QUESTIONING IN CHEMISTRY AT THE UNIVERSITY

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Abstract

Current research in science education indicates that the levels of interaction between teachers and learners in formal instructional settings can be very low. In particular, this is often the case in undergraduate studies where the formal settings can constrain students` learning styles and may influence the quality of learning outcomes.

A variety of research studies, at different school levels and contexts, indicate that students commonly avoid asking questions. However, there is also strong evidence that if appropriately conducive conditions are created, students are willing to ask meaningful. In the last decade, a growing number of educators have been emphasising the importance of student generated questions in the teaching/learning process and investigating ways to stimulate students to generate questions.

The aims of the study reported here are: (i) to encourage and explore the positive generation of questions by undergraduate chemistry students; (ii) to develop innovations in course design and planning procedures to use a wide range of learning methods, in particular, the use of computers to facilitate teacher-learner interactions; (iii) to explore ways of providing academic support for students' questions in chemistry.

To realise these aims, a pilot study was conducted with a group of 32 first year undergraduate students, attending an introductory chemistry course at the University of Aveiro, Portugal, during the academic year 2000-2001. The first semester was used mainly to develop, test and evaluate classroom tools, chosen with the aim of providing students with as many opportunities as possible to easily register their written questions. During the second semester, new teaching strategies were explored, with the intention of observing the effects on students' questioning behaviour and aimed at consolidating analysis and interpretations of previous results. The following classroom tools were used in the study:

(i) a 'question box' (a box placed in tutorial and laboratory classes where students could present written questions);
(ii) interactive computer facilities (e-mail and a special <Q/Q> program);
(iii) students' laboratory workbooks.

A short period of time was used to motivate students, explain the project and introduce them to the use of these tools. Students were informed that all questions would be treated on their merit and considered as a positive factor on their final evaluation. Written questionnaires and semi-structured interviews were also used to gain additional information about the effectiveness of the tools, to explore the students' opinions about their views of the experiment, and to ask for suggestions, though these aspects of the research are reported elsewhere.

Preliminary results obtained show that: (1) undergraduate students are very positive in their appreciation of this opportunity to interact with teachers, and it was clear that they took good advantage of this innovative strategy. The majority asked meaningful questions and most of them most frequently using the classroom 'question box'. Of the three methods, the laboratory workbooks were used least; (2) the kind of barriers to asking classroom questions as reported by several other researchers were overcome to some degree by the approaches used here; (3) the 'quality' of classroom interactions, as indicated by the questions asked, has clearly improved with the project.

Questioning in Chemistry at the University

Section 1: Introduction

There is a noticeable shift in the business of teaching and learning in higher education. Not only are there more demands and challenges arriving on almost a daily basis, but it is also quite clear that the prevailing discourse is changing rapidly, in some respects adopting the register of management systems in commerce and industry. For example, the common use of terms such as ‘quality provision’, ‘quality assurance’ and ‘excellence’ has led Coffield and Williamson (1997:1) to call this the ‘industrialisation of the language’ of academia. Recently, Light and Cox (2001:4) have discussed higher education in terms of a large business and called attention for some of the implications in teaching and in learning within such an ‘enterprise’. While these authors are broadly critical of such developments, they also note some of the positive aspects of this natural evolution claiming that:

> *‘the challenge of ‘excellence’ is not entirely a negative phenomenon’, as we might think. The move towards professionalism in teaching and learning is a natural manifestation of the discourse of excellence…. While the nature of the challenge – immersed as it is in an ‘accounting’ mode – is deeply suspect, it provides a necessary jolt to critical thought and reflection. This does not mean, however, that it should be passively accepted or, for that matter, the academics should rage blindly like modern ‘Lears’ within their ‘towers’, as the ‘storm’ strips off the last remnants of ivory veneer. It is vitally important that academics take up this challenge to think’* (p.7).

Increasingly, higher education is aiming to ‘deliver’ to society students (individuals) who have developed, alongside their subject specialisms, both a range of ‘transferable’ or key skills and the more general ability and willingness to ‘learn to learn’, sometimes called the capacity for meta-learning. These key skills include such broad capabilities as good communication skills, teamwork, problem solving, information technology and so on, together with the ‘core skill’ of the graduate’s ability to continue to learn new knowledge, capabilities and practices (Light and Cox, 2001).

