



TEACHING FOR QUALITY LEARNING IN CHEMISTRY

José J.C. Teixeira-Dias

Departamento de Química, Universidade de Aveiro, Portugal.

E-mail: tdias@dq.ua.pt

M. Helena Pedrosa de Jesus, Francislê Neri de Souza

Departamento de Didáctica e Tecnologia Educativa, Universidade de Aveiro, Portugal.

E-mails: hpedrosa@dte.ua.pt and fns@dte.ua.pt

Mike Watts

Centre for International Research in Science and Technology Education, Faculty of Education,
University of Surrey Roehampton, U.K.

E-mail: M.Watts@roehampton.ac.uk

Abstract: In Portugal, the number of students in Higher Education increased from 80 000 in 1975 to 381 000 in 2000 (a change from 11% to 53% in the age group 18-22), meaning a major change in the diversity of student population with consequences well known and studied in other countries. The teaching of Chemistry at the University of Aveiro, for the first year students of Science and Engineering, has been subjected to continuous attention to implement quality and student centred approaches. The work devoted to excellence and deep learning by several authors has been carefully followed and considered. This communication reports research work on Chemistry teaching, associated with those developments for first year students. The work included the design of strategies and the adoption of teaching and learning activities exploring ways to stimulate active learning by improving the quality of classroom interactions. In addition to regular lectures, large classes' teaching based on students-generated questions was explored. In order to improve students' motivation and stimulate their curiosity, conference-lectures were adopted to deal with selected topics of wide scientific, technological and social interest. Quantitative analysis and discussion of selected case studies, together with the organization of laboratory classes based on selected enquiry-based experiments, planned and executed by students, stimulated deep learning processes. A sample of 32 students was followed in the academic year of 2000/01 and the results obtained are here discussed in comparison with those of a sample of 100 students followed in 2001/02. Particular attention was paid to the quality of classroom interactions, the use of questions by students and their views about the course design.

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1. INTRODUCTION: QUALITY LEARNING AND THE NATURE OF ENGAGEMENT

This paper is underwritten by two broad assumptions, that:

1. To increase interaction between the learner, teacher and learning task is to improve the quality of the learning experience, and that
2. One indicator of this interaction is the number and level of student-generated questions within the learning context.

We deal with these two assumptions first before describing work within undergraduate Chemistry that is aimed at enhancing the quality of learners' experiences. Our principal interest lies in raising the quality of teacher-student and student-student interactions in university classrooms and – in this case – university laboratories. To achieve this, our research has been designed to develop innovations in course design and planning procedures to incorporate a wide range of learning methods and, more specifically, to encourage and explore the use of 'quality questions' by undergraduate Chemistry students.

To explore the first of the assumptions above is to consider 'quality learning', which Biggs (1982, p174) describes as:

..the development of students' intellectual and imaginative powers; their understanding and judgement; their problem-solving skills; their ability to communicate; their ability to see relationships within what they have learned and to perceive their field of study in a broader perspective, to stimulate an enquiring, analytical and creative approach; encouraging independent judgement and critical self-awareness (our emphasis).

The key verbs in that description are 'to develop', 'to stimulate' and 'to encourage'. While these actions do lie within the learner's ambit, they are also those that relate to the teacher: it is part of the teacher's responsibility to develop, stimulate and encourage. Biggs' picture of learning dovetails neatly with what has been called 'engagement in learning'. In Watts & Alsop (2000), for example, a model of 'engagement' is proposed which is then explored through the eyes of learners, their first-hand experience of what it means to be fully engaged in a learning activity. A learner engaged with a particular topic, it is argued there, is someone who is seen to be engrossed in, and actively challenged by what is involved - connected to and immersed in a particular topic for a significant period of time. During that time, the topic is thought to be intriguing, stimulating and even entertaining. The learner acts independently, is enquiring, explores relationships, solves problems creatively, is critical and aware. Clearly, to arrive at such a state of being is not to be underestimated. Along these lines, then, we suggest that 'Quality learning can be defined as changes in learners' actions and interactions that take place as a result of being fully engaged in a quality learning experience'.

To be dis-engaged is, of course, the converse of the above. Such a learner becomes uncommitted, disinterested, uninvolved and withdraws from the general sphere within which this learning might otherwise have taken place. There are likely to be many reasons for disengagement, some attached to the learner, some to the environment, the curriculum, the task and the approach to teaching. Disengagement with science has

been discussed by, among others, Baudoin, *et al* (1999), Stark & Gray (1999), Millar & Osborne (1999) and Osborne & Collins (2001).

