The use of criteria in argumentation and the construction of environmental concepts: a university case study

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Abstract

We have analysed the processes of argumentation of three university student groups (A: 6 students, C: 5 students and J: 7 students) while making a decision about an environmental problem (selection of a heating system). The discussions took place in three 1 ½ hour sessions that were audio taped and transcribed. For the analysis of the oral discussions, on the one hand, we have taken into account some of the dimensions characterising the quality of this decision-making process, including the number and variety of criteria utilised, whether criteria which did not favour the selected option were considered and whether priorities were established among criteria, and, on the other hand, the use of environmental concepts such as renewable and sustainability as well as the meanings that were constructed for both concepts. We have determined that the students in this study proposed and utilised, both explicitly and implicitly, a high number and great variety of criteria to support their choices, although they were rarely able to consider contradictory evidence; that is, those that demonstrated disadvantages of the option selected. In terms of the construction of knowledge, we observed that in some groups the proposed task favoured the construction of a concept of sustainability that took the future into consideration and which was utilised as the most important justification in their selection. In terms of the concept of renewable, we found that they did not only relate depletion of resources to economic consequences. We discuss the implications for the educational competence development.

Environmental education and open-ended tasks: introduction and objectives

The objectives of environmental education, as set forth in the Stockholm Conference (UNEP, 1972) and ratified in the Belgrade Charter (UNESCO, 1975), at the Tbilisi Conference (UNESCO, 1977), the Río Summit (UNEP, 1992) and in the United Nations Decade of Education for Sustainable Development (UNESCO, 2005), as well as the objectives of science education as recognised in the

Budapest Declaration (UNESCO-ICSU,1999) and more recently in the OCDE Pisa Project (OECD-INECSE, 2006) include the development of decision-making capabilities and critical thinking.

Therefore, the challenge posed to those of us who dedicate our efforts to scientific education and to environmental education is to produce critical students who are able to choose from among different options in such a way that they can make decisions throughout their lives as citizens. To attain this goal it is necessary to design learning contexts that foster the acquisition of these capacities. Within these contexts, one of the strategies used to promote discursive processes is the investigation of open-ended socio-scientific problems (Zeidler, Sadler, Simmons & Howes, 2005).

This type of problems, called authentic, can be characterised as contextualised in real life, relevant to the students, open-ended and possessing the capacity to generate a variety of possible responses as a function of the criteria utilised (Author 3, 2008). Posing these kinds of activities fosters debate and discussions among students, creating a need to justify options and ensuring that the resolution process is as important as the eventual solution.

The process of arriving at a decision concerning a problem involves the reasoned selection from among various alternatives, referring to personal or public aspects that require undertaking value judgements. In other words, students must be able to present points of view argued in situations of choice among different alternatives (Aikenhead, 1985; Kortland, 1996).

To improve students' ability to make decisions it is necessary not only to know the products of their discussions but also how the students carry out the decision-making process. As Hogan (2002) notes, it is important to understand the nature and the content of the students' discussions about problems, to know how they construct criteria for decision-making and to see whether they are able

to evaluate and take into account the available information (and not just that which conforms to their opinions). All of these aspects form the basis for preparing individuals to actively participate as citizens in arriving at decisions.

Furthermore, the discussion process also provides an opportunity for intellectual innovation and for the construction of knowledge. Sadler, Barab and Scott (2007) propose that the investigation of open-ended socio-scientific problems constitutes an important context for learning about scientific content and processes, since in carrying out these kinds of activities the student situates the content within a broader context, which gives it meaning.

From a situated cognition point of view, knowledge is part and product of the activity, the context and the culture in which it is developed and used (Brown, Collins & Duguid, 1989). From this perspective, knowledge construction takes as fundamental the idea that knowledge is constructed by the student, that current knowledge is used in the construction of new knowledge and that the capacity to use knowledge in different situation relates to the situation in which this knowledge must be used. Since social interaction is an essential component of learning, authentic, coherent and meaningful educational practices should be presented. Learning is understood as a process of social participation in which the context and nature of the situation have a great deal of influence (Author 3, 2008). Author 3 and colleague (2002) refer to these learning contexts as knowledge-producing communities, as opposed to the view of students as a community of knowledge consumers.

This idea is related not only to socio-scientific problem-solving but also to the way in which we conceptualise interactions produced in the class between students and teachers and which depend, to a great extent, on the way in which the classroom is organised. Brown (1992) proposes that the classroom be organised as a learning community in such a way that learning becomes a group

activity in which students teach each other, helping each other to learn in a process referred to as reciprocal learning. Students discuss and solve problems, look up information, share what is learned and are able to produce reports about the problem addressed. In these contexts students not only learn scientific content, but also learn to think scientifically.

This article is part of a broader project about university students' decisions when faced with an environmental problem, in which argumentative capacity and quality are analysed. The research questions are:

- What are the criteria constructed by the students to evaluate different options and come to a decision about an open-ended environmental problem?

- What meanings do the students construct for key concepts in environmental issues, such as 'renewable resource' and 'sustainability,' when they use these concepts?

