DEVELOPMENT AND ASSESSMENT OF WEB BASED CURRICULUM MATERIALS FOR DECISION MAKING ABOUT SOCIO-SCIENTIFIC ISSUES: THE EXAMPLE OF TRACE CHEMICALS IN DRINKING WATER

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ABSTRACT
This paper reports on a research effort targeted at helping high-school students develop decision-making skills, in the context of an important socio-scientific issue that is not traditionally included in school curricula. This issue relates to the evaluation of the quality of drinking water on the basis of its ingredients and their concentration. Selecting among different bottled waters becomes complicated because (a) students do not typically interpret the information shown on the label in an appropriate manner (e.g. they cannot identify which of the constituents of the water are harmful for human consumption or which limits are prohibitive); (b) the concentration of each constituent is not common for all commercially available bottled waters; and (c) the content of solvents in the water, varies from one type of water to another. The paper reports on an attempt to design an activity sequence that seeks to help students develop the optimization strategy in the context of selecting the most appropriate bottled water considering a number of factors, such as the physico-chemical composition in terms of essential constituents, the suitability of certain waters regarding special age groups (infants and young children) and labeling requirements. Through this example, we seek to help students appreciate certain aspects of the decision making process, such as the important role of criteria and the need to rely on them in justifying the selection of a certain alternative option. The learning materials that have been developed in the context of this study are web-based and they are embedded in a special inquiry learning environment, the STOCHASMOS platform. The activity sequence engages students in the process of collecting information concerning the quality of drinking water and guides them to process the available information and construct arguments about the quality of drinking water. The paper provides an overview of the activity sequence, its underlying rationale and preliminary results from a pilot implementation.

KEYWORDS
Decision making, socio-scientific issues, drinking water, bottled water quality, web-based materials, STOCHASMOS platform.

INTRODUCTION

In a society that undergoes continuous change, new knowledge, new abilities and new skills are required in order to correspond to the challenges that result both from the intensive socio-economic changes and from continuous technological and scientific developments. The knowledge that is typically developed in the framework of the current educational system, does not suffice and does not correspond to the essential knowledge needed for continuous personal growth. One important skill is the ability to manage new information in a way that permits good judgement.

The main purpose of the project is to explore how students learn to make decisions, what knowledge they activate in decision making processes and how they use multiple criteria to weigh different options. This issue is addressed in the context of a topical socio-scientific issue, which relates to the selection of appropriate drinking water. In particular, the paper reports on an attempt to design an activity sequence that is intended to help students develop the optimization strategy in selecting the most appropriate bottled water considering a number of factors, such as the physico-chemical composition in terms of essential constituents, the suitability of certain waters regarding special age groups (infants and young children) and labeling requirements. This is expected to help students (a) appreciate the importance of developing criteria to guide the decision making process, (b) develop arguments to support their decisions and (c) appreciate various health issues related to the chemical composition of bottled water.

BACKGROUND

Decision – Making

Several science educators have argued for the inclusion of socio-scientific issues in science classrooms, citing their central role in the development of a responsible citizenry capable of applying scientific knowledge and habits of mind (Driver et. al, 2000). Knowledge of how pupils deal with such issues is of relevance to the discussion of public understanding of science as it provides information on lay people's use of, and need of science and it is also important when designing curricula aiming at science for citizenship (Kolstø 2001). Critical thinking and argumentation are key components to successful decisions and are closely linked to student's decision making skills. Each of these components goes beyond rote memorization of factual information and requires students to do more: to seek additional information when it is needed, to recognize inconsistencies in problem formulation, to evaluate the truth of claims made in a statement or text, and to combine information and techniques in ways that are not exact parallels of previous situations. The development of decision-making skills is not directly addressed by traditional school curricula in science education, even though it could help students activate their thinking and problem-solving abilities. Moreover, the use of socio-scientific issues as a context in which these skills are developed, not only links science education with everyday life, but also helps students gain a better understanding of the impact of the choices they make on themselves and society as a whole.

