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Citizenship Education to Nanotechnologies: Teaching Knowledge About Nanotechnologies and Educating for Responsible Citizenship

We present a research based on a project for citizenship education to nanotechnologies in a French high school which aims at teaching the specific characteristics of nanotechnologies, of their fields of application and of the controversies which are linked to them. At the junction of Socially Acute Questions didactics and of the cultural-historical Vygotskian theory, we analyze the knowledge at work in a debate on the promises and risks connected with nanotechnologies. The knowledge mobilized by the students (17- to 18 years-old) in their dialogical interactions can refer back to the archetypal narratives whose origin lies in men's social and cultural history. Through the joint effect of cumulative talk and exploratory talk, the students co-construct the concepts linked to the Social Ethical Issues: risks and human enhancement. We show that the debate at school leads students to be able to construct reasoned opinion and to position themselves in their environment in a responsible way. This educational innovation appears to be relevant for combining the learning of academic and cultural contents with social competencies necessary for committed citizenship education in the field of nanotechnologies.

Keywords
education for nanotechnologies, socially acute questions didactics, social ethical issues, debate, dialogical exchanges analysis

Cette recherche porte sur un projet d'éducation citoyenne aux nanotechnologies dans un lycée français dont l'objectif est d'enseigner les spécificités des nanotechnologies, leurs champs d'application et les controverses associées. Pour analyser les savoirs en jeu dans un débat portant sur les promesses et les risques liés aux nanotechnologies, nous croisons la didactique des Questions Socialement Vives et la théorie historico-culturelle vygotskienne. Les savoirs mobilisés par les élèves (17-18 ans) au cours de leurs interactions dialogiques peuvent se référer aux récits archétypiques puisant leur origine dans la culture humaine. Les élèves co-construisent des concepts liés aux questions socio-éthiques (risques et augmentation humaine) par le biais de l'articulation des discours cumulatifs et exploratoires. Nous montrons que le débat scolaire amène les élèves à construire une opinion raisonnée en se positionnant dans leur environnement de manière responsable. Cette innovation pédagogique semble pertinente pour articuler l'apprentissage des savoirs disciplinaires et des compétences sociales nécessaires à une éducation à une citoyenneté engagée dans le champ des nanotechnologies.

Mots clés

éducation aux nanotechnologies, Questions Socialement Vives, questions socio-éthiques, débat, analyse des échanges dialogiques.

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1 Introduction

Over recent years, programs prescribing educating for have become widespread. The Council of Europe (2008) promotes global education as a holistic "education that opens people's eyes and minds to the realities of the globalized world." The United Nations support Peace Education Programs which teach children and young people how to acquire social competencies in order to better live together and to commit themselves as citizens. Educating for responsibility is a recurrent theme in French official texts. Citizenship and Health Education Committees aim at the development of individual and social responsibility behavior: the official circular of July 2004 at the origin of Environmental Education for Sustainable Development (EESD) stipulates that students must be able to "position themselves in their environment and act within it in a responsible way".

These educational actions are more concerned with the development of social and civic competencies than with the knowledge assigned to academic subjects which have been differentiated by French institutions since the 19th century.

We present a project for citizenship education to nanotechnologies in order to answer the following question: which scientific and technological culture should 21st century school be promoting? (Simonneaux, Legardez 2011; Lebeaume 2011). We would like to show the interest of combining the *teaching of* characterized by academic and cultural contents with *educating for* characterized by social competencies to promote a new form of teaching appropriate to contemporary techno scientific evolution (Panissal, Brossais 2011). This new approach aims at teaching the specific characteristics of nanotechnologies, of their fields of application and of the controversies which are linked with them.

Our research lies at the junction of Socially Acute Questions (SAQ) didactics and of the cultural-historical Vygotskian theory to analyze the knowledge at work in a debate on the promises and risks connected with nanotechnologies.

Our research questions are as follows:

Which knowledge related to the social ethical issues connected with nanotechnologies (SEI) do students mobilize in their dialogical interactions?

Do students co-construct the knowledge stemming from the SEI?

2 The Controversies Related to Nanotechnologies

Research into the risks of nanotechnologies for humanity and the environment as well as into its ethical, legal and social effects has been developing for about ten years. So has research on the technological and scientific aspects. In the USA and Europe nanotechnology is now firmly embedded in the consideration of ELSI (Ethical, Legal and Social Issues).

The public debate organized from October 2009 to February 2010 in France, regarding the general options in terms of development and regulation of nanotechnologies is part of this perspective of "Precocious consultation of the government towards the population before the decision-making and the concomitant production of high-quality information made available to anyone interested". The positive aspects of nanotechnologies in the medical field are underlined (for instance, the hopes linked to cancer therapy or the miniaturization of the electrodes directly implanted in the central nervous system). Such a personalized type of medicine would be based on the quality of diagnosis and on the powerful action of treatments. Fears and reproaches have been voiced as well: there are numerous uncertainties in the field of health risks, about impact on the environment, in the field of individual freedom or potential uses regarding security; the development of nanotechnologies would be a factor

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increasing the gap between countries from the North and countries from the South (Benoit-Browaeys, Colin-Detcheverry, Lebret 2010; Bürgi, Pradeep 2006; Falkner, Jaspers 2012).

In this effervescent context linked to the excitement caused by nanotechnologies, categories of SEI have been defined in civil society. We present those by Lewenstein, Professor of Science Communication, by Sandler, a philosopher on Ethics and Technology, by Bensaude-Vincent, a science philosopher and by Benoit-Browaeys, a science journalist.

