Improving students' use of content knowledge when dealing with Socio-Scientific Issues: the case of a physics-based intervention

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Abstract. In this paper we present the results of a four-week laboratory-based intervention aimed to improve 14-15 years old students' capability of exploiting Physics content knowledge when discussing Socio-Scientific Issues (SSI). Energy transfers and conservation, modelling and data quality were addressed using four SSI scenarios as teaching contexts. A mixed method approach was adopted to analyze students' responses to pre- post- and delayed assessment tasks. The analysis shows that after the intervention students were able to meaningfully exploit the addressed Physics concepts to support in an informed way their decisions about the proposed SSI; moreover, results show no significant differences in the students' outcomes according to the activities followed during the intervention. Overall, the study here presented provides support for introducing in Physics and Science school curricula SSI-based interventions.

1. Background and focus of the research

Socio-Scientific Issues (SSI) approaches are situated learning contexts (Sadler, 2009) which engage students in authentic practices (e.g. hands-on activities), and stimulate their own moral thinking and judgment about issues that affects society. As Zeidler et al. (2005) argue:

"SSI education aims to stimulate and promote individual intellectual development in morality and ethics as well as awareness of the interdependence between science and society. SSI therefore does not simply serve as a context for learning science, but rather as a pedagogical strategy with clearly defined goals" (p. 360).

SSI encompasses general ethical dilemmas or personal moral concerns which require students to exploit: arguments based on content knowledge; informal reasoning; explicit reflections on relevant epistemology aspects; personal connections at micro- (familiar), meso- (state citizenship) and macro- (human race perspective) level with the issues. In the SSI environments, environmental, economical, political, moral and ethical considerations are needed to offer students learning opportunities to prepare them to act as contributors to the life of the society which they live in or as future active citizens (Bencze, Sperling & Carter, 2011; Mueller & Zeidler, 2011).

Previous studies have shown that SSI approaches may be powerful contexts to enhance key skills as argumentation (Jiménez-Aleixandre & Pereiro-Muñoz, 2002; Dawson & Venville, 2010; Evagorou, 2011), reflective judgment (Zeidler et al., 2009), informal reasoning (Wu & Tsai, 2007; 2010) and decision-making (Grace, 2009; Gresch, Hasselhorn & Bögeholz, 2011). Despite these results, the extent to which students actually learn Science contents through SSI approaches remain an unresolved issue (Von Aufschnaiter et al., 2008; Sampson & Clark, 2008). To this concern, although positive outcomes of SSI approaches on students' understanding of Science concepts relevant for the addressed issue have been reported (e.g. Sadler, Barab & Scott, 2007; Castano, 2008; Venville & Dawson, 2010), few studies investigated in a deeper way the relationships between students' science knowledge and the quality of their informal reasoning about a given SSI from the scientific viewpoint (see, e.g., Zohar & Nemet, 2002; Sadler & Zeidler, 2005a) and, more specifically, how students rely on more elaborate scientific knowledge when they engage in discussions about SSI (Lewis & Leach, 2006; Sadler & Fowler, 2006).

Only recently, the interest amongst scholars in investigating the effectiveness of SSI instruction on students' learning of science contents has grown up (e.g., Bravo-Torija & Jimenez-Aleixandre, 2011). In particular, specific teaching interventions have been developed with the explicit aim of improving students' use of content knowledge in SSI discourse.

For instance, Klosterman & Sadler (2010) and Sadler, Klosterman & Topcu (2011) reported data about a teaching unit on global warming implemented with Secondary School students. The unit addressed both the content and the controversy about global warming; the activities featured tasks aimed at the identification of students' opinions about the global warming issue, laboratory exercises and the elaboration of a policy report on the basis of climate data. In the laboratory tasks the students could explore the concentration of CO2 in different air samples, the production of CO2 and its effect on air temperature in greenhouse models. A multi-level assessment was used for documenting students' learning: a standard-aligned test and a curriculum-aligned open questionnaire about the global warming. The authors report significant gains in the standard-aligned test as well as in the curriculum aligned questionnaire where students expressed more accurate and sophisticated ideas about the addressed issue. However, the analysis of the curriculum-aligned questionnaire addressed knowledge about global warming rather than students' use of such knowledge about the issue.

The learning unit proposed by Dolan, Nichols & Zeidler (2009) proposes a set of activities for pre-service elementary teachers courses aimed at showing how to situate in school practice the teaching of basic science contents into SSI scenarios. In the proposed unit, contents about Earth and Life Science (mechanical erosion, food chain, ecosystems) are first explored through hand-on activities then a moral question is posed to let students use acquired content knowledge to negotiate about the issue. A further activity addresses basic contents in Mechanics (velocity, momentum and friction). First the students are engaged in a laboratory activity concerning the effect of reducing friction during the motion on a Slip and Slide (a toy constituted by a long plastic track in which water flows to allow children to slip): during the activity the students record the time needed to slip over the plastic track without soap trials (greater friction situation) and with soap trials (smaller friction situation) and then calculate their velocity and momentum. Then, the students are required to apply their acquired knowledge in a debate about current speed limits and whether they should be changed.

Both the above examples reflect a view which is quite different with respect to other SSI approaches, where contents from frontier Science (Kolstø et al., 2006; Simonneaux & Simonneaux, 2011) are the foci of issue (e.g. genetics, Puig & Jimenez-Aleixandre, 2011). While this view preserves the authenticity of the controversial context, "core" Science contents which are still central for traditional school curricula run the risk to be left out, with the possible reinforcement of the existing barriers that prevent SSI approaches to spread into school practice (Sadler et al., 2006; Tytler, 2011).

To address this problem, we argue that it is necessary to reconsider the choice of the contents addressed in SSI approaches in order to investigate the extent to which classroom interventions may actually impact on students' capability to exploit their knowledge of scientific contents when dealing with SSI. In particular, this study contributes to the SSI research field addressing how Physics conceptual understanding is used by students when they are engaged in discourse about SSI. Physics has been until now very rarely addressed in previous SSI studies although informed discussions about, e.g., nuclear plants, environmental pollution, illness due to mobiles phones, global warming, etc…, would require a profound knowledge of Physics concepts and methodologies. On the contrary, using Physics-based SSI may guarantee the co-existence in the intervention of both an up-to-date content and a relevant human-related ethical tension.

The research questions that guided the study are:

1. What are the effects of a physics-based intervention on students' capability to use relevant content knowledge when engaging in SSI discourse?
2. Are there differences between students performances due to the activities followed during the intervention?

2. Materials and Methods

2.1 Research background for the design of the intervention

The choice of the contents to address in the intervention was inspired by the few previous studies which concerned physics-related contents as the quality of scientific data (Albe, 2008a; 2008b) and the usage of nuclear energy (Yang & Anderson, 2003). The studies by Albe basically investigated the effects of the proposal by Hind, Leach, Ryder, & Prideaux (2001). This proposal is subdivided into three teaching units concerning the purposes of scientific investigations, the nature of theoretical explanations in science and the assessment of the quality of data. The activities of the units focus mainly on the methods used by professional scientists to carry out their investigations, to construct theoretical modelling of observed physical phenomena and to interpret and validate the collected data. The related physics contents (e.g., measurements' uncertainty, components and functions of a scientific model) are addressed throughout six activities, one of them focused on the controversial issue of mobiles phones risks. Students' use of acquired content knowledge is assessed through a number of probes: for instance, one concerns different positions of scientists on which theoretical model provides the best data interpretation, another is focused on what conclusion to be drawn from contradictory research findings. After the pilot implementation, the authors report a general positive trend associated to all the units (e.g. increased awareness of the role of models in science). However, some difficulties in relying on content knowledge were detected in the discussion about the conflict between contrasting models. From the excerpts reported by Albe in both studies, it emerges that after the class activity technological and scientific knowledge were poorly exploited by students in their argumentation patterns; students in their argumentations referred most frequently to personal opinions (*"According to me, cell telephones have an effect of physical health and I think have long-term effects on psychological health"*). The reported data provide only in few cases evidence about students' use in their argumentations of correct content knowledge (*"Electromagnetic waves are rich in energy and we also know that high frequency waves are high energy one and that the mobile contains both the transmitter and the receiver in a single unit, so cell phones are dangerous for health"*), referring also to the trustworthiness of scientific research methods and the necessity of reaching a consensus in the scientific community to make an informed decision about the issue.