One important parameter cited by Yang (2004) is the fact that whenever students express uncertainty on their decision about a SSI, they tend to associate it with insufficient information. Several studies that address reasoning in areas of everyday life situations refer to inadequate ability, even by adults, to make scientific arguments about social issues (Kortland 1996, Kunh 1991, Ratcliffe 1996) and reveal that high-school students´ judgment of information is largely affected by emotional factors (Yang and Anderson, 2003). The context of selecting bottled water was deemed appropriate, since it presents aspects that are common to decision making situations, such as the need to make tradeoffs between alternative options. This need emerges from the fact that the concentration of solvents in the water, varies from one type of water to another. An additional reason justifying the selection to focus on this issue relates to available research evidence, which suggests that students aged 14 – 18 are not able to correctly interpret the information shown on the label of bottled water (i.e. they cannot identify which of the constituents of the water are harmful for human consumption or which limits are prohibitory). In our work we are trying to help students develop the optimization strategy (Baron, 2000) in processing available information to reach a decision. This strategy is appropriate for multi-attribute decision-making situations (Baron 2000) and it includes adjusting for the variation on measurement scales, through the conversion of available measurements on a unique scale, and for the variation in the relative importance of the criteria, through assigning weights.

METHODOLOGY

Data Collection

The overall number of participants was 26 secondary school students, sixteen males and ten females. The study entails two parts. The first part relates to the investigation of students' initial ideas with respect to the factors that influence the quality of bottled water and the second concerns the pilot implementation of the activity sequence for the optimization strategy.

Study 1

The purpose of this study was to investigate students' initial ideas about the criteria used for decision-making on bottled water. These data were taken into account in developing assessments tasks that were used in the second part of the study. Data were collected through 20-minutes individual interviews with fourteen of the participants. The questions included in the interview protocol are presented in Table 1. Questions 1 through 4 evaluate aspects of students reasoning regarding the selection of drinking water. The first asks students to select the best alternative between three different commercially available bottled waters. Questions 2 and 3 examine students' background knowledge concerning the quality of drinking water and the fourth question explicitly asks students to compare the quality of five different bottled water, on the basis of their ingredients and their corresponding concentration. Finally, questions 5 and 6 evaluate students' ideas on credibility issues regarding labeling. Questions 1 and 4 evaluated students' behavior when deciding about bottled water.

The bottled water labels of question 4, present the concentrations of sodium (Na^+), nitrates (NO_3^-), chlorides (Cl^-) and arsenic (As). Sodium poses no health risks to the average person, however a typical guideline has been set at 200mg/l. Nitrate levels should not be higher than 10mg/l although it is recommended that water should not contain nitrates, especially if it is used for infant formula. High nitrate may cause methemoglobinemia (infant cyanosis or 'blue baby disease). High concentrations of chloride ions may result in an objectionable salty taste to water (typical higher limit set to 250mg/l), in contrast with arsenic, which is dangerous for human consumption and should be absent from any kind of drinking water. Finally, questions 2 and 3 examined students' background knowledge concerning the quality of drinking water, whereas interview questions 5 and 6 evaluated students' ideas on credibility issues regarding labeling.

Table 1. Interview protocol for students' bottled water decision-making

1. Which of these three bottled waters would you choose to drink and why?
2. With who of the following students do you agree or disagree, and why? *Student 1*: There is no difference between the three waters. They are all bottled waters. They all contain hydrogen and oxygen in ratio 2:1. The only thing that differs is the brand name on the label. *Student 2*: Bottled water also contains trace elements and salts which are not similar in every bottle. Nevertheless, all bottled waters are healthy, because bottled water companies select the water from natural sources and because all bottled waters are controlled by the government. *Student 3*: I think that the best way to select bottled water is to read the chemical analysis on the label and select the one that contains the most ingredients. The more ingredients it has the best for our health.
3. Where does bottled water come from?
4. Which of the following bottled waters would you choose to drink and why?

Nα	5 mg/l
NO_3	3 mg/l
Cl	35 mg/l
As	0 mg/l

Nα	25 mg/l
NO_3	10 mg/l
Cl	65 mg/l
As	12 mg/l

Nα	15 mg/l
NO_3	0 mg/l
Cl	10 mg/l
As	0,02 mg/l

Nα	35 mg/l
NO_3	0 mg/l
Cl	0 mg/l
As	0 mg/l

Nα	18 mg/l
NO_3	20 mg/l
Cl	0 mg/l
As	0,01 mg/l

5. Is it necessary to have a label on bottled water? Explain your reasoning. If yes, which information you believe is important to include on the label?
6. Is it possible for consumers to know if the information shown on a label is trustworthy? Explain your reasoning.