Beyond the documents produced by the National Science Foundation, Lewenstein (2005) creates a category of what is considered as a SEI in nanotechnology. He enlists this way the environmental issues (toxicity, resources, pollution), the job market issues, the educational issues (implementation of interdisciplinary prescriptions, students' education...), life privacy issues (individuals data base, access control to private data), national and international political issues (developed countries and under-developed countries, territory management), intellectual property issues (patents) and finally, human enhancement issues (boundary between treatment and modification, natural/artificial, definition of a "normal" human). Sandler (2009) proposes a SEI typology. He considers that nanotechnologies, even if very promising, will not be able to fully exert their potential if they are not associated to an adequate ethical and social questioning. His categorization in five items is an intellectual grid to identify a reasonable and reasoned development about nanotechnologies. He distinguishes: the social and environmental context (toxicity, inequalities, education...), the morally contestable practices (weapons, synthetic biology...), the role of nanotechnology in the social system (technoculture), the issue of life and impact on social standards (nanomedicine progress, privacy...), and finally the issue of human being transformation considered thanks to NBIC (Nano, Bio, Info, Cognitive) convergence. A report entitled "Nanotechnology, Biotechnology, Information Technology and Cognitive Science: Converging Technologies for Improving Human Performance" draws up a diagnostic of the NBIC technologies progress and their most promising aspects for humanity's future as well as a road-map for their development (Roco, Bainbridge 2007). It is not only a nanoconvergence (convergence of the scientific disciplines) but also a NBIC convergence that includes disciplines such as sociology, cognitive psychology, artificial intelligence, neuropsychology, etc. The core idea of this report is to orientate research activities of all disciplines towards the enhancement of human physical as well as intellectual capacities, through sensory capacities increased tenfold by implants, computer-human brain interfaces, and interfaces between human brains for a better communication. This human enhancement, also called "transhumanism"[1], would render post humanity possible thanks to the technological transformations that it would permit (Larrère 2008; Schummer 2009).

The ethical and social issues are structured around four main preoccupations. (1) "How can we accept products containing nanomaterials?" refers to the issues of toxicity and control; (2) "Is the nanoworld and its ubiquitous computing technology desirable?" is linked to the potential attacks on individual freedom; (3) "What are the objectives of nanotechnologies?" address the possible deviations in terms of artificiality vs. nature and of enhancement of the human

[1] Transhumanism is an international intellectual current campaigning for the extensive use of science and technology for improving and enhancing physical and mental human performances. This project considers that ageing, illness, suffering, handicap and eventually death need to be eradicated, thus revisiting deeply human condition.

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being; and (4) the question "Who will have access to the benefits of nanotechnologies or who will be exposed to their risks?" regards the issues of balance between the countries from the North and those from the South, between the populations who are economically favored and those who are not (Benoit-Browaeys et al. 2010, 17).

Bensaude-Vincent (2012) takes up again the checklist of the ELSI approaches: (1) Risk assessment, cost/benefits (transparency, labelling), (2) Privacy, individual freedom, (3) Security (uncontrollability, terrorism…), (4) Enhancement of human nature and (5) Social justice (global divide). In her opinion, among the advantages of this approach we can find Health and Security alerts and the raising of scientists and politicians consciousness. However, she criticizes them for giving the illusion of mastery and control with this standard checklist. Moreover, the ELSI may make people think that public opinion is concerned only with risks which might be technically solved.

In this paper, we focus on how these controversies are dealt with at school through the SAQ teaching that aim at contributing to training students for understanding nanotechnology issues, for identifying the actors, their points of view and the reasons why they adopt them, for anticipating the consequences of the choices which could be made, even for directly taking part in the public debate (Audigier 2011).

3 Socially Acute Questions (SAQ) Didactics

SAQ didactics lies within the trend of educating for: sex, health, safety, security, sustainable development education and above all citizenship education since all these actions promote educational projects (Audigier 2000) and also aim at readjusting an educational model, mainly focused on knowledge, by reasserting the role of the social agent in a citizenship perspective (Lange, Martinand 2010). Indeed SAQ combine scientific and social problems, values and ethics (Simonneaux, Legardez 2011), dealing with them requires knowledge but also the taking into account of social issues, of values and ideologies. Within the frame of this nanotechnologies education project (Panissal, Brossais, Vieu 2010; Brossais, Panissal 2013), our aim is to confront students with authentic situations in relation with today's technologies so that they develop, beyond ways of acting, ways of thinking and to provide them with keys to their environment. Indeed the transformation of our societies through powerful technoscientific acceleration requires adaptation skills and conceptualization which were not available in the previous culture (Lebeaume 2010).

SAQ didactics also lies within the field of Post Normal Science (Funtowicz, Ravetz 1993) and post modern risk society (Beck 1986). According to Post-Normal Science, science is affected by uncertainties and value-commitments, facts are uncertain, values are in dispute, stakes are high and decisions are urgent: scientific demonstration must be complemented by a broad societal dialogue. Therefore, nanotechnologies lie within the field of Post Normal Science as a science with strong links to human needs, thereby leading to large uncertainties, major issues, values, and requiring urgent decisions. Decision processes of PNS should include open dialogue with everyone concerned thus introducing the concept of "extended peer community" and including strong consideration "to extended facts" that is to say, data from sources outside the orthodox research. Consequently the questions raised by the development of nanotechnologies are very important. The whole training process that we present below takes into consideration that "extended facts" are not limited to the scientific field of nanotechnology.

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The production of new scientific knowledge aims at solving the numerous negative effects (waste, pollution, new illnesses) induced by technosciences (Beck 1986). According to Beck, the worlds of technology, industry and science form a network of general complicity leading to general irresponsibility. By giving considerable importance to uncertainties and risks, he criticizes scientific rationality. Science cannot be mere theoretical production; through what he calls "reflexive scientifisation", researchers have to anticipate the consequences, the uncertainties and risks of scientific progress.

The risks linked to new technologies are unfamiliar, they are considered as being imposed, having irreversible consequences, being beyond repair once identified and above all concerning everybody including generations to come. In a risk society, technological development benefits the community and the individual but at the same time increases the risks related to the creation and application of these technologies. The interest of teaching new technologies (Lebeaume 2010, 2011) might consist in allowing students to integrate the way of acting and thinking required by technosciences and more particularly by nanotechnologies, in order to go beyond the old and recreate the new (Vygotski 1985), and in fostering the adaptation of new generations in a social, economic and technoscientific environment. Lebeaume (2011) adds that current technoscientific transformations require the redefinition of the cultural project of the school system so as not to create disjunctions between ways of life and ways of thinking.

Within the frame of SAQ didactics related to nanotechnologies we have shown the interest of actions such as "citizenship education to nanotechnologies" (Panissal, Brossais, Vieu 2010; Panissal, Brossais 2011) which contribute to educating for risks that may be caused to humanity and their environment by nanotechnologies (Simonneaux, Panissal, Brossais 2011).

