# Students´ Questions as Organisers for Small Group Learning in Chemistry

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**Abstract**

Designing inquiry-based-learning with and for university students develops problem-solving skills, logical reasoning as well as reflective thinking. It involves working as a member of a team, questioning, being creative, and shaping the skills for continued intellectual development. It is argued that inquiry-based group-work is one of the most important learning experiences because it enables the exploration of theoretical ideas and conceptual change. This paper presents results about the use of students' questions to shape these processes. In fact, student-generated-questions can be used as efficient guides in the preparation, focus, diagnosis, development, implementation and evaluation of group-work.

This research has involved one group of three students developing a mini-project on the 'Thermochemistry of fitness'. The aims of the study are to i) examine ways that university students use questions to organise and structure small group activities in their study of chemistry and ii) evaluate the effectiveness of these questions for the development of problem-solving skills.

Data was collected through participant observation of group meetings and of meetings with the tutor, through semi-structured interviews with both members of the group and the group as a whole, through an analysis of the questions asked by the group in the development of the project (oral and written) and through an oral presentation by the students. The students were aware of the investigation and were stimulated to formulate questions as explained elsewhere (Pedrosa de Jesus *et al*. 2003 a, b).

The results show that the questions formulated during the development of group mini-projects performed several important functions in the structure of the students' work such as: organising ideas, delimiting the scale of the project, identifying and reflecting on the many strands and sources of information, and in reflecting on the project as a whole. The 'function' and 'quality' of the questions varied with the context in which they arose: factual and conceptual questions are distinctive from organisational and reflective questions. It was found that students' need to articulate questions and to try answers within the group in order to choose the best solution for the initial problem. The questions used have contributed to students' engagement in the discipline, bringing an increase of interaction between teacher and students, an increase in the confidence and trust of the students in the asking of questions, and therefore an increase in the quality of classroom interactions in the learning and teaching of chemistry.

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**Introduction: Organisational questions**

This paper is based upon a growing body of work shaped by the 'Questions in Chemistry' project at the University of Aveiro, Portugal (Pedrosa de Jesus, Teixeira-Dias & Watts, 2003, Pedrosa de Jesus, Neri de Souza, Teixeira-Dias & Watts, 2003). The central strand to this work relates to the nature and quality of students' questions during the process of learning chemistry, and the ways in which university lecturers can manage the processes of teaching in response to these.

In much of this work our studies have augmented a growing emphasis on students' questions as these relate to conceptualising and structuring learning matters (Graesser & Olde, 2003; Marbach-AD & Sokolove, 2000; Maskill & Pedrosa de Jesus, 1997; Otero & Graesser, 2001; Pedrosa de Jesus et al., 2003; Watts et al., 1997). In this paper, however, we follow a different tack. Rather than explore the content of students' knowledge and understanding from the questions they ask, we examine instead their procedural knowledge in the context of inquiry-based-learning. We focus upon ways that university students use questions to organise themselves and structure small group activities, tasks undertaken as part of their study of chemistry. Procedural knowledge concerns the techniques and procedures for acquiring, organising, validating and evaluating knowledge. *Organisational questions* can be thought of as those that marshal, and lead to, procedural knowledge, the '*Knowing how to* …? rather than the '*Knowing what* …? of learning.

In our research we have identified two forms of organisational questions. First are those that are involved in organising cognitive processes, questions that allow learners to manage their thinking. Our data in these instances derives from recordings of students' cooperative learning dialogues as they 'think aloud' around the tasks with which they are occupied. Second are those questions that focus on organising and proceeding with the physical tasks at hand, and it is these that form the subject of this paper – we will deal with students' 'think aloud' questions in a future paper. Alfke (1974) uses the expression 'operational questions' to indicate those that imply what must be done - in her terms: 'questions which lead back to doing something with materials in order to derive answers' (p18). Hodson (1998), too, discusses operational questions, referring to questions that spark classroom activities and exploration. He says (p35) that stimulating classroom questions is important for:

> *First, creating a classroom climate within which [students] will be stimulated to ask questions; second, ensuring that questions are expressed in operational form (that is, they are in the form that supports investigation). Thus there are both affective and cognitive dimensions: we have to show that questions are welcomed and we have to ensure that students know what constitutes a good or productive question.*

**Small group organizational questions**

In this work we have focussed upon a specific initiative that involves small group activities within the broad pattern of teaching chemistry at Aveiro. Our research has entailed investigating ways that students use their own questions to construct and manage group tasks: activities that instigate inquiry into the chemistry subject matter to be learned.

