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# How does epistemological knowledge on modelling influence students' engagement in the issue of climate change?

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**Summary.** — Involvement in climate change has been proven to be hindered by emotional and social barriers, as well as by conceptual difficulties that students may encounter in dealing with scientific content related to particular issues such as the greenhouse effect. In this study, we start from the conjecture that behind many conceptual difficulties and emotional barriers lie particular epistemological obstacles related to a naive and stereotypical view of science. These include, in particular, the belief that science still has the role and power to provide a unique, unquestionable, and certain explanation of events and processes. Such a naive idea clashes strongly with the intrinsic complexity of climate science. This paper sets out to investigate *if* and *how* the improvement of epistemological knowledge can influence behavioural habits and foster students' engagement in climate change. In order to explore such an issue, we focus on five interviews collected at the end of a teaching experience on climate change, carried out with secondary school students (grade 11; 16-year olds). This study is a follow-up of other two analytical studies aimed at investigating, respectively, the impact of the experience on students' epistemological knowledge and on their behavioural habits.

## 1. – Framework and research questions

Involvement in climate change issues has been proven to be hindered by emotional and social barriers (*e.g.* Lorenzoni, 2007; Pongiglione, 2012; Weintrobe, 2012), as well as by conceptual difficulties that students can encounter in understanding the scientific content of the issue (*e.g.* Besson, 2010). Furthermore, climate change represents a demanding epistemological challenge for students and, more generally, for citizens (Pasini, 2003; Osborne and Dillon, 2008). Scientific debates on such a topic imply sophisticated epistemological argumentations which refer to the vital issue of the predictive power of climate models and to the crucial passage from classical deterministic models to non-linear complex ones. A large body of research demonstrates that students are not usually pressed

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to develop refined epistemological knowledge and that they achieve only a poor understanding of the nature of science (Pluta *et al.*, 2011) and of what models are (Treagust *et al.*, 2002; Koponen, 2007).

In our study, we made the conjecture that many conceptual difficulties and emotional barriers have their roots in naive and stereotypical beliefs about science – namely, that science still has the role and the power to provide a unique, unquestionable, and certain explanation of events and processes. Such a naive idea about modelling clashes strongly with the intrinsic complexity of climate science (Pasini, 2003; IPCC, 2007; Tasquier *et al.*, 2015).

Based on this conjecture, we designed teaching materials where special emphasis was laid on the epistemological *fil rouge* of "models and the game of modelling", and where students were guided to think about the epistemological implications of complex non-linear systems (Tasquier, 2014; Tasquier *et al.*, 2015). The materials were implemented in a class of secondary school students (grade 11; 16–17 years old), over a total period of 15 hours. During the implementation many different data were collected to trace students' development along each of the three dimensions (Tasquier *et al.*, 2015; Tasquier and Pongiglione, 2015; Tasquier, 2015). In particular, a fine-grained analysis allowed us to identify some markers to make visible *if* and *how* students enriched and refined their epistemological knowledge (Tasquier *et al.*, 2015). The markers concern: i) the use of the vocabulary, *i.e.* the number and quality of epistemological words used by the students in writing and talking about physical phenomena and their modelling; ii) the patterns of argumentation used by students in talking about the Model-Experiment-Reality relationship. The marker data highlighted a significant collective improvement in the quality of students' epistemological vocabulary and in the refinement of their argumentation patterns. The open issues, addressed in this paper as research questions, are: *Did the improvement of epistemological knowledge influence students' behavioural and social attitudes and their personal involvement in climate change issue? If so, how?* In order to answer these questions, the analysis focused on five students and the data collected through their individual semi-structured interviews, which include both societal/behavioural and epistemological questions. Prior to the presentation of the analysis, the context of the study is described.

## 2. – Context

The teaching experience consisted of an after-school laboratory course held in a science-oriented Italian secondary school. The course involved one class of 28 students (grade 11; 16 year olds) and took place five times (table I).

The teaching materials designed and implemented in the course aimed to foster (Tasquier, 2013; Tasquier *et al.*, 2014):

– Deep understanding of the basic concepts involved in global warming and climate change (*disciplinary dimension*);

– Critical thinking about the Man-Nature-Society relationship in order to acquaint students with past or current political and economic debates (*societal dimension*)

– Appropriation of a refined epistemological discourse where: i) controversies and scientific debates find legitimacy; and ii) modelling in climate change is discussed and progressively framed within the epistemological perspective of complexity (*epistemological dimension*).