It is this kind of professional challenge within teaching and learning in higher education that has created some of the pressure for change. The challenge stems from (i) an increasing number of students in classrooms, (ii) the increasing diversity of students’ ‘learning backgrounds’, (iii) the varying experiences and needs which students present, (iv) the requirement for greater curriculum transferability. Most important is the conceptual shift required in thinking about practices in teaching and learning, from the more traditional format of simply ‘delivering knowledge’, to developing and fostering independence of learning in which students develop the ability to discover and reconstruct knowledge for themselves. Indications are of an emerging 'paradigm' - a *professional paradigm* - that has been developed in response to this challenge, more accurately a paradigm of 'reflective professional practice'.

The study described here is work in progress, and aims at finding ways to facilitate student learning in higher education. In particular we explore developments in teaching and learning as these impact on the pursuit of undergraduate chemistry. Our principle 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, the research has been designed in order to: (i) develop innovations in course design and planning procedures to incorporate a wide range of learning methods, (ii) more specifically, to use computer systems to facilitate teacher-learner interactions and, in particular, encourage and explore the positive generation of questions by undergraduate chemistry students; (iii) explore ways of providing academic support for students' questions in chemistry.

The vast majority of research studies on questioning in education have focussed on those asked by the teacher: this study focuses exclusively on 'student-generated-questions', principally in this paper on students' written questions. Studies at different school 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 the last two decades, a growing number of educators have been emphasising the importance of students' questions in the teaching/learning process and the number of investigations looking for ways to stimulate students to generate questions (Commeyras, 1995; Rosenshine *et al*, 1996; Maskill & Pedrosa de Jesus, 1997a; Watts *et al*, 1997; Marbach-Ad & Sokolove, 2000) is growing.

This paper highlights, too, the use of 'new' computer technologies. Light & Cox (2001) have listed some positive as well as negative effects of the use of communications and information technology (C&IT) in teaching and learning. They discuss these effects in terms of four 'learning dimensions' so that, in relation to an 'intellectual dimension', they consider the promotion of interactive learning, increases in written output, opportunities for reflection, the access to multiple frameworks/ discourses/ perspectives to be positive effects. In terms of a 'practical dimension' come the acquisition of computer skills, and opportunities for 'learning by doing'. The 'personal dimension' includes the 'empowerment' of the learner, opportunities to develop self-skills and opportunities to take control of one's learning. Finally, the 'social dimension' incorporates opportunities for dialogue with wider groups, increase collaboration between teachers and learners and between learners.

While we are concerned with the first three of these dimensions, in this paper we are most interested in the social dimensions related to student-generated-questions, and the impact of the use of different tools by which these may be generated. Current research in science education indicates that the levels of interaction between teachers and learners in formal instructional settings can be very low. In particular, this is the case in undergraduate studies where the formal settings can constrain students learning styles and may influence the quality of learning outcomes (for example, see Biggs, 1999). On the other hand, it is well understood that the quality of personal interactions is an essential factor for the quality of learning. Improving closeness and confidence with students can optimise the role of the teacher as a 'learning mediator' or 'learning facilitator'.

Cunningham (1999), for instance, has made use of the 'language of industry' noted earlier to stress the role of interactions in what he calls 'strategic learning'. In traditional models of higher education, he says, the teacher may interact with a particular learner (labelled B on Figure 1 below) - during a lecture, asking the student to respond to some point or other - and the learner responds (A). The teacher will also relate to other learners in the same way (C). The relationship between learners (D), though, is often largely ignored or deemed unhelpful, a diversion, an unwelcome intrusion or, in some cases, a sign of poor etiquette and/or disrespect for the teacher. In an atmosphere conducive of question-asking, however, the process can work differently. First, the learner's question can precede the teacher's opening remarks so that the initiation of learning comes from the learner (A). Second, the interaction between learners (D) is regarded as a key part of the learning process and it is to be encouraged. The process with other learners occurs in the same way.