Study 2

The second part of the study included the implementation of the activity sequence and the evaluation of students for possible learning gains. The implementation was carried out in three 160-minutes sessions and participants were sixteen students who worked in groups of three. Students' evaluation was carried out through open-ended tasks that were individually completed by each student prior to and after the implementation of the activity sequence.

Instructional Context

The example of the trace chemicals in drinking water constitutes a context that provides the opportunity to link concepts learned in traditional school curricula with experiences with the real world . The use of socio-scientific issues in the development of corresponding teaching and learning materials helps students extend their learning beyond the classroom, as they apply their knowledge and decision skills to real world problems. In this investigation, students are asked to choose the best alternative through a number of examples of bottled water that are commercially available, taking into consideration a number of factors. This process requires that students collect information, develop the optimization strategy, and select and manipulate relevant evidence in order to construct arguments to be presented to other students. Inquiry-based learning is gaining increasing support in science education, with a growing number of educators becoming interested in project and inquiry-based teaching (Polman, 1998). The teaching approach that we used was based on the 'Physics by Inquiry' pedagogy (McDermott et. al, 1996). In this approach students always work in groups and interact with the learning materials without being exposed to lecturing or teacher directed instruction. Certain stages in the activity sequence serve as checkpoints where students are asked to discuss their reasoning with the teacher. During these discussions teachers do not directly communicate any information to students. In contrast, they attempt to help students articulate their thoughts and negotiate epistemological, conceptual, practical and other difficulties they might encounter.

One of the primary assumptions of this approach is that the process of science cannot be learned by reading, listening or memorizing. Effective learning requires active mental engagement while at the same time, the teacher needs to undertake the role of a

knowledge facilitator. Scaffolding is succeeded primarily through careful questioning and less often through explanation. It is an approach which engages students in activities which mirror methods of scientific investigation, with content interwoven with or addressed in the context of inquiry (Kubicek, 2005). One of the main goals of inquiry-based curriculum materials is the acquaintance of students with authentic scientific inquiry. Chinn and Malhotra (2001) define authentic inquiry as a complex activity which employs expensive equipment, elaboration of procedures and theories, highly specialized expertise and advanced techniques for data analysis and modeling. According to Polman (1998), inquiry-based learning should stress the importance of learning the 'process' of science, such as formulating empirically investigable questions and supporting claims with evidence. It is important to note that students should be provided with time for discussion and argumentation in order to make their ideas explicit and reach an evidence-based conclusion.

The STOCHASMOS web-based platform

The web-based materials for the implementation of this study were designed in the STOCHASMOS platform (Kyza & Constantinou, 2007). STOCHASMOS is a web-based learning and teaching platform that allows teachers to create new inquiry-based learning environments with embedded reflective supports (Kyza & Constantinou, 2007). The STOCHASMOS platform is comprised of two distinct environments: a) the learning environment, where students have the opportunity to collect and organize data, articulate their ideas and construct evidence-based explanations and b) an authoring environment, where teachers can create or modify various inquiry environments. The STOCHASMOS learning environment is designed to facilitate students' sense-making process, through a number of different features such as the *glossary*, *hints-on-demand*, the *data capture tool*, as well as the *templates* and the *toolbox* which are located in the WorkSpace area. While students interact with the materials in the learning environment, they have the opportunity to work in two different areas, the Investigation area and the WorkSpace area. The Investigation area assigns student a certain mission and provides the information needed to support their decisions. The WorkSpace area facilitates the process of organizing and interpreting data. In the WorkSpace area, the students can use the templates made by the teacher in order to support their findings and justify their group's final decision. The learning environment of STOCHASMOS offers the possibility of a data capture feature (''Click to load camera''). Students are able to select information of interest to automatically store it in the Work Space Area and they can access and use this information, using the toolbox provided in the *templates*, in formulating arguments and presenting their final decision.

Outline of the web-based materials

In the context of this study, we developed two inquiry-based environments on the STOCHASMOS platform. The first, titled *'Decision Making Strategies'*, is intended to help students develop the optimization strategy. The second, titled *'Choosing the most appropriate bottled water'*, engages students in the process of processing the available information in order to identify the most appropriate drinking water.