Table I. – *Structure of the lab course.*

| | |
|---|---|
| $1^{st}$ | Introduction to climate change: scientific research and new terms of the scientific controversy (*general climate science*) |
| $2^{nd}$ | Experiments on examples of interaction between radiation and matter (*physics*) |
| $3^{rd}$ | Experiments for the construction of a Greenhouse Model (*physics*) |
| $4^{th}$ | The epistemological perspective of complexity: Introduction to the basic concepts for investigating complex systems (*mathematics and physics*) |
| $5^{th}$ | Political and Economic scenarios: overview of climate treaties and proposals to cut emissions (*political, economic and sociological science*) |

Table II. – *Epistemological fil rouge throughout the lab-course.*

| Lesson | Epistemological message |
|---|---|
| $1^{st}$ | To look at real world phenomena, following a systemic, non-reductionist approach. Crucial concepts were: notion of feedback; space-time scale in Climate Science; the passage from deterministic to probabilistic models. (*The construction of global lenses*) |
| $2^{nd}$–$3^{rd}$ | To deal with the relationship established by the process of modelling between real world, lab experiments and theoretical knowledge. Students were guided to isolate a phenomenon, and identify its conceptual skeleton along with its potential for interpreting global change. (*Zooming in on isolated phenomenon*) |
| $4^{th}$ | To introduce perspective of complexity so as to refine the epistemological discourse on Climate Science. Crucial concepts included: notion of feedback; time evolution and probabilistic nature of non-linear models; relation between individual and collectivity. (*The epistemological perspective of complexity*) |
| $5^{th}$ | To use physical and epistemological skills in order to look at global change with a rational attitude. The complexity of natural phenomena was used both as mirror and metaphor of the societal complexity. (*Reading the world with our lenses*) |

Throughout the entire course, special attention was paid to developing an epistemological *fil rouge* in order to foster the progressive development of new and robust awareness about modelling, as well as about the causal schemes implied by different types of models and modelling (Tasquier *et al.*, 2015). The *fil rouge* is briefly reported in table II.

## 3. – Methods

As already mentioned, many different data were collected at the beginning (B), at the end (E) and during (D) the whole teaching experience. The data sources were designed so as to take into account the different dimensions involved in the study (disciplinary - DD, epistemological - ED, societal - SD). Table III provides a map of the data sources and of the dimension that each source was intended to investigate.

In order to answer the RQs (*Did the improvement of epistemological knowledge influence students' behavioural and social attitudes and their personal involvement in climate change issue? If so, how?*), we focused on the five interviews collected at the end of

TABLE III. – *Data sources. Key: B: beginning of the path; D: during the path; E: at the end of the path; DD: disciplinary dimension; ED: epistemological dimension; SD: societal dimension.*

| Main data sources | moments of submission | | | Checked/tested dimension | | |
|---|---|---|---|---|---|---|
| | B | D | E | DD | ED | SD |
| Pre-Questionnaire ($Q_1$) | X | | | X | X | X |
| Questionnaire on the idea of model ($Q_m$) | | X | | | X | |
| Post-Questionnaire ($Q_2$) | | | X | X | X | X |
| Tutorials (group work) | | X | | X | | |
| Audio-recording lessons | | X | | | | |
| Notes from researchers | | X | | | | |
| Written task inspired by inventory from EU research | | | X | X | | |
| 5 individual semi-structured interviews | | | X | X | X | X |

the teaching experience. The five students were chosen in order to represent different attitudes toward the activities. Student 6 (S6) represents a *"shy"* person in the class, he actively took part in the lab activities but he was not pro-active in the collective discussions; student 13 (S13) represents the *"excellent"* student of the class, he was much appreciated by the teacher and recognized by the classmates as a leader; student 16 (S16) represents the *"sceptic"* attitude toward climate change, he was not interested in the issue and demonstrated mistrust toward the activities; student 25 (S25) represents the *"outsider"* of the class, he was not particularly interested in the activities in general and also in the climate change issue; finally, student 26 (S26) represents the *"thoughtful"* attitude toward knowledge, he was very heedful but silent throughout the whole process. Table IV provides a summary of the sample, aims of the interview and the protocol outline.

