involved but also to solve problems (Problem-based Learning). Problem-Based Learning is a teaching strategy crucial for developing skills and confidence in students. These students 'are learning a process which will be an essential part of their work as professionals' [17]. The ability to think autonomously and in cooperation with other students is an essential characteristic of engineering professionals. The exercises thought and planned for each course should relate the subject to the real world, so that students have a stake in solving the problem.

RESEARCH AND INFORMED-BASED TEACHING

In many national systems, as in many institutions, policies for teaching and for research are conceptualised and delivered separately – with little or no attention to how they might be linked or indeed their possible impacts on each other [18]. If we perceive one of the roles of universities as guiding students to become effective lifelong learners, then the connection between teaching and research should be more carefully addressed.

There is a difference between research and informed-based teaching. The first concept implies teaching strategies to actively engage students in research or inquiry activities. The second concept does not necessarily engage students in research. It informs students on the state of the art research about a specific topic being covered in the class. It is important for students to be engaged in research since year one, if they are to learn to cope with complexity. According to Barnett [19] the world is not complex, but super-complex. Engineering students face serious problems in developing abstract thinking and it is common to hear academics complaining about the lack of students' skills in understanding even simple problems [20]. The failure to cope with complexity can be avoided by engaging students to deal with complex problems. Problem-based learning or inquiry-based learning are both effective strategies to help students understanding what knowledge is and how it is generated.

Academics can often focus their attention on their research paradigms forgetting the implication that their research might have on teaching and learning. In some cases, academics' lack of motivation for teaching can lead them to dedicate most of their time to research. What are the reasons for such behaviour? One explanation might be related to the political pressures for research quality at universities, which in many cases has resulted in a lower interest in teaching.

The ideal situation might be to valorise teaching and research in HE equally and to encourage staff to see potential links between these activities so as both to motivate them, enrich student learning and affirm the particular importance of the teaching/research nexus to degree level learning.

CASE-STUDY 1: UNIVERSITY OF AVEIRO

The engineering and science courses at the University of Aveiro (UA) are organised in laboratories, traditional lectures and a mixture of theoretical and practical classes where there is a blend of traditional exposure to theoretical contents with some practical examples. The mixture between theory and practice allows students to reflect on the concepts during the class and to start thinking about the exercises delivered at the laboratories. Nevertheless, this model is not always followed by all faculty members. The traditional style of lectures, focused on information transfer, is still dominant at the University.

At the laboratories students solve exercises with the supervision of the lecturer. The time allocated for labs is in some disciplines (such as Programming) higher than the time allocated for lectures. This model emphasises the importance of practice and/or problem solving in engineering courses, meeting the objective of a more student-centered approach and the development of inquiry-based learning.

In year 4 and 5 (integrated masters) academics have the opportunity to engage students in research activities carried out by the department or by themselves. In final years (integrated masters) students need to present disciplinary projects, which in the Bologna context are called dissertations.

There are also workshops and short term courses, available to students, aiming to promote the discussion of research topics carried out by the research units or associated laboratories. Most students who attend these activities are mainly from years 4 and 5. Another strategy to engage students in research activities is to invite final year students, especially the ones with a good record of academic success, to integrate research teams. In this case, the proposed tasks are not related to the core of the curriculum. Little involvement in research or projects is carried out at undergraduate level.

The University created in 1997 the Polytechnic school 'Escola Superior de Tecnologia e Gestão de Águeda (ESTGA)'. The main objective of the school is to bring more students to engineering. This school follows the methodology of problem and inquiry based learning and represents a good example of effective active learning by the students. The successful results might be explained because of the reduced number of students (around 900), which allows small group interactions but many of the teaching and learning strategies could also be used at the University.