The use of cooperative small group work is an important and well-researched element of learning and teaching (Barbosa, Jofili & Watts, 2004; Felder & Brent, 2001; Haller et al., 2000; Sisovic & Bojovic, 2000; Slavin, 1995). Small-group discussions have been advocated for a number of years as one of a range of learner-centred teaching approaches or 'active learning' strategies. These are where students have a significant degree of autonomy over the learning activity as a means of stimulating interest in what they are studying. Such groups are a fertile arena for researching students' questions because, as Wlederhold & Kagan (1992, p.206) say:

> *Students' question can be the focus of cooperative lessons, allowing time to think critically: first in constructing questions, second in asking them, third in responding, and again in paraphrasing, praising, and augmenting them.*

Cohen (1994) adds that:

> *Students in a group communicate about their task with each other. This includes* ***asking questions***[1]*, explaining, making suggestions, criticizing, listening, agreeing, disagreeing, or making joint decisions.*

Pearson (1999, p28) suggests that some broad organisational questions might be:

> *Where are we now?*
>
> *Where do we want to get to?*
>
> *How shall we get there?*

And, once in progress:

> *How well are we doing?*

More specifically, Jones et al (1992) illustrate how both teachers' and students' organisational questions can be used to develop 'open' investigations in science. Teachers can pose questions to students that suggest areas for investigation, but that then leave the process and content of the work open for the students to pursue. The students are encouraged to ask themselves a series of questions that help in the structuring and management of their work. For example:

[1] *Emphasis added to the original text*

*What are we going to find out about?*

*What do we already know about this?*

*What do we think will happen?*

*What equipment will we need?*

*What will make it a fair test?*

*What have I found out I did not know before?*

In the work described by Jones et al (1992), teachers too are encouraged to ask themselves questions in order to evaluate this kind of classroom work, for example:

*Does this kind of open investigative work meet curriculum needs?*

*How much initiative am I prepared to give the students?*

*What changes are required to carry out this kind of work?*

Like Pearson (op cit), Holcomb's work (1996) shows that questions can also be used as efficient guides to the performance of groups in the preparation, focus, diagnosis, development, implementation and evaluation of their work. Specific questions can be used to guide these group processes so that, for example in the 'focus' stage, the question might be: *Where do we want to go?* While implementing, monitoring, and evaluating on the other hand, the questions might be: *How will we know we have got there?*

**Questions in undergraduate chemistry**

The 'Questions in Chemistry' project is based within a programme for Year 1 university students in sciences and engineering at University of Aveiro. This work rests upon the conviction that it is possible to promote active inquiry-based learning in chemistry through promoting question-asking between teachers and students. With this in mind, patterns of teaching have been developed to encourage students to ask questions of their teachers, within two modules (Chemistry I and Chemistry II) in the academic year 2002-2003 (~100 students). Many of these approaches were developed during a prior investigative phase (Pedrosa de Jesus et al., 2001a, b) in cooperation with the staff of the Department of Chemistry at Aveiro. The main approaches are:

1. Tutorial lectures, centred in the resolution of particular case studies in chemistry
2. 'Questions in Chemistry' lectures, call 'Q/Q' lectures, based on students' questions on a specific theme
3. Conference-lectures, based on themes of high scientific, technological and social interest
4. Laboratory lectures, reconstructed to enable questioning and to promote student autonomy

5. Mini-projects, small group work to initiate investigations on themes chosen by the students.

These approaches to teaching have been supported by systems to promote the asking of oral questions, and to collect written questions through, for example, a software programme installed upon select computers distributed throughout the Chemistry Department buildings. This software programme includes Internet access for entries to be posted off-campus. A simpler, physical, system has entailed Question Boxes, prominently positioned in classrooms and in laboratories, where students could post written questions anonymously.

Within the lectures, tutorials and laboratory sessions, students have been asked to undertake 'mini-projects', relatively short investigations on topics in chemistry. Students choose from a list of 28 suggested themes such as: 'Electric vehicles', 'Fuel cells', 'Greenhouse gases', and 'Terra-forming Mars'. One outcome of these mini-projects has been an oral presentation by the group to teachers and peers, followed by questions from this audience.