4 The Role of Social Interactions in the Cultural-Historical Theory

We have chosen Vygotski's cultural-historical theory as frame of reference to analyze the students' language practices during a debate on a SAQ. Social interactions play an important role in the process of cognitive development (Vygotski 1985): they allow the development of individual reasoning. While Vygotski acknowledged the importance of help from others, he nevertheless put the emphasis on the activity of the individual subject who appropriates knowledge and internalizes it:

> "Learning gives birth to, wakes up and activates in the child a whole series of internal development processes which at a given period, are only accessible to him through communication with the adult and collaboration with his peers, but which once they are internalized will become a conquest by the child himself" (Vygotski 1985, 112).
>
> Intellectual development is undoubtedly of a social nature both "because it is the product of the appropriation of psychological tools, of systems and of semiotic behavior constructed throughout human social and cultural history and because this appropriation can only exist in social communication and cooperation practices" (Rochex 1997, 128).

Vygotski considered that human action on their own behavior and on others' (and conversely others' action on one's own behavior) is mediated though systems of signs he called psychological tools: "language, the various forms of counting and calculation, mnemonic techniques, algebraic symbols, works of arts, writing, schemata, diagrams, maps and all possible signs, etc." (1985, 38).

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Many teaching activities in sciences are also characterized by the use of specific, culturally defined ways of using language as social modes of thought: Reasoning is fundamentally dialogical: the use of language as a cultural tool for collective reasoning could be expected to shape individual reasoning.

We have adopted a Vygotskian perspective of peer knowledge co-construction; that is to say, a social construction of thinking. The artificial or cultural development takes over from a first stage of development, considered as more natural in so far as it is not yet shaped by the tools of culture. In its cultural sense, development consists in the appropriation and internalization of the tools initially culturally constructed. In that case, intellectual development is considered as acculturation or progressive construction of a complex system of higher mental functions which are social (Dolz, Moro, Pollo 2002). For these authors the debate is a matrix of a specific type of communications and interactions and in the same time a tool for exploring opinions, deepening knowledge, building new significances and relevances, transforming attitudes, values and norms. The dialogical dimension of the verbal activity in Vygotski's theories leads us to consider the debate between students as a psychological tool allowing the construction of nanotechnologies SEI in the contemporary world and more widely the elaboration of the relationships existing between science and society. This is the basis for our analysis.

5 The Research Project and Protocol

We propose to link the didactic field of SAQ with the cultural-historical approach. According to Kantian epistemology, human beings tried to explain existing nature and the simplified models proposed were attempts to approach the reality while also maintaining the idea that the reality is inaccessible. As far as the technoscientific attitude is concerned, the model is used as real and the reasoning is indifferent to outside reality (Bensaude-Vincent 2009a). Therefore the aim of technosciences is no longer to explain nature but to observe the intervention of the researcher in the infinitesimal. Science is no longer considered as neutral (without human intervention) but as a cultural and social object (Beck 1986) which transforms itself and is passed on from generation to generation (Vygotski 1985).

For Vygotski, education was not only a telltale sign of natural development, it restructured psychic (higher mental) functions. The function of an educational action is therefore to mediate these tools, produced by culture, to transform them so that they can be learned. Any tool sets the proprieties of this or that language practice. Thus the debate participates in the transformation of values, beliefs, in the exploration and construction of knowledge, in the development of higher mental functions such as the abilities for arguing, resourcing in analogies, rephrasing, rebutting and speaking in public. We study the didactic transposition of a citizenship debate in social practices, in an oral formal genre which can be taught (Schneuwly, Dolz 1997). The debate at school is a textual genre. It "is always a controversial social problem for which diverse solutions are possible, but it is orientated towards the collective construction of a solution. It is a language tool for exploring opinion fields, for getting deeper insight into the knowledge needed for the construction of new meanings and the transformations of attitudes, values and norms" (Dolz et al. 2000, 44).

From the cultural-historical perspective we refer to, the initially external nature of complex cognitive activities is asserted. These psychic capacities preexist in the "products of culture" identifiable under the generic appellation of tools. These tools (historically created artificial means of action) refer to concepts, works of art, theoretical systems and also to "the specific means of

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transmission of cultural pre-constructs, namely educational means and systems" (Dolz et al. 2000, 39). Thus, children's learning depends on the internalization of these external tools via language practices with adults and with peers. Student verbal interactions in debates are therefore a media of learning (from the outside to the inside) and the mark of this learning.

The use of debates is a device for teaching SAQ, which are issues whose reference knowledge is discussed both in the scientific sphere, in the social and media sphere and in the school sphere when they are taught (Legardez, Simonneaux 2006).

We position ourselves within the frame of SAQ didactics concerning the analysis of students' socioscientific argumentation (the way they build, justify their opinions and conclusions as far as a socioscientific issue is concerned). More precisely we consider that peer social interactions play an important role in the construction of thinking. Our aim by referring to the Vygotskian frame is to question how, in a debate, students mobilize scientific, economic, ethical, political knowledge about the controversies related to nanotechnologies (SEI), and the way they collectively construct knowledge as well as social and civic competencies.

Let us present now our methodology and first the context of the experimentation.

We have chosen for this teaching a theme referred to a study on nanotechnologies and health carried out by the CNRS researchers, more particularly the study of a nanosystem for medical diagnosis. Lectures are based on several concepts of the curriculum which are involved in the design, fabrication and characterization of this biodetection nanosystem. After those classes, during practical sessions in laboratories, the high school students make and then use this biodetection nanosystem.

Tab1e 1: Main steps in the experimentation of the teaching scheme

Class	Scientific Senior year
Nature of project	(1) Courses given by young researchers dealing with concepts of the secondary-school final-year program are presented under an interdisciplinary perspective and are called up for the nanotechnology project of that class (20 hours in high-school); (2) A practical experiment conducted in the frame of a laboratory, close to the current scientific practices (6 hours); (3) Organization of debates to encourage a reflection to face the uncertainties related to technosciences and their impact on society (14 hours).
Disciplines involved	Physics-chemistry, Biology, philosophy, English, history-geography, Civic, Legal and Social Education.
Time duration	6 months (40 hours) from September to March