TABLE IV. – *Summary of interview features.*

| | |
|---|---|
| Number of students | Five (4M, 1 F)[a] |
| Features of the sample | Heterogeneous group (the shy, excellent, sceptical, outsider and thoughtful class members) |
| When? | One week after the end of the teaching experiment |
| Aims | – To check conceptual understanding<br>– To investigate students' idea of modelling in physics<br>– To gain feedback on how students experienced the lesson on complexity |
| Protocol outline | – *First part*: students' ideas about modelling in Physics<br>– *Second part*: students' ideas about the specific models addressed in the Climate Change path<br>– *Third part*: students' ideas about complex models |

[a] In order to guarantee anonymity, we will refer to all the students by using *he* or *him*, neutrally and regardless of actual gender.

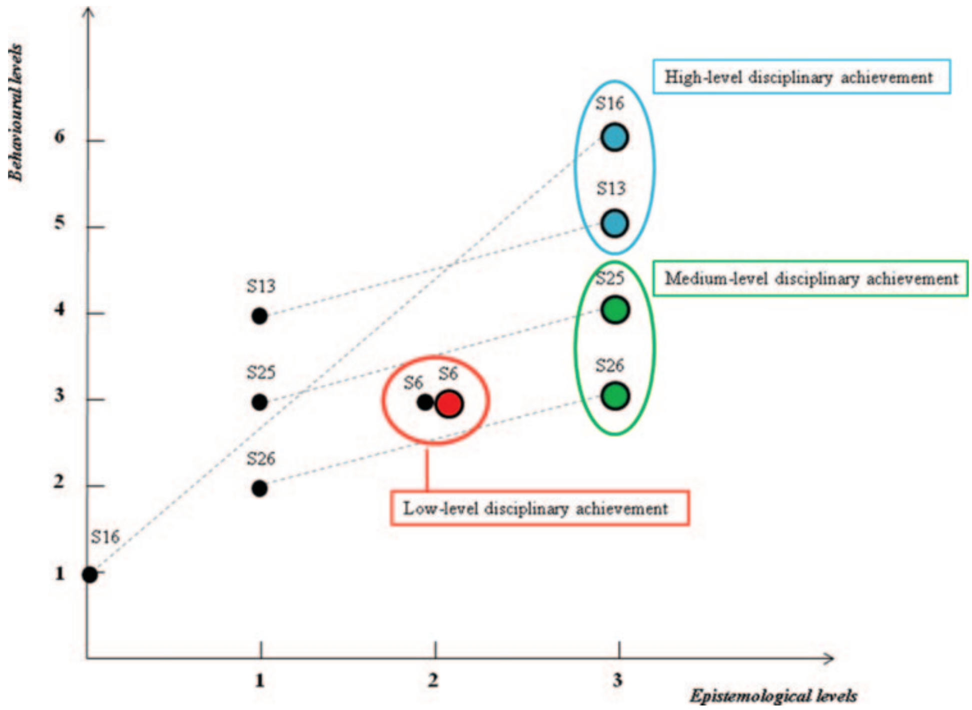


Fig. 1. – Students' changes along the dimensions.

The graph of fig. 1 sums up the changes of the five students along the epistemological and the behavioural dimensions as achieved in the previous analyses (Tasquier *et al.*, 2015; Tasquier and Pongiglione, 2015).

In the graph, the epistemological scale is on the $x$-axis (from 1 to 3). On this scale, the lowest level (1) is represented by a total lack of an epistemological language that leads students, for example, to identify a model with an experiment. The highest level (3) is represented by a mastery of epistemological arguments, which leads students to describe the relationship between models, experiment and reality as an iterative back and forth relationship. The behavioural scale on the $y$-axis represents different patterns of behaviour (from 1 to 6). On this scale, the lowest level (1) is represented by a lack of willingness to take action on climate change or change one's own lifestyle and habits in order to prevent climate change. The highest level (6) is represented by the willingness to take action or to change habits, together with a detailed explanation consistent with the content of the course. The black dots represent the position of the students at the beginning of the course and the coloured dots represent the position of the students at the end of the whole course; the different colours of the dots, in the final state, show the different level of disciplinary achievements. The graph shows that only S6 (*the shy*) did not change significantly in the epistemological and behavioural dimensions. Furthermore, he encountered strong difficulties with the disciplinary dimension. Indeed, he was able to provide short answers to very specific questions with the help of the teacher, but he had difficulties in autonomously managing the basic physics concepts treated during the course. For instance, even at the end of the course, he was confused about the difference between emission and reflectance, and made mistakes when tackling the physical properties discussed in the course for interpreting the greenhouse effect. The other four students made visible changes along both dimensions of the graph and also achieved good results in the disciplinary dimension. In particular:

– S13 (*the excellent*) reached an excellent level of knowledge in the written task. He was the best in the class, even though he still had problems transferring what he learned in contexts differing from what was usually required by his teacher. He improved his epistemological knowledge on the Model-Experiment-Reality relationship. Regarding the behavioural dimension, the small improvement can also be attributed to the fact that he was already interested in the topic of climate change.

– S16 (*the sceptic*) achieved a high-level of disciplinary knowledge. Even though he did not achieve the best mark in the written task, like S13 he demonstrated a real ability to use the concepts of physics learned during the course for interpreting the greenhouse effect and its relationship with global warming. S16 was the student who demonstrated the biggest improvement in the epistemological and behavioural dimensions, despite the fact that the topics of climate change and, more in general, physics were initially very far removed from his personal interests.

– S25 (*the outsider*) reached a medium-level of physics knowledge. He understood the most important concepts in physics but he had some difficulties in managing the concept of emissivity. He showed a big improvement in the epistemological dimension and finally came to grasp the sense of the discourse about models and modelling. He had a medium-high improvement in the behavioural dimension, despite the fact that at the beginning the topic of climate change was very far removed from his field of interests.

– S26 (*the thoughtful*) reached a medium-level of physics knowledge. He understood the most important concepts in physics but he needed to talk about physics properties, like transparency, by relating them to the specific experiments carried out during the course. He showed significant improvement in the epistemological dimension and, regarding the behavioural dimension, he progressively changed his reasons why, in his opinion, few things could be done to prevent climate change. In this sense, he showed a significant improvement also along the societal/behavioural dimension.

In the light of such a map, the RQs become: *Is it possible to find correlations among the reactions of these students along the three dimensions? What general inference can be drawn from these cases?* The analysis of the interviews has been carried out to answer these questions.

## 4. – Data analysis and results

Operationally, we decided to answer the RQs by analyzing students' interviews so as to design "profiles" of the students (Levrini *et al.*, 2014). During the interviews, we observed significant differences among them. Some students were particularly involved and used articulated arguments, whilst other students had to be systematically encouraged by the interviewer. These different types of interaction revealed, in our opinion, two different kinds of reaction: some students felt embarrassed whilst others felt at ease and developed their arguments without any "pressure" from the interviewer. Such an impression has

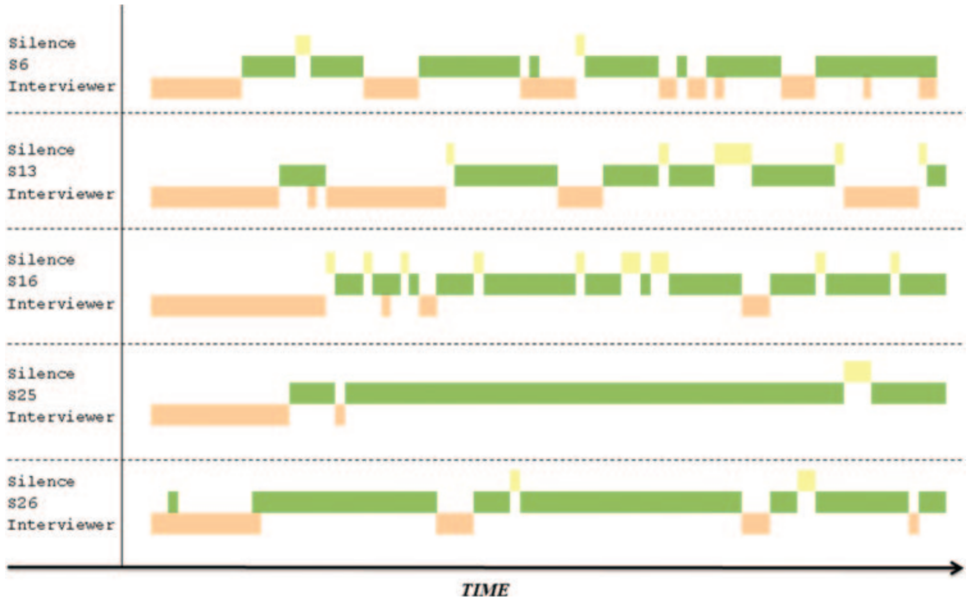


Fig. 2. – Excerpts of temporal maps from students' interviews (time unit: 2 seconds).

been captured in the temporal maps of fig. 2 that show the different pace and type of interaction between each student and the interviewer (Fantini *et al.*, 2014). The participants and the silence are represented along the $y$-axis and each participant's talking time is represented along the $x$-axis (the time unit is two seconds).