**Questions that delineate a structure: a 'thermochemical' case study**

In this paper we have chosen to discuss the cooperative teamwork of three students who developed a project on the 'Thermochemistry of fitness'. Our data consists of participant observation of a group, their meetings and their meetings with their tutor. It is a case study, and we have added semi-structured interviews with all members of the group and the group as a whole, along with an analysis of the questions asked by the group in the development of their project. As we observed this particular group, it became clear to us that their questions performed several important functions in the structure of their work in, for example, organising ideas, delimiting the scale of the theme, identifying and discussing on the many strands and sources of information available to them, and in their reflections on the whole theme. The extent to which one can generalise from a case such as this is an open question. By definition, a case study is 'the examination of an instance in action' (Walker, 1993, p.163). As noted earlier, the present case study was undertaken as part of our wider research studies and here the case is intended to 'test' the ideas we have discussed against data collected from these young people and teachers. The case works well – as we discuss in the final section.

These students' organisational questions about thermochemistry have acted as a powerful management tool in the preparation for the oral presentation. We identified seven distinct phases to their work:

1. Team organization
2. Accumulation of ideas
3. Divergence of ideas
4. Structure and Production

5. Writing
6. Oral presentations and exhibition of the poster and
7. Assessment and evaluation of the overall process.

Needless to say, these phases are not rigidly marked by a sequence of occurrences, rather they were present to a smaller or larger degree in successive meetings as the group recapped and then made progress towards their aims.

The **first phase** was characterized by group organization and the initial choice of theme for the mini-project. At this point the three participants were not part of a friendship group and so there was a period of 'getting to know each other'. *Paula* had come from another classroom and was asked to join two established friends who had been together during the first semester. She joined *Inês* and *Cidália* to make this a more viable group of three people. The initial lack of immediate rapport within the group meant that each stage in the progress of the project was more drawn out and prolonged than for other groups based on established friendships. This feature enabled us to examine their processes in greater detail because each stage had to be explicitly and clearly articulated between themselves, rather than the group moving forward quickly on more implicitly and tacitly understood assumptions. By the last phase of the mini-project it was clear that *Paula* had become well integrated within this small group.

At the start the teacher led the sessions to set out the overall parameters and provide some options for ways of working. It was important, however, that this phase not be prolonged so that responsibility for their work is devolved quickly and unambiguously to the groups. As Light & Cox (2001, p.121) say:

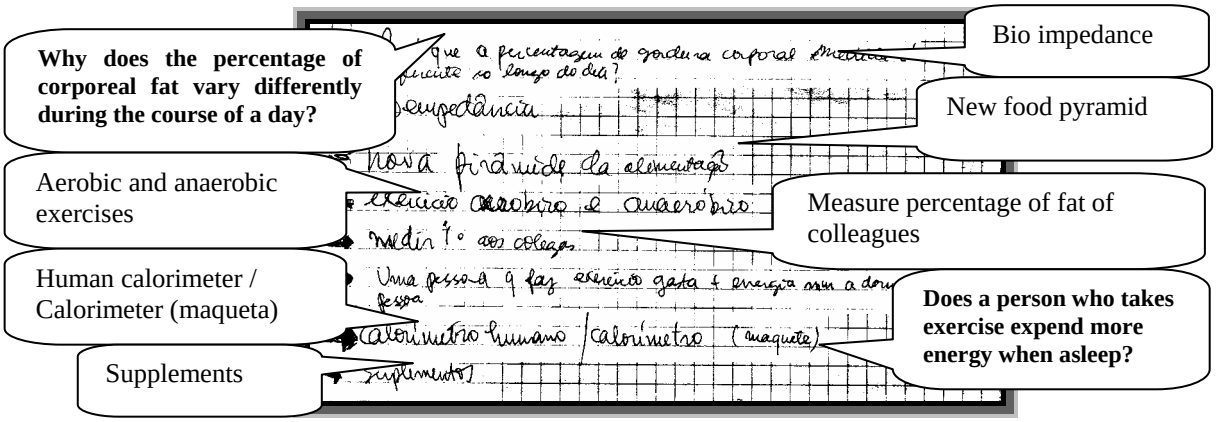
> *Expecting students to be independent when they are uncertain both about themselves and the group might create serious difficulties.*

The balance in the initial phase of the project can, to a certain extent, define the successful active involvement of the students in their projects. In this instance, the teacher led in asking the groups to nominate roles, choose themes and agree rules, and then handed the initiative over to the groups and then took a 'facilitative role' only.