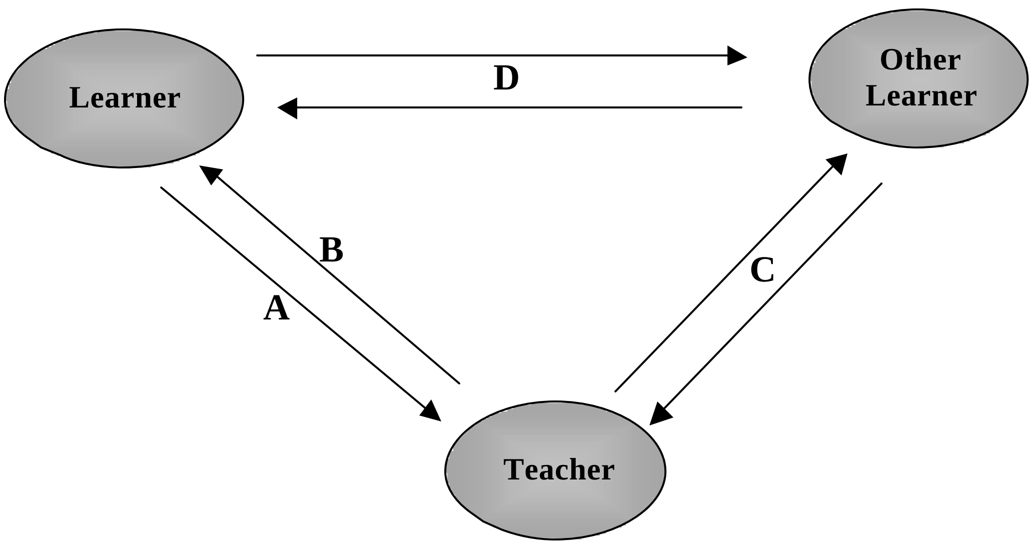

Figure 1: Channels of classroom interaction.

Many researchers and educators (for example, Browne and Keeley, 1998) consider the process of question-generation as an important means of developing critical thinking skills. However, it is also recognised that, while a learner may frequently be able to raise questions, may be even eager to ask them, a number of personal, social, psychological 'blocks' may intervene and not allow him or her to externalise these. While classroom contexts at university level are different from those at primary and secondary level, there are still some similarities in, for example, the frequency and the quality of students' questioning behaviour. Understandably, the expectations of university undergraduates can be seen to be much higher and more demanding than elsewhere in the educational system. At the same time, though, they are also considered more mature and more independent as learners – so implying that they should be able to cope with the basic social interaction of asking questions. In our experience, the vast majority of first-year undergraduate students need to learn how to work autonomously and to use critical thinking skills. They need appropriate scientific stimulus as well as support in various ways, including those from the affective domain. Self-confidence, self-assurance and self-esteem are important ingredients in developing self-directed learning. Where levels of confidence increases, that is, where students have more self-confidence and a greater level of interaction with the teacher, it is expected that the kind of blocks or barriers referred to earlier may be weakened and students will interact more frequently and the nature of the interactions will also be different.

Furthermore, our supposition is that, with the advance of new technologies and its wider use in teaching and learning, it is possible to extend and enhance the potential for the basic types of social and human interactions through which teachers and students have traditionally engaged, and address the 'quality' of learning. For instance, interaction B (between teacher-learner) that may take place during traditional lectures and tutorials – arenas not commonly open to easy interaction - might now be incremented by the use of e-mail systems which can also induce interactions at A. Similarly, interaction C (between teacher and learners), usually through lectures and seminars, can by optimised by video-conferencing; interaction D (learner-learners), traditionally enacted through projects and lab-work, can now be encouraged by the use of internet and intranet systems. These new technologies clearly provide different opportunities for developing interpersonal contexts. However, Mason (1998) notes that only highly motivated independent learners, good at self-pacing, computer literate and interested in computer-mediated environments are likely to make the most of them.

In order to ameliorate this situation, models of practice should be the result of construction from teachers and students within situated interactions. It might be difficult to try to change some of the 'tacit' rules socially and sometimes institutionally established in universities. Nevertheless, we strongly believe that it is possible to improve learning environments within the university system, stimulating teachers to engage in innovative (new) ways of thinking about their own practice.

Section 2. Chemistry as an interactive area of study

Chemistry is an interdisciplinary subject that provides an important understanding of our material world at the molecular level. It shares important ties with biochemistry, biology, pharmacy, environmental sciences along with many other disciplines, and its most central and practical objective is to synthesise new forms of matter. In this sense, it is present in and clearly has an enormous impact upon virtually all aspects of everyday life as, for example, in the production of pharmaceuticals, pesticides, fertilisers in agriculture or novel materials for the electronics industry.

