Citizen science, engagement and transformative learning: a study of the co-construction of a neuroscience research project in Catalonia

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Abstract

Citizen science can raise people's understanding of science while helping scientists to conduct their research. Yet, its potential for driving transformative learning is empirically underexplored. We present the results of focus groups and participant observation with secondary-school students engaged in the first three years of a citizen science project, from the formulation of the research questions to data analysis and discussion. Students learnt about and increased their interest in neuroscience. They were also able to reflect on the role of science for society and valued their involvement as active participants in the research. We discuss the opportunities and challenges of approaching citizen science for transformative learning.

Key words: *public engagement, science education, scientific citizenship, transformative learning, young people*

INTRODUCTION

As early as 1999, at the World Conference of Science jointly organised by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council for Science (ISCU), policy makers and scholars highlighted the important challenge of finding new ways of communication, dialogue and involvement in order to engage people in science (Pockley, 1999). Citizen engagement in scientific and technological projects, or the so 'called 'citizen science', has been widely referred to opportunities for education and communication to establish such dialogue and to reduce the remaining distance between lay people and science (Powell & Colin, 2008; Gray et al., 2012). Citizen science, however, has become an abstract concept subjected to various interpretations, political standpoints and aspirations which have been applied with mixed results.

On the one hand, citizen science is typically proposed as a win-win solution to raise people interest in science through involving them in real scientific research while contributing to the development of projects of scientists (Silvertown, 2009). Examples of such citizen science experiences can be found in natural sciences and physics among other disciplines, such as research projects in which volunteers help ornithologists in data collection as bird watchers (Brossard et al., 2005) or help physicists to recognize interstellar dust particles and to classify galaxies (Hand, 2010). Prevailing interpretations consider that through their participation citizens increase their interest in scientific learning (Riesch & Potter, 2013). On the other hand, a less empirically explored and documented conceptualization of citizen science developed by Irwin (1995) understands citizens as active agents capable of developing science that can potentially address their needs and concerns. Such approach is translated in activities intended to build capacities among citizens to have a meaningful voice in the scientific practice, including the research design. Participants in these projects have been involved, for example, in the selection of the topics to discuss with nanotechnologists and the design and organization of nanoscience outreach events (i.e., Nano Cafés). Such engagement has fostered their abilities to engage in scientific discussions and adopted a proactive role in decision-making (e.g., sending letters to policy makers with recommendations on nanotechnology) (Powel & Colin, 2008). To what extend this citizen science approach can enhance participants' motivation and learning about scientific issues and change the way they perceive and understand the scientific practice, however, has scarcely been studied at all.

Moreover, the scientific research community relies on shared attitudes, norms and values (Merton, 1942; Allchin, 1988), such as honesty, collective work, skepticism, taking initiatives. The participation of citizens, as active agents, to a scientific research project within the scientific community, could therefore lead citizens to question, reframe or evolve their own attitudes, values and norms, and constitute an empowering experience. Such changes are referred to as transformative learning (Mezirow, 1997; Kitchenham, 2008) (box 1). In this article, we analyse if and how students involved in a specific citizen science projectexperience transformative learning.

BOX 1. Citizen science and transformative learning

Citizen science projects on new technologies and biodiversity monitoring in which volunteers participate as data collectors have been particularly successful in both rising volunteers' knowledge on scientific and technological issues and saving scientists' time and resources in data gathering (Cohn, 2008; Hand, 2010).

Scientific knowledge and interest in science, however, are not necessarily related to each other but differently incentivized by activities and interactions with scientists (Lin et al., 2012). For instance, evaluation results from a bird observation project in the United States show that volunteers involved in data collection increased their knowledge of bird biology but their motivation for science remained without significant changes (Brossard et al., 2005). Highly motivated individuals are usually those who get involved in citizen science projects as volunteers in data collection, which can partly explain such lack of significant changes. But citizens' disenchantment for science can be also related to a prevailing perception that scientific research and scientists are removed from societal concerns and needs (Hughes, 2001; Steinke et al., 2007; Ruiz-Mallén & Escalas, 2012). Under the lens of the political approach to citizen science, science challenges citizens and researchers alike to address daily complex problems and concerns through transdisciplinarity, reflexivity and transformative learning (Jenkins, 1999).