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From the perspective of nanotechnologies, the knowledge lies both in the method of fabrication of this molecular diffraction network (soft lithography), in the specific interaction between biomolecules and in detection sensitivity which closely depends on the size of the molecular patterns of the network (here nanometric sizes). In Physics class, the contents concern the diffraction of light. The way light behaves in front of an obstacle, a slit or a thread is taught in a scientific senior year. The way light behaves in front of a molecular network simplified by a series of equidistant slits is taught in the experimental Scientific Senior year with special courses in nanotechnologies. In Mathematics class, the contents concern the modelization of diffraction, in particular with the functions $\sin x / x$, et $(\sin x / x)^2$. It is necessary to plan and simulate through calculation the variations of the light intensity diffracted by the detection device during the immunological test. The calculation provides information on the sensitivity of the device and thus on its potential interest for medicine. Consequently Mathematics is more likely to appear in the students' eyes as a necessary school subject for the modelization and predictability of scientific phenomena. In Chemistry class, the contents concern the organic materials and their specific properties. The fabrication process implemented during the experiments uses an elastomer polymer and requires the preparation of glass surfaces, treated with chemical molecules allowing for the adherence of proteins. In Life Sciences class, the contents concern the antigen/antibody reaction as well as the biological tests of ELISA detection (Enzyme-Linked Immunosorbent Assay for the detection of antibodies) and the Western Blot (for the detection of viral proteins): AIDS is the example studied in a Scientific Senior class. The study of the functioning of the nanosystem mobilizes the knowledge which has been acquired during the lesson and enables its comparison with the other immunological techniques previously studied.

Analysis of argumentation is widely used in the field of science education (Sadler 2004; Simonneaux, Legardez 2011) where the students are generally invited to debate and handle an argumentation in class on SSI. Often, debates are deliberative: they lead to decision making. In our case it is a debate whose objective is to mobilize and confront ideas, facts, information by favoring the expression of different viewpoints. The interactive phase of the debate is preceded by a preparation phase.

The students use a documentary file prepared by the researchers. The file is composed of a selection of quotes from scientific publications, philosophical documents, French and international contemporary ethical reports, press articles, articles from associations opposed to nanotechnologies. The documents deal with 4 topics: health, enhanced human, environmental and fail-safe risks, control and individual freedom. It allows a first approach to encourage students to deepen their reflection with personal researches. They meet successively two specialists (a philosopher, and a geneticist) and address them the questions arisen from this first approach during one hour. The specialists are researchers whose research activities deal respectively with genetics and science ethics and with nanotechnology ethics.

Then a debate took place during regular courses in the standard class. The students discussed the SAQ collectively selected: "Do we have enough control over nanotechnologies to modify the human being, and do we have the right to do so?" The debate moderator is the History-Geography teacher. Fifteen students (17- to 18 years-old) took the floor during this one-hour discussion.

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6 Methodology for Analyzing the Verbal Interactions and Results

We proceeded to classify and to analyze thematically the arguments, based on their contents (Bardin 2001). In other words, the thematic categories are not given *a priori*, and are revealed by spotting of keywords a posteriori. This needed to take in account the speaking turns.

In our view, the modalizations are crucial hints in so far as they allow to spot the students' involvement in their utterances. A modalizer is a word or group of words which express the opinion, the attitude or the feeling of the speaker towards his/her own speech. We consider them as valuable parameters to sense the involvement of high school students, in other words to measure the degree of adhesion or doubt of the subject towards his own arguments. These modalizers consist in adjectives (sure, certain, clear, evident, doubtful, uncertain, probable, possible...), adverbs (eventually, certainly, necessarily, really, undeniably, obviously, likely, maybe, probably ...), modals (should, would, might, could, may), verbs (to claim, to assert, to certify, to admit, to think, to believe, to suppose, to wish, to hope ...), impersonal forms (it is sure that, it is clear that ...).

We chose to use the categorizations developed in a Vygotskian perspective by Mercer (1995) from the analysis of linguistic interactions between students. This approach established connections between the utterances by placing the exchanges in the dynamics of the debate between students. Mercer (1995) elaborated the definition of three kinds of talk representative of "social mode of thinking". He distinguished the following three types of discourses: disputational, cumulative and exploratory talk.

- Disputational talk, where characteristic discourse features are short exchanges consisting of claims and challenges or counter-claims. The relationship is competitive, differences of opinion are stressed rather than resolved, and the general orientation is defensive. Speakers defend their own selves and the most relevant point is to disagree.
- Cumulative talk, where characteristic features are repetitions, confirmations and elaborations. Ideas and information are shared, and joint decisions may be reached, but there is little in the way of challenge, or constructive conflict, in the process of constructing knowledge.
- Exploratory talk, during which speakers engage in critical but constructive discussion about each other's ideas; when challenges are made, they are backed up with argument and alternative viewpoints are suggested. Compared with the other two types, knowledge is made more publicly accountable, and reasoning is more visible in the talk. Students oppose but they provide justifications.

The analysis of the knowledge at stake in the dialogical exchanges focused firstly on the themes discussed and on the archetypal narratives. The identification of speaking turns ensures the exclusive character of the categories brought to light. Thus, a clause can only belong to one category (Bardin 2001). The results show a high level of inter-observer agreement (87 % agreement between the three observers). We present in table 2 an example of speaking turns for each theme addressed. The themes highlighted are the keywords which allowed the classification of the clause in the category.

The use of nanotechnologies for the modification of the human body in view of a healing is valued: "healing I don't see why we should be against it because it is finally a goal to heal a person who suffers from a disease" (Thierry, 73). Lifetime extension and drug delivery appear like positive advances. Nevertheless, the question of body improvement divides. Some are in favor: "of course we have the right to modify the human body we don't have to consider the human body like a taboo object which we don't have the right to touch" (Penelope, 5) in

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keeping with the National Science Foundation (NSF) report (2009, 30) discussing rights and obligations "Is there a right to be enhanced?" To others, the fears and toxicity of nanoparticles prevail: "I think finally if we directly put nanoparticles for (inaudible) leaving them there knowing that for the moment we don't know much that is a problem (...) we cannot say from now on hey let's modify the body and we will see what happens (Claire, 54). Indeed nanoparticles adopt new types of behaviour by easily diffusing in the human body and by crossing the biological barriers like the hematoencephalic barrier or the placental barrier, which traditionally ensure the protection of the vital parts of the human body (Benoit-Browaeys *et al*. 2010, 14). Another form of risk is the temptation of demiurge. Nanotechnologies are perceived as providing the omnipotence which characterizes God: "we consider a little ourselves like God" (Joel, 25). In his reference to God, Joel expresses the accomplishment of the Promethean myth at the risk of destroying humanity. The students draft arguments on the vagueness of the boundaries between nature and artifact (Bensaude-Vincent 2009a, b) by evoking the fact that nanotechnologies permit the access to the elementary bricks of living, the atoms.