The study by Yang & Anderson (2003) provides some evidence of a generic use of physics content knowledge in 12th grade students' arguments about nuclear energy. A 24 items Likert-scale type questionnaire (12 items addressing scientific viewpoint, 12 a more socially related perspective) and a semi-structured interview concerning a nuclear plant water pollution incident were used to assess students' orientation towards the issue and to investigate students' informal reasoning. During the interview, the students were provided with an increasing amount of scientific information about the issue. Amongst the background variables there was also the level of knowledge about properties of atoms and radioactivity. Results from the questionnaire show that students were keen to use both scientific and social perspectives. However, in the interviews, students more oriented towards the scientific perspective were more able to draw on scientific content knowledge in their discussion about the pollution incident *"…it was the wastewater… the water was used to cool the reactor, it could have very high temperature…" "…the cause was probably the wastewater because the amount of radiation human can take might be very different from what the fish can take…"*. Moreover, it emerged that also equally oriented students were able to draw upon scientific information to support their reasoning in the negotiation of the issue. Finally, a regression analysis showed that students who performed well on the nuclear energy knowledge test more likely used a scientific oriented perspective.

2.2 The physics-based SSI teaching materials

Drawing from the above studies, energy was chosen as a possible transversal content to be addressed in intervention. In particular, we focused on:

- energy conservation (CE) and transfer (TE) in industrial plants;
- mathematical models and graphs (MM), data validity and reliability (DQ) in establishing risks for human health due to the use of traditional and renewable energy sources.

The specific topics were adapted for the first two years Secondary School Curriculum (students' age 14-16). The reason was related to the fact that these contents are supposed to be addressed at that level in all the sci-

entific subjects (Physics, Biology, Chemistry and Earth Sciences) of the different Italian Secondary School streams (Classical, Scientific and Socio-Pedagogical Lyceums, Technical and Vocational Schools).
Correspondingly, we designed four SSI scenarios, extensively debated in Italian newspaper in the past two years:

- construction of an energy recovery waste incineration plant (WI);
- development of research to increase the production of electric cars (EC);
- construction of a nuclear plant (NP);
- increase of bio-fuels production (BF).

In particular, WI received an extreme exposure on international press due to the waste crisis in the author's hometown, while discussions about the risks of NP in Italy were re-fuelled due to decision of the government in 2009 to start a nuclear program after 23 years of interruption
For each of the four scenarios, two contrasting perspectives about the addressed issue were provided, with an explicit focus on content knowledge and its relationship with the ethical controversy embedded in the issue.
The intervention featured six class activities, each of about two hours, carried out with students organized in small groups.

- in the first two, each group discussed the scenario through the reading of a fictitious newspaper article which reports the two contrasting perspectives; afterwards, the students, through a class discussion, were guided to elicit the physics concepts relevant for the discussion of each issue;
- in the third, fourth and fifth one, the small groups performed laboratory measurements addressing the specific physics content relevant for the issue discussed in the previous activity; worksheet-driven inquiry tasks were assigned to each group with the basic aim of collecting and analyzing data;
- in the sixth one, the students were asked to discuss in small groups the findings of the previous laboratory session and to communicate to the other groups, in the form of a conference-like brief talk, how they have resolved the assigned issue and if and how the addressed physics content helped them.

A guide was developed to help the volunteer teacher in the implementation of the activities. An updated version will be available soon. The guide presents suggestions for the class discussions focusing on the content underlying all the debated issues. An outline of the intervention is reported in Table 1. A brief summary of the four used scenarios are reported in Appendix A.

Table 1 Outline of the intervention

SSI scenario ***Physics content***	**Presentation of content focused conflicting perspectives (Activity 1)** **In favour**	 **Against**	**Related experimental activity (Activity 2)** ***Learning objectives***	**Review of evidence to resolve the SSI scenario (Activity 3)**
Energy recovery waste incineration plant *Energy conservation*	Waste incinerator plants can produce energy from urban wastes	Low energy efficiency and high pollution risks	Analysis of voltage vs. time graphs in a RC series circuit *To understand that energy is quantity that can be measured before and after any process and that its amount is constant through the process*	Energy cannot be produced during the waste incineration process; rather, part of the initial energy can be stored and re-used, part is dissipated in the environment and cannot be re-used
Development of research to increase the production of elec-	Absence of CO_2 emissions	Scarce autonomy and excessive water consume	Determination of the equilibrium temperature in the mixing of two water masses at differ-	The energy of an electric car battery has to be transferred to all of its part (brakes, wheels,

tric cars *Energy transfer*			ent initial temperatures *To understand that energy can be transferred spontaneously from an object at a higher temperature to another at a lower temperature*	lights, …). Amount of energy needed would require bigger batteries or very frequent recharges with a corresponding increase of water consume
Construction of a nuclear plant *Mathematical models and modelling*	Increasing social energy need Low health risk due to low radiation emissions as supported by linear models	High health risks even at low levels of radiation emitted as supported by complex models	Measurement of s(t) and v(t) of a walking person *To identify the main characteristics of linear relationships* *To understand that the predictive power of models depend on their assumptions and components*	Linear relationships between health risk vs. radiation quantity is inaccurate due to coarse hypotheses at the basis of human body radiation absorption models. Predictions of more accurate human body radiation absorption models give account of cancer and leukaemia evidences nearby nuclear plants
Increase of bio-fuels production *Data quality*	Low CO_2 emissions, as supported by a simulation software concerning one bio-fuel	Greater CO_2 emissions throughout the production process as supported by experiments on several bio-fuels	Measurements of masses with a dynamometer and a force sensor *To understand that the number of measurements and their repeatability increase the reliability of the findings*	Evidence provided by studies that are not repeatable or focused only on one aspect are not reliable.

2.3. Context and sample

The intervention was implemented by the first author, a teacher with about 10 years of experience in Secondary School. The school was located in a small but highly populated suburban town in South Italy, with dramatic problems of micro and organised criminality. The implementation lasted overall 4 consecutive weeks during curriculum hours, three hours per week. Twenty-four 14-15 years old girls (intact class) of the socio-pedagogical Secondary School stream were involved. The students were subdivided into four groups, each committed to work on one of the four issues throughout the entire intervention. As a consequence, each group could deepen only the physics content corresponding to the discussed issue. The assignment of the students to the four groups was made in agreement with the teacher.

2.4 Instruments and data analysis

To assess the effectiveness of the intervention, a pre-post design was adopted. Two instruments were used

- a semi-structured interview (Interv. 1) featuring three questions about the scenarios discussed during the intervention and reported in Appendix A: 1) Are you in favour of…?; 2) On what do you base your decision?; 3) If someone does not agree with you, how do you respond to such criticism?);
- a semi-structured interview (Interv. 2) on different SSI as: possible effects on human health of mobiles' use, and the pseudo-scientific dispute about possible catastrophes that should happen on the Earth in 2012. The reason for including the 2012 issue is related to the fact that pseudo-science can

be fruitful a context to investigate how students rely on science when defending their positions in debating controversial issues (Afonso & Gilbert, 2010). This interview featured three questions: 1) what do you think about what you have read? 2) on what do you base your point of view? 3) if someone has a different viewpoint, would you try to convince him/her? These two complementary scenarios are reported in Appendix B.

The aim of using two interviews was to draw evidence about students' capabilities of using the acquired knowledge in the assigned SSI as well as transferring it in different socio-scientific contexts, thus increasing the reliability of the findings. To investigate follow-up effects of the intervention, students were all interviewed about the assigned SSI scenario also three months after the end of the activities using Interv. 1 protocol. The interviews were audio-taped and transcribed for investigation purposes.

To answer the first research question, pre- and post-intervention students' responses to the first two questions of Interv. 1 and Interv. 2 were globally analyzed using a set of a-priori categories, inspired to those developed in the studies by Zohar & Nemet (2002) and Fowler & Zeidler (2010; 2011). The categories feature overarching levels which reflect students' progression in the use of content knowledge in their argumentation about the proposed SSI. The adopted categorization focuses on arguments which explicitly refer to scientific evidence and concepts: at the highest level, there are arguments with grounds based on multiple references to scientific evidences and concepts; at the lowest level, there are arguments with no scientific grounds or based only on other types of factors (e.g. economical, social, religious, moral, ethical,…). A similar categorization scheme was used to analyze the responses to the third question of both interviews. The description of the adopted categories and corresponding typical students' responses to Interv. 1 are reported in Table 2 and 3.