Scientific transdisciplinarity implies the integration of different disciplines and realms of knowledge to address scientific topics. Transdisciplinarity is essential in citizen science as it grounds scientific concepts into societal contexts and processes, going beyond the viewpoints offered by a single discipline (Pohl, 2008). Reflexivity is related to conscious deliberation on the ways individuals see, understand and position themselves in relation to their experience and action (Taylor et al., 2006). When related to citizen science, reflexivity involves recognizing that the individual and collective knowledge and experience of participants constructs and conditions the scientific topic addressed (Chilvers, 2013). In doing that, reflexivity can improve participants' understandings about their own role and position in the production and appropriation of scientific knowledge. Furthermore, becoming critically reflective of one's own and others' convictions has been suggested to be 'the key to transforming taken-for-granted frames of reference', that is, to transformative learning (Mezirow, 1997:9).

Transformative learning is thus key to the citizen science political approach, as it expects to empower participants to think as autonomous learners in collaborative and democratic contexts (Irwin, 1995). Empowerment is a multi-dimensional social process that challenges people's assumptions about the way things are and can be, and fosters power in people for using it in their own lives and communities, by acting on issues they define as important (Page & Czuba, 1999). In the context of citizen science, empowerment and transformative learning imply transforming structural assumptions through which scientific experiences are understood, leading to changes in attitudes, values and social norms (Mezirow, 1997; Kitchenham, 2008). Such reframing can be facilitated, for instance, through inquiry-based science education approaches that enable participants to develop critical thinking, reflection and creativity (Minner et al., 2010). Interactive participation, co-decision and self-mobilization can be fostered by involving participants in the development of their own research projects, by taking their own actions and decisions. Situated or contextualized learning can also provide meaningful connections to real world situations and experiences in science education in order to enhance learners' interest and motivation for science (De Hann, 2006; Ruiz-Mallén et al., 2010). Beyond increasing knowledge and scientific understanding, the focus is on participants' agency and their acknowledgement as capable and creative knowledgeable actors to empower them and enhance their motivations and engagement in scientific inquiry[1].

We report on a citizen science project involving Catalan secondary-school students, where students took part in a research project based on a question generated by them. We investigate the impact of this experience on the students, focusing on their perception and attitudes towards science and knowledge and skills acquisition, and the potential of this approach to drive transformative learning, understood here as students' empowerment and increased capacities to think as autonomous learners of science within collaborative contexts (Irwin, 1995).

This project is the first of its kind developed within the Fondation de France program of Nouveaux Commanditaires – Sciences (NCS, box 2). NCS is based on a previous program in art funded by the same foundation since the 90s and consisting of creating art pieces based on requests from groups of citizens, and through a dialogue between citizens and artists (Nouveaux Commanditaires – Arts,

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[1] Self-perception of competence is a factor influencing intrinsic motivations (Ryan & Deci, 2000). Similarly, engagement is influenced by individual capacity to mobilize the cognitive and behavioural resources needed to successfully execute a specific task within a given context (Bandura, 1997).

[http://newpatrons.eu/]). Such interaction gives committed citizens the opportunity of requesting a piece of art, an option typically reserved to the wealthy and public institutions. NCS in turn invites groups of citizens to “request” research projects that can answer open questions that address their particular concerns. In this respect, the habit of scientists elaborating research questions is broken, with the ultimate political objective of promoting democracy, enhancing citizens' legitimacy for an active involvement in scientific research. By so doing, it promotes democracy and empowers citizens with the tools of critical thinking. The aim of this program is to develop original research projects, involving citizens in the full-length research process, including the design of the question, co-conception of the protocol, participation to the acquisition and analysis of data, co-production of the publications. The typical duration of a scientific research project, without any participative dimension, being also several years, NCS projects are expected to develop on a long time scale, 5-10 years, to allow citizens to be involved along all the research process (incidentally, in the NC-Arts program, projects developed along 5 to 15 years). The project which we study here was launched in 2012, in the city of Molins de Rei, near Barcelona, as the first pilot of the NCS program.