We call the **second phase** the 'accumulation of ideas' and, in our case study group, a great number of ideas was generated, mostly by Inês. The other two treated these ideas very seriously and enlarged upon them with their own suggestions. In Figure 1, we show a student's draft where we can see some of the accumulation of ideas. In this figure there are two questions in bold. The 'content' question: "Why is the percentage of corporeal fat different during the course of a day?" was stimulated by the

instructions manual of a balance, brought by Inês, to measure the fat percentage through bio impedance. This indicated that percentages of fat could vary along the course of a day. Figure 1 does not represent all of the group's ideas - many were introduced along the phases but not recorded in this way. Inês's natural leadership in this phase was characterized by her many suggestions for sub-themes.

**Figure 1:** Student's draft during the 'accumulation of ideas'.




This was not an overt exercise of leadership, it was nevertheless present in many of the phases we identified, as she herself admits in the interview:

> Things could have run a different way, if I had wanted them to, though I did not have to 'command' anything to happen, right? Look, we would send each other text (mobile phone) messages: "Are we going to meet somewhere?", "Can you make this place?" and so on. It means everybody could take part in the same way - I did not have to order anybody around. They are both grown up people and each one knows what they have to do, don't they? But, there has to be <u>some</u> initiative.

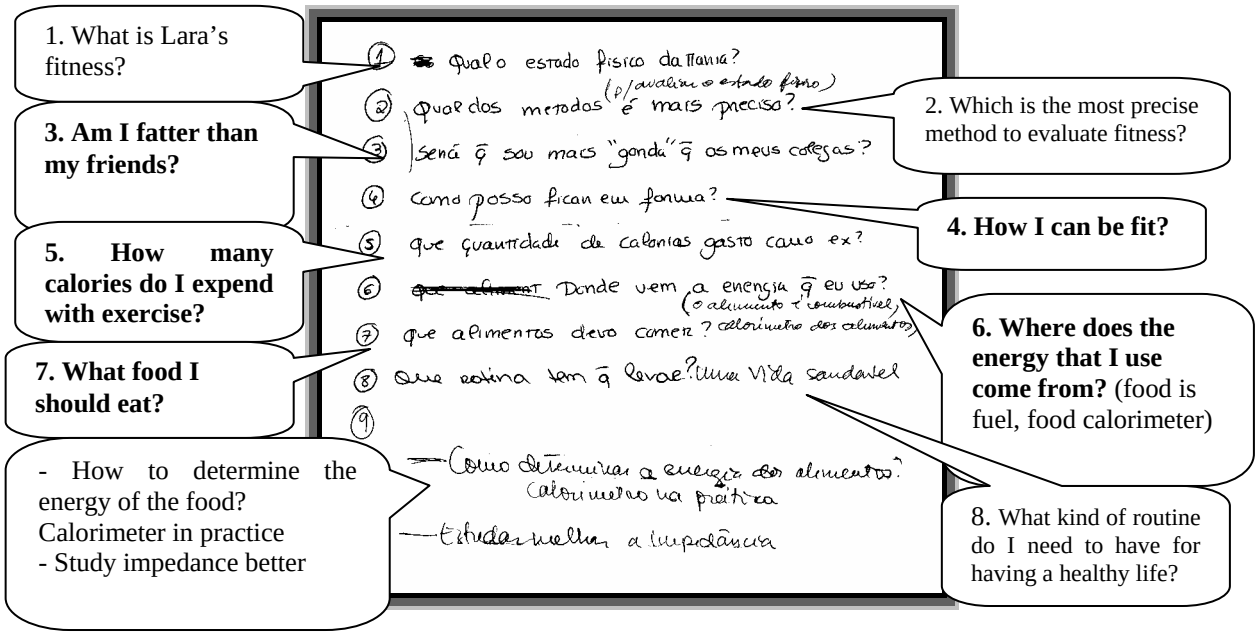
This interview took place at the end of the mini-project, where she reflects upon the process as a whole. She felt a little that she had been pressed into leadership, not so much be her own inclinations (although some of that was evident) but by her two colleagues' dependence on her to make decisions.

