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Secondary students' views about scientific inquiry

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Summary. — In this study we investigated the views about Scientific Inquiry (SI) of about 300 students at the beginning of the secondary school course (14–15 years old). An adapted version of the Views On Scientific Inquiry (VOSI) questionnaire was used as research instrument. The questionnaire, focused on six specific aspects of SI, was submitted before and after a six-hours in-classroom delivery of a teaching-learning sequence (TLS) that targeted explicitly the six SI aspects. We first analyzed responses using a five-level categorization: a) informed view; b) mixed or partially correct view; c) naïve view; d) unclear; e) not given. Two independent researchers iteratively analyzed the data with a final inter-rater reliability of about 90%. Then, we collapsed the initial categories into three macro-categories: C1) informed/partial view; C2) naïve view; C3) unclear or not given; and calculated the shift in the macro-categorization between pre- and post-test. Finally, we investigated a possible relationship between how the TLSs were enacted and the students' achievements. Data show that the percentage of students' informed responses only slightly increased between pre- and post-test in the majority of the targeted aspects. Moreover, students' achievements seem to depend on how the teachers enacted the TLSs. Our results suggest that short inquiry-based teaching interventions are not sufficient to effectively teach SI aspects. Moreover, our results suggest to develop specific training courses aimed at improving teachers' own beliefs and practices about SI.

1. – Introduction and aims

Scientific Inquiry (SI) has been since long time acknowledged as a teaching methodology that can promote a meaningful understanding of concepts (science "facts") through active investigation of phenomena and processes, measurement, classification, experimentation, data analysis and drawing of reasonable conclusions (Novak & Krajick, 2006). Basically an inquiry-based learning environment should resemble that of professional scientists, focusing at the same time on contextualized, every-day situations (Bybee, 2006)

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in order to promote students' engagement and motivation. Moreover, inquiry-based learning environments may also help students develop "an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture" (NRC, p. 21). Hence, didactical objectives may be widened, shifting focus from the understanding of science "facts" to the understanding of science as an interpretative body of knowledge, *i.e.*, to understanding of (aspects of) Nature of Science (NOS) (Schwartz & Crawford, 2006).

Only recently (NGSS, 2013), however, the nature of SI has been acknowledged as a content itself. Through inquiry, students should not only be engaged in epistemic practices (Kelly, 2008), but also learn what are the basic aspects of SI or, in other words, know what are the essential aspects that should be featured in an investigation in order to consider it a "scientific" one. Therefore, only few studies investigated students' knowledge about SI as a content (*e.g.*, Lederman *et al.*, 2014). The authors of these studies suggest that just as for NOS aspects, a meaningful understanding of what SI is should be obtained by an explicit teaching and not only by engaging students in activities, in which, often, inquiry features are tacitly adopted and exploited. Similarly, still no studies have thoroughly investigated the effects of an explicit teaching on students' knowledge of the Nature of SI, so that the influence of "declared" inquiry-based teachers' practice on students' knowledge of SI remains largely unknown. To address these issues, we selected and adapted seven inquiry-based teaching learning sequences (TLSs) in which the students not only are engaged in meaningful epistemic practices but are also explicitly taught about the main SI aspects through which scientific knowledge is developed (Schwartz, Lederman, & Crawford, 2004). We then observed the teachers that implemented the TLSs and investigated whether the actual practice of teachers affected students' achievements in a pre-post test. Hence, this study was guided by the following research questions:

- Which is the students' knowledge of SI before and after participated to an inquiry-based TLS? (*RQ1*)
- Which aspects of the Nature of SI can be best promoted through an explicit teaching of SI? (*RQ2*)
- To what extent do students' knowledge about SI depend on teachers' practice? (*RQ3*)

2. – Methods

2·1. *Instrument.* – To answer our research questions, we used a modified version of the Views On Scientific Inquiry (VOSI) questionnaire (Lederman *et al.*, 2014). We first compared the SI aspects targeted in the original questionnaire with the Italian secondary school science practice. The comparison was carried out with the help of the teachers that would have been involved in the submission of the questionnaire and the in-classroom delivery of the inquiry-based TLSs (see below). As a result, we selected the following aspects, listed below in alphabetic order:

A1. All scientists performing the same procedures may not get the same results

A2. Explanations are developed from a combination of collected data and what is already known

A3. Research conclusions must be consistent with the data collected

A4. Scientific data are not the same as scientific evidence

A5. Scientific investigations all begin with a question but do not necessarily test a hypothesis

A6. There is no single set and sequence of steps followed in all scientific investigations.