To answer the second research question, the categories were scored to compare the results obtained by those students who followed the energy-related activities (CE and TE) and those who followed the modelling/data quality-related activities (MM and DQ).

To increase reliability of the findings, three raters analyzed the students' responses. The initial analysis was performed by the authors of this paper to identify a first categorization of students' responses and possible amendments to the categories emerging from data; then, an expert in physics education performed an independent analysis of a random group of students' responses using the adopted categories to check validity of the initial analysis; finally, discrepancies between the raters were discussed and a final analysis was agreed. The same categories were used to analyse the delayed-post interview responses.

Table 2 Description of categories and typical students' responses (first two questions of Interviews)

Code	Category description	Example response (Scenario)	Score
Questions: are you in favour of…?; on what do you base your decision?			
C0	No answer or answer generically; no reference to scientific evidence or concepts	*… I would support the construction of a waste incinerator plant near my house … nobody wants it but unfortunately garbage production increases and therefore it is the only solution (WI)*	0
C1	Some reference to scientific evidence; no or incorrect reference to scientific concepts	*…I would support the development of research to increase the production of electric cars since there would be less pollution and no dangerous emissions (EC)*	1
C2	Some reference to scientific evidence and to correct scientific concepts	*…I would not support the construction of a nuclear plant near my town since the graphs that I've seen tell that this kind of energy is very dangerous for both environment and people… (NP)*	2

C3	Multiple reference to scientific evidence and correct scientific concepts	*... I would not support the increase of bio-fuels production since they are up to 5 times more polluting than oil... There has been a great number of repeated laboratory experiments that prove this... (BF).*	3

Table 3 Description of categories and typical students' responses (third question of Interviews)

Code	Category description	Example response (Scenario)	Score
Question: if someone does not agree with you, how do you respond to such criticism?			
D0	No answer or answer generically; no reference to scientific evidence or concepts	*.. I do not want to change another person's opinion about the waste incinerator, everyone is free to think whatever he wants (WI)*	0
D1	Generic or incorrect reference to scientific evidence;	*...I would respond to critics showing how wrong are some models about nuclear energy risks (NP)*	1
D2	Some reference to scientific evidence and correct scientific concepts	*...I would respond to critics saying that the number of experiments carried out is sufficiently large for the conclusions to be reliable (BF).*	2

3. Results

3.1. Research Question 1

Interv. 1

The distribution of the categories of answers to the first two questions of the Interv. 1 is reported in Figure 1. From the qualitative analysis it emerges that nine out of 22 students (two were absent during the intervention) were able in the post-test to support their decision about the intervention-related SSI scenarios referring in a correct way to one or more of the addressed physics concepts and that this number has not decreased significantly after three months (seven out 22).

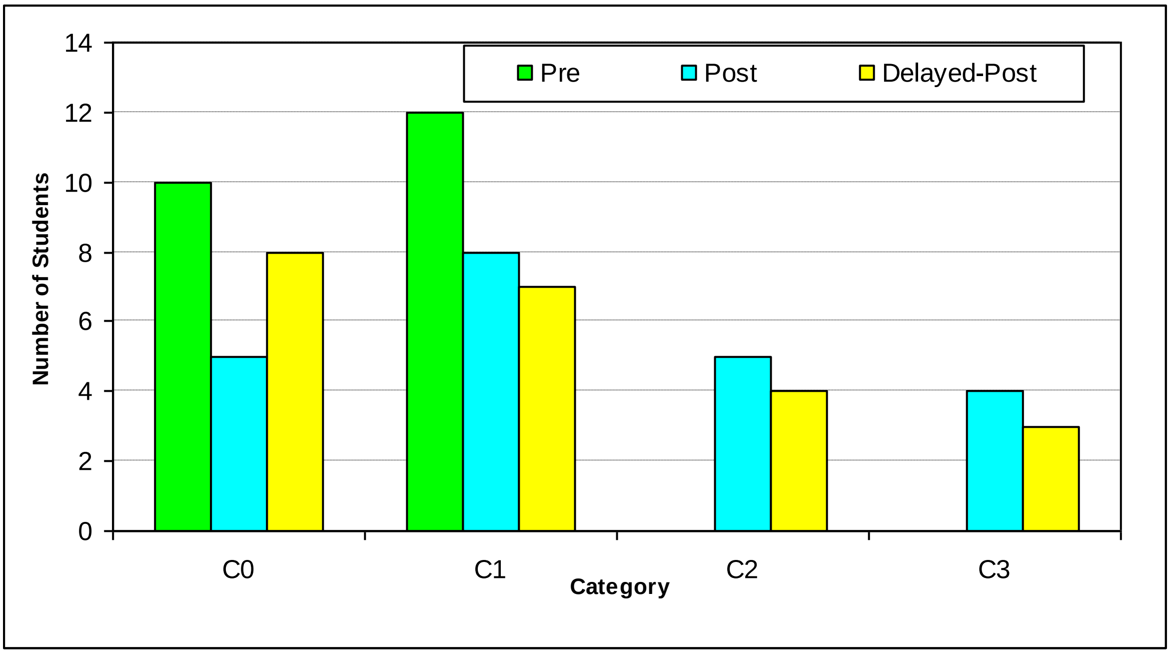

Figure 1: Category distribution of answers to the first two questions of Interv. 1 according to administration time

More specifically, the analysis shows that 13 students increased the quality of their arguments about the SSI addressed in the intervention between the pre- and post-test interview. The case of the student S6 is exemplar. In the pre-test interview this girl seemed to have some difficulty in distinguishing between evidence and abstract models.

I: So what is your decision about the issue?

S6: ... well... I’m in favour of the protests against the nuclear plant since scientists have calculated on the basis of a model the risks…

I: What do you mean by this?

S6: ... that the predictions about the risks can be proved through graphs and data which show the percentages of deaths…”

Since she does make a reference to scientific knowledge but it is incorrect, the pre-test category is C1. In the post-test interview this student seems to use in a more appropriate way the risk model to support her decision.

I: So you did not change your idea, right?

S6: Yes, I still support the protest because the models for the [radiation] risk based on previous studies and actual results demonstrate that this energy can be dangerous for the environment and the people…we have read that emitted radiations are harmful… Actually there are millions of persons who died by cancers due to nuclear radiations…

I: Can you elaborate more on this?

S6: Well… according to me it is wrong to be in favour of the nuclear energy saying that there are many plants (in countries) near Italy... not only data and models prove that nuclear energy produces damages but there are the environmental issues of the leftovers…

When asked to clarify her idea about models and why models are important for her she answered:

S6: Models are important because they give us more objective information…graphs are more objective than simple language…

From these excerpts, it emerges that she uses multiple reference to scientific knowledge (data, models, radioactive residuals), so the post-test category is C3.

In another case, a change in the viewpoint between the pre- and post-test corresponded to a progression in the argumentation quality. In the pre-test this girl reasoned in the following way:

I: So what is your decision about the law in favour of biofuels?

S24: I'm in favour… since the viewpoint in favour of biofuels is more reliable… it is right to diminish the use of not renewable resources... moreover it is an initiative useful for the whole world… the second viewpoint (against) is not right since, although it goes against poor countries, the use of biofuels can help to solve the problem of pollution.

Here the student seems to use prevalently a moral judgment reasoning to support her decision although the justification relies on an environmental viewpoint (to reduce the air pollution). Since there is a generic reference to the evidence of pollution and to the renewable energies, the pre-test category is C1. In the post test, this student changed her idea and to support it she made a reference to the fact that a conclusion based on more than one experiment can be considered reliable:

S24… I changed my idea since from the articles I have read and from the experiment we carried out I have understood that the viewpoint for which biofuels are more polluting than oil is more reliable…

I: Are you sure? What more would you say?

S24: …Yes, I'm sure… my decision is based on the several experiments carried out…

From these excerpts, a progression in the argumentation quality is evident and therefore the category is C2. In the delayed test this student was able to include in her arguments multiple references to scientific methodologies therefore the argumentation quality can fall into the C3 category.

I: …So, do you remember the issue… what is your idea now about the biofuels bill?