The **third phase** of the development of the mini-project was marked by a search for information through several sources, but mostly via the Internet. This information search brought a considerable number of further ideas and sub-themes that, although of being linked to the main theme, could not all be treated in same mini-project. Here, the three discussed and diverged in the extent to which these, given the parameters in which they were working, could be treated in the project. For example, the students gleaned through the teacher that to undertake a calorimeter measurement in a real calorimeter, something they thought they might do, is not routine process. Moreover, the three also ran into comprehension difficulties with some of the texts, giving rise to a series of fact-finding questions. These questions were formulated so that Inês could represent the group in meetings with the teacher to generate some feedback and technical support. This 'information overload' contributed to a sense of

loss in direction for the project. During an interview meeting with the researcher, *Cidália* relates how she challenged her colleagues with the prospect that they were losing sight of what they were trying to achieve because of the diversity of ideas and themes they were trying to develop.

The beginning of **phase 4** is marked by the point where *Cidália* suggests the creation of a fictional girl character (Lara), who is worried about her fitness and voices this through a series of questions. These questions bring into play many of the sub-themes the students would like explore. 'Lara's' questions are made to appear like a 'brainstorming session' (see Figure 2) that then serve to organize the group's work into several sub-themes.

**Figure 2:** Some orientations questions formulated in the 4th phase




In the Figure 2, we highlight in bold the questions asked in the character's voice. These questions formulated by Lara give the group three key sub-themes they wanted to develop. For example, the questions "What food should I eat?" and "Where does the energy that I use come from?" are opportunities to talk about the calorimetry of food. In this context, the questions became a tool for the elaboration, organization and presentation of ideas and the importance of these and of other kinds of questions arose in Inês interview:

> **Inês:** OK, we had a theme, right? This (showing a page of notes) was at the beginning and here (a second page) was for the meeting with the teacher. Then, we had this idea of Lara ... (leafing and placing pages of notes in order to give to the interviewer) …
>
> **Interviewer (I):** Here, where you wrote 'Orientation questions'. Is that because I encouraged you to ask questions or because...
>
> **Inês:** It's useful...
>
> **I:** What do you mean "It's useful"? Do you mean that asking questions is useful? I know that you have already done some other work about asking questions, structuring ideas with questions.

**Inês:** No, I don't think so... (She continues leafing through her notes, talking about the notes.)

**I:** When you think about this work and other work you have done in the past, have questions facilitated you work, or not?

**Inês:** They are a useful way to guide. I don't know! I don't remember all my other work, but I know that questions worked really well here.