Our purpose in this paper is to discuss means by which engagement can be enhanced rather than diminished. Biggs (1999, p73) suggests that to *increase* quality in learning is to increase the interaction between the learner, teacher and learning task which, in turn, trades upon

1. A learner's well-structured knowledge base
2. An appropriate motivational context
3. Learner activity, so that active learning is better than inactive, or passive, learning

One means of achieving this, we believe, is through the stimulation, encouragement and development of student-generated questions during the process of learning.

2. STUDENT-GENERATED QUESTIONS

In this paper we are concerned not just with learning styles but also with the questions asked by learners, in this case university Chemistry undergraduates as they embark upon a search for understanding in their studies. Our work is concerned exclusively with those questions asked by learners and not with the routine asking of questions by teachers. In everyday life questions take on a multitude of forms and purposes. Ordinarily, to question is to ponder, seek answers to a puzzle or a problem, to encounter a perplexity that requires resolution. In this sense, we follow a route suggesting that the questions learners ask is indicative of their need for some degree of interaction with both teachers and other students within sessions, for understanding within the domains in which they are working and studying and for some resolutions in their thinking. Student-generated questions, therefore, are an important element in the teaching/learning process, for at least the following reasons:

- i) Questions can lead to improvement of understanding and retention of what a student encounters, and
- ii) Questions can drive classroom learning and are highly effective in increasing student interest, enthusiasm and engagement and
- iii) Learners' questions can be diagnostic of their understanding. Even when questions are poorly formed they indicate 'an active, interrogative attitude that not only seeks appropriate information and opinion but also allows some determination of the worth of what is read or heard.' (Watts & Pedrosa de Jesus, 2001).

A growing number of educators now emphasise the importance of students' questions in both teaching and learning for understanding, and the number of investigations looking for ways to stimulate students to generate questions is growing (Commeyras, 1995; Rosenshine *et al*, 1996; Maskill & Pedrosa de Jesus, 1997a; Watts *et al*, 1997; Marbach-Ad & Sokolove, 2000). Studies at different educational levels and contexts generally indicate that learners avoid asking questions (Susskind, 1969, 1979; Dillon, 1988; Pedrosa de Jesus, 1991). However, there is also strong evidence that if

'good' conditions are created (appropriate conditions conducive to the generation and asking of student questions) then students are willing to ask meaningful questions (Pedrosa de Jesus & Maskill, 1993; Maskill & Pedrosa de Jesus, 1997b). In general, learners will ask questions where they have high levels of self-confidence and self-esteem within the learning context, and where their questions are seen (Watts *et al*, 1997) to be valued. In some cases, asking even poorly formed and tentative questions can indicate an active, interrogative attitude that not only seeks appropriate information and opinion but also allows some determination of the worth of what is read or heard.

3. PROMOTING ENGAGEMENT

In Portugal, the number of students in higher education increased from 80,000 in 1975 to 381,000 in 2000 (a change from 11% to 53% in the age group 18-22), meaning a major change in the diversity of student population with consequences well known and studied in other countries. With this in mind, the teaching of Chemistry at the University of Aveiro, particularly for the first year students of Science and Engineering, has been subjected to continuous attention to implement quality and student centred approaches.

Course objectives for Chemistry at Aveiro are set out in the Guide for Students and Students Manual. The first of these is to encourage student participation and to restore student initiative to the centre of the learning process. This has included the design of strategies and the adoption of teaching and learning activities that explore ways to stimulate active learning by improving the quality of classroom interactions. We have explored the use of teaching based on students-generated questions in small group work, tutorials in addition to regular lectures and large class sessions. In order to improve students' motivation and stimulate their curiosity, conference-lectures were adopted to deal with selected topics of wide scientific, technological and social interest. Quantitative analysis and discussion of selected case studies, together with the organization of laboratory classes based on selected enquiry-based experiments, planned and executed by students, have been used to stimulate engagement.