In order to make the maps comparable, they have been created using the same part of each interview, *i.e.* the first part. The pace of the discussion between the interviewer and student confirmed the impression that 3 students (S16, S25, S26) felt more at ease during the interview than the other two (S6, S13). Indeed, the first two maps show more frequent, interventions by the interviewer than in the others, even though the topic of discussion was the same.

Moreover, students' argumentations and their choice of words were significantly different. In particular, S16, S25 and 26 took the interview as an opportunity to express a main message about their experience in the course and, in the third part of the interview, each of them centred the argument on different key-words and terms related to the perspective of complexity. Our impression was that their use of specific words in the interview was representative of how they experienced the path on climate change and how the epistemological dimension touched both their scholastic attitude (as students) and behavioural attitude (as young citizens).

In the light of such considerations, we designed the profiles of S16, S25 and S26 as follows:

i) we took into account the *temporal map* of the single student in order to identify for each of them a specific pattern of interaction between the students and the interviewer;

ii) we identified the *main message* expressed by the student about his personal experience in the course;

iii) we identified *words or expressions* that each student repeated several times during the interview to express and articulate their main message.

As will be shown, comparison of the three profiles allows us to produce a draft argument to answer the RQs.

The draft argument will be tested and refined against the cases of S6 and S13, which appear significantly different from the previous three cases. Besides the different pace of the interviews, in the transcripts of S6 and S13 it was neither possible to identify the emergence of a main central idea, nor to identify words or expressions related to the complexity that had captured their attention. The profiles of students S6 and S13 were built so as to further explore the credibility of our argument and to outline its limit of validity (Anfara *et al.*, 2002). In this sense, S6 and S13 acted as contrastive cases.

**4·1.** *S16: "The sceptic"*. – i) *Temporal map.* During the interview, S16 appeared at ease from the outset. Although there were several moments of silence, there were only few and short interventions by the interviewer. Particularly, the moments of silence seem to be important moments of reflection, functional to the discourse. In this sense, the map shows that S16 was constructing his discourse and the interviewer allowed him time to do this.

ii) *Main message.* From the very beginning of the interview, S16 told us that before the course he had been sceptical about the issue of climate change and the scientific reliability of information provided by the media. He expressed the need to have correct and solid information in order to avoid being manipulated by the media. The alarmism that, in his opinion, characterizes the way in which this subject is often treated, does not represent a guarantee of the real existence of global warming. His position later evolved as a result of the whole course and particularly thanks to the introduction of the perspective of complexity and of the features of modelling of complex systems. In particular, the model of Schelling was an element that led him to activate the societal dimension, which was initially absent: "*Let's say that before I knew little on the subject, because at the beginning this was not a topic of interest for me. But as these meetings went on, providing more information, I arrived at the understanding that these are instead important topics that must be followed and they are in fact interesting.* [...] *Before that course, I thought it was all just huge alarmism and nothing else"*.

iii) *Key words.* In the interview, S16's discourse was strongly characterized by the repetition of words like *to determine exactly, regularity, to know exactly.* These are words that he systematically used in every part of the interview and that seem to express his need to know exactly what happens. In the following excerpts, for instance, S16 explains how the Lorenz attractor has revolutionized his idea of "the determination of the behaviour of a body": "*[in classical physics] I can determine where it will be at a certain point after a certain period of time, whilst here [in the Lorenz's butterfly] I cannot do that. Here it is impossible, I know where such a point moves but I cannot know exactly where it is now. Whereas before the course I was convinced that there was only classic physics, in this case the whole situation has reversed ... and I was a little bit disoriented but fascinated"*. Consistent with his view, the word of complexity around which he developed his reasoning was *unpredictability.* Indeed, when the interviewer asked S16 about the words and concepts that he found more interesting or that changed his perspective, S16 claimed: *"Surely 'unpredictability'; let's say that all the other words of complexity, I think, serve to explain this word ... let's say that the most important word* *is 'unpredictable' because with this word I explain what it means to study phenomena on a global scale"*. In order to give credibility to the issue of climate change, S16 expressed a need to elevate unpredictability to the rank of a scientific concept and to attach a more refined meaning to the provisional power of science and the kind of data and models on which science founds its previsions: *"I realized that, for example, the melting of glaciers and a rise of just one degree of the average temperature, can lead to important consequences. I understood that these things need to be evaluated on a very dilated scale of time. Whereas I was initially convinced that the data variation from year to year was enough to understand these things [changes in the climate], instead I understood that we must have data based on years and years of experience"*.