S24: Well, I have not changed my idea again… according to some experiments carried out in the laboratory, the biofuels resulted 5 times more polluting than oil and moreover they are much more expensive…the simulation was not as convincing as the experiment since it was made by the same group… hence it cannot be repeated… on the contrary the experiment can be repeated by other groups…

Also the following student showed a progression related to a change of viewpoint about the issue. In the pre-test interview, she was in favour of the waste incinerator.

I: Can you clarify your view…? Why do you support the construction of the incinerator?

S12: … Well actually I would like to have more data, I would like to see if the pollution of the air is higher after using the waste incinerator…

In this answer there is a generic reference to scientific evidence (need for data) therefore the initial category is C1. In the post test interview, she showed an improved capability in using scientific concepts to support her decision:

S12: … Now I would support the protests against the incinerator since, even if it burns the wastes, part of the energy is dissipated in the air as pollution and this could bring serious damages to our health… It is wrong to say that it creates energy…

In this case there is a reference to the concept of energy and to the issue of its dissipation when burning wastes. Therefore the category is C3. Finally, in the delayed interview, this student confirmed to have acquired the capability of using meaningfully content knowledge when discussing about the proposed issue:

S12: …I'm against the waste incinerator… it pollutes a lot and it is not as useful as I thought at the beginning since it is not true that it produces more energy… some documents wanted us to believe that at the end more energy comes out… but we have seen that it is the contrary… this enters and the same goes out… moreover there was the fact that it pollutes as three cars… it cannot be true, since the waste incinerator plant is actually very big...

Results of the analysis of students' answers to the third question are shown in Figure 2. Note that in the post-test, eight out 22 students were able to defend their decision with correct reference to scientific contents, hence showing a significant progression with respect to the pre-test; however, in the delayed-test only five students were still able to defend their decision in a correct way from the scientific viewpoint.

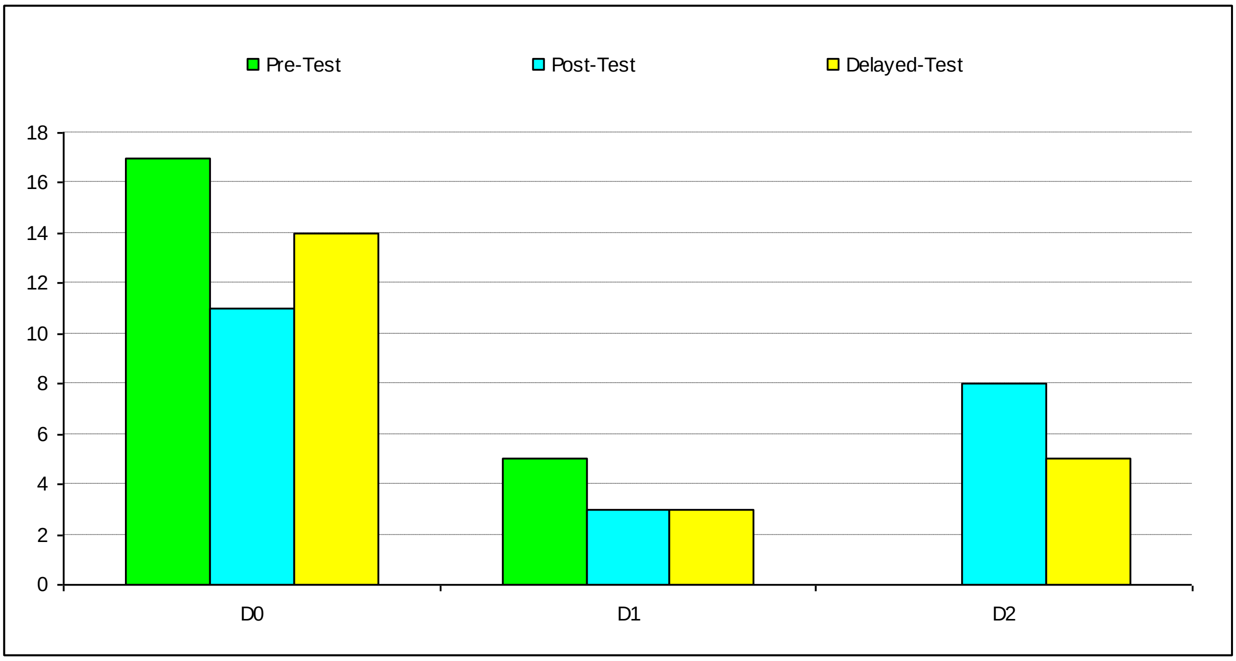

Figure 2: Category distribution of answers to the third question of Interv. 1 according to administration time

Interv. 2

Figure 3 shows the distribution of the categories of the responses to the first two questions of Interv. 2. Whereas in the pre-test only 2 students were able to discuss about the 2012 and mobiles controversies with at least some reference to scientific evidence, in the post-test, about 10 out of 22 students were able to do so; among these, 4 students in the sample made significant reference to scientific evidence and concepts when discussing about both controversies.

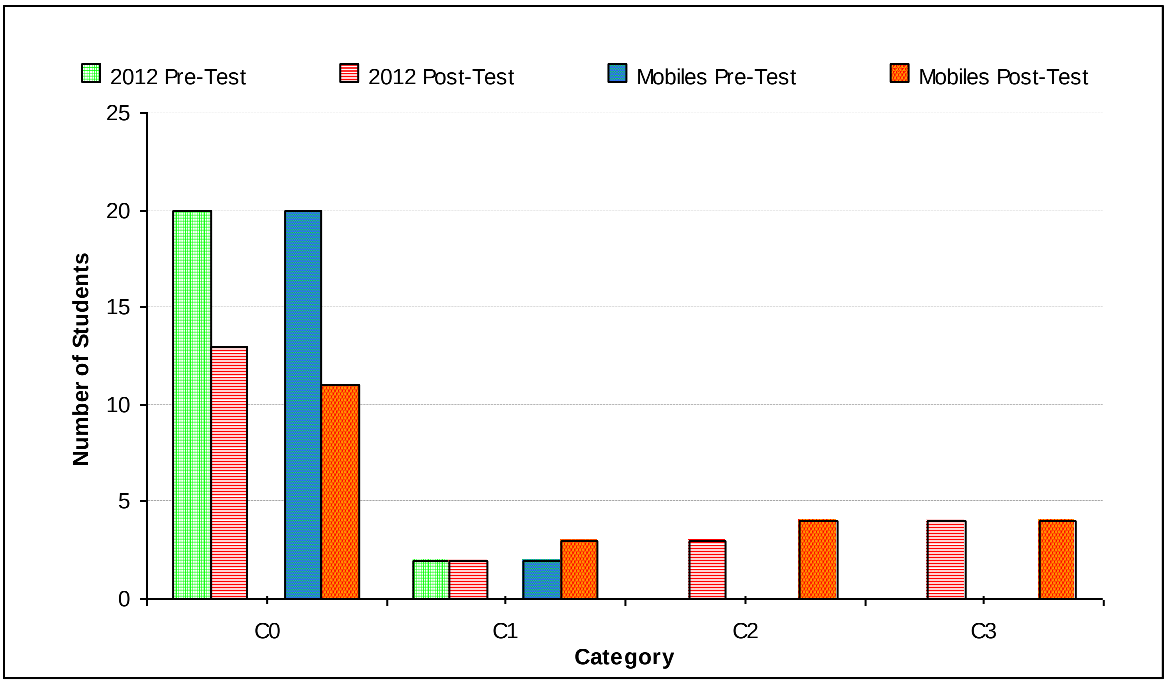

Figure 3: Category distribution of answers to the first two questions of Interv. 2 according to administration time

The following student, who followed the DQ activities, showed a relevant progress between the pre- and post-test interview about the mobiles issue. In the pre-test interviews she seems to believe whatever the media say about the issue:

I: so what your idea about what you have read?

S8: I think it's true that to stay too close to a mobile phone too much time can cause damage…

I: why do you think this?

S8: It is well known that electromagnetic radiation cause diseases with time… I have seen this in the TV news, in advertisements on this topic…

Since the position is based on a generic and naïve reasoning, the initial category is C0. In the post-test she shows a more informed and reasoned position on the mobiles issue:

I: so, what's your idea now about what you have read?

S8: in my opinion, it is not yet possible to say who's right since we should base our decision on the research methods followed in both bases and on the number of experiments carried out to prove what these authors are claiming… I would like to have more data to express a position.