The essence of PBL in engineering courses is to learn by working on open-ended problems, which in this case assumes the form of projects. Each project is dedicated to a specific theme which has a set of so called 'associated disciplines' to support the project, by covering the basics of the theme's scientific content [21]. The project and associated disciplines make up a Thematic Module which is the core of the semester. The associated and autonomous disciplines are administered in blocks of typically 4 hours, and their time share decreases stepwise in the course of the semester as opposed to that of the project [21](Figure 1).

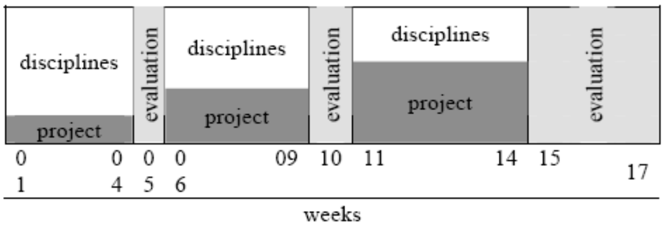

FIGURE 1
TIME SCHEDULE OF A PBL SEMESTER

CASE-STUDY 2: SAN JOSÉ STATE UNIVERSITY

The following are examples of non-traditional teaching methods at SJSU, based on recommendations from the engineering education literature. These methods are designed to address a variety of learning styles, thus increasing student engagement and student learning. Several engineering faculty members use these methods, as their effectiveness has been tested and recognized in a variety of classes.

Diagnostic assessment: At the beginning of a course, students take concept inventories for prerequisite subjects. For example, in the aerodynamics course (AE162) students take the Fluid Mechanics Concept Inventory [22] while in the compressible flow course (AE164) they take both the Fluid Mechanics as well as the Thermodynamics Concept Inventory [23]. The purpose of these tests early in the semester is to establish student understanding of basic concepts and / or misconceptions, so that the course can be adjusted appropriately based on the students' background.

Formative assessment: In the first 10 min of class students take a short quiz (2 – 3 questions) on the assigned reading. They are also asked to write any questions they may have from their reading assignment. This is one variation from a number of techniques presented in [24] as a way to engage students. Moreover, in the last 10 minutes of class students take a second quiz, this time on material discussed in class. For both tests their answers are collected and used as part of their course grade but they are also shared on a voluntary basis as a way of establishing a common base of understanding before tackling complex problems.

In-class active / cooperative learning: A typical class session involves presentation of new material, example problems presented by the professor but also one or two problem-solving sessions in small groups [25]. This is an opportunity for students to apply new concepts and for the professor to assess student learning. Research shows that giving students opportunities to 'approximate' what is being taught while 'response' (i.e. feedback) from significant others is readily available are two conditions that must be met for learning to take place [26]. While working in small groups students constantly receive feedback from their team mates. Moreover, professors have opportunities to walk around the classroom, observe student work, and more importantly, provide their own feedback.

Problem-based learning (PBL): The majority of the 'problems' solved by engineering students during their undergraduate training are well-defined, with explicit statements, providing all the information necessary to arrive at the one and only correct answer [27]. These 'problems' are sometimes referred to as exercises in the literature [27], [28]. Although a necessary step in the learning process, exercises do not prepare engineering students for the real world [27]. To help students master problem-solving skills, several open-ended problems have been introduced in the curriculum [28]. Open-ended problems are ill-defined, provide a new context which may be unfamiliar, and have no explicit statement telling students what principles to use or what assumptions to make. Moreover, there may be more than one acceptable answer as well as more than one approach to arrive at those answers. Students are also encouraged to identify their own problems of interest, which integrate material from two or more courses [29].

A study of the teaching styles in the College of Engineering at SJSU revealed the following [30], [31]:

- 24% of the faculty use active / cooperative learning in their classes on a regular basis. This percentage is small, considering the evidence in the literature about the benefits of active / cooperative learning and the attention the subject has received in engineering education conferences. Nevertheless, the impact on student learning is significant. Both students and faculty who use active / cooperative learning reported improvements in understanding of engineering concepts, communication skills, team skills, problem-solving skills, and design skills, as a result of cooperative learning. The study also showed that
- 39% of the respondents use visuals in every class session and another 26% does so at least once a week.
- 43% use inductive while 52% use deductive methods to introduce new concepts.