Decision-making on socio-scientific issues: literature review

The construction of criteria on the part of the students has received attention in other studies. For example, Author 3 and colleague (2002) analysed the criteria constructed by 17-21 year-olds in the process of deciding on the installation of a drainage pipe in a marsh, concluding that subjects prioritised ecological values over economic concerns. Economic and ecological criteria are two of those that always appear when addressing environmental issues, and in fact they received special attention by Hogan (2002) in an analysis of how eight groups of students engaged in debate concerning an environmental management decision about the invasive zebra mussel. Patronis, Potari and Spiliotopoulou (1999) categorized the arguments used by 14-year-old students during a debate about planning of a major road near their school as 'social', 'ecological', 'economic' and 'practical'. This categorization scheme was adapted by Wu and Tsai (2007) who transformed the 'practical' category into 'science-oriented or technology-oriented' while analysing the reasoning

mode of Grade 10 students debating on whether or not a fourth nuclear power plant should be built in Taiwan. Kortland (1996) and Ratcliffe (1997) also studied the use of different criteria in the decision-making process, and besides, they analysed the process itself comparing the steps in a normative framework and the process followed by the students. Kortland (1996) studied 13-14 year-old students as they decided on the purchase of variously-packaged milk containers, in view of the waste management issue. Taking a normative framework for decision-making as a reference, Kortland analysed the process with a focus on the sequence of decision and debate, the quantity of criteria used to compare the alternatives, the implicit and explicit comparison of the alternatives with respect to the criteria and the prioritisation of results in cases of conflict. He concluded that his subjects worked with few criteria and that these few were usually those that supported the decision, thus avoiding the need to prioritise criteria that entered into conflict.

Ratcliffe (1997) analysed the decision-making processes of 15 year-old students in five tasks. She developed a six-step decision-making process, and the students were explicitly asked to follow the steps when the task was presented to them. She identified eight criteria used either in oral discussions either in written reports, along the five tasks. In the case of written reports, she made a distinction between 'the percentage of written reports in which particular criteria are cited under criteria and used in reasoning'. Like Kortland (1996), Ratcliffe concluded that her subjects began to evaluate options at the same time as they identified criteria. In those cases in which important criteria were explicitly identified, this helped to focus the discussions, since the students who did so were aware of the information relevant to these criteria and could see whether or not they supported the various options. Ratcliffe (1997) concluded that apparently, when a conflict appeared and the group was able to assimilate it, the reasoning was clearer.

Decision-making and knowledge construction

In terms of the contribution of the decision-making processes to the acquisition of new knowledge or better comprehension of scientific concepts, studies have yielded varying results. Mason (1996, 1998) suggests that the dialectic produced in the discussion process, in the episodes of shared knowledge construction (co-construction) as well as in critical opposition, permits the sharing and negotiation of ideas, fostering the construction of concepts and knowledge. This is in part because the co-construction allows for the reinforcement and deepening of knowledge and in part because critical opposition allows for ideas to be subjected to rational examination.

Kortland completed his study of the decision-making processes involved in the problem of waste management (Kortland, 1996) by analysing the meanings students constructed for some concepts related to waste during these processes (Kortland, 1997). He determined that while students did indeed learn during the proposed task, they did so to a lesser degree than desired and that the task itself did not ensure the production of a conceptual conflict.

Better conceptual comprehension by means of a task that included debate was statistically demonstrated by Yang (2004), who analysed the number of directly and indirectly connected ideas in concept maps extracted from student discourse before and after the task. Yang's findings seem to agree with those of a recent study by von Aufschnaiter, Erduran, Osborne and Simon (2008), who conclude that the discussion process does not seem to make the student construct new knowledge, but that, nevertheless, these discussions provide an excellent opportunity for the students to deepen and reinforce their ideas, helping them to make connections between contexts that afford better subsequent learning.

The construction of meaning of environmental concepts during a process of decision-making has been analysed by Author 3 and colleague (2007), who investigated the use of and meaning

constructed for the concepts of 'sustainability', 'environmental impact' and 'renewable resource' based on written production and the final oral discussion of the problem that was analysed in this investigation. Their results demonstrated that the students identified impact with pollution, associated whether or not a resource was renewable with economic factors and referred to the future fundamentally in terms of the duration of the building to be constructed. Among their conclusions, these authors highlighted that 'appropriating these notions is a prerequisite for constructing their own criteria for environmental issues and for developing critical thinking'.

The contribution of this study is to analyse how university students constructed notions of sustainability and source/renewable energy and how they used these notions in the process of constructing criteria. In another paper submitted we analyse the process followed as each group arrived at a decision. The studies of decision-making about socio-scientific issues described above focused on pre-university students. In our research, we believe that we can expect our university students to demonstrate a higher level of maturity that will translate into higher argumentative competencies in terms of the consideration of a greater number and variety of criteria. Similarly, our students are pursuing a degree in Social Education, which suggests that they have a stronger than average social conscience and possess a sense of social responsibility and commitment to equity, which can translate into a higher consideration of social criteria.

Methods and participants

The design of this investigation is based on a similar study conducted with secondary students (Author 3 & colleagues, 2006), who were presented with a case in which they needed to decide upon a heating system, basing this decision on economic and ecological criteria. In our own design, subjects were presented with the same problem: we had students select a heating system from among five possibilities without providing them with selection criteria. In addition, we developed a

23 pages dossier, containing information about the characteristics of the different energy sources, the environmental problems of their use and various data about the economic costs and emission of gases and particles. Besides, the students had six articles about the same issues. We tried to make this dossier as complete as possible, since it would be the most important source of information that would be available to the students.

The study took place in one section of the elective course 'Environmental and informal education' in the Social Education degree programme over the course of four 1½ hour sessions in May, 2004. The first three sessions were dedicated to cooperative work in small groups that involved reading the information and making decisions and the fourth session was dedicated to sharing results.

25 students participated (23 women and two men). Subject ranging in age from 18 to 23 years old were divided into the four groups.

We based this design on the idea of forming learning communities (Brown, 1992). Since students were placed in small groups to work together, they helped each other to learn. Furthermore, students who work in groups tend to demonstrate more positive attitudes and increase their self concept for the study when compared with students who are not grouped, demonstrating numerous changes associated with the establishment of collaborative learning environments (Oliveira & Sadler, 2008).