BOX 2. The Nouveaux Commanditaires – Sciences program

NCS mediators stimulate groups of lay people to express open questions on science and technology, which used to be a scientists’ privilege. When reaching a question that is of interest for a group and lacks any academic answer, mediators identify researchers who would be willing to add this question to their research agenda. If needed, researchers may have to request new research funds from funding agencies as they do for any research project. In this respect, researchers do not take the lead, rather they co-construct the research with citizens and collaborate to refine the associated questions, define and perform the corresponding protocols. Research can be then performed collaboratively or by the researcher alone when needing specific equipment or when there are ethical or security restrictions. Comparing to science shops (Stewart & Havelange, 1989), NCS can be identified as a travelling shop, reaching people who would never have imagined themselves devising a valid question to science. The program sets out to include citizens from underprivileged or isolated communities, who are far from the academic world, such as young people in poor suburbs, elders and students in small villages. Also, NCS involves professional researchers on a long term (up to 10 years) rather than university students (for up to a year). NCS is currently developing five citizen science projects in France, Portugal and Spain.

THE PROJECT

The NCS project in the Catalan village of Molins de Rei initiated as a result of the spontaneous participation of three 15 years-old secondary-school students in a science video contest. In the video, the students asked an open question about how the colors of the walls in the school influence school performance. This emerged from their concern about the poor conditions of the school buildings and students' low attention and enthusiasm in classes. The video was the only one of the contest which expressed an open question. One of the competition judges was to become a mediator of the NCS program. He contacted teacher who had mentored the students who did the video and who voluntarily engaged in the project together with his students. All fourth-year secondary-school students were invited to participate in a 'science project with professional scientists'.

Fifteen students and their teacher initially joined the project and finally nine of them (seven girls and two boys between 15 and 16 years-old) engaged in the project. Students' participation was voluntary and beyond any school obligation. The mediator invited two neuroscientists from the Donders Institute in Nijmegen, Netherlands, specialized in the study of attention behavior who would be appropriate to explore with the students these issues. While the researchers involved in the project were hesitant at the beginning, they are now advocates of this approach, convinced that it allows to produce socially relevant research and challenges their traditional approach to do research (Bonnefond et al., 2015). All of them regularly took part in a series of face-to-face and virtual meetings from 2012 to 2015[2]. Through such collaboration they prepared, co-constructed and performed research projects that were further communicated to academic and non-academic audiences (Figure 1). Students named the project as 'Investigating how Colors Influence Learning' (ICIL).

[2] At the time when we write this paper (2016) the collaboration between students and scientists is still ongoing.

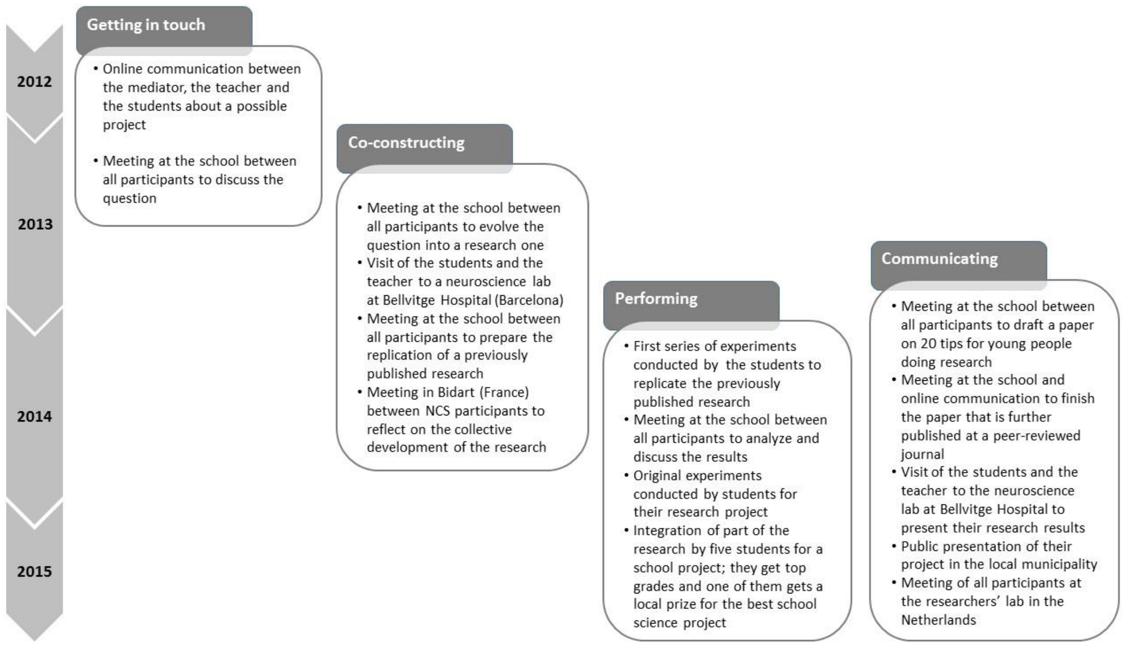

Figure 1. ICIL project activities and interaction among participants.