The original questionnaire featured seven open questions. We slightly changed the order of the questions and carried out the following modifications aimed at aligning the questions with Italian secondary school curricula:

- Question 1 was split (1c as a stand-alone question) and two more contexts, related to astronomy and physics were added.
- Question 5 was left out.
- Questions 6 was tripled introducing two more contexts, one related to chemistry (a time-temperature two-column table for an ice cube that melts on a wooden and a metal surface); the other related to physics (a time-velocity two-column table for a ball thrown in the air).
- Question 7 was split (7c as a stand-alone question) and a new question about mathematical modelling of a spreading fire in a forest was added.

Overall, the adapted VOSI instruments featured eleven questions. To validate the new questions, we pre-tested the whole questionnaire with a sample of about 20 students of the second year of a secondary school and then discussed the results with the teachers involved in the research study.

2·2. *Description of the adopted TLSs.* – Since an important aim of the study was to investigate the effectiveness of explicit teaching of SI on students' achievements as measured by the VOSI instrument, particular care was devoted to the selection of the TLSs that should have been implemented in classroom practice. We first selected eleven existing research-based modules (SHU, 2009) and already validated in different educational contexts. Then, we modified them with the teachers that would have delivered the TLSs in classroom to include activities in which the SI aspects of the VOSI questionnaire could be explicitly taught. At the end of the process, seven TLSs were finalized. All the TLSs exploit realistic research contexts and engage students in the production of a meaningful research question related to the context and to the design of investigations to answer the question. In designing their investigations, the students work in small group, collect and analyze data and communicate their results to their peers. Emphasis is put on justification of conclusions on the basis of the collected data and evidences. According to the context, the students are asked either to produce written research-like papers, or to prepare videos and slide shows to present their results. A brief description of the TLSs with the prevalent SI targeted aspects is reported in table I. Despite modifications carried out, the TLSs could not focus in the same way on all the six SI aspects, so differences in students' achievements due to specific TLS they were engaged into might be expected.

TABLE I. – *Description of TLS used in the study.*

Title	Context	What students do	Main SI aspects
Collision Course	Students, as scientists of the "Stellar Center", have to produce a written report for NASA about possible risks for Earth due to collisions with asteroid	Investigations about the momentum and energy of objects in hits	A5-A1-A2
ET Phone Earth	Students, as TV journalists, have to prepare a television broadcast in which the possibility of extraterrestrial life will be discussed	Argument about evidence in favour and against the existence of extraterrestrial life	A6-A1
Green Heating	Students, as researchers of an advertising company, have to produce a document about advantages of solar thermal collectors for domestic use	Investigations about the role of materials in energy transfers between radiation and matter	A3-A4-A5
Green Light	Students, as consultants of Energy Efficient Lighting Committee, have to produce a document on main advantages of using compact fluorescent lamps	Investigations about the energy dissipation of a compact fluorescent lamp and an ordinary filament lamp	A3-A4-A5
Mars-ology	Students, as researchers at the Institute of Planetary Research, are asked by the NASA to propose a research study to be carried out with a space probe on Mars	Investigations about the role of lava viscosity on the shape of a volcano	A2-A3-A6
Out of site, out of mind	Students, as members of a city committee, have to study the risks of pollution due to landfills	Investigations about diffusion of polluting agents in the soil	A1-A6
Plants in Space	Students, as researchers of a department of bio-astronomy, have to develop suitable plans for a life sustaining unit for use on possible future space flights	Investigations about the dependence of photosynthesis on radiation wavelength	A4-A2

2˙3. *Sample*. – The selected TLSs were delivered in 10 classrooms of five Italian secondary public schools including scientific lyceums and vocational schools. Overall, about 300 students of the first two years (14–16 ys) were included. All students took on a regular basis physics and sciences courses, for at least four hours weekly. Seven biology, chemistry and physics teachers delivered the TLSs (one for each teacher). They ranged in experience between 20 and 30 years and were introduced to *Inquiry Based Science Education* (IBSE) throughout a training course of about 30 hours in which aspects of NOS and SI targeted in the VOSI were explicitly taught. Particular attention was put on the main features of the TLSs when the teachers themselves carried out the activities. They also discussed the draft version of VOSI questionnaire during the course and their comments were used to generate the final version of the instrument. Hence, the involved