At the beginning, we simply gave each group a handout describing that their mission was to decide upon a heating system for a future building from among the options of diesel oil, natural gas, propane, bio-mass and electricity. Once the students offered their initial opinions, they were provided with the informative dossiers.

The first three sessions were audio-recorded and the fourth was video-recorded. Each group also generated reports in the form of session diaries, which were also collected.

For the analysis of the quality of the decision-making process, we focused on two factors adapted from Kortland (1996), taking into account:

- the number and variety of criteria used by each group
- the consideration of conflicting criteria and evidence, that is, whether group members were able to use criteria which did not support their own choice, whether they were able to consider the disadvantages of the decision that they made and to establish priorities among conflicting criteria.

For the analysis of the construction of concept meaning, we focused on two relevant environmental concepts, renewable and sustainability, taking into account all the occasions in which they were cited and interpreting its meaning.

The research falls within the interpretative methods of research (Erickson, 1986) that try to interpret the meaning actors give to their actions. The first author was the teacher of the group, and she and the second author were participant observers during the task. The results presented here are based on the oral discussions of three groups during the three first sessions as they arrived at a decision concerning the selection of an energy source. The transcript of the fourth group's discussions was lost due to technical issues. Students have all been assigned gender-appropriate pseudonyms. The pseudonyms assigned to Group A students all begin with the letter 'A', those of Group C students begin with 'C' and those of Group J students begin with 'J'. Group A was composed of six women, Group C consisted of four women and one man, and Group J included six women and one man.

Results: criteria construction and its quality

Results are shown in two sections. In this one, we will first briefly describe the decision making process of each group emphasizing the criteria used. Then we present the results obtained concerning how meanings of the concepts of renewable and sustainability, two of the emerging criteria taken into account in the process, were constructed.

We will discuss the process of criteria construction in each small group comparing their quality. Although the results are based on the analysis of the oral discussions of three groups, we must mention that the fourth group members wrote in their written diary that they chose biomass using as their most relevant criterion that it is a renewable resource.

Group A: 'think about those who will come later'

Group A was the group that handled the most criteria and also the group in which the decision-making process was the most complex, since the discussions that emerged as a result of disagreements among group members caused several of them to change their stance on more than one occasion.

At first, in the absence of information, they all opted for natural gas because they saw it as being ecological, cheap and comfortable. Nevertheless, after reading the information, Amaia became conscious of the finite nature of fossil fuels, pointing it to the rest of the group:

> 72 AMAIA: Well, if we continue consuming it (*natural gas*) at the rate it is being consumed now, that if we continue consuming the same quantity as we do now, its duration will be that (*pointing to the table*).

Next, a division of opinions developed within the group. Ane and Amaia proposed that they rule out electricity, drawing upon the economic criterion, the dangers of nuclear energy, the various kinds of impact generated by other sources of electricity production and the fact that this electricity was of unknown origin.

Arantza and Arrate took an opposing view, defending the continuing consideration of electricity as an option based on their views that it can be obtained from sources other than nuclear and that it pollutes less than natural gas. They also believed that natural gas would be more expensive in the long run that they would have the possibility to produce part of the energy that they used, which would in turn reduce costs, and that gas reserves are limited.

In the second session Group A members continued their discussions using the same criteria until finally they decided to take a vote in which everyone would make a decision and defend it. Just after each group member had expressed her opinion there was an exchange that may be considered key to the process that followed, since it involved making explicit the criterion of taking into account a vision of the future in terms of future generations (see Arrate, line 533, reproduced in the next section). This criterion caused three more people to defend electricity.

The ensuing discussion lasted until the end and drew upon and debated economic and pollution criteria, since group members did not agree on whether the use of solar panels would be able to produce electricity that would pollute less and be less expensive.

Group C: 'it's a question of principles'

The first criteria that Group C members seemed to work with, without making explicit the basis upon which they would make their choice, was comfort. This group decided upon natural gas,

which they saw as more 'modern' and more comfortable. They also proposed that one of the criteria should be environmental impact.

They eliminated natural gas upon learning that it lasted a short time, adding that this would result in a cost increase. In addition, this group established from the beginning of the task that they did not wish to contribute to the unsustainability of the model, that they did not want to contribute to the disappearance of resources or to exacerbate social differences, which seemed to constitute the basis for their decision. We noted that the members of this group assigned the social criterion more importance than the other groups, expressed in such ways as 'we should not promote social differences', 'we have to do it for the common good' and 'it's a question of principles', referring to the fact that they were going to be social educators.

Finally, they opted for electricity, given that one of their most important criteria was the fact that it might improve and that it has the potential to become a clean energy source, which seemed to them to be in line with their first criterion of not contributing to unsustainability or to resource depletion.

Although they looked into the costs of the various options, this was not a factor that they seemed to find particularly important. Nevertheless, they did value this factor in the sense that they believed that their choice would be a financially sound inversion in the long run.

Group J: 'natural gas is going to get expensive'

For Jon, the criterion of innovation remained fundamental throughout the process. He believed that the university should act as a model for society, and this belief led him to lean towards bio-mass.

Nevertheless, the rest of the group did not accept this decision due to the numerous drawbacks that they associated with bio-mass, as they viewed it as causing pollution and deforestation.

It seemed that some members of the group were somewhat scornful of the economic criterion, as can be observed in the following comment:

> 631 JULIA: Well, we're not going to think about money. It says here that…that we decide

Nevertheless, implicitly, it was one of the concerns that came up most frequently and, in fact, when the depletion of resources was mentioned, this was associated with rising costs:

> 734 JON: (…) natural gas isn't…isn't just…well, in the end they try to get it from the oil, when the natural gas reserves are all gone and it'll be, that is, it's going to get expensive again.