These results are somewhat encouraging, as they show that at least some engineering faculty members follow recommendations from education research and practice.

FINAL CONSIDERATIONS

Innovation is often promoted by external influences. The Bologna Process has the potential to induct the so expected auto-transformation at the national, institutional and individual level [32], but it is our responsibility to proceed to changes that meet the country economic and cultural reality. It is important to explore how academics integrate teaching and research in their daily activities and to evaluate the impact that it might have on students' learning achievement. The case studies presented in this paper represent the effort of faculty members to actively engage students in inquiry-based learning and to promote research and informed-based teaching. These strategies are key issues of mayor importance for the future of quality teaching, learning and research in higher education.

ACKNOWLEDGMENT

This research is supported by the University of Aveiro, Foundation for Science and Technology (FCT) and the POCI 2010.

REFERENCES

[1] *The Green Report: Engineering Education for a Changing World*, Joint Project Report by the Engineering Deans Council and Corporate Roundtable of the ASEE, 1994.

[2] Criteria for Accrediting Engineering Programs, Effective for Evaluations During the 2006-2007 Accreditation Cycle, Engineering Accreditation Commission, Accreditation Board for Engineering and Technology website [Online], Available: http://www.abet.org/forms.html

[3] J. E. Stice, R.M. Felder, D.R. Woods and A. Rugarcia, "The future of engineering education IV; Learning how to teach", Chemical Engineering Education, vol. 34, no. 2, 2000, pp.118-127.

[4] A. Rugarcia, R.M. Felder, D.R. Woods and J.E. Stice, "The future of engineering education I; A vision for a new century", *Chemical Engineering. Education*, vol. 34, no. 1, 2000, pp.16-25.

[5] A. Rugarcia, R.M. Felder, D.R. Woods and J.E. Stice, "The future of engineering education III; Developing critical skills", Chemical Engineering. Education, vol. 34, no. 2, 2000, pp.108-117.

[6] R.M Felder, D.R. Woods, J.E. Stice and A. Rugarcia, "The future of engineering education II; Teaching methods that work", *Chemical Engineering Education*, vol. 34, no. 1, 2000, pp.26-39.

[7] R.M. Felder, A. Rugarcia and J.E. Stice, "The future of engineering education V; Assessing teaching effectiveness and educational scholarship", Chemical Engineering. Education, vol. 34, no. 3, 2000, pp.198-207.

[8] D. Harvey and M. Reed, "Social science as the study of complex systems", in *Chaos Theory in the Social Sciences: Foundations and Applications*, L. D. Kiel & E. Elliott Ed. Ann Arbor: University of Michigan Press, 1997, pp.295-324.

[9] R. Felder and L. Silverman, "Learning and teaching styles in engineering education,*" Engineering Education*, vol. 78, pp. 674-681, 1988.

[10] D.A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*. New Jersey: Prentice-Hall Inc., 1984.

[11] R.M. Felder, D.R. Woods, J.E. Stice and A. Rugarcia, "The future of engineering education II. Teaching methods that work," *Chemical Engineering Education*, vol. 34, 2000, pp. 26-39.

[12] R. Glaser, "Education and thinking. The role of knowledge", *American Psychologist*, vol. 39, no 2, 1984, pp. 93-104.

[13] R. Schmeck, *Learning Strategies and Learning Styles*. New York & London: Plenun Press, 1988.

[14] Male, S., Lawrance and W., Flintoff, "Support schemes for first year computing students and electrical and computer engineering students at Curtin University of Technology", presented at Teaching and Learning Forum 2002: Focusing on the Students, 2002.

[15] A.T. Chamillard and K.A. Braun, "Evaluating programming ability in an introductory computer science course," *Proc., Thirty-First SIGCSE Technical Symposium on Computer Science Education*, Austin, Texas, 2000.