Table II. – *Values of the Cohen's kappa for reliability of the VOSI questionnaire.*

Question/SI Aspect	Initial Cohen's kappa	Final Cohen's kappa after discussion on specific cases
Q1/A6	0.74	0.97
Q2/A5	0.61	0.88
Q3/A1	0.46	0.96
Q4/A4	0.78	0.98
Q5/A2	0.70	0.77
Q6/A5	0.75	0.76
Q7/A2	–	0.76
Q8/A2	0.28	0.82
Q9/A3	–	0.78
Q10/A3	0.91	0.91
Q11/A3	0.47	0.94

teachers were safely supposed to hold informed view about SI when they implemented the TLSs. Classroom activities lasted on average about 6 hours for each TLS.

2˙4. *Classroom practice observations*. – When the seven TLSs were delivered in classroom practice, two external observes took field notes and video recorded the lessons. Overall, about twenty hours of video were collected, three hours for each TLS. Observations were guided by an adapted version of the Reformed Teaching Observation Protocol, (RTOP, Sawada *et al.*, 2002), already validated by previous researches (*e.g.*, Nam, Seung, & Go, 2013). Due to the specific focus of our study, we adapted some of the RTOP items so that they could describe the extent to which the teachers implemented the specific inquiry aspects featured in the TLS and in the VOSI instrument. Overall, the used protocol featured 19 items, on a scale from 1 (item not descriptive) to 6 (item very descriptive). Eleven items strictly concerned SI aspects targeted by the VOSI questionnaire, while eight items concerned more general classroom management aspects.

2˙5. *Data analysis*. – In order to analyse students' answers, we first defined five categories, labelled from 1 to 5. For each question, we assessed as *Informed* (1) those answers that were correct and wholly congruent with the target response for a given aspect of SI. Answers which were incomplete yet on the whole coherent with the adopted view of a given aspect of SI were labelled as *Mixed or Partially correct* (2). Responses that were in contradiction with the adopted view of a particular aspect, or that corresponded to a known misconception about SI, were scored as *Naïve* (3). When it was not possible to understand a student's response or if the answer was only a "yes"/"no" statement without any justification, the answer was categorized as *Unclear* (4). Lastly, we assessed as *Not given* (5) all the questions left blank by students.

Reliability of categorisation was assessed as follows. Two authors first analysed all the answers separately; then, for each question, Cohen's Kappa was calculated (table II, second column). As the initial values of Cohen's kappa were not satisfactory (for instance, for Q7 and Q9 it was not possible to calculate it), the two raters discussed discrepancies in the categorisation and ratings were repeated to improve agreement. We then calculated again Cohen's Kappa values (see table II, third column). Values higher than 0.75 for all questions were obtained and hence a final categorization of students' responses was agreed.

TABLE III. – *Students' responses recoding after first categorization.*

First categorization	Typical answers for Q2: *"Do you think that scientific investigation has necessarily to start with a research question?"*	Macro-categorization/ Explanation
Informed	*"Yes, because only if you have clear in mind the research question you can design a coherent scientific investigation in order to answer the question."*	C1/ Responses in this category reflect knowledge that is totally or partially consistent with the adopted view of the specific SI targeted aspect
Mixed	*"Yes, otherwise we could not begin an experiment"*	
Naïve	*"No, because a scientific investigation could start also because the researcher is curious something"*	C2/Responses in this category are not congruent with the adopted views of the specific SI targeted aspect
Unclear	"*Yes because without a question there could not be an answer*"	C3/ Responses in this category are incomprehensible, unintelligible, or in no relation to the specific SI targeted aspect
Not given		

After having obtained a first categorization of student's answers, we re-coded the initial five categories into three macro-categories, labelled as C1, C2 and C3 (table III).