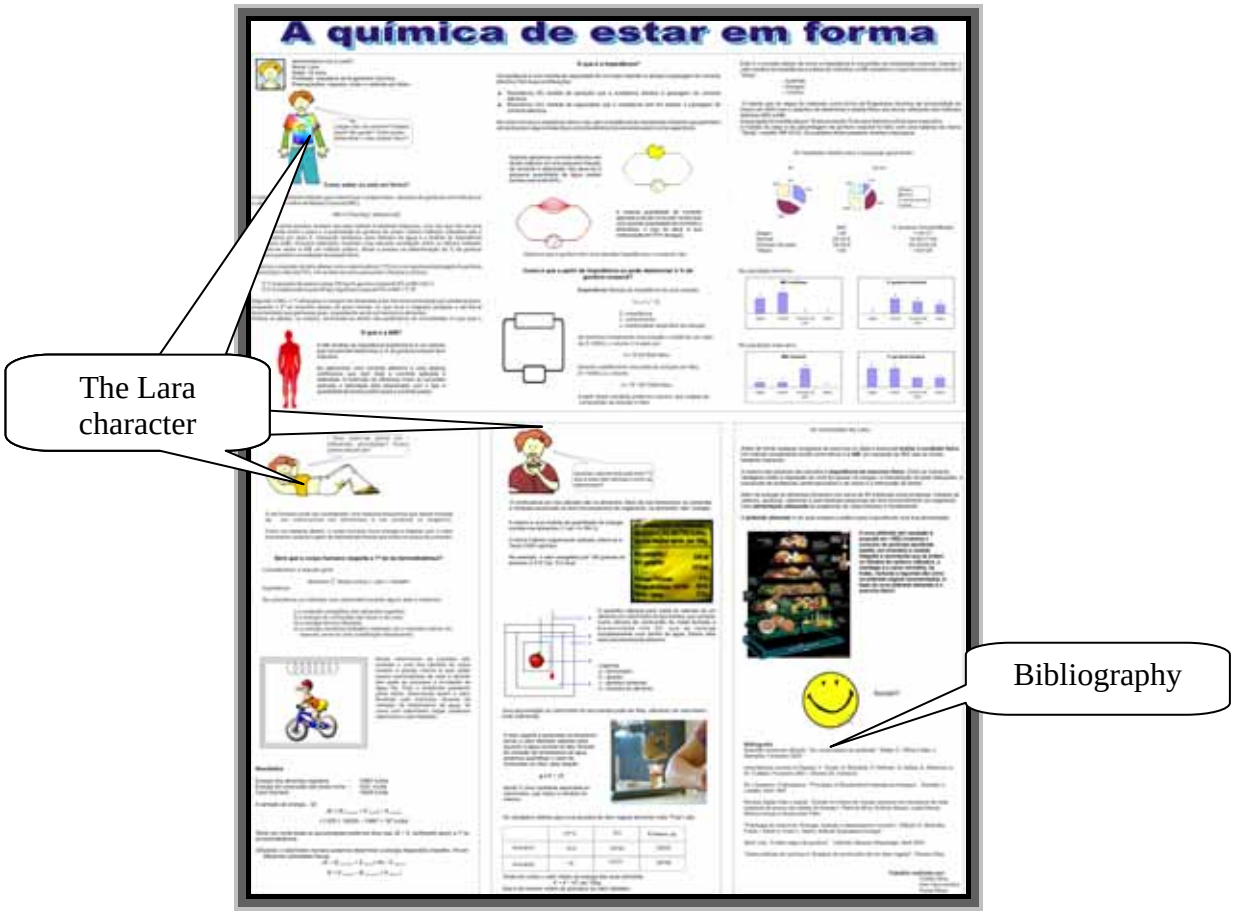
The two other students in this small group also saw that asking questions had advantages. For example, *Cidália* added at the end of her interview that she was now asking questions as an aid in studying for her final examinations in chemistry. To this extent, it is worth noting that all the advantages pointed out by Holcomb (1996) and Wlederhold & Kagan (1992), in a more systematic and structural way, were arrived at by these students through spontaneous processes. The use of questions in this phase prompted a greater convergence and a more systematic approach to the mini-project. For example, they experimented with a rudimentary calorimeter in the laboratory and, later, measured (with *Inês's* balance) the fat percentages in a sample of students.

In the **5th phase**, the group composed the poster and the slides for their presentation. This phase was accomplished in *Paula*'s absence, who only came back to join in the group's processes for the next parts of the work. In this phase the written work was eased by the use of the questions that served in organizing the sequence of the presentation, and in reflections on the text. The meetings with the researchers at this time were marked by the writing of the final prose that would embellish the poster and slides as part of the oral presentation of the project. The learning in this phase was more intense for *Inês* and *Cidália*. For example, in one interview *Inês* noted that she had developed skills in working with the software used to the make the poster and the slides for presentation, as shown in Figure 3. She noted, too, that the act of asking questions had served as a means to organize processes and procedures, and to connect their written ideas.

During the oral presentation (**6th phase**) each group had to present their work to the assembled class. Lemke (1993) argues that:

> *Learning sciences means learn to talk science. It also means learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, and in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of scientific and to act as member of the community of people who do so (p. 1).*

**Figure 3:** Poster to presentation of the mini-project 'thermochemistry of fitness'




To Lemke (1993) 'talking science' means observing, describing, comparing, classifying, analysing, discussing, hypothesizing, theorizing, **questioning**[2], challenging and arguing. These oral presentations constituted such an opportunity for these first year students to do just this. Each group had 15 minutes of presentation and a further 5 minutes for questions and discussion.