[16] I. Huet, O. Pacheco, J. Tavares and G. Weir, "New challenges in teaching introductory programming courses: a case study," *Proc., 34th Frontiers in Education Conference*, Savannah, 2004.

[17] P. Ramsden, *Learning to Teach in Higher Education*. London: Routledge, 1992.

[18] M. Healey and A. Jenkins, "Linking teaching and research in national systems," presented at International Policies and Practices for Academic Enquiry, Winchester, 2007.

[19] R. Barnett, *Realising the University: In an Age of super Complexity.* Buckingham: Society for Research into higher Education and the Open University Press, 2000.

[20] I. Huet, J. Tavares and G. Weir, "Insights on best teaching practices for promoting students' learning", presented at the European Association for Research on Learning and Instruction (EARLI) conference, Cyprus, 2005.

[21] L.M. Pereira and J.M. Oliveira, "How to attract students to Geo-Information courses: a different approach," *Proc., XXth ISPRS Congress*, Istanbul, 2004.

[22] J. Martin, J. Mitchell and T. Newell, "Development of a Concept Inventory for Fluid Mechanics", *Proc., 33rd IEEE / ASEE Frontiers in Education Conference*, 2003.

[23] K. C. Midkiff, T.A. Litzinger and D.L.Evans, "Development of Engineering Thermodynamics Concept Inventory Instruments", *Proc., 31st IEEE / ASEE Frontiers in Education Conference,* 2001.

[24] T.A. Angelo and K. P. Cross, *Classroom Assessment Techniques: A Handbook for College Teachers*, 2nd ed., Jossey-Bass, 1993.

[25] N.J. Mourtos, "The Nuts & Bolts of Cooperative Learning in Engineering", *ASEE Journal of Engineering Education*, vol. 86, no. 1, 1997, pp.35-37.

[26] N.J. Mourtos, "From Learning to Talk to Learning Engineering, Drawing Connections Across the Disciplines", *World Transactions on Engineering and Technology Education*, vol. 2, no. 2, 2003, pp.195-200.

[27] D.R. Woods, A.N. Hrymak, R.R. Marshall, P.E. Wood, C.M. Crowe, T.W. Hoffman, J.D. Wright, P.A. Taylor, K.A. Woodhouse and C.G.K. Bouchard, "Developing Problem-Solving Skills: The McMaster Problem-Solving Program", *ASEE Journal of Engineering Education*, vol. 86, no. 2, 1997, pp.75-91.

[28] N.J. Mourtos, N. DeJong-Okamoto and J. Rhee, "Open-Ended Problem-Solving Skills in Thermal-Fluids Engineering", Invited Paper, *UICEE Global Journal of Engineering Education*, vol.8, no.2, 2004, pp.189-199.

[29] N.J. Mourtos, P. Papadopoulos and P. Agrawal, "A Flexible, Problem-Based, Integrated Aerospace Engineering Curriculum", in *Proceedings of the 36th IEEE / ASEE Frontiers in Education Conf.*, 2006.

[30] N.J. Mourtos and E.L. Allen, "Introducing Cooperative Learning through a Faculty Instructional Development Program", *ASEE Journal of Engineering Education,* vol. 90, no. 4, 2001, pp. 669-675.

[31] N.J. Mourtos and E.L. Allen, "Assessing the Effectiveness of a Faculty Development Program, part 2: Teaching & Learning Styles", Lead Paper, *Proc., 6th Annual UICEE Conference on Engineering Education*, February, 2003.

[32] I. Alarcão, A. Andrade, F. Couceiro, L. Santos and R.M. Vieira, "O Processo de Bolonha para renovar o ensino superior: o caso particular na formação de professores do ensino básico da Universidade de Aveiro", *Revista de Educação*, vol. XIV, 1, 2006, pp. 57-76.