We then calculated, for each question, the percentage of students' responses in the three macro-categories and then averaged these percentages for the six SI targeted aspects. To evaluate whether students improved their views of SI after being involved in the proposed TLS, we compared, for each student, the results of the questionnaire submitted before and after the implementations. To this aim we defined, for each student, a "gain", *i.e.*, the difference between the pre- and post-implementation scores according to the macro-categorization of table III for all the VOSI questions. Students' gains could range from -2 to $+2$: a gain of 0 meant no improvement, $+1$ and $+2$ a positive improvement while -1 and -2 a negative improvement.

Finally, we looked for a possible relationship between students' gains and the way teachers implemented the TLSs. Two authors independently analysed video recordings of the classroom deliveries through the RTOP instrument. Out of the 19 adopted items, we calculated the average score only for the eleven items that concerned the targeted SI aspects. Then, since we wanted to investigate possible correlations between the overall enactment of the TLS on behalf of the teachers and the students' achievements, the mean values of the eleven SI items were again averaged so to obtain a *global* score for each teacher. On the basis of this score, we then categorized as *resonant* those teachers who obtained an average RTOP "high score" (greater than or equal to 4 on a scale of 6) and as *not resonant*, teachers who obtained an average RTOP "low score" (lower than 4). The cut-off threshold of 4 was chosen since it indicates that, on average, the RTOP items were clearly descriptive of what was going on in the classrooms. *Resonant* teachers

TABLE IV. – *Percentages of students' answers in the three macro-categories of analysis for each SI aspect.*

CI aspects	C1 (informed/ mixed)		C2 (naïve)		C3 (unclear/ not given)		Gains (%)	
	Pre	Post	Pre	Post	Pre	Post	No or negative	Positive
A1	9.4	9.4	61.6	57.2	29	33.3	77.5	22.5
A2	48.1	59.2	39.4	36.7	12.6	4.1	69.5	30.5
A3	19.3	20.0	56.5	65	24.2	15	73.9	26.1
A4	7.2	23.9	42.9	49.3	50.7	26.8	58.7	41.3
A5	12.7	10.9	53.3	58.4	34.1	30.8	76.1	24.0
A6	2.9	5.8	63.8	73.9	33.3	20.3	71.7	28.2

were hence more likely keen to explicitly adopt and actually implement in their practice the specific aspects of SI present in the TLS. On the contrary, *Not Resonant* teachers modified the TLS so that specific aspects of inquiry were ignored or taught only implicitly. A chi-square analysis was finally carried out to investigate whether the hypothesized relationship between students' achievements and teachers' way of implementing the TLS was statistically significant.

3. – Results

The pre-instruction VOSI questionnaire was completed by 227 students while the post-instruction questionnaire was completed by 156 students. Overall, 138 students completed pre-post questionnaires. In table IV we report the distribution (in percent) of the students' responses for the six SI aspects targeted in the questionnaire in the three macro/categories for the pre and post-test. Summative students' gains are also reported.

Data show that the percentage of informed responses slightly increased between pre- and post-test in the majority of the targeted aspects. Examples of naïve conceptions emerged in both pre- and post-test are: science can be either deductive or inductive; data are the results of an experiment, whereas evidence is a clear result; scientists draw conclusions mostly on experimental certainties; any mathematical expression is a result of a scientific investigation; any hands-on activity could be an experiment; performing the same procedure must lead scientists to the same conclusions.

Average percentage of informed or partially informed responses increased only from 16% to 21%. Accordingly, while about 30% of the students responses shifted towards an upper category in the post-test, this was due mainly to a decrease in the percentage of students' unclear responses or not given answers (from 31% to 21%).

To seek for an explanation of the limited impact of the TLSs, we looked at the relationships with teachers' practice. According to the average RTOP global scores, only four teachers (total of about 82 students) were on the whole *resonant* while three (total of 56 students) were globally not resonant. Table V shows for each SI targeted aspect the percentage of students whose view of SI improved between pre- and post-test for resonant and not resonant teachers. Results show that the majority of students who showed a positive gain between pre- and post-test were involved in TLSs implemented by resonant teachers. For three aspects (A1, A4 e A6), the differences are statistically significant.