The structure of teaching pattern used at this university provides lectures for some 130 students at a time, an audience comprised of students from a range of courses related to mainstream foundation chemistry but who would later specialise in their final degrees. More focussed teaching takes place in seminar-tutorial sessions where groups of 30 students cover issues with the same lecturer as in the large classroom. These seminar-tutorial sessions are used for clarifying and illustrating, in dry-lab situations, the concepts previously explained in the large classroom. Laboratory sessions are run for groups of 12-14 students, and are supervised by teaching assistants and technical staff. In this way, the teaching is undertaken by a number of academic staff, who work hard to ensure that the programme is coherent and well coordinated, to diminish any fragmentation and to create good interpersonal interactions with students.

The students in this course are invited to raise questions on and around the subject matter and address them to the teacher. The answers are provided in two ways. First, through a dedicated computer software system through which the students are given explanations and are then advised to follow clues and suggestions for further reading provided in the answers in order to raise follow-up questions. While answers are given

to specific student questions, the answers are available to all who log into the system. Second, provision is made within the lecture system to tackle both general and particular student questions, so that answers are made available to the whole student group who attend. These innovations are aimed at improving the students learning process and helping them towards constructive and engaged learning.

What Biggs (1999) calls ‘constructive alignment’, we have called ‘tuning’. This is the deceptively simple idea of aligning intended learning outcomes with teaching and learning activities, with both these in turn being aligned with assessment procedures. The course at Aveiro has been tuned, or aligned, through consecutive course editions towards both the requirements of the curriculum and the satisfaction and involvement of the students, within which student-generated-questions play an important role. This activity of tuning is not so much a result of a once-for-all modification, but a relatively constant concern that requires almost permanent consideration of students’ questions and to student-teacher and student-student interactions. As a result, the course matter has undergone both major tuning and fine tuning, such as shifts in subject emphasis or minor subject diversions required or suggested by students. A major precondition for the success of this work is that students feel free to ask questions of the teacher and are encouraged to do so at any time in the classroom. That is, the atmosphere surrounding the student should provide plenty of stimulus and encouragement for development.

In order to enhance the student’s willingness to interact in the classroom, the course matter should not, in principle, divert into deep or long theoretical arguments and explanations that reduce the student to the role of simple spectator in the classroom. In a first year university Chemistry course, it is always possible to create this situation, and baffle the learner with science.

As mentioned above, student-generated questions are highly effective in increasing student interest, enthusiasm and engagement and can drive classroom learning. Capitalizing on this, we introduced, at the end of each lectured chapter, one additional lecture based on student-generated questions on a related, yet not previously lectured, case study. These large classroom lectures, named ‘QQ-lectures’, were based on the questions students presented to the day before the lecture, on the selected case study. The students were advised to read the selected topic on the recommended textbook in order to increase the number and improve the quality of their questions.

In addition, we introduced lectures on selected Chemistry topics of wide scientific, technological and social interest, named conference-lectures, which were intended to stimulate and enhance student’s curiosity in Chemistry. These lectures, not included in the regular lectures timetable, provided material for selecting and assessing the best students, while simultaneously enabling us to estimate the degree of students’ enthusiasm and interest in Chemistry. During the second semester of 2001/02, three conference-lectures were presented on the following topics:

- *Electrochemical Energy Conversion: Electrochemical Cells and Fuel Cells*
- *Synthesis of the Chemical Elements*
- *Oscillating Reactions*

While the seminar-tutorial sessions were considered natural extensions of the large classroom lectures, they provided better opportunities for interpersonal

interactions with the students, since the classroom in these sessions did not exceed 32 students. Instead of simply providing the students with lists of dry-lab exercises, each of these tutorial sessions presented a particular case study related with the subject matter previously lectured in the large classroom. These case studies aimed at providing the student with the opportunity of learning the process of “doing science”, of investigating the principles of chemistry and occasionally of discussing their current social and economic applications. In contrast with formula-based exercises which addressed specific dry-lab situations and whose main difficulty frequently relies on finding a particular formula and substituting in the provided data which was so chosen to produce ‘neat’ results, these tutorial sessions focussed on more general situations. They required the student to analyse the case study in hand, propose a structured line of thought, proceed in finding and selecting the data in a provided book of data (a copy for each group of two students) and, finally, discuss the results, present conclusions and explore practical applications in day-to-day situations. In these seminar-tutorial sessions, the student was encouraged to interact with his/her fellow student and/or with the teacher in a relaxed atmosphere. In turn, the teacher intervention in the classroom was not intended to substitute the student, but rather to orient and encourage students to recognize their difficulties and in finding adequate and efficient strategies.