Tacitly, it seems that they wanted to opt for a non-polluting system. Even when evaluating renewable electricity sources they took into account the impact they would have on the landscape, for example in evaluating wind and water-produced energy, as well as the atmospheric pollution and deforestation that would be produced by bio-mass energy.

Categorization of the processes

The categories stated here were not set-up beforehand. Taking into account the nature of the task, previous studies (Author 3 and colleague, 2003) and the information in the dossier, we expected 'economic' and 'environmental' issues were going to prevail. We read all the statements made by the students and figured out that our students made statements of other categories, such as

'comfort'. Besides we also thought that we should pay special attention to some other interesting issues. For example we divided into two separate categories aspects that comprised the single category of 'ecological' in other studies (e.g. Patronis et al., 1999; Simonneaux, 2001; Author 3 & colleague, 2002; Wu & Tsai, 2007), separating criteria referring to environmental degradation from those concerning resource depletion. We also considered sustainability and the future to be a distinct criterion. Although we started with the hypothesis that environmental degradation or pollution would predominate as in Author 3 and colleague (2003), we have found our students' references to resource depletion and sustainability to be particularly interesting. Taking these categories into account, we categorised all the statements made by the students in which they were either establishing that an issue should be considered as a criterion (explicit criterion) or either evaluating an option using a criterion (implicit criterion). This is similar to the procedure employed by Ratcliffe (1997) and may be the source of the great variety of criteria identified.

We will try to explain the difference between implicit criteria and explicit criteria taking the next transcript of Ane (Group A):

> 259 ANE: Electricity is more expensive than natural gas. You also have to think that it's for the university, that is, that it has to be comfortable and cheap.

Sometimes students say that they have to take into account one criterion, for example, in the last part of Ane's intervention, she is pointing out that the heating system they finally choose has to be comfortable and cheap, that is, she is stating that 'economic' criterion and 'comfort' criterion are important for the decision. We interpret these as explicit criteria.

But sometimes, the students actually do use the criteria to make their claims, for example, in the first part of that intervention ("Electricity is more expensive than natural gas"). There she is

evaluating the options of electricity and natural gas using the 'economic' criterion to establish the comparison. We have categorized this as implicit because she is using the criterion but without saying that this is a criterion that has to be considered.

Ratcliffe (1997) also made a similar distinction between 'the percentage of written reports in which particular criteria are cited under criteria and used in reasoning'.

We grouped the type of criteria into seven categories, here listed in order of frequency (see Table 1):

1 ECONOMIC: related to criteria of an economic nature, that is, price of consumption, installation and transport costs, etc.

2 POLLUTION: includes all unspecified references to ecology and environmental concerns, as well as references to impact and pollution.

3 PRAGMATISM: those statements which call for pragmatic choices, for example, that a proposal did not ensure the energy demanded in light of the geographical location of the building, the local climate or technical installation problems.

4 RESOURCES: includes exchanges which mentioned the finite nature of reserves, the conservation of resources and the use of renewable resources. Deforestation and loss of biodiversity also fell into this category in cases where the student identified these problems as a loss of resources.

5 COMFORT: references related to comfort of use. We also placed in this category problems such as the interference of air generators with television reception, noise, etc.

6 SUSTAINABILITY: contains references to the future, to future generations and to sustainability. This category is related to the previous one, but we consider statements to take on a somewhat different and more complex shade of meaning when the future is explicitly alluded to.

0 OTHERS: a collection of very diverse criteria, such the importance that the selected option offer possibilities for improvement, the possibility of autonomous supply, the duration of the new building, illnesses produces by nuclear energy, etc. From these, two could be mentioned. First, social (criteria which take into account solidarity and social justice), which appear nine times in Group C and only a few times in the other two. Second, innovation (including statements that take into account the value of innovation, to be pioneers and to provide an example) which appears a few times in Group A and J.

In order to validate the identification and categorisation of these criteria, the two first authors conducted the analysis of Group A separately and compared the results, reaching a 85% of agreement. The disagreement were discussed until a consensus was reached.

[Insert table 1 about here]

Number and variety of criteria

The first result that should be highlighted is the high number of references to criteria, principally of an implicit nature, and the great variation in this number across the three groups. The group dynamics differed widely from each other. For example, in Group A the constant discussions among factions defending different stances fostered the continuous reference to the different criteria, while we think that the lack of significant disagreements among members of Groups C and J meant that these students did not perceive a need to call upon the criteria quite as often. In addition, Group J dedicated more time to informing themselves, this resulted in the appearance of fewer references to criteria.

The criteria which stood out in an implicit sense were 'economic' and 'pollution' across all groups, although differences could be observed. In Group A, these two criteria were noticeably prominent, since they were debated until the very last moment. 'Pragmatism' came in third place, referring to the geographic location, the local climate and technical problems that Amaia and Ane saw in the installation of photovoltaic panels on the building. In any case, while they were not quantitatively predominant, the 'resources' and 'sustainability' criteria were key points for the other part of the group, those who leaned toward electricity.

In Group C, the criteria 'pollution' and 'economic' were the most frequently mentioned, along with 'resources'. It is worth noting that Table 1 reflects the desire of this group to make a pragmatic proposal and it has to be noted that, in this group, the criterion 'social', included in 'others' category, received more references than in the other groups.

In Group J, the criterion 'pollution' stood out, followed by 'economic', 'resources' and 'pragmatism'.