''Decision Making Strategies'' investigation

The *''Decision Making Strategies''* investigation environment involves five steps - one in each of the five different tabs (*Students' Role*, *The Problem*, *Decision Criteria*, *Criteria Weighting*, and *The Optimization Strategy)* through which students are introduced to the optimization strategy in the context of buying a new watch (figure1). Through the eyes of Alex, a young imaginary boy, they follow the procedure of adjusting for the variation on measurement scales and adjusting for the variation in the relative importance of the criteria, weighting measurements, accordingly. Students are then asked to implement this strategy in a different context, the construction of a new power station.

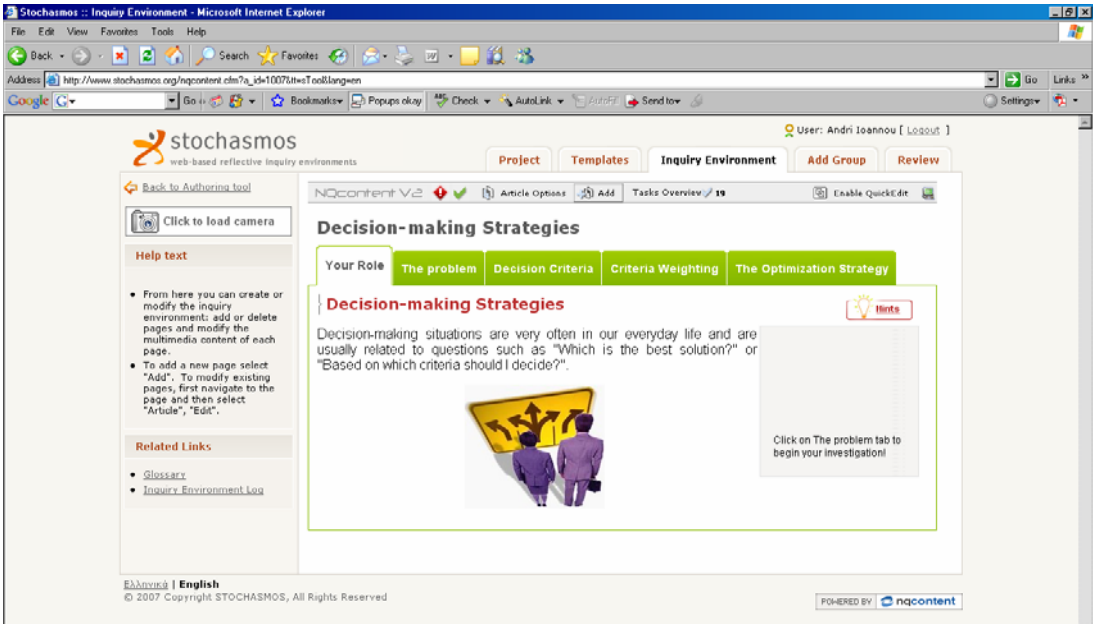


Figure 1. An example of the learning environment *Decision Making Strategies*.

"Choosing the best bottled water" investigation

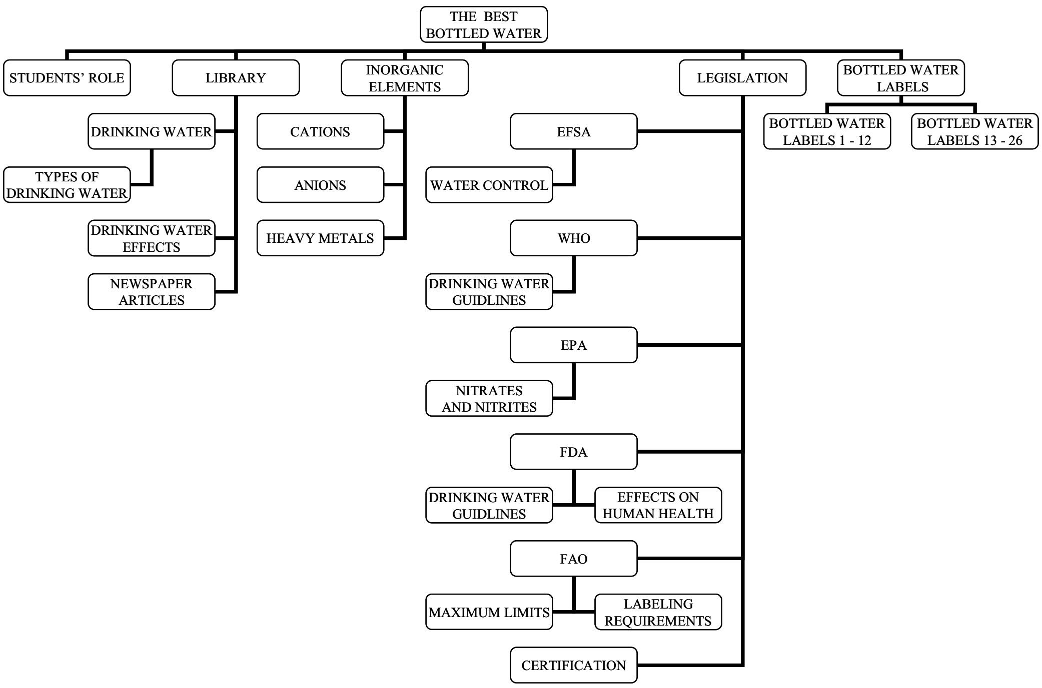
In this environment students are provided with information concerning the quality of drinking water, the legislation and specific guidelines proposed by international organizations referring to the allowable limits of trace elements in drinking water and information regarding other characteristics of bottled water (diagram 1). The learning objectives targeted at by this unit include the development of students' ability to:

(a) collect and evaluate data.

(b) apply the optimization strategy in decision-making.

(c) appreciate the need to understand the role of the various ingredients of water in determining the quality of bottled water.

Diagram 1. Chart flow of the learning environment '*Choosing the best bottled water'*.



The tabbed nature of the learning environment serves to organize the content of the environment and reduce possible cognitive load (Kyza & Constantinou, 2007). Specifically, the environment includes five different tabs: *Students' Role*, *Library*, *Inorganic Trace Elements*, *Legislation* and *Bottled Water Labels* (figure 2). In the first tab, students identify their task, which is the determination of criteria on which to base their decision about the best bottled water. The task is introduced through an open-ended dialogue between a boy and his teacher, discussing the constituents of drinking water. The *Library* tab contains information concerning types of drinking water and their physico-chemical composition in terms of essential constituents, drinking water's quality and control, possible effects on human health and the water's suitability regarding special age groups (infants and young children). The *Library* tab also contains information on labelling requirements proposed by international food organizations, and various newspaper articles on drinking water's quality.

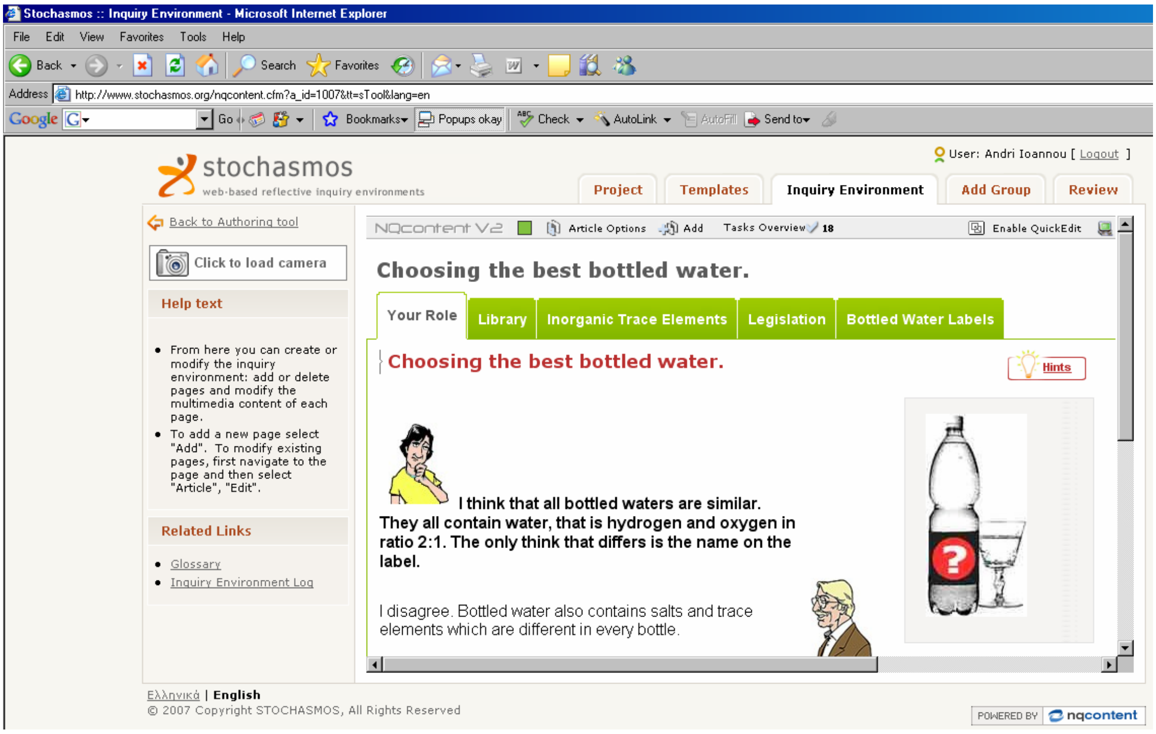


Figure 2. An example of the learning environment *Choosing the best bottled water.*

Students are provided with the opportunity to recognize the terminology and symbols of the trace elements that are commonly contained in drinking water, through exploring the *Inorganic Trace Elements* tab. In this tab, we have used a particular feature provided by the STOCHASMOS platform, the *hints*, which offers expert advice on demand. In particular, we created a hint to give learners further information through the on-line exploration of the periodic table of the elements. Both the *Library* and the *Legislation* tab include information regarding recommendations on quality guidelines, international laws and certification requirements, drawn by various international organisations, such as the EFSA (European Food Safety Authority), the WHO (World Health Organisation), the EPA (U.S Environmental Protection Agency), the FDA (U.S Food and Drug Administration), the FAO (Food Agriculture Organisation of the United Nations) and others. Finally, the last tab of the inquiry environment, the *Bottled Water Labels* tab, presents students with twenty-six scanned bottled water labels, which they are asked to process using the optimization strategy in order to find the best alternative.

Data Analysis

The methodology used in the analysis of the data followed a systemic network coding scheme, first suggested by Bliss, Ogborn, & Monk (1983). These networks allow for several parallel aspects of individual responses to be viewed in relation to each other and present a more complete account of how children respond to questions on a given topic (Osborne, Wadsworth, Black, & Meadows, 1994). The development of the network presents a dynamic process in that its structure is not imposed at the outset. It evolves during the data analysis process and it continuously undergoes modifications, as needed, so as to better describe the data.

The various branches of the network are connected through either a 'bar' or a 'bra'. The 'bar', an example of which is shown in figure 3, presents a part of the network of the various criteria employed by students in selecting water. The final categories of a bar are called 'terminals' and they are mutually exclusive in that students can only be assigned to a single terminal.

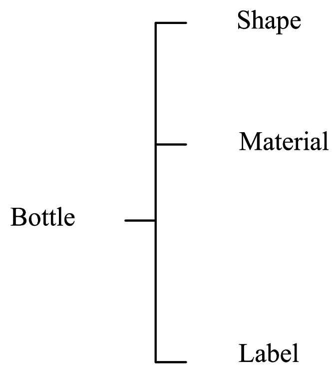


Figure 3. An example of a 'bar' used in systemic networks.

The 'bra' (figure 4) presents the converse case in that the categories are inclusive and students who fall under a certain category can be classified in any of its subcategories.

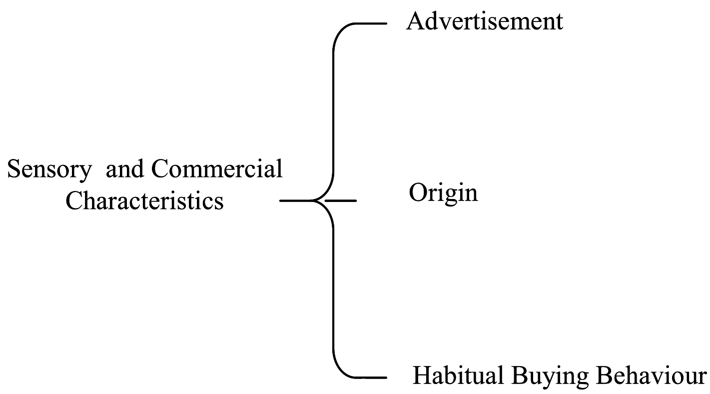


Figure 4. An example of a 'bra' used in systemic networks.