Chemistry is an extremely practical science, and is continuously undergoing change as new advances are made: it is not simply a static and abstract body of knowledge to be transmitted wholesale from teacher to student. While abstract theoretical and mathematical matters are vital to chemistry, it is its very 'worldliness' that also allows it to be contextualised quite readily within real and practical contexts and applications. This 'context rich' nature of chemistry provides many opportunities to promote interaction, discussion and debate between teachers and learners, to embed the subject within the lived experience of students. The appropriate selection of materials in lectures and tutorials can lead naturally to strong and sustained interactions between teachers and students and between students themselves. The physics of quantum mechanics, for example, holds no such ready anchors to everyday reality. Here, the teacher is manifestly the 'true' guardian of the disciplinary dogma in such a way as to disenfranchise the student from easy dialogue with the teacher on such issues.

'Worldliness' is not quality which is exclusive to chemistry. It does, however, mean that chemistry is fully embroiled in issues of commerce, industry, social necessity and environmental impact. This social dimension of chemistry provides a dynamic arena through which the teacher can stimulate dialogue and debate: through which classroom interactions can be developed, enabling learning which contributes significantly to learners' critical social and cultural awareness.

Section 3. The project, instruments and conditions for student generation of questions

The research we report here is in its early stages, and is the fruit of a collaborative venture between two universities, in Portugal and UK. A pilot study was conducted with a group of 32 first year undergraduate students, drawn from the 1000 students attending an introductory chemistry course at the University of Aveiro, Portugal, during the academic year 2000-2001. The structure of teaching pattern for this programme 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 32 students cover issues with a specialist lecturer. Laboratory sessions are run for groups of 16, and these are often 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, to diminish any fragmentation and to create good interpersonal interactions with students.

The data collection began at the beginning of Semester 1, at the start of November 2000 and continued until the end of Semester 2, in the middle of June 2001. The start of the first semester was used mainly to develop, test and evaluate classroom tools, chosen with the aim of providing students with as many as possible opportunities to easily register their written questions. A short period of time was used to explain the project, to introduce them to the use of these tools and to describe the ways in which the assessment system would be used to reward question-asking. The lecturer negotiated with the students at the outset that, as an incentive, all questions generated would be judged and weighted as a positive factor on their final evaluation. The lecturer used the flexibility inherent in the grading system to award 'top-up' marks to students' other assessment grades to reward the generation of good questions. Students could gain a maximum of three points to add to their semester score (normally an average of points from several assessed elements of the course on a range of 0-20). Where a student had a score of 15, then he or she might gain a maximum bonus of 3 points through their asking of good questions, a score of 16 made them eligible for 2 bonus points, a score 17 allowed for 1 – meaning that no student could exceed 18 points for the semester through this system. It is normal practice on the course to gain scores of over 18 only after submitting to an oral examination with lecturers. Both this system and the email tagging of questions, meant that question-asking in this pilot study could not be an anonymous affair.

In addition to their other classes, the pilot group met each week with their lecturer to discuss the written questions that had been generated by them in that week, providing an opportunity for answers to be presented and explored in further detail. This additional tutorial session was voluntary for the students, although all chose to attend. It was a challenge for the lecturer in terms of attempting to deal with the range of questions - and was clearly important in the development of understanding of chemistry in the group.

During the second semester, new teaching strategies were explored, with the intention of observing the effects on students' questioning behaviour and aimed at consolidating analysis and interpretations of previous results. Two written questionnaires (one on the beginning and another one on the end of the year) and semi-structured interviews were also used to gain additional information about the effectiveness of the tools, to know the students' opinions about their views of the experiment, and to ask for suggestions. In this paper we report only the data that has come from counting the number of questions generated over this time, other aspects of the data are explored elsewhere (Pedrosa de Jesus, Teixeira-Dias and Watts, 2001).

From the very beginning particular tools were developed aimed at facilitating question generation, and were:

(i) a 'question box'

(ii) interactive computer facilities (e-mail and a special <Q/Q> program);

(iii) students' laboratory workbooks.

All the supports/tools, questionnaires, pencils, etc, could be easily recognised and connected to the project by its colourful logo:

(i) The Question Box

Several Question Boxes were deliberately and strategically placed in all tutorial and laboratory classes in order to act as a stimulus. They have been made of transparent acrylic material, about the size of two shoeboxes, with a 'post-box' in the lid and a pad of 'Post-its' secured to one side. On the other side were colourful instructions that read:

How and when should I use the Question Box?