While *Paula* had not taken part in the previous writing phase she returned to cooperate with *Inês* and *Cidália*, sharing the presentation into three parts and with the other two guiding and supporting *Paula* through the talk. Inês introduced for character 'Lara' and her questions. In the Figure 4 and 5, we show the two first slides she used.

[2] bold added to the original text

**Figures 4 and 5:** Two first slides used in the oral presentation



The first slide introduces the character and in, the second slide (Figure 5) shows Lara formulating the first question: "These trousers do not fit me!!! Am I so fat? How I can know how fit I am?" Questions like this were used during all the presentation as means of introducing and connecting sub-themes to each other and serving as 'organising' sub-titles:

*How can I know my fitness?*

*What is impedance? And 'How can I determine the % fat of a body from its impedance?'*

*How many calories are in this cake?*

*How many calories are expended in different physical activities?*

*How can I calculate this?*

*Does the human body obey the 1st law of the thermodynamics?*

The class reacted extremely well to these presentations – not least to this one by the group of three. A swell of questions - and debate - arose at the end of the presentation.

After the oral presentation the posters were gathered in by the teachers for a more detailed assessment (**7th Phase**). The department have inaugurated a complex arrangement for adding the assessment of the group's work to other, more theoretical parts of the overall programme. A score for each person's participation in the mini-project was added to the average of the theoretical components, taking into account each student's involvement, not only in the presentation of mini-project but in its full development. Using specified criteria related to the level of engagement of the students, the teacher's assessment of the 'Thermochemistry group' placed *Inês* with the highest score, followed by *Cidália* and then *Paula*.

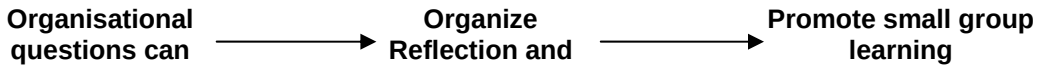
**Summary questions**

Finally, we ourselves ask two questions: *How well are we doing?* and *Where do we go from here?*

This particular strand of our work on organisational questions is in its infancy but has sparked a range of possible avenues for further exploration. The organisational questions asked by the students are very useful instruments in the self-management and processing of group work. For example, in this short study, Phases 1, 2 and 3 of the project development were characterised by questions geared to the initial exploration and organisation of the group's theme. During the 4th phase, deeper questions were asked, such as: "What methods are the most precise for measuring physical states?" The 5th phase is characterised by the organisation of the final poster and oral outcomes.

We have seen that questions have contributed to students' engagement in their study of the discipline, bringing an increase in interaction between teacher and students, and an increase in the confidence and trust of the students in asking questions. For example, creating the character called Lara allowed them to ask (sometimes naïve) questions then used to organise the remainder of the work and their reflections as the group. One of the questions 'asked by Lara', for example, was: "Am I fatter than my friends?" and was used later in the 6th phase.

The 'function' and 'quality' of these organisational questions have varied with the context in which they arose and were used, so that factual and conceptual questions are distinctive from organisational and reflective questions, and we see a flow as follows:




The overall consensus of those that undertook mini-projects was that these were enormously valuable, enjoyable and very well worth the time and effort invested in them, and that the questions generated in-group, and by audience responses to the presentation, were highly formative of thinking and learning. In this sense, these organisational questions have been useful incentives to promote the active learning of chemistry. Designing inquiry-based-learning with, and for, university students has developed their problem-solving skills, logical reasoning as well as reflective thinking. It has involved working as a member of a team, questioning, being creative, and shaping the skills for continued

intellectual development. For Light and Cox (2001), this is one of the most important learning experiences that a university can offer because it enables the exploration of theoretical ideas and conceptual change. This paper has presented some small ways in which students' questions can be used to shape these processes.

Needless to say, some of the future research questions that flow from this study might be:

*How typical are these organisational questions across other groups?*

*Are these organisational questions general or are there more generic questions that can be used to guide this kind of student investigative work?*

*How effective is it to organize work in this way – does it suit different kinds of students, different teachers and different kinds of working practices?*

*Is it worth teaching the use of organisational questions as a vehicle for promoting planning and strategic purposes?*

*What is the relationship between questions that organize thinking and those that organize practical tasks?*

We plan further work in this field to provide some answers to these questions. As noted above, however, we are principally concerned with this last question, and will be presenting data and discussions on these issues in the near future.

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