In a typical secondary chemistry laboratory manual, little is left to the student initiative or circumstance: all the laboratory works and procedures are carefully listed and planned in the provided manual, and frequently the student is simply asked to fill in the open spaces left in a previously structured and well planned report template. At the end of a laboratory session, the student did not have a real opportunity of understanding or learning the process of “doing chemistry”, i.e., of investigating in chemistry or, at the very least, of identifying his/her learning difficulties. Everything went so smoothly in that particular laboratory session to originate any significant learning!

By contrast, if the student is to engage in deep learning in a laboratory session, it is important that he/she has the chance of identifying the main objectives of the work, of planning and executing it, of identifying the conceptual and practical difficulties encountered, recording and discussing the results and observations and, eventually, of suggesting practical alterations and improvements. For the laboratory work to dispense with a long and eventually complex list of procedures and with elaborate equipment has to be based on a simple idea and to require simple equipment, easily available in the laboratory. In particular, equipment which could only be dealt with as a large black box is not suited to our ends. In addition, it is important that the work provides many and significant opportunities for the student to be really engaged during the laboratory session. The lab tutor should not at any moment substitute the student in any encountered difficulty, but should instead provide appropriate orientation and guidance for the student to overcome by himself/herself the difficulty. In all his/her work, the student should record the observations and results in an individual laboratory book. This is not meant to be a report book, but rather a logbook that should not be removed from the laboratory room in order to be a tutor’s reliable document for student assessment which, in turn, is concentrated on the student’s progress rather than on performance on individual lab works.

4. SOME OUTCOME: USING STUDENT GENERATED QUESTIONS

In this paper, student-generated questions are used as diagnostic of the willingness of the students to engage in classroom interactions. Particular attention has been paid to the quality of classroom interactions, the use of questions by students and their views about the course design. In addition, the students' capacity to design and present 'quality questions' during phases of their learning, and the extent to which these questions are indicative of particular styles of interaction in the classroom are also assessed.

The following results refer to a sample of 100 students followed in 2001/02. Occasionally, they are compared with those of a pilot study on a sample of 32 students in the academic year of 2000/01.

For an initial analysis of the student-generated questions, the bipolar taxonomy of Pedrosa de Jesus *et al* (2001), which distinguishes between confirmatory and transformation questions, was adopted. According to this taxonomy, confirmatory questions look for clarification of previous knowledge, try to discriminate fact from speculation, aim at solving specific difficulties, ask for illustration and/or definition. In turn, transformation questions aim at reorganizing and/or restructuring the knowledge and comprehension of the learner, suggesting that he/she is apparently familiar with the subject and is able to hypothesize and deduct, looking for inferences and improvements of prior knowledge.

Table 1 presents the number of confirmatory and transformation questions, addressed by students during the second semester of 2001/2002, using the question's box and the software system. As it can be seen from this Table, 70% of the questions were classified as confirmatory, in consonance with the result obtained during the pilot study (69%; results not shown). A larger number of students (75%) have preferred the question's box to the dedicated software system. Yet, an appreciable number of students (30%) asked questions while they were away from the university, thus showing the relevance of the software system.

Insert Table 1

Table 2 shows the number of confirmatory and transformation questions per month, during the second semester of 2001/02. While the total number of questions peaks in March and May, the relative number of transformation questions per month increases along the semester, thus pointing to a relative improvement in the quality of the questions. This trend, already observed during the pilot study, lends support to the objectives of the present work and is in consonance with the occurrence, in the learning process, of a "quantitative stage" prior to a "qualitative stage" (Biggs, 1999).

Insert Table 2

In the second semester of 2001/02, the QQ-lecture topics, *Acid Rain*, *Fuel Cells*, *Ozone Layer* and *Conducting Polymers*, were considered, corresponding to previously lectured chapters on Acids and Bases, Electrochemistry, Chemical Kinetics, Organic Chemistry, respectively. These QQ-lectures originated peaks in the distribution of

student-generated questions along the semester (see Figure 1) and contributed to appreciably increase the level of students' enthusiasm and engagement in these lectures.

Figure 1 about here

Table 3 shows the distribution of questions by different kinds of classes (lab sessions, QQ-lectures, and remaining large classroom lectures plus tutorials). As it can be seen, laboratory sessions and QQ-lectures stimulated the presentation of questions, as approximately 80% of the total number of questions originated from lab sessions or QQ-lectures. Since approximately 48% of the students did not support their questions for QQ-lectures on the recommended readings, a large percentage of these questions (approximately 77%) were confirmatory, requesting relatively basic information on the considered subjects. Second in the number of raised questions are the lab sessions with approximately 33%.