This Box is another invitation to present your Questions. Use it as explained, making use of the specific papers placed on the side.

(ii) Interactive computer facilities

The intranet system was developed for limited access through a series of computer terminals within the chemistry department, in the laboratories, tutorial rooms and the interconnecting corridors, thus giving relatively free access to chemistry students. The software allows those students who have use of Internet facilities outside the university to work at a distance from the department and to access the system through the use of an appropriate password. The intranet system is fully coded so that students can follow through the various options with ease. Some example pages are shown in Figures 2, 3 and 4 below.

Figure 2: The third page of the menu, after the student has entered the system with a password.

Figure 3: This page allows the student to write questions and send these to the teacher.

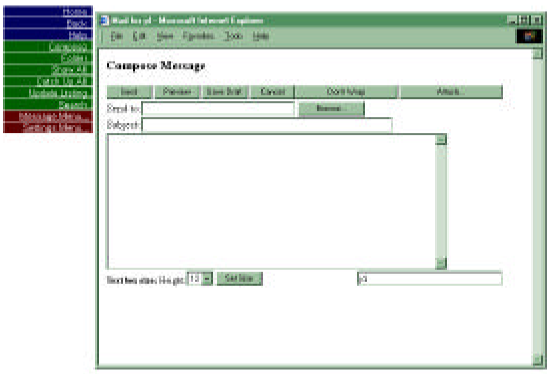

Figure 4: On this page students can write questions to each other .

These three software pages are indicative of the possible channels of classroom interaction discussed earlier.

(iv) Laboratory workbooks

The project workbooks are adaptations of standard laboratory workbooks. A first page was inserted which prompt students to 'pause for thought' and to record questions that occur them during laboratorial classes. A pen with the 'project logo' was also attached to each logbook, as a gift for the end of the project. The instructions read:

How and when should I use the Laboratory workbook to register my Questions?

The project Questions in Chemistry (<Q/Q>) was designed to develop your interest and curiosity for Chemistry. Whenever you have any doubt about the experiment you are doing you should talk to the teacher. However, if your doubt is a real "Question", you should write it on your workbook, using the pen attached to it.

These three 'tools' are intended primarily to capture written questions – separate approaches were used to collect oral questions in class, and will be reported elsewhere. In this particular instance, there is good reason for focussing on written questions in that they are likely to be more provocative of thought (more stimulating) about the topic of the question and might allow for more reflection on the question itself. The act of writing is well documented as a powerful stimulus to learning, and so using written questions is one way of enabling clear expression of thinking in that students can then decide 'Is that the exact question I wanted to ask?'. This contrasts somewhat to oral questions where the shaping of a question can be both very rushed and unstructured (because the act can happen quickly) and because such questions are not easily subject to evaluation before the point of utterance.

Results

It is important to note at the outset that we have been dealing here with written questions submitted through three 'collection tools' through which the identity of the question asker is known. While we have monitored and recorded oral classroom questions, we report this in detail elsewhere. We are also researching student's disposition to ask questions and the extent to which anonymity is an important issue in asking questions in undergraduate studies.

Our preliminary results discussed here show that these undergraduate students have been very positive in their appreciation of this opportunity to interact somewhat differently with teachers. During interviews and informal conversations they have found the emphasis on generating questions to be an interesting and challenging departure from the norm. Our data shows that they took good advantage of this innovative strategy, with the majority asking meaningful questions – very few indeed resorting to playful or mischievous questions. The teachers involved in the course were also keen to see what emerged from the pilot and worked hard to ensure that students had opportunities to post their questions. All the questions were directed at the teacher – none of the students took the opportunity to email or use the Question Box to ask questions to each other. This inter-student element of the study will be explored through other means.

The graph in Figure 5 shows the total number of questions asked by the pilot group over the period of the first semester.