FINDINGS AND DISCUSSION

The complete network that emerged from the processing of students responses provides an overview of the various criteria they used in selecting among different types of bottled water (figure 5). It also shows the umber of students that relied on each criterion prior to and after the teaching intervention. The first level of the network consists of three main categories of response. The first concerns criteria that are directly relevant to the *quality* of drinking water, the second relates to *other bottled water's characteristics* and the third includes students who mentioned that they do not have any preference for a particular water and, hence, do not appreciate the need to use any criteria. The *Content in chemical substances*, the *Certification* and the *Source* categories, are represented by an inclusive 'bra', which indicates that students who fall under the *Quality* category referred to one or more of these aspects. The *Other Characteristics* category produces two 'terminals'. The first includes students who relied on external characteristics of the bottle, such as shape, material and label information. Students who referred to label information mentioned either the language or the units that appeared on the bottle. The second terminal (*Sensory and Commercial Characteristics*) includes five subcategories represented by a twofold 'bra'. The first two, are *Taste* and *Price*, followed by the water's *advertisement* policy, the water's *origin* or students' *habitual buying behaviour*. This categorisation suggests that prior to the intervention students relied on social rather than scientific factors in selecting bottled water and this is consistent with findings reported in the literature indicating that high school students' evaluations of information is affected by emotional factors (Yang and Anderson, 2003).