Insert Table 3

Together with the results of questionnaires answered by the students, the above data suggest that the introduction of the QQ-lectures and the strategies adopted in the lab sessions were relatively successful and should be pursued with the fine tuning that the permanently recorded student feedback might suggest.

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Table 1. Number of confirmatory and transformation questions, addressed by students during the second semester of 2001/2002, using the question's box and the software system.

Used instrument	Confirmatory questions	Transformation questions	Total
Question's box	109	44	153 (75%)
Software system	33	18	51(25%)
Total	142 (70%)	62 (30%)	204

Table 2. Number of confirmatory and transformation questions per month, during the second semester of 2001/02.

Month	Confirmatory questions	Transformation questions	Total
February	7	1 (13%)	8
March	92	23 (20%)	115
April	10	8 (44%)	18
May	33	30 (48%)	63

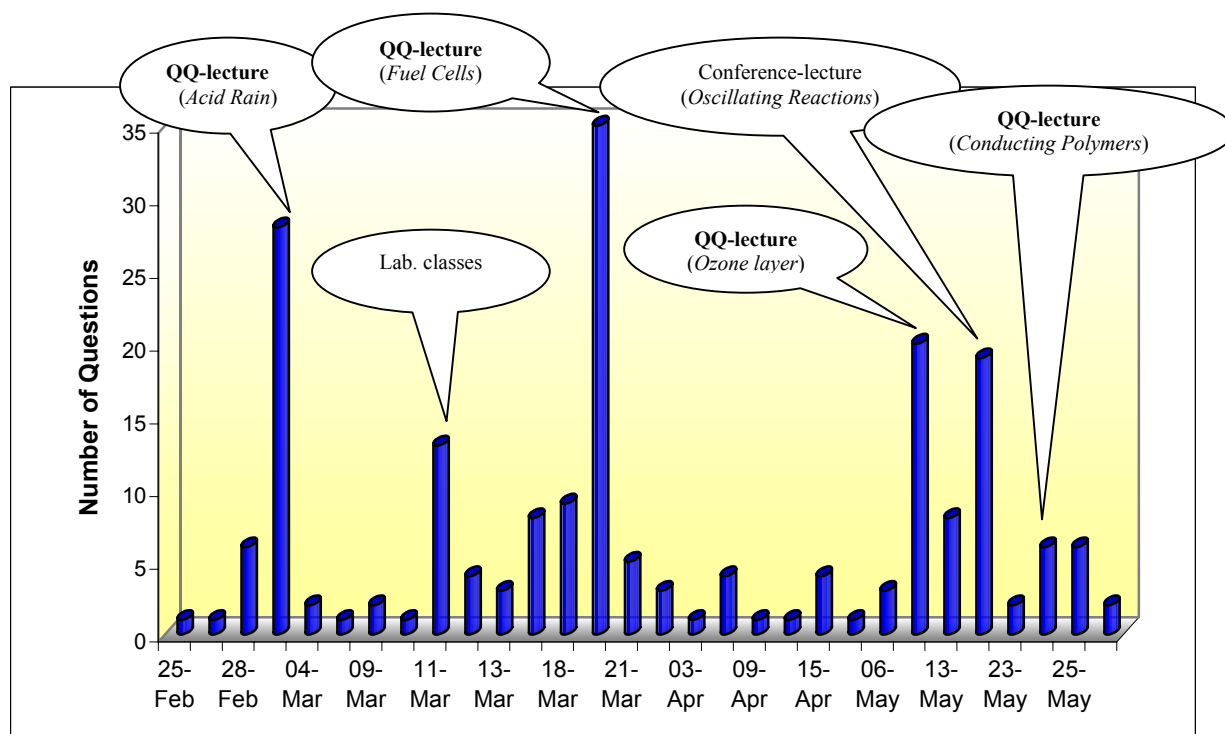


Figure 1: Daily distribution of student-generated questions, during the 2nd semester of 2001/2001.

Table 3. Distribution of questions for distinct kinds of classes.

Kinds of classes	Confirmatory questions	Transformation questions	Total
Lab sessions	46	21	67 (33%)
QQ-lectures	73	22	95 (47%)
Remaining lectures plus tutorials	23	19	42 (20%)
Total	142 (70%)	62 (30%)	204