Table 2: Themes discussed by the students in the debate

Themes addressed	Total of turns of speech	Examples of turns of speech
Enhancement of the human body	25	5. Pénélope: I think that well yes we have the right inasmuch as it is going *to improve* a little the *life of the people who have problems who are disabled* or even without being disabled it is going *to allow improving the performances to improve his life* of course we have the right to modify the human body we don't have to consider the human body like a *taboo object* er which we don't have the right to touch
Dangerous effects of nano-technologies	19	59. Thibaud: in the file there was an article which dealt with a household product with nanotechnologies and we saddled with 40 users straight *at hospital* because it had nanotechnologies in the lungs we don't control technologies already to *protect the human being*
Scientific experimentation	14	11. Nathan: what has to be said is that it cannot be commercialized from the beginning but that er we can *test* it on a human being to see what it does but of course er we are not going to commercialize directly something we don't know the consequences but er to find the consequences there is a need to er at the beginning more or less in quotation marks er *guinea pigs*
Benefit for all progress of nano and science	8	50. Nelly: In any case what has been to modify the human body it has to be known that if we come to er something that can be beneficial er it will be beneficial anyway *to the largest number possible*
Law, control	6	93. Nathan: we also have the drug-taking which modifies the functions of the organism so nanotechnologies should be er *regulated* like other products and er and make *a law* that is why there has to be a *regulation*

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They state that a human is not only a body but a psyche as well and evoke the implants that can modify the human body's functions and be assimilated by the living itself. This type of argumentation dealing with the dangers of human body's modification testifies to the values involved and the objectivity taken with respect to these new technologies. The students set up a difference between healing and enhancing, the first desirable and the second undesirable. Healing lies in a necessity order, for the well-being of humanity, whereas enhancement appears as accessory. Regarding good life, the question is raised: will enhanced people be happier, and if not, why bother with enhancement? (NSF 2009). The uncertainties, the introduction of nanoparticles inside the human body, the irreducibility of the human being, endowed with psyche to an organism composed of atoms, the loss of free choices are mentioned. The enhancement of human capacities, central issue of convergence retrieved by transhumanists and extropians, is subject of acute controversies (Bensaude-Vincent 2009a; Larrère 2008; Schummer 2009; NSF 2009). But students do not evoke during the debate the theme of transhumanism or post-humanity. They explore the question about the limit between nature and artifact (Bensaude-Vincent 2009a) in the health and military fields (NSF 2009).

The question of the harmful effects of nanotechnologies is articulated around the approval/disapproval couple. Some students point at the noxiousness of nanotechnologies. Thus, for Serge (73), "there is a need to do the necessary research to avoid the noxious effects you are talking about". The vocabulary is slighting: "noxious, risks, drifts, dangerous, detrimental". Conversely, others consider we are worrying for nothing: "I think that there is no need to be paranoid with respect to nanotechnologies" (Penelope 109). This optimism is related to a great confidence in science such as Serge who thinks that: "research will tell [the positive or negative consequences of nanotechnologies]" (Serge, 105). If students are worried about the lack of information, they do not necessarily mention the idea of stopping scientific research on nanotechnologies. But they share the idea that nanotechnologies "intrinsically set a serious problem of ethics: how far do we have the right to go?" In the same way, most participants in a Swiss citizen panel expressed hopes regarding the potential benefits these emerging technologies might bring in the future, while at the same time expressing concerns for the possible risks they might imply (Burri 2009).

"Modifying the human body I know it is a responsibility (...) if we put the nanoparticles directly inside the body what effect will that have I mean?" (Claire 68). Indeed, the modification can be irreversible and affect the entire human kind. The students discussion on the risks and detrimental effects echoes the stand taken by researchers (Académie de technologies 2009; Marano, Lahmani, Houdy 2010) and by environmental associations who believe that the sanitary and environmental risks are neglected and the studies on these risks incomplete. In respect of the precautionary principle, these associations propose a moratorium on research on nanotechnologies and on their commercialization.

The concept of scientific and technological mastery reflects an expression of a quasi-absolute confidence in science and in a scientist representation of its progress. The students identify the tests and experimentations as a need for science allowing it to progress: "there is a need to er at the beginning more or less in quotation marks er guinea pigs" (Nathan, 11). The idea of an eventual moratorium is rejected in the name of the scientific progress: "techniques need to be developed (...) so starting from that point there is a need to continue the experiments and researches and above all: do not stop!" (Nelly, 39). Here, the clauses are marked by the use of "there is a need to" and sometimes modulated by the auxiliary "do". The utterances are injunctive and prescriptive. The use of

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concessions ("even if", "in that case", "then"), the introductory verbs "I think" and "there is a need to", and more widely speaking the density of modal items (clearly, even, absolutely, we can say...) mark an argumentation dominated by affirmations centered on scientism. This discussion stands apart from the ethical questions related to nanotechnologies (SEI) but testifies to the preoccupations of teenagers enrolled in scientific scholarships who take advantage of this debate on nanotechnologies to argue their general conceptions about the construction of science.

The students describe a difference in the access to scientific discoveries and innovations: "when we make a discovery it is compulsory at the beginning it is the wealthy countries that take advantage of it" (Léo, 34). It concerns the social categories and the inequality between wealthy countries and emerging countries (Lewenstein 2005; Mnyusiwalla, Daar, Singer 2003; Sandler 2009). The prescriptive formulas such as "they have to be given to everyone" (Thibaud, 38) and the confident forecasts ("it will benefit anyway the largest number possible" Nelly, 50) tend to foresee the reduction of the disparities and the democratization of the benefits related to nanotechnologies. The will to avoid ratifying to a rupture between richer and less rich people can be spotted, beyond the modal items (it would better, cannot), and the use of verbs emphasizing the recourse to standards (limit, control). Everyone's access to nanotechnologies and science progress is a teenagers' concern, revealing values of sharing and altruism. The view that the development of nanotechnologies will be a "factor in widening the gap between countries in the North and in the South" (Commission Nationale du Débat Public, CNDP 2010a, 6) is reflected in the criticisms of these technologies identified in the public debate. In the report commissioned by the French development agency, this preoccupation appears clearly through references to the benefits to be shared in an inclusive society and to the exposition of the populations to the sanitary and environmental risks. (Benoit Browaeys et al. 2010). The dialogical exchanges about everyone's access to nanotechnologies, about the dialectics between healing and enhancing, about the individual liberty, about the physical integrity etc. convey values like respect, justice, equity, sharing, honesty, solidarity even if they are never explicitly named by the students.