**4·2.** *S25: "The outsider"*. – i) *Temporal map.* During the interview, S25 appeared very at ease. In the excerpt below there was only a moment of silence and only within S25's discourse, to indicate a moment of reflection. Hence, it seems that he was ready to articulate his discourse.

ii) *Main message.* During the interview, the main message which emerged is that, despite the difficulty of the subject and of physics in general, the game of modelling and the progressive complexification of models offered S25 a key to address the topic. Particularly, the lesson on complexity was a fundamental moment in his learning path because it represented an intellectual challenge that he decided to take up. Furthermore, the perspective of complexity allowed him to analyze a scientific issue from multiple points of view, and to form a global and coherent picture. At the end of the interview, S25 revealed that he was a musician and that he loved art and math, whilst he was not particularly interested in science: "*The lesson on complexity was particularly interesting, i.e., more than anything else, it was like a challenge, so I said 'okay, let's try to figure it out'. Then it was nice to find out how to go from a laboratory model of a virtual model, imagine how they might go, if everything goes as we imagine things; how things could go in space, or in a place connected to us. That is to say, it is nice to know and to be able to predict some things"*.

iii) *Key words.* S25 did not select only one word of complexity around which he organized his discourse. He was fascinated by all the words of complexity and their evocative power. During the lesson, he was guided by the charm that those words evoked and he tried to collect all the stimuli that the new perspective of complexity transmitted to him. The fascination for the aesthetical dimension that stimulated his interest dominated his whole interview. In commenting on the course, he focused on a picture of the Dutch graphic artist M.C. Escher, which was used as a cover page for the lesson on complexity. S25 gave the picture a special significance in explaining the idea of global and local view, the difference between macro and micro, and the concepts of regularity/irregularity and order/disorder.

He revealed that at the beginning of the project, he was bored by the idea of dealing with climate change. The *fil rouge* on modelling and the lesson on complexity were the two elements that captured his attention and that initially attracted him to the issue. The aesthetical dimension and, in particular, the new and more fascinating perspective on science introduced by the lesson on complexity represented a way to engage such a student. Particularly, in the perspective of complexity he found an opportunity to study science in a game between freedom and constraints in which creativity can also play a role, just like for a painter or musician.

**4**˙3. *S26: "The thoughtful"*. – i) *Temporal map.* During the interview S26 appeared at ease. He was able to take responsibility for his answers. He managed the discourse by himself with pauses when necessary, even though he sometimes needed some minor assistance from the interviewer.

ii) *Main message.* S26 immediately explained that he needed to address every issue in a practical and concrete way: *"The laboratory experiments were clear and explicit. However, in my opinion, it is easier to learn by doing things rather than just by listening.* [...] *Indeed, I better understood the issue of models when I made models by myself, by seeing and creating them, and also thanks to the tutorial that was given to us during the experimental lessons"*. His need to learn by doing was not only related to the lab-activities but also to the implementation of computer-designed models. S26 was also really attracted by the computational aspects of modelling, indeed he was interested in the way Lorenz concretely elaborated his theory.

iii) *Key words.* Throughout the whole interview there was the recurrence of the words "complicated" and "complex"

which at the beginning of the interview were used alternately in a confused way. In our opinion, his sentences revealed a more or less conscious need to find a way to distinguish what is complicated, and then reducible to something simpler, as opposed to what is complex, then non-reducible. In coherence with his linguistic style, he chose "irreducibility" as the most evocative word of complexity, around which he organized his thoughts: "*Well, irreducibility is the word that I better understood* [...] *irreducibility in the sense that there are things that cannot be reduced to only one parameter, as we saw in the example of the iteration of Lorenz ... when he inserted his values into the computer and then cut some significant digits, then he had a different situation from what he expected ... there is a limit to the simplification"*.