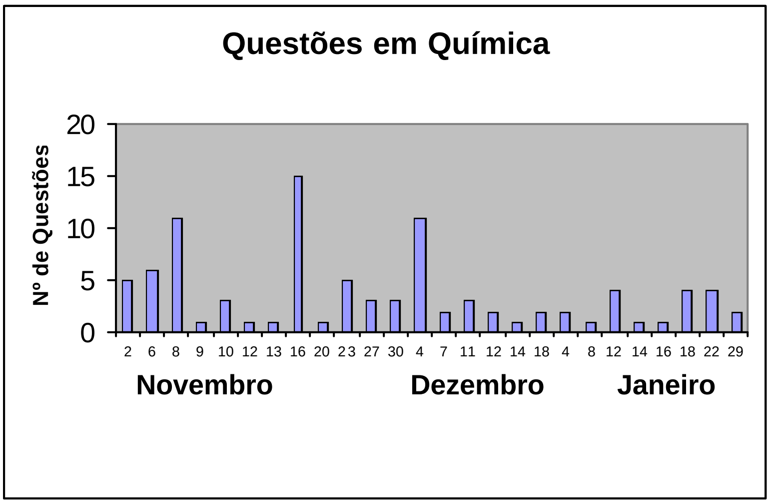

Figure 5: The number of questions asked by students each day of the class 'Química I' in the first semester.

There are two issues to note here. First, the most frequently used way students posted questions were through the classroom Question Box and, of the three methods, the laboratory workbooks were used least. Second, the general level of questions generated runs fairly evenly at about 3 questions per session throughout both semesters. In Semester 1 there are three peaks, on November 8th and 16th, and on December 4th. The first of these was most likely stimulated by first attempts to explore the system, and to test the extent to which question-asking worked within the computer intranet. This novelty of the emphasis on questions acted as a stimulus and prompted a first rush of activity.

The session on the 16th November was a lecture for 130 students and here it was clearly the topic and presentation that was provocative of questions. In this instance, the topic related to a theoretical discussion of molecular architecture and organisation and both the difficulty and abstract nature of the issues involved generated a large number of questions. The questions on the 4th

December followed a particularly complex practical activity in the laboratory and these questions arrived through the students' laboratory notebooks.

In the second semester the overall number of questions each day, as shown in Figure 6 below, remains similar to Semester 1 bar the 'surge' on April 19th. The reason for this relates to the introduction into the course of a series of mini-projects that the students needed to complete by the end of the semester – students raised a number of questions surrounding the topics they were expected to investigate.

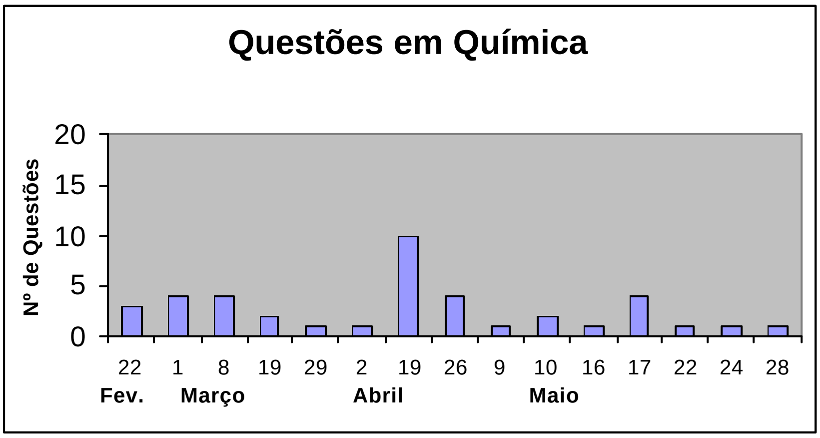

Figure 6: The number of questions asked by students during 'Química II' in the second semester.

What emerges from these two graphs is that it is clearly possible to create a 'questioning environment' where asking questions (and receiving answers) becomes an integral part of everyday transactions between teachers and students. Throughout the two semesters the students maintained a steady flow of questions, although these could be stimulated on occasions by other events. We discuss the distribution of questions within the class of 32 students in detail elsewhere, though we can note here that some students asked many more questions than others, with some students asking no questions at all – regardless of the possible assessment gains to be made by doing so. We can also note that the type and quality of the questions increased over the two semesters as teachers and students acclimitised to question-asking processes.

The key issue to arise from this point onwards is the extent to which the pilot study impacted on student performance. In this instance we have assessment grades for the end of Semester 1 only and so results are very tentative indeed. Figure 7 below shows the grade scores, out of 20, for the 850 students in the whole chemistry first-year cohort .