Concerning the differences between making an explicit reference to the importance of a criterion and later using the criterion implicitly, it should be noted that in Groups A and C the 'sustainability' criterion was acknowledged explicitly as a criterion to a greater extent than that to which it was used implicitly, although we might consider that when an implicit reference was made to conserving resources, this reference also took into account the future and one of the dimensions of sustainability.

The case of the 'economic' criterion in Group C also deserves attention. Although it was not identified as an important criterion, it was one of the most frequently implicitly cited issues. One

possible interpretation is that when the students made explicit reference to make a pragmatic proposal, they may have been drawing upon economic criteria.

Conflicting criteria and evidence

It is important to use a variety of criteria, but it is also important to consider those criteria and evidence which do not support the selected option and to be able to prioritise among different criteria which would lead to different options.

We found that Group A members were able to indicate the disadvantages of their choice on several occasions (see Table 2) and what we interpret as more relevant is that they were able to use this acknowledgement of the disadvantages of their option as an element of persuasion in the negotiation process. This process is analysed deeply in another paper (Authors, submitted), and it can be seen that every time Arantza takes part in the negotiation, she starts admiting a disadvantage of her option before justifying it:

> 594 ARANTZA: It (*electricity produced with solar cells*) is going to be more expensive, but that expense… While you go to the future, it will be the only one.
>
> 598 ARANTZA: This is for future, because if you say 'now, which one?' it is clear that we all would choose natural gas, but as we are looking at the future...

[Insert table 2 about here]

Prioritising among conflicting criteria happens only once:

> 792 ARRATE: But something, it's that you produce something, something (*with electricity produced with solar cells in the building*). With natural gas you're not going to produce anything, it's going to be all consume, consume, consume.
>
> 793 AMAIA: Fine, consume, consume, fine, but how much do you pollute with electricity? Look at the table.

794 ANE: And how much do you pollute with nuclear?

795 AMAIA: You pollute double. You're going to produce a minimum (*you produce very little electricity with solar cells in the building)*. Do a rule of three and you'll see by what proportion you'll pollute more.

(...)

797 ARRATE: Let's see, you'll pollute, but at the same time you'll produce, the other way (*choosing natural gas*) you'll only pollute.

798 AMAIA: Fine, but what do you produce? Because I also have leaned toward this option (*electricity*), I've seen it and with a view of the future, that they (*fossil fuels*) are all running out and that it's a way to be producing your own energy, I think that's great but you're going to pollute a lot more (*with electricity*).

825 AMAIA: But, no for not polluting (*that is not the reason to choose electricity*), it is for making it last: electricity, because I know natural gas is going to run out, yes, I agree, but…

Amaia, was conscious that they were prioritising among conflicting criteria. Kortland (1996) described as 'conflicting' criteria those that had to be taken into consideration when deciding, but that were in conflict because they led to different decisions. Amaia pointed out that the members of the group who opted for electricity were placing the conservation of resources criterion above the pollution criterion, and we interpret that she wanted them see that both criteria were ecological and that she and Ane opted for natural gas because they considered it to be the more cost-effective and less polluting option at the current time. The rest of the group did not seem as conscious of this situation; they did not enter into the debate over prioritising the criteria but rather limited themselves to arguing that electricity would be cheaper and more cost effective without taking into account that they had conflicting criteria.

For Group C we identified six occasions where members contemplated drawbacks for the selected option, electricity:

84 CARMEN (*with respect to fossil fuels*): So these three pollute a whole lot. Well, at the moment we don't like these, right?

85 CORO: Right, but we don't like…

86 CARLOS: … a level that is ecological

87 CARMEN: And economic level?

88 CARLOS: Well

89 CARMEN: And at a social level

As a result, they did not have to prioritise criteria. As illustrated in the segment above, they seemed to appear willing to consider various criteria separately, comparing their results when necessary. However, while fossil fuels did not seem to pass an evaluation based on the ecological criterion and did satisfy the economic criterion, these students did not go on to establish priorities among the three criteria that mentioned in this exchange.

One of the characteristics of Group J is that they became overwhelmed by the drawbacks demonstrated by the options when they were evaluated according to the different criteria. The following excerpt, towards the end of the task when they were still not sure which option they would go with and were in dialogue with the teacher, illustrates that they found the task of taking several criteria into account in decision-making to be difficult:

726 (No id): It's difficult, eh?

727 Teacher: If you were going to have to put heating in your house, wouldn't you think about it, taking these many things into account?

728 (No id): No, come on…

Given that this group did not adopt a clear stance until the end and that they worked with relatively few criteria, there were not many occasions when they encountered 'conflicting' criteria. In fact, when they discovered a conflict as they considered an option, they simply discounted that option. We can interpret this to mean that it was not that they were not aware of the existence of different

criteria and that these might lead to different decisions, but that they were not able to take them into account in making their decision. In terms of considering diverse criteria, this was the only group who managed to declare any advantage to having nuclear power plants.

> 272 JON: Also what happens…there aren't many so, here we are, in the nation we're…we don't have many nuclear power plants compared with other places and we aren't independent, the nation as such isn't energy independent at all and hasn't gone in for nuclear plants. In France they have a lot more and in the end it's a sodding handicap…and if there aren't any real alternatives sometimes it's just that there's nothing…there's nothing else.

Results: construction of concept meaning

We analysed the construction of meaning for some of the environmental concepts, focusing on the concepts of renewable and sustainability. This focus is based on the relevance of these concepts to addressing environmental issues as well as the relatively low level of consideration afforded them by the students (Author 3 & colleague, 2003; Summers & Childs, 2007) and the difficulties that arise in assigning them meaning (Author 3 & colleague, 2007).