METHODOLOGY

When the project in Molins de Rei started, the mediator asked the first author to provide a critical assessment of the project development by focusing on the following aspects: students' ability to express and take ownership of an open scientific question, and to share it with the researchers involved in the project; students' change in their perception of science as a result of their participation in the project; students' engagement in collective questioning and constructive criticism within the research project and their empowerment to take active roles in their local community. To assess the potential of this citizen science project to drive such a transformative learning, the present study gathered data on students' views, knowledge and skills acquisition and empowerment on science along the development of the ICIL project. The methodology consisted in (i) focus groups, in which discussion was stimulated by specifically designed questions, (ii) participant observation during project activities, and (iii) participatory workshops including specifically designed activities (i.e., interview training). Given that only nine students were involved in the project, the present study does not aim at providing quantitative data, but it offers a qualitative insight into the students' learning experience.

Focus groups. In July 2013, one year after the project started, we organized a first focus group at the school. During two hours, the nine students involved in the project were guided by the first author to engage in a process of dialogue and collective discussion about their experience and expectations with scientific research and the project. Specifically, students were asked to construct a time line to document their main learning events during the project, the changes they perceived in their interaction with scientists and their educational perspectives and interests related to the project.

In August 2014, during two days, we organized two focus groups with eight students (one of them could not attend) in Bidart, France, as part of a meeting with researchers, mediators and citizens from other French and Portuguese NCS programs. We explored potential changes in students' perceptions and attitudes towards science, the acquisition of knowledge and skills on scientific research and the specific topic (i.e., neurosciences) and their role as active actors in the research process. Each focus group consisted of a session of approximately three hours. In the first focus group students were asked to fill a Participatory Assessment Mural (MAP, Mural d'Avaluació Participativa in Catalan), a method based on a Likert scale that also includes qualitative data and was implemented collectively (Güell, 2004). It consisted of eight sentences designed by the first author to assess students' perceptions about the role of science in society and their attitudes towards science. Each student scored each sentence by using a color stick according to their level of agreement (blue = totally agree; green = agree; yellow = disagree; and red = totally disagree). They were also invited to write on post-its complementary explanations, comments and ideas related to the assessed sentence. Scores and answers were then collectively discussed to find out common explanations on their perceptions, attitudes and motivations. In the second focus group, we asked students to participate in a role-playing game to explore their learning and empowerment with scientific research and specifically with the project. Each student was provided with a card with information on the role that s/he was supposed to represent. The play was about a group of students and their teacher visiting the laboratory of two researchers. Two students then assumed the role of researchers working in a laboratory on cognitive neuroscience, three of them acted as students who had participated in the ICIL project (i.e., as themselves) and the other three acted as annoying students who were not interested in the visit. In this activity the teacher also participated playing his own role. After 30 minutes playing, we engaged students in a discussion about how the students assuming the role of scientists used the knowledge they acquired on neuroscience , and if and how they, together with students playing as themselves, motivated those non-interested students to pay attention (see Appendix 1).

Participatory workshop. Also in Bidart, and as an innovative aspect of our methodology, students were engaged in the collective construction of an interview guide on the acquisition of scientific skills and knowledge, as well as the development of critical thinking, as a result of their participation in the project. During a participatory workshop, we asked students to imagine that they were researchers trying to explore this learning process and to suggest questions by using the leading question 'What did the students learn from the ICIL project?' and discuss their validity (see Appendix 2). The interview guide was thus co-constructed with the students, who contributed in formulating the questions based on their experience of the ICIL project. We gave them a basic training on how to conduct the interview. Students worked in pairs and interviewed each other, writing down the answer to each question. The first author conducted participatory observation of this process. This choice of method relies on the trust relationship built between the first author and the group of students, allowing to test new participatory data collection methods and to gather information relevant to the present study (e.g., unexpected aspects of students' learning experience) through informal interactions. This relates to approaches such as critical ethnography, the one used to study science education in shelters in the US (Barton, 2001).