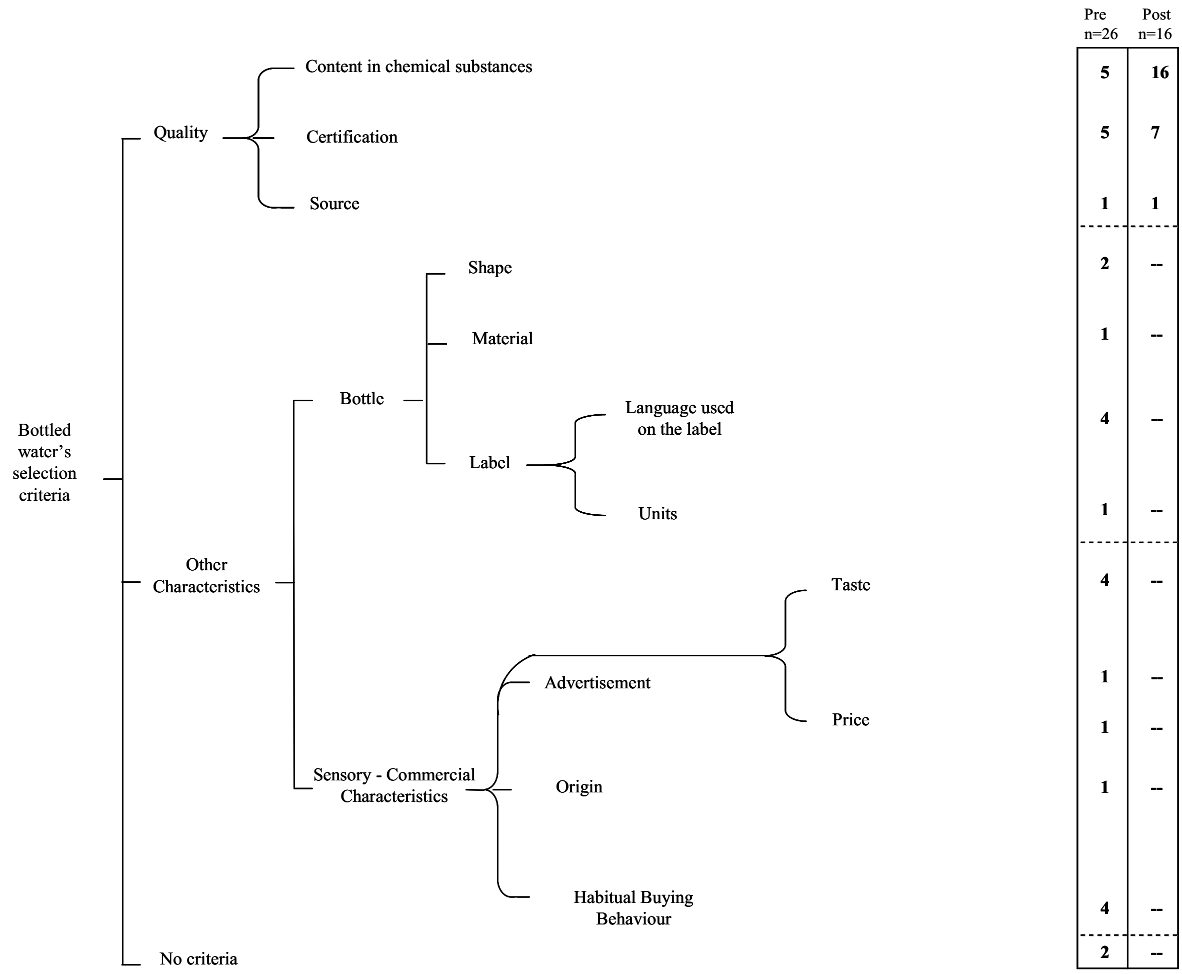


Figure 5. Final network used to categorise students' responses from the pre and post – instruction tests.

Table 2. Examples of student answers for each category of the network.

Content in chemical substances	*I choose this one because it is high in minerals which are good for our health.*
Certification	*I prefer this one because it is approved by the government.*
Source	*I choose this water because it's more pure. It comes from the mountains.*
Bottle Shape	*I choose this bottled water because its bottle has a nice shape and it helps me hold it.*
Bottle Material	*This bottled water is better because the bottle is strong.*
Language on the label	*This bottled water, because it states the constituents both in Greek and in English.*
Units	*I choose this water because the information on the label is stated both in Greek and in English, and also I can see the measurement units.*
Advertisement	*I choose the 'Ayios Nicholaos' bottled water because I see it very often on television.*
Origin	*I choose the 'Agros' bottled water because it is produced in Cyprus.*
Habitual Buying Behaviour	*I usually buy this one, so… I prefer this one.*
Taste	*This one, because it tastes good.*
Price	*This one, because it's the cheapest.*
No criteria	*I don't have any particular preference. For me, all bottled waters are the same.*

Table 3. Percentages of students' answers in each category.

				Pre n=26	Post n=16
QUALITY	Content in chemical substances			19,2 %	100,0 %
	Certification			19,2 %	43,8 %
	Source			3,8 %	6,3 %
OTHER CHARACTERISTICS	Bottle	Shape		7,7 %	0,0 %
		Material		3,8 %	0,0 %
		Label	Language	15,4 %	0,0 %
			Units	3,8 %	0,0 %
	Sensory – Commercial characteristics	Advertisement		3,8 %	0,0 %
		Origin		3,8 %	0,0 %
		Habitual Buying Behaviour		15,4 %	0,0 %
		Taste		15,4 %	0,0 %
		Price		3,8 %	0,0 %
NO CRITERIA				7,7 %	0,0 %

One important finding that should be noted relates to the comparison between the frequency of the students who fall into the various categories of response prior to and after the teaching intervention (Table 3). Prior to the teaching intervention only a small part of students relied on quality criteria, while many of them and many of them referred to external characteristics of the bottles or suggested that there is no real need to make a choice between different bottled water. On the contrary, after their interaction with the learning environment all participants relied on quality criteria and all referred to the ingredients of water.