This excerpt seems to indicate that this student was able to use her acquired knowledge about the quality of data to discuss about the issue. Therefore, the category in the post-test is C3. Another student, who followed the MM activities, showed, in the pre-test, some difficulties in discussing the 2012 controversy due to a scarce knowledge about the Earth' motion:

I: So, your idea about the 2012 is….?

S6: I don't think that the end of the world will come…

I: Can you elaborate more?

S6: … despite all the efforts, Science will never know for sure if the world will end on that day since there are no certain information even for the origins of the world… the end of the world will come slowly, caused by man himself…

This student shows the tendency to rely, at least in a generic sense, to scientific knowledge; hence, the category in the pre-test is C1. In the post-test discussion, this student seems to have acquired the capability of using part of what she has learnt during the intervention:

I: …So, what do you think about 2012 now?

S6: ... I still don't believe in the claims about the end of the world… there is no proof for this thesis provided by models or other evidences obtained through reliable scientific studies…you know, I would like to have some mathematical equation… some graphs.. There's nothing…

Hence, although the student seems to have not acquired new knowledge about Earth's motion between the pre- and post-test interview, it clearly emerges the capability of using multiple reliable sources of information, in terms of models, evidence and predictions, to discuss from the scientific viewpoint about the issue. Hence, the post-test category is C3.

The analysis of the answers to the third question (Figure 4) confirms the above positive results. In the post-test, four and five students were able to defend their position or showed the will to change contradictors' position with a correct reference to scientific knowledge on 2012 and mobile issues, respectively.

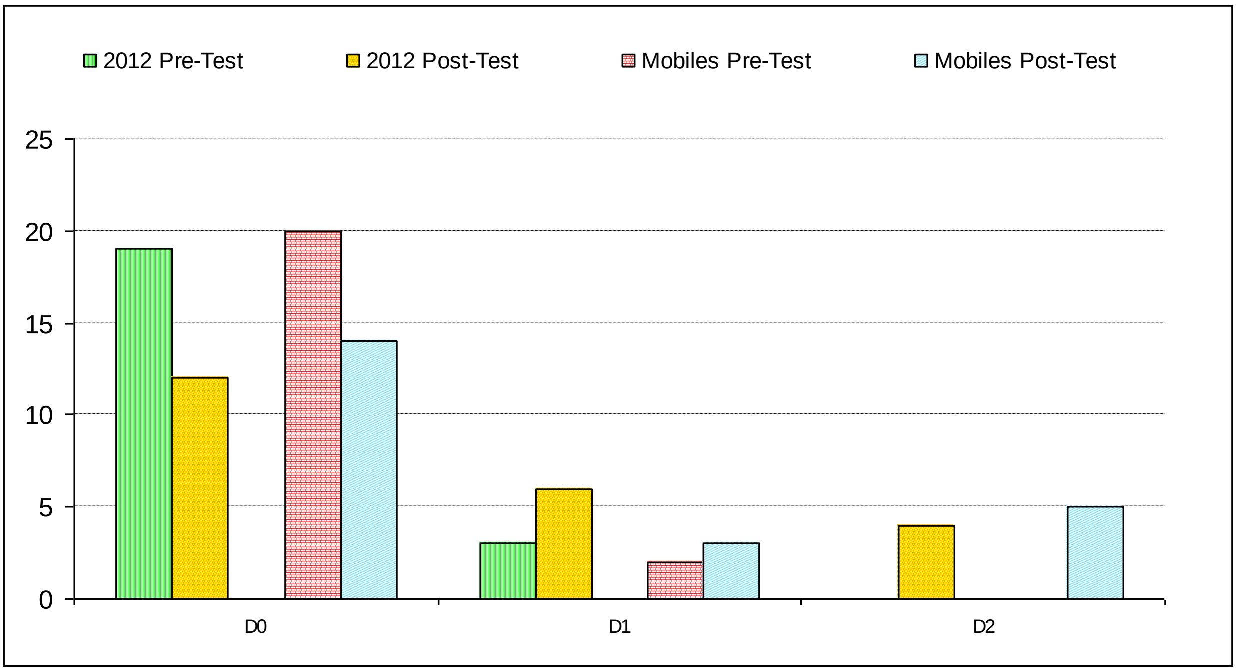

Figure 4: Category distribution of answers to the third question of Interv. 2 according to administration time

The quantitative analysis of the whole sample average scores obtained in the three questions of Interv. 1 and Interv. 2 (Table 4 and Table 5) confirms that the differences between the students' outcomes before and after the intervention are statistically significant for all the assessment probes. Non parametric tests were used due to the small number of students in the sample. The Cohen's *d* effect size analysis confirms a significant impact of the intervention's activities.

Table 4 Students' mean scores to Interv. 1 and Interv. 2 first two questions (Maximum score: 3)

Scenarios					
Intervention-related		2012		Mobiles	
Pre	Post	Pre	Post	Pre	Post
0.55	1.36	0.09	0.91	0.09	1.05
Z = -3,286*		Z = -2,565**		Z = -2,836***	
Cohen's d = 1,02^{+}		Cohen's d = 0,94^{+}		Cohen's d =1,11^{+}	

Wilcoxon Signed Ranks Test: * *significant, p= 0,001;* ** *significant, p= 0,01;* *** *significant, p= 0,005;* $^{+}$ *Large Effect*

Table 5 Students' mean scores to Interv. 1 and Interv. 2 third question (Maximum score: 2)

Scenarios					
Intervention-related		2012		Mobiles	
Pre	Post	Pre	Post	Pre	Post
0,23	0,86	0,14	0,64	0,09	0,59
Z = -3,071*		Z = -2,428**		Z = -2,428**	
Cohen's d = 0,89+		Cohen's d = 0,80+		Cohen's d = 0,84+	

Wilcoxon Signed Ranks Test: * *significant, p= 0,002;* ** *significant, p = 0,015;* + Large;

3.1. Research Question 2

For analysis purposes, the students were aggregated in two groups (CE/TE and MM/DQ), according to the type of activities followed during the intervention. The results are reported in Table 6 and Table 7. Differences between the two groups of students are not statistically significant in the pre-test for all questions of Interv. 1 and Interv. 2. In the Interv. 1 post-test, the MM/DQ group scored better than the CE/TE group in all the three questions but these differences are not statistically significant. In the Interv. 2 post-test, the differences between the mean scores of the two groups are statistically significant only for the first two questions. Correspondingly, the differences between the pre- and post-test scores for the MM/DQ group are statistically significant for all the questions of Interv. 1 and Interv. 2. For the CE/TE group the differences are significant only for the first two questions of Interv. 1.

Table 6 Students' mean scores to Interv. 1 and Interv. 2 (first two questions, maximum score = 3) grouped according to the type of activity followed during the intervention

	Scenarios								
	Intervention-related			2012			Mobiles		
	Pre	Post	Z	Pre	Post	Z	Pre	Post	Z
CE/TE (N= 10)	0,50	1,10	-2,12+	0,10	0,20	-1,00	0,10	0,30	-1,41
MM/DQ (N = 12)	0,58	1,58	-2,59+	0,08	1,50	-2,43+	0,08	1,67	-2,56+
Z	-0,38	-1,06		-0,13	-2,23*		-0,13	-2,41*	

Mann-Whitney Test: * significant p < 0,026; Wilcoxon Signed Ranks Test: + significant, p < 0,039;

Table 7 Students' mean scores to Interv. 1 and Interv. 2 (third questions, maximum score = 2) grouped according to the type of activity followed during the intervention

	Scenarios								
	Intervention-related			2012			Mobiles		
	Pre	Post	Z	Pre	Post	Z	Pre	Post	Z
CE/TE (N= 10)	0,20	0,50	-1,73	0,20	0,30	-1,0	0,10	0,20	-1,00
MM/DQ (N = 12)	0,25	1,17	-2,60*	0,08	0,92	-2,27*	0,08	0,92	-2,27*
Z	0,83	0,14		0,67	0,14		0,97	0,14	

Wilcoxon Signed Ranks Test: * significant, p < 0,023

Looking at follow-up effects of the intervention, we report in Figure 5 the mean scores of the two groups in the pre- post- and delayed-test for the three questions of Interv. 1.