S26 overcame the idea that "irreducibility" was a limitation or something which was possible to solve thanks, for instance, to advanced technology, or something that was possible for him to unravel. Instead, "irreducibility" became an implicit feature of the nature of certain phenomena. Thanks to this development in his thinking, he matured in his awareness both of this topic specifically and also more generally about science. However, this process is still underway at the time of the interview. The conflicting use of the words "complicated" and "complex" is proof of this. This conflict was positively managed, indeed the interview helped S26 to progressively recognize the distinction between the two words and to change his way of looking at the relationship between the individual and the solution. Such a distinction has an important role in defining the shift of perspective from the classical models to complex models: from an initially very pragmatic approach to the awareness needed in a more complex and non-reductionist approach in searching for solutions.

**4**˙4. *Discussion of the first set of profiles.* – Through the comparison of the three profiles, we can infer examples of *functions* played by the epistemological dimension in triggering an attitudinal change toward climate change.

For S16, the epistemological dimension served to nurture his intellectual interest by providing a sort of "scientific reliability" to any discourse about climate change. In particular, the elevation of unpredictability to the rank of a scientific concept allowed him to overcome his initial scepticism and to find room for a personal social involvement. As for S25, the charm of the epistemological dimension functioned as an attractor capably of nurturing his aesthetic pleasure. Indeed, the challenging character of said dimension touched his artistic personality and triggered the activation of a social involvement. For

S26 at least, the epistemological dimension acted as a key i) to overcoming the personal barriers created by his pragmatism which prevented him becoming involved in something too complicated; and ii) for tackling scenarios with new possible and reliable, even though more complex, methods of thinking.

To sum up, the draft answer to our RQs is as follows: the epistemological dimension and, in particular, the perspective of complexity was, in some cases, productive in triggering a change in students' attitude towards climate change. The examples show a spectrum of three different specific functions that it played: to provide scientific reliability, to infuse intellectual charm to the discourse, to extend the field of possible actions. These functions are, of course, idiosyncratic and we suppose that many other functions could be found if we enlarged our empirical basis. Nevertheless, our three cases alone allow us to conclude that significant correlations can be found between the epistemological and behavioural dimensions and that the teaching path was able to create, for some students, a virtuous dynamic state among them.

The two cases that we will consider now provide further contributions to understanding why that happened with these students and why it failed with others.

**4·5.** *S6: "The shy"*. – The interview was dominated by very short answers from the student and by many pauses with the frequent use of expressions like "*ehm*". S6 systematically needed the interviewer's help in articulating his thoughts.

From the beginning, this student stated that his attention was focused on things he found "easy", such as the experiments. For him the lesson on the perspective on complexity represented an intellectual obstacle that he did not even try to address.

His interview discourse was fragmented and not articulated enough to enable us to evaluate to what extent his thinking was globally consistent from the points of view of disciplinary content and epistemological message. Indeed, he listed the words of complexity, simply saying that he did not understand them and that he did not relate the first part of the course to modelling with the perspective of complexity: *"What caused me difficulty was the circular relationship and then the non-linear causality ... ehm ... I cannot connect it to the idea of complexity"*. Within his discourse it is not possible to identify the presence of a core idea around which he organizes his thoughts. The poorness of the discourse leads us to conclude that S6 found the path too difficult. This student reacted with occasional short answers that do not reveal any attempt to find a personal method to understand the content. This is demonstrated by the recurrence of the expression "*I did not understand*".

He ended the interview by saying that he was happy to have tackled this "modern environmental problem" because he trusted his teacher but that the difficulties he met with the content prevented him from following the epistemological and societal *fil rouge*.

**4·6.** *S13: "The excellent"*. – From the very beginning, the embarrassment of S13 is evident. From the map and the short and fragmented answers he provided, we can see that he did not feel at ease. S13 systematically needed the help of the interviewer in articulating his discourse.

Looking at the other data collected from this student, it emerged that he reached top levels in each dimension (see fig. 1). He understood the scientific discourse (the concepts of absorbance, transmittance, reflectance and the greenhouse mechanism). He managed the discourse on models well (up to the lessons of the laboratory) and he also changed some aspects of his behaviour. Despite such results, he showed many difficulties during the interview and the tone revealed a sort of "cold acceptance". Why did this happen?