Renewable

Whether or not an energy source was limited, or whether or not it was renewable, was a criterion (which we categorised as 'resources') that every group used in their decision-making process. It is useful to understand what our students understood as a renewable resource.

In another study, Author 3 and colleague (2007) concluded that their students evaluated the consequences of depletion of resources in almost exclusively economic terms.

As long as the renewable nature of the biomass was the most relevant criterion for the fourth group, it would have been really interesting to analyse how do they understand what renewable is, that is,

what meaning do they construct for this concept and how do they converge, but, as we have already mentioned, this has been not possible.

In the case of the students of the three groups analysed, we found that, on the one hand, they did not have a clear idea of what it meant for a resource to be renewable and, on the other, they did not always evaluate the consequences of resources depletion in economic terms.

As for the first finding, it seems that Group A members did distinguish between renewable and non-renewable. Nevertheless, it seems that both Group C and Group J had problems that emerged in the process of categorising bio-mass as renewable or non-renewable. Both groups believed that renewable sources were those that they considered inexhaustible: water, wind and sun.

> 118 JON: But, are we saying that bio-mass would pollute less than electricity obtained from renewable energies, like solar and wind can be? Because in the chart it says yes, but…

Group C constructed their notion of renewable as inexhaustible; in fact, once this concept was constructed, they tended to use more colloquial phrases such as 'doesn't run out' and 'doesn't have an expiration date':

> 515 CORO: Yes, we want them to increase wind energy, and hydraulic energy.
>
> (...)
>
> 517 CORO: (...) We want them to increase, for example, these three because they are the least polluting and we believe that the resources of wind, water and air are really unlikely to run out, and it's the most natural.
>
> 518 CARLOS: It's almost impossible (*that they run out*)
>
> 519 CORO: I'm talking about that you're going to exploit a natural resource for the good of the community
>
> 520 CARLOS: Although bio-mass…
>
> 521 CORO: Maybe it pollutes a little more. But that's what I'm talking about, that we can group them like this: wind, solar, hydraulic. We would increase the percentage because they're natural resources, less polluting.

522 CARLOS: Renewable energy.

523 CRISTINA: And that they don't have an expiration date.

Coro (517) introduced the concept of natural, which added more confusion to the concept of renewable, since it seemed that Coro (521) identifies natural with less polluting and seemed to eliminate bio-mass from the notion of natural. This identification produced a situation where the true meaning of renewable resource seems to have been lost. That is, in the first session they started with the data demonstrating that some resources run out, they went on to construct or make public their understanding that bio-mass is renewable, and to select the sources that do not run out. However, at some moment, they identified these sources as natural and natural as non-polluting. Therefore, following formal logic in the purest sense, they came to identify renewable as less polluting (Carlos, 530), even though they had a clear idea of the concept (Cristina, 531 and Carlos, 532):

529 CRISTINA: And that, as the years go by, we won't have this energy.

530 CARLOS: We said that solar, wind and hydro-electric, because they're renewable, don't pollute.

531 CRISTINA: And it's a source of energy that doesn't run out, that doesn't have…

532 CARLOS: By saying that they're renewable…it's the same.

In terms of the consequences of the depletion of resources, every group, but particularly Group A, seemed to be conscious that it was a serious problem, although every group related this depletion with economic consequences, either before of after.

In the first part of the discussion that took place in Group A there were numerous occasions where group members seemed to express that there is something intrinsically negative in the depletion of a resource.

338 ARANTZA (*referring to natural gas*): and also the reserve is limited and when it runs out, it runs out, there's no more.

Group A was the only one to explicitly associate the potential of a resource to become depleted with being less ecological. This is interesting, since normally an energy source's pollution level, and not its potential for depletion, is the only factor considered in determining how ecological a resource is (Author 3 & colleague, 2003):

83 ANE: So over time natural gas is going to disappear

84 ARANTZA: So looking at it that way, it's better to stop consuming natural gas, because then we stop using it up.

87 ANE: Ecological, indeed, now I'm seeing it a little…less

88 ARANTZA: Right

This was a group that valued the preservation of resources for future generations and didn't exclusively see the consequences as an economic issue:

90 ANE: Oh!, we're sucking all the energy for future generations.

91 ARANTZA: Yes.

92 AMAIA: How selfish we are!

Nevertheless, when a discussion was initiated in the group, the group members who defended natural gas used the economic criterion as one of the most important while the other members constantly argued that natural gas would become more expensive as it ran out, that is, referring to the economic consequences of running out. We believe they did this in an attempt to convince the other group members using their own criteria. In fact, at one point towards the end of the discussion, Arrate noticed that they have abandoned their concept of the consequences of resource depletion:

991 ARRATE: Wait a second; natural gas is going to run out if we go on like that

992 ALAIEN: It will run out.

993 AMAIA: OK, but let's be pragmatic, we're talking in the present and saying that they're going to have to give us more money for this and Education or whoever decides the kind of energy that gets used, what do you think? That they're not going to look at the money that they're going to spend? They'll just look at the pollution? How nice!

Selecting an energy source that wouldn't run out was an important criterion for Group C, the only group which considered for almost all the energy sources whether or not they were inexhaustible:

573 CRISTINA: But they run out too, right? I don't know about nuclear power, but coal…does nuclear run out?

574 CARLOS: Coal runs out, nuclear would be unlikely

575 CORO: Nuclear, no

Nevertheless, on several occasions the fact that resources ran out had an economic meaning, which coincides with the conclusions of another study (Author 3 & colleague, 2007):

106 CARLOS: There's going to be less and less.

107 CARMEN: And it's going to cost more.

However, on one occasion students seemed to be aware that future generations would suffer the consequences of the depletion of resources:

595 CARLOS: I don't know how long it'll last, 40 years or so? We'll be sixty and…?

596 CRISTINA: So our children, poor things, I don't know.

Group J seemed to consider the economic consequences above all, but in a more complete way, since they didn't just talk about the increase in price but also referred to the consequences that depletion of resources would bring to an economic system centred on petrol. Nevertheless, this was

still a perspective that considered consequences for the current generation and our current system, and did not consider future generations.