TABLE V. – *Distribution of summative students positive gains in % for resonant and not resonant teachers. The asterisk (∗) indicates aspects for which the different distribution of students' responses is statistically significant.*

SI Aspects	Resonant teachers	Not Resonant teachers
A1*	74.2	25.8
A2	69.8	30.2
A3	65.8	34.2
A4*	73.7	25.3
A5	67.2	32.8
A6*	82.1	17.9

4. – Discussion and conclusions

Concerning RQ1, we can observe that students' views about SI at the beginning of secondary school stream are generally not informed. Actually, for five out of six aspects, the percentage of C1 responses is lower than 20%. Only for one aspect (A2), the pre-test percentage of responses coded as C1 is about 50%. Such a positive result may be related to the fact that students may have been taught about how to make scientific inferences from experimental data and justify conclusions already at the middle-school level. As an alternative explanation, the related questions (Q7 and Q8, table II) used contexts (spreading of fire in a forest and assembling of a dinosaur skeleton) which likely resulted more familiar to students. The lowest percentage of C1 responses in the pre-test, 2.9, was obtained for the SI aspect A6. This results could have been due to the usual presentations of physics textbooks, which often underline the existence of only one scientific method, the one described by Galileo Galilei. On the other hand, biology and chemistry science textbooks usually focus on the existence of *two* scientific methods, one based on induction, the other based on deduction. In both cases, textbooks underline that there is a fixed sequences of steps to follow during a scientific research. Despite during the TLS delivery the teachers did not use textbooks, students could have used textbooks before the classroom activities thus influencing questionnaire's results.

Concerning RQ2, we found a statistically significant improvement, from 7.2% to 23.9%, for the SI aspect that concerned the difference between scientific evidence and data (A4). This result was somehow expected, since most of the TLSs' activities helped students discuss about the results and conclusions obtained by the different working groups. In this way, students could understand the difference between having a single experiment data collection and having results coming from more and/or different experiments. Moreover, such evidence suggests also that most teachers put emphasis on data collection and the meaning of scientific evidence. On the contrary, quite unexpected was the low C1 frequency for the A3 aspect, about 20%, in both pre- and post-test. Actually, at the beginning of the secondary school, students are supposed to have the competence of reading tables and graphs. For this reason, teachers may have overlooked students' difficulties with this SI aspect during the implementation of the TLS. Similarly, the frequency of C1 responses for the A1 aspect was quite low (about 10%) in both pre- and post-test. This result may likely be due to the lack of time devoted to discussing with students alternative investigation procedures and explanations of collected evidences. Finally, for the A5 aspect we observed a slight decrease between pre and post-test. When looking in more detail the two questions related to this aspect (Q2 and Q6, table II), we noticed that the students performed much better in Q6 than Q2. The latter asked explicitly if a scientific investigation should start with a research question: while the TLSs focused on the generation on behalf of students of a research question to begin the investigation, most students in the post-test claimed that a scientific investigation starts also from a real problem. This answer may be related to an over-emphasis on the realistic contexts of the TLSs.

Overall, our results suggest that only one TLS implementation in a very limited period of time may be not sufficient to have a significant positive impact on students' views about SI. It must also be taken into account that not all the TLSs targeted the SI aspects in the same way (table I), so further investigations are needed to understand if only some aspects can be promoted throughout an explicit teaching of SI. We plan to modify some of the TLSs to make them more suitable to target all the above SI aspects, and to implement them with a new sample of teachers and students.

Concerning RQ3, we found that the majority of positive gains have been related to implementations carried out by the four "resonant" teachers, who did adopted most of the SI inquiry aspects in their practice as measured by the RTOP. This result is in agreement with recent studies (Bartos & Lederman, 2014) and supports the claim that students' views about SI depends on the quality of the engagement into inquiry activities and on the teachers' way of teaching SI as a content.

However, the fact that three teachers were not resonant with the targeted SI principles was a quite unexpected result given the 30 hours training course that all the teachers followed. Although attention was put on addressing teachers' own naïve ideas about SI as emerged during the discussion of the draft version of the VOSI questionnaire, the course failed to provide teachers with a solid knowledge base about SI in order to effectively implement the TLS. In particular, the teachers lacked coherence between what they declared when discussing the questionnaire and what they did when delivering the TLSs in their practice. Hence, more research is needed to investigate the factors underlying teachers' adoption or transformation of inquiry-based teaching approaches. To this aim, we plan to investigate which are SI aspects that teachers mostly adopt or transform after training periods devoted to the explicit teaching of SI as content.

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