The need for a regulation is exclusively claimed by male students: "yes we must proceed to a draconian control of nanotechnologies research" (Serge, 122). These normative comments reflect however a sense of powerlessness to impose that control: "there's a need to control but we will never be able to control there will always be people" (Joel 95). The students debated on a key question discussed at length during the public debate, that of the governance of nanotechnologies, in particular, an "open and responsible governance covering everything; regulatory issues on a national and also European level (...) setting up a real partnership between science, research and society" (CNDP 2010a, 11). This governance is considered to be "modern" by the "civil society", the key words being transparency, participation and shared responsibility (CNDP 2010b, 106).

The five themes explored by the students can, in our opinion, refer back to the "arche" stories described in the European research program DEEPEN (Deepening Ethical Engagement and Participation in Emerging Nanotechnologies). The DEEPEN programme identifies five "narratives" that influence responses about nanotechnologies: (1) Messing with Nature (The Sacred;); (2) Opening Pandora's box (Evil); (3) Be careful what you wish for (Desire); (4) Kept in the dark (Alienation); (5) The rich get richer, the poor get poorer (Exploitation). The DEEPEN program drew inspiration from the concept of "master narrative" developed by Heller (cited by Dupuy 2010).

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The first three – the Sacred, Evil, Desire – refer to the cultural heritage from Antiquity, the last two - Alienation, Exploitation – to modern heritage: these "arche" stories are "the deeply embedded cultural resources which lay-people use to discuss the ethics of nanotechnology" (Dupuy 2010, 154). The first narrative proposes that one should not interfere with the relationships existing between nature and human beings. The theme "Enhancement of the human body" refers to the risk of all-powerfulness of the sorcerer's apprentice who manipulates the living and to the desirable artificialization (healing) or to the undesirable artificialization (enhancement).

Pandora's Box was a tempting box which when opened released all human evils. This narrative incorporates the ideas of power, uncertainty, pride, and finally disaster. It identifies the risks, uncertainties and unforeseen dangers of technologies that are regarded as inevitable and produced by proud and arrogant science that manipulates while not yet completely understood. This narrative appears when the noxious effects of nanotechnologies, which one should be suspicious of, are discussed.

The narrative "Be careful what you wish for" refers to the ideas of perfectibility and of desirability. This narrative warns the reader that he should beware of the seductive promises of nanotechnology because getting exactly what you want may ultimately not be good for you and letting yourself be seduced by these temptations could have harmful consequences. This narrative can be read between the lines in the students' statements in so far as they reveal how confident they are in science and its progress when they discuss tests and scientific experiments.

In the narrative "Kept in the dark" people are convinced they are not informed of current and potential technologies and feel they have little impact on their development. This narrative weaves together a whole range of ideas about control and power, combined with modern alienation towards secret and inaccessible institutions such as government, corporations and the military, with their questionable motives of power, interest, and money. If the theory of a technosciences conspiracy is absent from this debate, the question of the uncertainties linked to the development of nanotechnologies and of the necessity of a sometimes illusory control is examined.

With the last narrative, the ideal of democratization of the access to nanotechnologies mentioned by students can be spotted. In this narrative the rich get richer and the poor get poorer; the promises of green or socially interesting technologies serve to hide the profits of the rich. In this narrative the ideals of justice and equality are used to criticize the potential development of nanotechnology.

The archetypal narratives structuring lay-people's representations about nanotechnologies enable us to account for the knowledge learnt by the students in the debate. We can then point out the talk categories and the co-construction of the social ethical issues concerning nanotechnologies.

Three out of the four themes developed by students apply to SEI related to nanotechnologies. We propose a new analysis of these themes.

We have categorized the students' interactions in the debate according to Mercer's methodology (1995), identifying three talk categories: disputational (DT), cumulative (CT) and exploratory talk (ET). We obtain an inter-observer agreement of 81 % between three observers.

These categories enable us to account for the dynamics of the exchanges (see table 3).

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Table 3: continuous excerpts of the debate showing alternating cumulative and exploratory talk about the dangerous effects of nanotechnologies.

105 Joel: We've been talking about organisms for a while, but we should ask other questions: will it have positive or negative consequences, only the future will tell. (CT)
106 Serge: research will tell. (CT)
107 Penelope: When you're saying people can choose in all honesty what they want to do, but if we are not aware of the consequences, if even it's impossible for them to know what's going to happen, can they really choose by themselves if they can't foresee the consequences, we might as well play.. (inaudible). (ET)
108 Bruno: The negative side of nanotechnologies, it flies around everywhere in the air, we breathe it in, there will be serious problems with lungs and the brain. (CT)
109 Penelope: I think that there's no need to be paranoid with respect to nanotechnologies, all the same we breathe in molecules every day, molecules, bacteria, and all that...they are not..., they're not necessarily dangerous, it's not because we're going to modify the human body that there's going to be things that are going to go everywhere, which are going to kill us. (ET)
110 Teacher: Two or three more questions.
111 Octave: For the time being there is no question of making self-replicating particles like viruses, the question does not even arise to know if we could be infected. (ET)
112 Caroline: I don't see why you're talking about viruses, just think, there are nanoparticles in exhaust pipes and we breathe them in every day and then they're in your body, they're not alive and they're everywhere, and they have negative impact on your body. (ET)
113 Joel: In relation to what you said.., in relation to what you said about viruses and all that, if we implant nanotechnologies inside the body, would it be possible, well, er.. from what we saw in biology, we saw that life always adapts, so would nanotechnology not be able to adapt to this technology and create even more dangerous things ? (ET)
114 Nathan: In relation to what Clément said about exhaust pipes, this morning how did you get here ? You came by bus, and on the bus there's an exhaust pipe as well, so you too are contributing in some way, if you're against, in that case. (inaudible) (DT)
115 Teacher: We're about to conclude, Nathan
116 Nathan: And what's more with or without particles exhaust pipes are bad for the organism. (CT)
117 Thibaud: Let's just have a look at the set of documents, the product they marketed was harmful, I don't remember if it was some washing powder? (CT)
118 Nathan: The detergent, it was not self-replicating like the virus, it does not have to be a virus, er.., to be made in order to be harmful to users, there's no need..er.. and they do not know if it is..., they have not conducted enough studies on that (CT).