Focus groups and participatory workshop were recorded and transcribed. These transcriptions together with students' notes from interviews and our notes from participant observation were coded and analyzed using Atlas.ti 6.2 (Newing, 2011). Data were classified according to three broad categories: 1) perceptions and attitudes towards science, 2) knowledge and skills acquisition and 3) empowerment.

RESULTS

Perceptions and attitudes towards science

Enjoying science. Overall, students' interest in science increased with their participation in the project. Two of them clarified they already liked science before. In the second focus group they explained that they used to perceive scientific issues to be boring because of their previous experience at science classes, although some topics and teachers' way of teaching were sometimes interesting. In the MAP exercise all of them agreed that science and scientific issues were "cool" but perceived science to be more related to curiosity and interest than to having fun (Table 1). Students also highlighted that the practical dimension of science (i.e., doing experiments) was "cooler" than the theoretical dimension since they could participate more actively. They enjoyed using the scientific method in the ICIL project because it allowed them to find answers by themselves.

Science is collective. They also had the idea that science must be conducted individually. One of them explained how her view about how to learn science changed: '*I thought that science was theory and remembering concepts, but here I see that science also involves much discussion*'[3]. Students also reflected that the stereotyped image they had about scientists had also changed, as a girl stated: '*We did not expect scientists to be such kind and friendly people*'. Many attributed the enhancement of students' confidence in their participation to the trust and transparent relationship generated between researchers and students.

Table 1. Number of students' answers to the MAP questions on perceptions and attitudes towards science

MAP sentences	Totally agree	Agree	Disagree	Totally disagree
I find science and scientific issues cool	4	4	0	0
I like science even though it is often too difficult and frustrating	2	2	3	1
I like to applying the scientific method because I learn about new issues	1	7	0	0
I would prefer science to be certain	0	2	1	5
After being involved in this project, I realize I can apply the scientific method to deal with daily problems	0	3	4	1
After being involved in this project, I think research is more complex than I thought it was before	1	0	4	3
After being involved in this project, I am now	5	1	1	1

[3] All quotes have been translated from Catalan by the first author.

motivated to study a scientific career				
After being involved in this project, I feel I could be politically active (i.e., contributing with my knowledge in social movements)	1	3	4	0

Science is complex. Half of students said they liked science in general (e.g., as perceived at school, through media or by participating in the ICIL project) and interestingly because they perceived it was tricky and frustrating. As one of them explained in the MAP exercise: '*Such complexity is a challenge that raises our interest and motivates us to try to understand science better*'. Students discussed the issue of frustration in research. Reflecting on his own experience during the ICIL project, a boy said: '*Our experiment was a turning point in the way we were learning to do science. It allowed us to understand that experiments often fail and to be aware that we needed to improve our experiment* [because it failed]. *We did not get frustrated but we learnt that it is complicated*'. Science was thus perceived to be complex, but interestingly, three of them also noted that their view changed after participating in the project. As they explained: '*I thought that science was too complex because of my experience at school, but now I see that I can deal with ICIL issues*'; '*I thought that science was not for adolescents and now I think that it is*'.

Science is full of uncertainty. During the MAP exercise students were also engaged in a guided discussion about the advantages and disadvantages of scientific uncertainty. Only two of them agreed that they would prefer less uncertainty in the scientific practice in order to reduce the amount of time and resources invested in developing new and accurate medical knowledge and technology to improve social well-being. Others disagreed by emphasizing that science uncertainty did not equate to lack of accuracy: '*When you get an answer you know how you have arrived at it*'. They also argued that scientific uncertainty allowed for social improvements: '*People have evolved due to uncertainty because they look for answers*'; '*Scientific uncertainty is what links science with philosophy*'. At the end of the discussion all of them acknowledged that science will necessary be uncertain whether they liked it or not.

Career plans and interactions with scientists. Six students mentioned that they were more motivated to study scientific or technological careers, although four of them were already thinking on that possibility before. Two students were not interested in such careers, but in conducting research on humanities and social sciences. All of them mentioned that the project had not influenced their attention at school but noticed they were more focused when discussing with scientists in the project meetings than they usually were at school. They explained that Bidart's meeting was an inspiring and crucial event for raising their interest in science and research across different disciplines mainly because they could interact directly with scientists from other countries and learn from them.