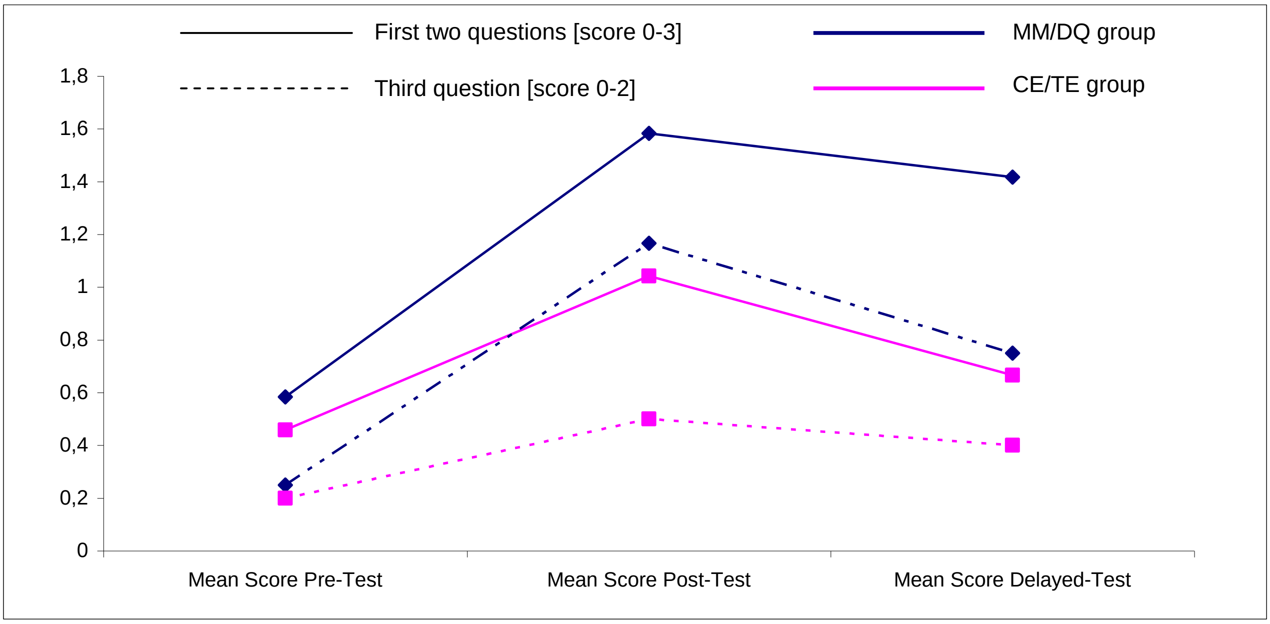

Figure 5: Students' mean scores to Interv. 1 according to administration time

The trend plausibly indicates that the MM/DQ group, with respect to the CE/TE group, showed a greater increase between the pre- and post-test mean scores and a smaller decrease between the post- and delayed-test mean scores. The progression of the MM/DQ group is consistent across all the assessment probes, as clearly shown by Figure 6 where we report the relationships between the pre and post-test mean scores in the first two questions of Interv.1 and the pre-and post-test mean scores in the corresponding questions of Interv. 2. It can be noted that in the pre-test, the distance between the two groups' mean scores in all the probes is smaller than that in the post-test; more specifically, for the MM/DQ group, higher scores in the Interv. 1 correspond to higher scores in the Interv. 2. An analogous pattern is evident for the scores of the third question of Interv. 1 and Interv. 2 (Figure 7).

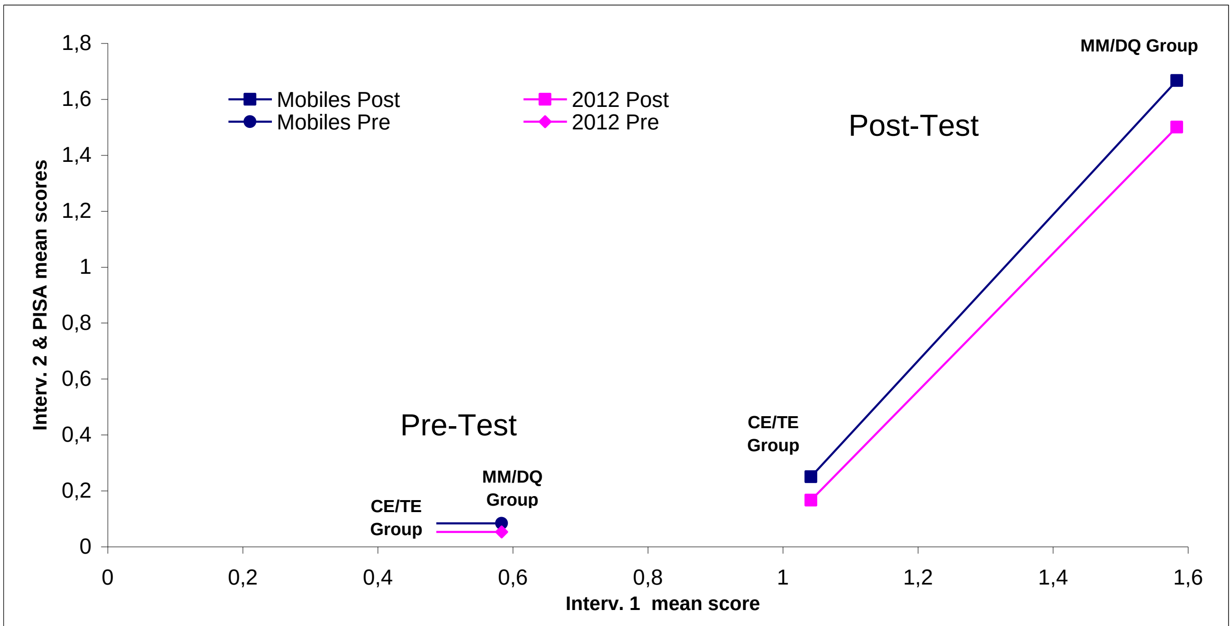

Figure 6: Pre- and post-test students' mean scores to the. Interv. 2 vs. Interv. 1 (first two questions, maximum score: 3)

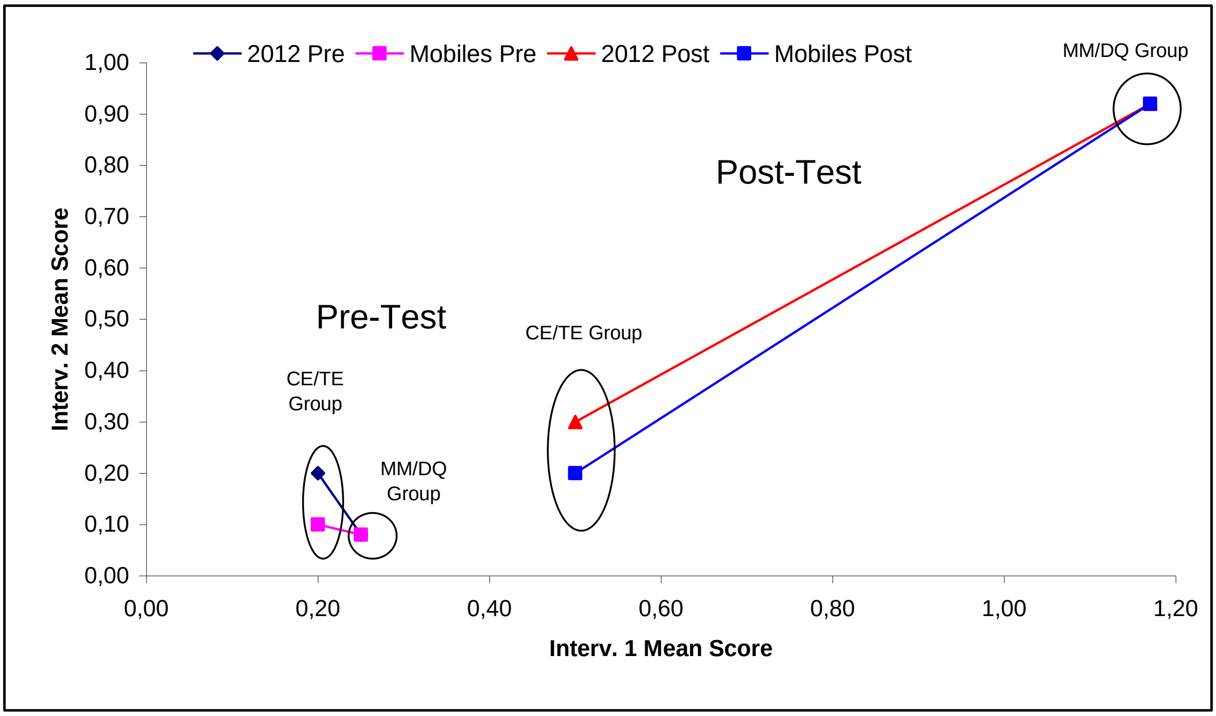

Figure 7: Pre- and post-test students' mean scores to the. Interv. 2 vs. Interv. 1 (third question, maximum score: 2)

A closer inspection to the results of each group may help interpret the differences between the MM/DQ and CE/TE groups. The disaggregated analysis of the first two questions of Interv. 1 is shown in Figure 8.