> 282 JON: (…) So in the case of petrol shortage and so on, there are only 90 days of assured petrol with all that brings, the whole economy would be paralysed and everything would be paralysed. (…)

Sustainability

Despite the fact that there was no mention in the dossier of future generations or the consequences that would result from resource depletion in the future, we observed that students used sustainability as a criterion in their decision process and that sustainability, in fact, constituted a key criterion for some students in Group A and accounted for some changes in position.

To examine the importance given to this concept across the three groups we analysed how many times the concepts of sustainability and sustainable development were mentioned during the oral discussions, in terms of the appearance of expressions such as 'future generations', 'those who will come after us', 'our children' and the term 'future'. The results are shown in Table 3. We took into account the dimension of considering future generations from among the seven discussed by Summers and Childs (2007) because we consider this dimension to be one of the most difficult to internalise, since it requires the ability to predict non-immediate consequences and to put oneself in the place of future generations and because this dimension constitutes the key to the definition of sustainability.

[Insert table 3 about here]

We can see that, quantitatively, the situation was very different across the three groups. While in Group A the concept of sustainability appeared on several occasions and in various forms (although the consideration of the future particularly stood out), the concept appeared less frequently in Group C and only once in Group J, whose members didn't take the time factor into account except to

mention possible local climate changes resulting from global warming. Nevertheless, mentioning a term doesn't mean that this term is used with appropriate meaning, which is why we proceeded with a more qualitative analysis, focusing on the meaning given to the concept by Groups A and C.

The members of Group C associated sustainability with moral value and equilibrium and were able to consider this to be one of its dimensions (Summers & Childs, 2007); but they did not seem to have constructed a clear meaning of the concept, nor did they consider the time factor or future generations:

663 CRISTINA: Well, that's it, right? Something like that, and here we write why we chose... because of the moral value, because... I don't know.

664 CARLOS: Sustainability.

730 CLARA: Sustainability is what…whatever makes better…No? Equilibrium.

Despite this, they did seem to take future generations into account on one occasion when evaluating the importance of resource depletion. Furthermore, they referred on two occasions to the unsustainability of the model and to the rate of consumption, and on these occasions they did seem to be considering the time factor; that is, they considered that the current rate of consumption could not be maintained. In the following segment, the students can be seen to refer to unsustainability twice (Carlos, 55 and 65) and on both occasions, although it is by negation, it does seem that they relate the (un)sustainability of the model with the (im)possibility of maintaining it over time:

50 CLARA: I would take it out, because gas does, the duration it's going to last is going to be short, and then it's also going to be expensive as time goes on. It's that it was also a derivative of petroleum

51 CRISTINA: How long is it going to last?

52 CARMEN: 70 years, and petrol 42 years

53 CARLOS: Besides, that is like pointing to what shouldn't…that is, what we don't want, in the global sense

54 CARMEN: They're going to take it in the first world, and in the third world… (*there will be no gas for the third world*)

55 CARLOS: Yes, and not just that, but…I mean, it's unsustainable to maintain this rate, so then if... Imagine another university more…

56 (No id.): More accelerated.

57 CARLOS: So that we're promoting more…

58 (No id.): So natural gas we're eliminating

61 CARLOS: Well, if we're seeing that this is going to have a negative effect at a global level, well then we…we have to try not to put our…

62 (No id.): Add our grain to the pile of sand

63 CARLOS: That's it, add our grain to the pile of sand

64 CLARA: (...) social, the differences are going to be exacerbated

65 CARLOS: Even environmental. If within a couple of years this is going to be unsustainable, well it's not… The less we promote…

The situation was different for Group A:

532 AINARA: (…) I also choose natural gas, (…). Natural gas is more cost efficient, more comfortable and well, although there are few resources, well, damn, there are still years left, right? And that's it, well, I don't know.

533 ARRATE: It's that, don't just think about the years that you're going to be here, think about those who will come later.

534 AINARA: Sure but...

535 AMAIA: Sustainable development.

738 AMAIA: Yes, since the others (*the other sources*) are going to come to a point where they're going to run out and thinking of the sustainable development of the country, it (*electricity*) would be the most appropriate option.

In this group, the concept of sustainability was used in clear relation to future generation and coherently as well, in a group that took future generations into account in considering the consequences of resource depletion.

The purpose of this investigation has been to analyse the decision-making process followed by three groups of university students when confronted with an open-ended socio-scientific problem. We have focused our analysis on the criteria used and on the construction of meaning of certain environmental concepts.

Conclusions and educational implications

The first thing we can point out is that the task provided made the students feel motivated and actively participate in the decision-making process. We take two evidences to say this: they participated in the discussion for a long period of time with hardly any teacher intervention, and Group C pointed this out in their written diary, although they were not asked to evaluate the experience:

> "We have also liked it (*the experience*) very much, because we think that besides having fun while working, we have learned quite a lot about the energy subject, which is a subject we have never been interested in. We didn't even know that there were so many and so different ones (*energy sources*).
>
> Because of that, we think it is necessary to say that this has been a very positive and enriching experience for all of us."