Most studies show that by analyzing the language of students during classroom debates there is mainly disputational and cumulative talk (Mercer 1995). This is not the case here and we observed few conflicts between students. Given the length of the protocol and preliminary work on documents and the preparation made during the expert meetings with the group of students, we believe that the effect of experimental group membership reduced such conflicts and that a microsocialization has occurred between these students. Instead of

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conflicts within each group, we observed cumulative talk and less often exploratory talk.

We notice in table 4 that two themes contain exclusively cumulative talk: "Benefit for all" and "Law and control". The students explore the SEI field by juxtaposing the types of talk.

Thus, the first six students' speaking turns highlight the question of the gap between rich countries and poor countries, but end up specifying that any innovation will inevitably democratize in the long term. They proceed by analogy with the case of television: "when a discovery is made, inevitably in the beginning rich countries take advantage of it, even without talking about the countries, a small part; for example, television. In the beginning when it was discovered not everybody had a TV set whereas now everybody has one (Léo, 34, CT). Nevertheless information provided in the debate is accepted without evaluating. These pieces of information are rephrased or repeated without being examined in more detail and without any challenging by the students. Similarly, the students all agree on the fact that research on nanotechnologies must be controlled: "Yes, research on nanotechnology must be strictly controlled" (Serge, 122, CT). However, the students neither specify the feasibility of the control nor the responsibilities involved. There is no critical distance in relation to the statements but just an evocation of the necessity of a control over research activities.

Table 4: Number of types of talk according to Mercer's categories

Theme	Total of turns of speech	Type of talk
Enhancement of the human body	25	DT : 2 CT : 16 ET : 7
Dangerous effects of nanotechnologies	19	DT : 2 CT : 9 ET : 8
Scientific experimentation	14	DT : 0 CT : 7 ET : 7
Benefit for all	8	DT : 0 CT : 8 ET : 0
Law and control	6	DT : 0 CT : 6 ET : 0

The association of cumulative talk and exploratory talk allows the students to investigate the field of the dangers linked to nanotechnologies and that of human nature. The cumulative talk underlines different aspects of toxicity linked to nanotechnologies such as still unknown noxious effects, in particular on health, needs to protect the human being, pollution, noxiousness:

> "I agree with what says. There are no long term studies on nanos. For example we know that nanotubes, we all know that it is somewhat like asbestos. We do not know what effects they're going to have on the human body" (Tom, 42, CT).

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The exploratory talk enables the networking of these different aspects of nanotechnologies' toxicity:

> "With the products using nanoparticles noxious effects have been noticed in particular on lungs on the brain and if we put nanoparticles directly into the body what effect is it going to have, then?" (Caroline, 71, ET).

Therefore, this co-construction of the concept of toxicity allows the students to point to the weaknesses of research in the field of toxicity: "We have to do research to avoid the noxious effects you're talking about" (Serge, 73, ET). As the question of the breaking through the hematoencephalic barriers by nanoparticles is being explored, two groups of students oppose each other, one group pointing to the dangers of nanotechnologies and the other relativizing them.

This relativisation of dangers is supported in the group by various arguments. Nanoparticles exist in nature; the capacity of self-replication of the nanorobots and their emancipation from human control in Drexler's notes[2] are laughed at: "for the time being there is no question of making self-replicating nanoparticles" (Octave, 111, ET). Similarly in the other group, in reply to this relativization, arguments are developed referring to a warning about the dangers that nanometric implants may represent in view of the adaptability of the living: "from what we saw in biology we saw that life always adapts, so would nanotechnology not be able to adapt and create even more dangerous things?" (Joel, 113, ET). He draws an analogy with the AIDS virus: "remember, the aids virus for example, it adapts to any situation... If we keep on developing nanotechnology in 300 years what will they do?" (Joel, 125, ET). Therefore, the fantasies conveyed about nanotechnologies are brought to light in the confrontation via interaction.

The cumulative talk underlines different sides of the human being's nature linked to nanotechnologies like the enhancement of the human body in the medical field, the toxicity of medical repairs, the interest of healing through nanomedicine, of analogy between body modifications and aesthetic surgery.

These three speaking turns express non justified exchange of opinions, that is to say cumulative talk.

90 Serge: "I'd like to react to what Caroline said, it means that today all those who have their lips or buttocks redone, it's useful for their organic development, it's the same?"

91 Caroline: "No, that's a modification but er... it's different."

92 Serge: "It's not useful."

The exploratory talk allows the networking of these different aspects of human nature whose very foundations can be called into question by the advent of nanotechnologies: drug vectorization, artificialization of the living being, modification of functions. The dialogical interactions on the question of the modification and on enhancement allow the students to distinguish what has to do with repairing a failing function from what has to do with adding capacities to a human being: "Healing, I don't see why we should be against it because the aim is to heal a person suffering from a disease, but concerning the modification

[2] In his book Engines of Creation (1986), Eric Drexler describes self replicating nano-objects capable to produce rapidly by self-assembly processes massive quantity of nano-entities.

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of the human body then you need to have a goal for nanotechnologies" (Thierry, 73, ET).

The question of the introduction of nanodrugs in the human body and of their hypothetical side effects in the long term divides the students. In these exchanges feeding the dialectic, we identify both cumulative talk (rephrasing, utterances without justification) and exploratory talk (justified arguments, justified questionings, evidence giving). Some only take the advantages of repairing into account and express their confidence in the technological feasibility: "I think that healing human beings thanks to nanotechnologies is something we master, scientists and doctors will act in order to achieve that" (Bruno, 56, CT). Again, analogies between medicine and aesthetic surgery support their arguments: "the human body, we've already modified it, for example with a battery in the heart" (Nathan, 85, CT). Others express their mistrust by exposing the risks of modifying functions: "the implants (breast implants) she gets, it has no interactions with her body, it only changes appearances there, whereas here with nanotechnologies functions can be changed" (Caroline, 93, ET). The interactions on the implants lead to questions on the artificialization of the human being and on the nature of man ranging from a cyborg-soldier to a body without a psyche: "True we can modify things for handicaps, but we can create soldiers who fear nothing" (Joel, 26, ET). "There's something which bothers me, we've been talking for a while of modifying the human being, there's something wrong, it's the word human being modifying the human being, that is to say that in the word being there's also the psyche" (Joel, 88, ET). To back up their arguments, the students have recourse to knowledge assimilated during the meetings with the experts: "as the researcher said the other day when we know how to create a cell from all parts" (Nathan, 26, ET).