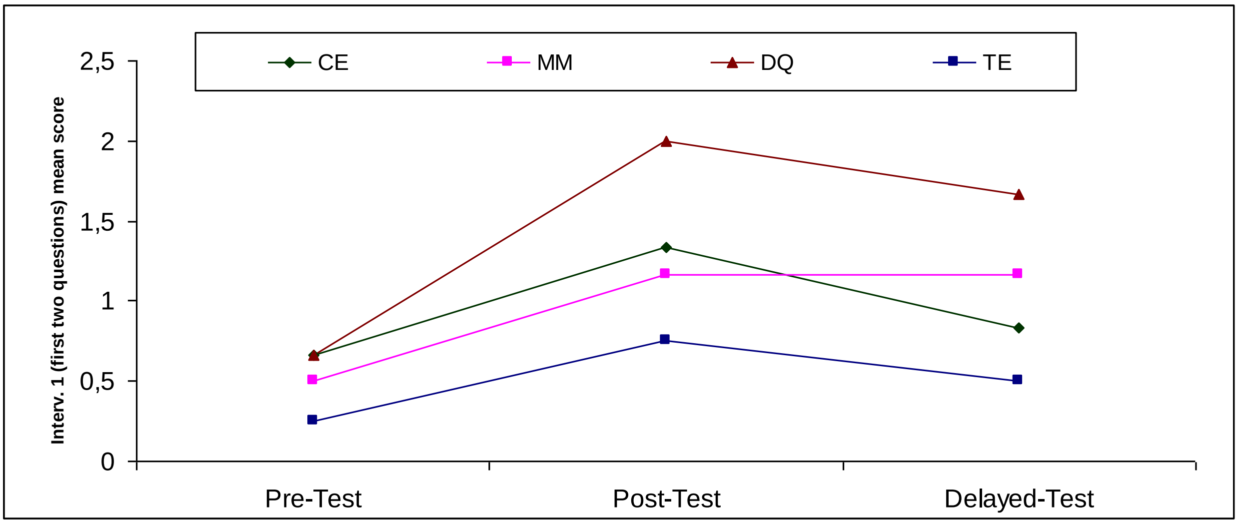

Figure 8: Disaggregated students' mean scores to Interv. 1 (first two questions, maximum score: 3) according to administration time

Overall, all the four groups had some initial difficulty in identifying the scientific controversy of the assigned SSI; on the contrary, after the laboratory activity, three groups had improved on average their understanding of the content underlying the scenario, while only one still showed some difficulty. However, the improvement has been not uniform within the groups.

For instance, in the MM group, 4 students in the post-test scored between 0 and 1, while only two scored between 2 and 3. More specifically, this group in the first activity did recognize neither that the assumptions of the two models presented in paper were completely different, nor that one of the models did not account for the actual deaths by cancer in the world. One of the girls of the group explicitly confused evidence and abstract ideas expressed in the triggering paper:

> *S6*: *... the observable evidences are that some scientists calculate a million of cancers due to nuclear power usage. Abstract ideas are those for which in the neighbourhood of the nuclear plants the percentages of cancers are greater than in other places…. .*

After the laboratory activity, the same girl claimed:

> *S6*: *... the damages to the body organs is the evidence, the bags of water which represent the organs are abstract ideas… the evidences are those phenomena that can be actually felt, models are approximated… as we have seen with the graphs obtained in the laboratory activities, models are useful to predict, calculate, verify predictions… they aim at knowing and understanding more about the real things…. In this case they verify and predict future data…*

Such an improvement may plausibly be related to a fruitful involvement of this girl in the laboratory activity: she was the first in the group who was able to understand that the positions vs. time of a regularly walking person could be approximated by a line and to determine the graph of the velocity vs. time starting from the position vs. time graph; she was also very active in trying to involve the other girls of the group, initially quite detached from the activity, in the discussion about how to relate the experiment with the discussed SSI scenario. In our view, the attitude of some girls in this group (i.e. to avoid participating to the discussions and especially to the laboratory activities) may explain the results of the post test.

The same average improvement in the reasoning pattern has been observed in the DQ and CE groups. In particular, the girls of the DQ group initially justified their decisions about the biofuels using arguments as the reduction of pollution, the usefulness of renewable sources, the risk of the increase of the rice and corn prices, which are all not related to the core controversy of the paper, i.e., the quality of the data featured in the two presented viewpoints. After having done in the second activity the two proposed experiments, one with the dynamometer and the other with a force sensor, one girl was able to understand that:

> *S19*: *... the main differences are that with the force sensor we have done more measurements… therefore, the result is more accurate and reliable….*

More importantly, this group realized that the same criteria used to evaluate the experiments they carried out could be applied to evaluate the viewpoints reported in the paper. As the same girl stated during the discussion in the third activity:

> *S19*: *... both viewpoints are valid since they both studied if the biofuels pollute…but I think that the second one is more reliable because data have been obtained in the laboratory several times….*

With respect to the group working with nuclear plant, the girls of this group participated actively in the discussions and the experiments and, as a result, only two girls in the groups scored 1 in the post-test.

The girls in the CE group at the beginning focused their attention on the pollution of the incinerator plant rather than on the energy issues discussed in the paper. After the laboratory activity with the RC circuit, four girls recognized that in the paper, one viewpoint was not correct from the scientific viewpoint. S12 for instance claimed:

> *S12*: *... it is false to say that the incinerator produces more energy… part of the energy after the burning of the wastes goes into the air in the form of pollution….*

When asked to justify her decision, another girl explicitly claimed:

> *S23*: *... we made that experiment in which we have seen that the quantity of energy is always the same… energy is only transferred… in our experiment the energy goes from the battery to the resistor and the capacitor….*

However, not all the girls in the group grasped the relationships between the experiment and the assigned SSI scenario. For instance, this girl, when asked about the relationships between the experiment and the scenario, claimed:

> *S14*: *…We have made an experiment that guaranteed that the waste incinerator pollutes hence I don't want it near my town…*

Another girl in the post-test seemed to not having understood the role of energy in the scenario:

S18: *…Garbage increases every day, the waste incinerator is the only solution… although it pollutes it is the only mean to solve the problem…"*

When explicitly asked about the issue of the production of energy she answered:

S18: *…I don't care about it…everyone thinks what he wants…*

Not surprisingly, and similarly to the first group, three girls of this group scored in the post-test between 0 and 1, while the other three between 2 and 3.

Finally, the TE group seems to have less internalized the relationships between the discussed SSI (electric cars) and the experiment carried out (mixing of the water masses at different initial temperature). In the first activity, all the students in the group seemed to be convinced that the electric car was more efficient than oil car since they focused on pollution, while they did not focus on if the quantity of energy provided by an electric car battery is sufficient for a usual journey. One girl focused on the unnecessary employ of water:

S9: *…the pollution of an oil car is very risky, the electric car does not pollute but it consumes much water… the production could be balanced… for instance one fourth oil cars, the other electric cars….*

This claim shows a good use of a trade-off reasoning strategy, but for the purpose of this study the proposed reasoning did not take into account any scientific viewpoint. Another girl proposed:

S20: *…let's make some experiment to investigate if the pollution of oil and electric cars is really different…*

Also this viewpoint did not explicitly use content knowledge, in particular energy. Although after the experiment, in the third activity, all the girls in the group were able to make a reasonable schema of the energy transfers in an electric and oil car, in the post-test only three girls were able to insert some generic reference to scientific evidence in their arguments (score: 1).