Since selection criteria were not specified in the task, the students needed to determine them, although several possibilities were implied by the information provided. The students were able to determine a variety of criteria and to use them, both explicitly and implicitly, to justify and support

their selection. On an explicit level, the groups identified social and ecological criteria as the important ones that guided their selection. In this sense, the economic criterion was not assigned importance by the majority of the students; nevertheless, this was one of the criteria that received the most implicit references. This suggests to us that the students were aware that the economic criterion is important, yet they prioritised the criteria of pollution, resource conservation and resource sustainability. In Group A, furthermore, students were able to construct a criterion of sustainability, which was not mentioned in the information provided, and to consider this criterion to be crucial to their decision-making process, as we have analysed in another paper (Authors, submitted).

The opening up of minds and broadening of decision-making abilities was also demonstrated by the variety of criteria used by all the groups, as members were conscious of the drawbacks of the option selected. This was particularly noteworthy for Group A, in which one group member, Amaia, was conscious that they were prioritising 'conflicting' criteria (Kortland, 1996), which demonstrates the high quality of the decision-making process followed.

However, there are some issues in the decision-making process that need further consideration. As we mentioned, students were only told they had to decide, but nothing was said about how to carry the decision-making process. Although they occasionally were aware of establishing the criteria that had to guide the process, we believe that it would have been more enriching if they were asked to choose the important criteria just after presenting the problem, and before reading the information. That way, we would have a more realistic view about which were the important criteria for our students *a priori*. We also think that doing so could diminish the possible influence of the dossier in the criteria chosen and could facilitate the process for the students as Ratcliffe (1997) points. Besides, we would have been able to compare the difference between the criteria established *a*

priori, and the ones used once the information was known and discussed, analysing the processes of the individuals and the groups.

In terms of the construction of meaning, we can conclude that taking on a decision-making task concerning an open-ended problem affords an opportunity and, in some cases, a requirement, to use existing understandings, allowing people to confront ideas they already have about different concepts and to construct them with others (Brown et al., 1989).

The concept of sustainability is not an easy concept to internalise, although the definition given in the Brundtland Report (*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own need,* World Commission on Environment and Development, 1987) may seem simple. Indeed, students in our classrooms often express the difficulty they have in assigning meaning to the concept, in part because the concept is both omnipresent and devoid of content in our current media. This difficulty in assigning a clear meaning to the sustainability concept was also discussed by Smyth (1995). Nevertheless, we were able to observe how a group of students was able, when forced to justify their decision and debate and persuade the rest of their colleagues, to construct a meaning for this concept and to use it in their argumentative process as the most important justification for their decision and as the primary principle behind their selection. In this sense, we are in agreement with other researchers (von Aufschnaiter et al., 2008) who believe that the argumentative task itself does not generate knowledge, but rather that students use their existing knowledge as a resource in the discussion process, which permits them to generate a higher level of abstraction and gives them greater confidence in this knowledge, which fosters future learning.

For these reasons, we believe that these kinds of tasks and methodological approaches comprise a good context for developing decision-making ability and critical thinking, both objectives of science education. These also reflect a possible movement toward action, as 'developing abilities to reach decisions is taking them to the door of political action' (Aikenhead, 1985), an objective of environmental education. Indeed, this task provided the students an opportunity to, while discussing about an environmental related problem, think about their own responsibility in the resource depletion problem (see for example Group A, 90-92 excerpt in the section of results for the concept of *renewable*), think with others about which direction changes should point to (see for example Group C, 61-65 excerpt in the section of results for the concept of *sustainability*) and reflect about what changes should they make in their lives. The following excerpt of Group J is a good example of this last assertion. They are discussing about nuclear energy and the possibility/impossibility of doing without it:

> 272 JON: (…) if there are no real alternatives (*to nuclear power*), many times there is no, there is no other (*possibility*).
>
> 273 JULIA: But, there are alternatives, aren't there? That is…
>
> 274 JON: Not on a large scale, no… They are going to… They must be on a large scale and at the moment it doesn't seem there are any alternatives. There are alternatives on the paper (*theoretically*) but I don't know.
>
> 275 JULIA: Well, it is clear that we will have to reduce our consume too, isn't it?

This learning and development of various abilities, among which we have highlighted the construction and utilisation of concepts, the search and utilisation of decision making criteria, the assumption of their own responsibility and pointing to changes in action, constitutes a competence development, in the sense that the ongoing construction of the European Higher Education Area seeks for, as the Tuning project (González & Wagenaar, 2003) states that "Competences represent a dynamic combination of knowledge, understanding, skills and abilities". Indeed, the learning based on competences is one of the hallmarks of this educational change process.

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Table 1: Implicit and explicit references to criteria in decision-making in three groups

CATEGORY	GROUP A		GROUP C		GROUP J		TOTAL
	Implicit	Explicit	Implicit	Explicit	Implicit	Explicit	
Economic	162	6	46	1	22	0	237
Pollution	93	3	49	3	34	1	183
Pragmatism	61	0	29	4	19	1	114
Resources	40	0	37	0	20	0	97
Comfort	23	2	11	0	9	0	45
Sustainability	19	4	9	4	0	0	36
Other	70	7	32	4	17	8	138
Total	468	22	213	16	121	10	850

Table 2: Number of times Group A members acknowledged disadvantages of their option

Group member	No. of occasions
Arantza	13
Amaia	11
Arrate	8
Ane	5
Ainara	2
Alaien	1

Table 3: Frequency of appearance of the terms related to sustainability in the oral discussions

Concept	Group A	Group C	Group J
Sustainability	2	4	0
Future generations	4	1	0
Future	20	3	1
TOTAL	26	8	1