We show (as Mercer 1995 does) that cumulative talk involves providing information, rephrasing and reflects the cohesion of the group and that the challenges, the oppositions in the exploratory talk serve knowledge co-construction in the context of a reflexive communication. Although exploratory talk is of course richer from an argumentative point of view, it feeds as well on cumulative talk. Therefore we'd like to emphasize their complementarity in relation to the argument construction shared by the group in this debate. We notice that the networking of the characteristics related to the concept of toxicity allows the students to create a system around that network, supported by the recourse to analogies. The importance of the use of analogies was stressed by Burri (2009) asserting that "citizen panel complied with uncertainty by using analogies." This co-construction of the concept leads them to highlight the weaknesses of toxicological studies research as well as the health effects of nanoparticles because of their small size and their capacity of interacting with the living. The networking of the properties of human nature allowed the co-construction of the possible calling into question of human nature by nanotechnologies. However, this joint construction does not have them fall into transhumanist deviations.

One of the functions of language, according to Vygostski (1985), is to enable learners to organize their own thoughts and give meaning to words. Indeed, Mercer (1995) states that we use language to transform our thinking through individual thought and collective action. This author argues that language can actually facilitate learning when it is used mainly as exploratory talk. Culture creates external auxiliary devices (tools, devices, technologies) which support the psychological processes. Language (cultural tool) interacts with thought and gives birth to new functions, it is in this sense that having tools created by

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culture (here the debate) available to students allows them to increase greatly their natural capacities and to restructure their higher mental functions. By appropriating the cultural tool, they train themselves as citizens in the practice of the debate in democratic life and they acquire new knowledge on the SEI. The role of school is here to have the students interact with the cultural tools: debates and SEI.

Conclusion: Towards Educating for Citizenship

At the end of this experiment, a high level of knowledge was observed among these high school students as they used nanotechnology notions to illustrate their ideas. And their level of reasoning equalled or exceeded that of some of the lay adults who had participated in the French public debate as shown above, including an awareness of SEI specific to nanotechnology.

The strategy tested in this educational innovation appears to be relevant for teaching science-society interactions in high-school education and, in particular, the role of technoscience in society. We have shown that nanotechnologies are particularly well-adapted to that educational issue including science lectures and social ethical reflection. We assert as Simonneaux, Legardez (2011) does that there is complementarity between SAQ and the taking into account of values.

From a Vygotskian perspective of social construction of thought, our results show that the students construct knowledge concerning the science-society interactions, and more particularly the nanotechnologies-society interactions. The knowledge learnt by the students – enhancement of the human body, dangerous effects of nanotechnologies, scientific experimentation, benefit for all progress of nano and science, law – can refer back to the archetypal narratives whose origin lies in men's social and cultural history. These narratives preexist the students as external entities created full of socially and historically elaborated significations, they are deeply rooted in European culture and passed on from generation to generation. In that sense, they are psychological tools for the individual subject because their origin lies in men's social and cultural history and because each one of us can only appropriate them through activities conducted through interaction with others.

The whole of the cumulative talk, when in sufficient quantity, as in the most talked about themes, enables students to lay the basis for a confrontation of viewpoints, the expression of oppositions and deepening the knowledge concerning the controversies related to nanotechnologies. In that sense, it can be said that through the joint effect of cumulative talk and exploratory talk, the students co-construct the concepts linked to the SEI. The peer-to-peer debate, as a social construction of knowledge, thus plays its heuristic and exploratory role. Therefore, the results confirm that debate, in SAQ teaching context, is a pertinent operation to sensitize students to the ethical issues of nanotechnologies and prepare them to their role of citizens to interrogate a thoughtful and reasonable development of nanotechnologies (Sandler 2009).

Indeed nanotechnologies can be found in numerous application fields and are simultaneously developed in research laboratories. The critical apprehension of their current and potential uses lies within a highly prospective perspective. The objective of citizenship education to nanotechnologies in the sense of responsible citizenship education is to train the citizens to reflect on the present and future issues of the world we live in when they are at school.

This citizenship education does not have a moral dimension in the sense of an *ex cathedra* teaching of values but rather in the sense of questioning values. In this debate, concepts like dignity or liberty are not first and foremost but instead they are implicated in everyday situations by the development of

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nanotechnologies. The citizenship education we stand for is characterized by its social dimension in a global society, marked by issues on a local and world scale where the citizen must be able to know how to analyze the issues, to take stand and to make choices as an individual actor, a social and economic actor as well as a citizen from a State. This citizenship education also takes into account the political dimension in a democratic society marked by discourses on the development of ethical responsibility and marked by the involvement of citizens in the exercise of power in the respect of equality of rights (Audigier 2000).

This manner of understanding citizenship and citizenship education is consistent with our conception of social construction of the individual subject and of their learning. Indeed, we understand the citizen from a Vygotskian perspective; that is to say, by considering human social being as a product from culture. Thus, the intellectual activities (comparison, cause, definition, explanation, justification...) require the engagement by an individual subject socially situated in cognitive and symbolic constructions, which are made possible by the mediation of interactions with others. The psychological tools at play in the debate (comparison, definition, archetypal narratives...) are inherited from culture and represent the foundation of critical thinking (Vygotski 1985).

Confronted with issues involving the development of nanotechnologies raising dilemmas, the students must acquire analysis tools enabling them to understand complex systems encompassing the debated issues. Therefore the role of citizenship education is to pass on some heritage and to teach the ethical principles and the legal frames (national and international) which characterize the act of living together. This means also that educating for citizenship include presently developing a scientific citizenship linking up scientific, technical and ethical knowledge.

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List of Abbreviations

CNDP: Commission Nationale du Débat Public

CNRS: Centre National de la Recherche Scientifique

CT: Cumulative Talk

DEEPEN: Deepening Ethical Engagement and Participation in Emerging Nanotechnologies

DT: Disputational Talk

ET: Explorary Talk

ELISA: Enzyme-linked Immunosorbent assay for the detection of antibodies

EESD: Environmental Education for Sustainable Development

ELSI: Ethical Legal Social Impacts

SAQ: Socially Acute Questions

SEI: Social Ethical Issues

SSI: Socio Scientific Issues

NBIC: Nanotechnology, Biotechnology, Information Technology and Cognitive Science

NSF: National Science Foundation