4. Discussion and conclusions

First of all, the above results plausibly suggest that a rigorous teaching of scientific concepts and methods may support informed decision-making process about SSI moral and ethical dilemmas, and conversely, and more significantly, that although ill-posed and open-ended, SSI-based scenarios can be fruitfully exploited in school practice to teach usual science curriculum contents. In particular, after the intervention, nine out 22 students were able to correctly refer to scientific concepts when defending and justifying their decisions about the proposed SSI scenarios. This result indicates that the proposed activities may improve students' capability to discuss and decide about controversial SSI, specially enhancing the validity and reliability of their propositions (RQ1). Moreover, the evidence that seven out 22 students, after three months the end of the activities, were able to correctly refer to scientific concepts to support their decisions about the same SSI, plausibly suggests also a maintenance of the capabilities acquired during the intervention's activities. Furthermore, the analysis of students' comments about the 2012 and mobiles controversies plausibly shows that the proposed activities may help students transfer to other contexts the acquired capability of relying on content knowledge when argumenting about SSI. These findings are consistent with and extend those of previous research efforts (Lewis & Leach, 2006; Sadler & Fowler, 2006) focused on the role of content knowledge in argumenting about debated SSI those. Moreover, this study contributes to the research stream interested in the effectiveness of SSI interventions since the proposed activities not only aimed to improve students' knowledge about and of the specific physics contents related to the addressed SSI but also students' capability of exploiting such contents in their SSI discourse in a meaningful way. However, from the evidence collected it is not possible to infer that the students involved in the activities have actually acquired a profound knowledge of the specific contents addressed. To this concern, it should be noted that even after the intervention the slight majority of the students (13 out 22) has not referred to relevant scientific concepts to justify their arguments on the proposed issues. While this evidence confirms previous results that students' informal reasoning about SSI often relies on personal experiences, emotive and social considerations rather than specific content knowledge (Patronis, 1999; Grace & Ratcliffe, 2002; Halverson, Siegel & Freyermuth, 2009; Wu & Tsai, 2007; 2010) it also suggests that the proposed activities need further improvements.

A second aspect which is interesting to discuss is that students’ capability of discussing about and deciding upon a given SSI relying on content knowledge may depend, at least to a certain extent, on what activities have been followed during the intervention (RQ2). More specifically, the students who were engaged in activities dealing with basic aspects of Nature of Science (NOS) as data quality and mathematical modelling showed a better capability to discuss meaningfully from the scientific viewpoint about the not addressed SSI (mobiles and 2012 controversies) with respect to the students engaged in activities concerning the specific content (energy transfer and conservation). While possibly indicating a different effectiveness of the proposed activities, we consider this a plausible result because the mobiles and 2012 controversies were explicitly focused on aspects of NOS, as the principles of measurements and the use of evidence, and MM and DQ activities had the explicit objective to show how such aspects may help resolve SSI controversies. Our findings thus confirm those of previous studies (Lederman, 2007; Abd-El-Khalick, 2005; Abd-El-Khalick, Bell & Lederman, 1998) according to which explicit teaching can improve students’ views of and about specific aspects of NOS. However, despite the differences in students’ outcomes, all the proposed inquiry activities seem to have at least the potential to help students disclose the relationships between SSI, specific scientific contents and NOS (Sadler & Zeidler, 2005b). This evidence supports recent claims (Zeidler & Sadler, 2011, p. 183) that SSI objectives may be explicitly aligned with those of inquiry-based approaches. More specifically, all the proposed SSI scenarios provided a fruitful context to design laboratory activities with two main objectives: on the one hand, to improve students’ knowledge of basic physics concepts and methodologies, in our case conservation and transfer of energy, measurements and mathematical modelling; on the other hand, to help students acquire familiarity with a prerequisite knowledge that could help them to develop high quality arguments about the discussed issues with the necessary degree of validity from the scientific knowledge viewpoint (von Aufschnaiter et al. 2008). Such an alignment may become a key factor for a faster introduction of SSI approaches in school science curricula.

Finally, it is worth reporting the attitude of some students that denoted a scarce interest about the addressed SSI in all the pre-, post- and delayed-post interviews, especially as far as the justification of decision is concerned. This attitude was detected especially for the NP and WI scenarios, which we thought could be the closest to students’ own life. Examples of this attitude are, for instance, sentences as: “I have decided in this way because I think so and you can’t change my mind” (NP) or “I would not try to convince anyone of my decision since everyone has his/her own’ ideas” (WI). When asked to elaborate more on these answers, these students seemed to attribute scarce authority to the newspaper articles describing the SSI, independently of the correctness of reported contents from scientific viewpoint and hence showed no will to involve themselves in the discussion. The role of the credibility attributed by students to the source of information used for discussing the SSI scenario emerges also from other data collected for this study which show that, on average, students judged scientists’ conferences as the most reliable source of information and school textbooks and science fiction television programs respectively more reliable than teachers’ lessons and newspaper articles. This evidence confirms previous research results (e.g. Kolstø & Ratcliffe, 2007) about the role of authority in students’ argumentations and the critical role of media in debating SSI and more in general about Scientific Literacy (Klosterman, Sadler & Brown, 2011; Wong, Wan & Cheng, 2011); however, our study suggests that the relationships between the source of information used to trigger the SSI discussion and the students’ quality of argumentations needs to be further investigated.

Overall, despite its limitations (small number of students involved in the implementation of the intervention, gender-biased sample), this study may contribute to the debate about the inclusion of SSI-based activities in Secondary School science curricula by providing research-based evidence of the effectiveness of these interventions to help students achieve significant learning outcomes from the content and NOS knowledge viewpoint. However, if more general learning goals related to Scientific Literacy have to be achieved, how to improve students’ capability to use content knowledge to support their decision-making and argumentation is an important objective for future studies in SSI research field.

Appendix A - Summaries of scenarios addressed during the intervention

Construction of a Nuclear Plant

Scientific models play a crucial role in the debate about the possible damages of radiation on human health since scientists construct models of human body to predict the effects of radiation doses on organs (risk models). Such predictions are at the basis of scientists recommendations for radiation threshold in many every-day contexts (e.g., body scanners in airports). If adopted models have wrong assumptions, the predictions are wrong and in some cases may lead to not correct recommendations. The focus of the activities is on how scientists construct and use scientific models of complex phenomena.

Construction of a Waste Incinerator Plant

The context is introduced discussed by means of a paper which presents two contrasting perspectives about the issue focusing on energy conservation and dissipation. One of the proposed viewpoints (creation of energy from the waste incinerator) is purposely fictitious for teaching purposes. In the module's activities, the focus is on the correctness of sentences as "production of energy", "energy created from wastes", "energy losses" referred to the process of incineration. where energy dissipation is evident (pollutant smokes and heat production).

Electric Cars production

The construction of electric cars has become a socio-scientific issue since an extremely high usage of water, needed for a massive production of electric cars to completely substitute traditional oil cars, would cause problems in developing countries and other regions of the planet, already suffering water need. The focus of the activities is to show the crucial role of energy transfers in general and in particular to improve electric cars autonomy which may lead to significant water savings.

Biofuels production

The production of bio-fuels has become a socio-scientific issue since a fast increase of bio-fuels could lead to food depletion in developing countries. The central point is that some studies have proved that bio-fuels have high emissions of CO2 during the whole process of production. The activities hence focus on the importance of establishing in an informed way the validity and reliability of the conclusions of scientific studies, since not valid conclusions may cause misleading decisions.

Appendix B - Scenarios proposed in the Interv. 2

Mobiles threaten man's health

Some scholars have speculated that electromagnetic waves emitted by mobile phones can cause harm to users. At present the research results have given controversial and challenged results: some have not shown any direct correlation between use of mobile phones and diseases such as leukemia and various cancers; others associated a prolonged exposure to electromagnetic radiation, protracted over time (ten or more years), to the increased risk of developing brain tumors. The existence of a significant risk to health is still controversial, so that the whole issue is seen as the result of a completely unjustified alarmism.

2012: the end of the world?

On 21 December 2012, the rotation of the Earth on its axis will undergo a stop that will last 72 hours. Afterwards, the Earth will return to rotate but in the opposite direction, resulting in a reversal of magnetic poles. According to many experts, this stop will probably give rise to abnormal weather events and large-scale earthquakes and mankind will suffer great losses. Global warming, tsunamis and recent earthquakes in

L'Aquila and Haiti, are all signs of the first events due to the abnormal slowing of the Earth. Other experts do not share this rather alarmist and consider the arguments above completely unfounded

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