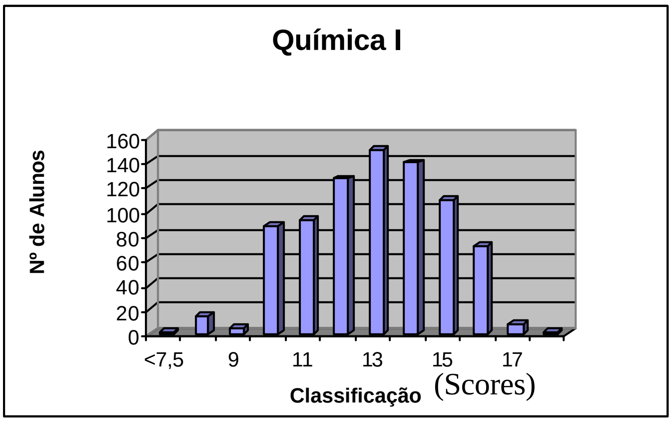

Figure 7: End of Semester 1 scores for all students.

This shows the expected normal distribution of scores across the cohort. Figure 8 shows the end-of-semester scores for the 130 students in one sub-group, from which the pilot group was chosen. Again, this shows a broadly normal distribution of scores.

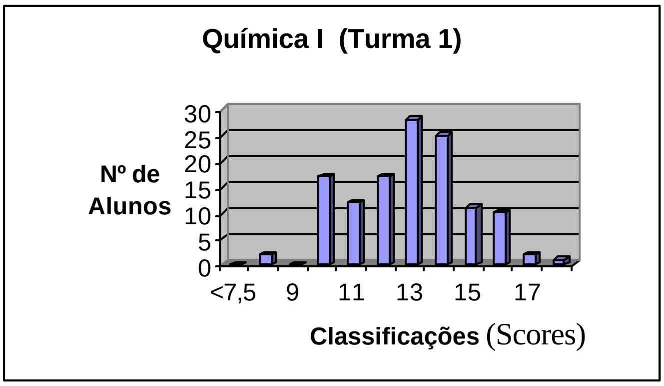

Figure 8: End of Semester 1 scores for students of "Turma 1"

The final graph in Figure 9 shows the scores for the pilot group. Here there is a small but detectable shift towards the upper grades, indicating that some of the students higher scores than might otherwise have been anticipated. As yet we have only supposition on which to work – there is further data to be processed which can shed light on what the reasons might be.

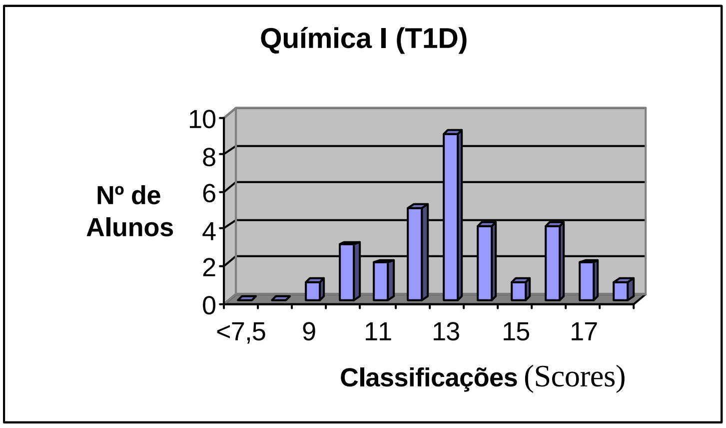

Figure 9: End of Semester 1 scores for the pilot group (T1D)

Whatever the reasons – whether due to the act of asking questions, the greater interaction with the teaching staff or the assessment methods used to reward question-asking (or combinations of all three) – we can be pleased that the focus of the project has not noticeably served to hinder students' progress. The pilot group has responded positively and, while there is much work yet to be done to untangle the various issues within their responses, the research undertaken so far augurs well for increasing teacher-student interactions.

In summary, the teaching of chemistry is part of the exercise within higher education of 'delivering' to society initiate chemists who have developed, alongside their subject specialisms, both a range of 'transferable' or key skills and the more general ability and willingness to 'learn'. This project is a small step along this route which has used the asking of questions as a means of encouraging good communication skills, teamwork, problem solving, and information technology capabilities. The project is yet in its infancy, and there is much more work to be done.

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