Concluding remarks

This study has investigated the criteria used by students in selecting among different bottled waters and examined the extent to which their interaction with the learning environment has helped them develop informed ideas concerning the criteria that determine the quality of drinking water. The results of the study suggest that students' interaction with the learning environment in the context of the bottled water

selection task helped them appreciate the need to carefully assess the quality of drinking water taking into account certain criteria related to quality and ignoring other issues that are not related to quality.
The use of socio-scientific issues in the development of teaching and learning materials helps students extend their learning beyond the classroom, as they apply their knowledge and decision skills to real world problems. The analysis of students' discourse revealed several criteria used by students for decision-making on bottled water, relevant to the quality of drinking water or other characteristics such as bottle, price, label, origin, etc. There were also some students who used no criteria for their decision. Our findings imply that the students involved in this study used certain criteria after the implementation of the materials. After the intervention, all students' arguments were based on quality matters, in terms of content in chemical substances, certification matters or source of the water. For example, all students used at least once in their explanations, the water's content in minerals or in chemical substances which are dangerous for human consumption. This is a case where there was a significant added value in employing web-based learning materials concerning socio-scientific issues in science classrooms. Furthermore, students appreciate certain aspects of the decision making process, such as the important role of criteria and the need to rely on them in justifying the selection of a certain alternative option.

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