One reasonable explanation for his blanket of embarrassment is provided by the student himself at the beginning of the interview, when he stated very clearly that he did not understand the link between the epistemological perspective of complexity and the rest of the course: "*More than anything else I do not understand the relationship that exists among: the models, what we did in the laboratory and the complexity*". His failure to link the different parts of the course seems to show that he accepted the path in all its parts but did not feel the need to form a personal view. Unlike the first group of students, it is not possible to find key-words or a central message in his interview.

The words he offered during the interview are not enough to provide a unique interpretation of the reasons for his reactions. The hypothesis that we find most convincing is that he approached the course in a scholastic way, in the sense that he expected to be spoon-fed the connections by the teacher as opposed to forming a personal view of the content and taking responsibility himself for acquiring the knowledge (Cornelius and Herrenkohl, 2004).

During the interview we perceived that he felt discomfort at being removed from an ordinary teacher-student situation and, thus, without the traditional rules of a common oral task (Brousseau, 1986; Yackel and Cobb, 1996). S13 limited his personal involvement in the epistemological and emotional dimensions probably because he wanted to keep under control his insecurity towards the apparently novel scholastic context. Still, as is evident from the beginning, he did not accept entirely the existence of an epistemological dimension, particularly the existence of an intrinsic complexity in the nature of science. Even though he grasped the scientific meaning passed on by the course, the inner epistemological debate about climate change hindered him in tackling a new emotional challenge.

**4˙7.** *Discussion of the two contrastive cases.* – Comparing the two contrastive cases with the previous results allows us to refine our draft argument and our answer to the RQs. In particular, the comparison leads us to identify some boundary conditions that are needed to trigger a personal and conscious involvement in climate change issue. From the analysis of S6's profile, it emerges that the first condition is the importance of meaningful learning of scientific content. In our course, the epistemological and behavioural dimensions are deeply rooted in the discipline and, without a significant learning of the basic concepts of physics, the other dimensions become meaningless. From the analysis of S13's profile, a second condition emerges, regarding the freedom of a social role that the student has to play (related to the expectations of his teacher and classmates). Indeed, S13 was the "excellent" member of the class and it seemed as though he had to defend this role for his self-efficacy (Bandura, 1994). His social interest toward the topic seems to be still effectively dependent on his teacher (Cornelius and Herrenkohl, 2004). On the contrary, in the first three profiles, we saw that they felt free to express their personality without behavioural constraints, they were free also to be initially sceptic and to follow a personal path of learning and view-forming.

## 5. – Conclusion and final remarks

The analysis presented in this paper is part of a wider investigation into the reaction of secondary school students to a multi-dimensional path on climate change. The project aimed to foster behavioural and personal involvement through a refined epistemological reflection on modelling and on the perspective of complexity. In order to investigate possible links between the epistemological competences and the behavioural attitude toward climate change, five students were selected and analyzed. The analysis highlighted different types of emotional reaction to the epistemological dimension: the general acceptance was coloured with enthusiastic intellectual satisfaction by some students, with "cold" acceptance, or with a prudent and responsible curiosity by others. The various types of reaction seem to have interesting links with students' emotional and social attitude toward climate change. Three cases concern students who had an initial distrust or resistance toward climate change issues and found personal new reasons for engagement in the epistemological perspective of complexity. Two of them found, in the epistemological dimension, a stimulating opportunity to nurture their intellectual or artistic talent. One (more pragmatic) found new arguments to see and evaluate possible directions of action. The other two students acted as contrastive cases and allowed us to see some boundary conditions needed to trigger personal involvement. These conditions regard the need to master disciplinary knowledge in order to recognize the value of the epistemological and social dimensions and the importance of feeling free from the teacher's expectations before being able to explore and find one's own position with respect to such complex issues. In the light of these results, we can assert that, under certain conditions, specific epistemological know-how can positively impact not only productive disciplinary engagement, but also a more personal and authentic involvement in climate change. However, the analysis of the two contrastive cases raises two open issues. The first one concerns the domain of validity and the problematic issue of searching for the boundary conditions that foster and support authentic behavioural responses. The second concerns the role, well-known in literature, of the external expectations (from a teacher or other people) in fostering or hindering proper, authentic and genuine involvement.

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