Knowledge and skills acquisition

Students' expectations for learning within the project were largely exceeded. During interviews, all of them agreed they did not expect to learn as much as they actually learnt.

Learning about the scientific method. They acquired basic concepts on neuroscience and learnt how to frame and conduct a research, including how to apply the scientific method, as a boy explained: '*We learnt about the scientific method and the purpose of a hypothesis, how to plan an experiment, how to obtain conclusions, how to interpret a sampling error, and how to determine sampling size*'. In the last focus group, students mentioned that many of these concepts were already covered in classes, but they only understood their meaning when ICIL scientists used real examples from their own research to explain them. Specifically, videos about statistical analysis in research showed by scientists during meetings were recalled as important tools for clarifying neuroscience concepts and methods. Also, the preparation and test of their own experiment gave them the opportunity of 'learning by doing' and improving their understanding of the research process. As one girl explained: '*We did not consider some aspects that could make our results different than we expected*'. Interestingly, they also referred to new knowledge they acquired and would be useful at school, such as statistics, as well as non-scientific skills they would need in their professional life, such as the improvement of their proficiency in English and French and the acquisition of public speaking skills. They also learnt to be patient and organized when working in groups and to avoid frustration when conducting research.

The role of the different actors to make sense of the project. Besides scientists, they identified the mediator as a key actor in encouraging them to reflect about the research. As a girl said: '*He asks us many questions, he makes us to think, so we learn*'. Students also mentioned the key role of the teacher in accompanying them through the learning process even though they did not learn about neuroscience from him: '*He is at the school like us so we can ask him about the project activities*'.

In the time line exercise students recalled the first visit of the scientists at their school as the most important learning event in the first year of the project because, as they explained: '*We had the opportunity to talk to experts about how to do research*'. Such direct interaction with people who actually worked in science was also recalled as a driver of learning in the second year of the project during focus groups discussions. However, the main learning event of the project was the meeting in Bidart because they lived a different learning experience than in the school: '*Here* [in Bidart] *I learnt how to do research; I also learnt it at school, but it is not the same, there are theory and exams at school, but it is better to learn it in practice, like we do here*'. In Bidart, the five students who had developed their own smaller and more focused research projects, all embracing the global ICIL research question on the interconnectedness between colors, attention and learning, could also share and reflect on their experience with the other participants. Such discussions, guided by one of the professional scientists, helped them realizing about the relevance of what they learnt and the level of autonomy they had reached.

Empowerment based on self-confidence and collaboration

During focus groups students identified two main and interrelated empowering factors resulting from their participation in the ICIL project: self-confidence and the experience of collaboration. The experience had led a girl to recognize that: '*I am aware I can do it, I know where I am going, and I like working with others*'. Both self-confidence and the experience of collaboration point to the different types of interactions students have been able to develop through the project.

Interactions with parents, friends and teachers. When participating the role-playing game, students referred explicitly to their improved sense of confidence. They mentioned that their parents were proud of them and typically told relatives and neighbors about the project: '*They know we are doing something different*'. Moreover, parents valued students' involvement in the project and encouraged them to continue, as a girl said: '*They told me: take profit of that, this opportunity only* *happens once in life*'. Differently, students reported that their friends and teachers were rather aware and not interested in the project. They claimed that some teachers did not even approve their participation in project during class time and attributed such attitude to a lack of understanding about the project content and activities: '*If they saw us working in this project their opinion would change*'.

Interaction with scientists. Students also mentioned their self-confidence and awareness of their abilities to collaborate, linking these with the evolution of their relationship with the scientists involved in the project and those attending the meeting in Bidart. They expressed initial surprise that scientists established a direct relationship with them, as a girl recalled: '*The first day of the project when they* [scientists and mediator] *came to the school I thought: they are wrong, they think that we are smarter than we actually are*'. Students perceived that scientists were interested in establishing a dialogue with them and could appreciate that scientists also learnt from such interaction. They also acknowledged they enjoy and learn from scientists. As they mentioned: '*they* [scientists] *like to help us and are inspired by us, listen and accept our ideas and take us seriously*'. Although students identified themselves as active participants who were able to ask questions on their own and offer their opinions to scientists, they perceived scientists as holders of knowledge in contrast to themselves as non-experts and learners. Still, such interaction was perceived as less top-down than other relationships they had with adult people, including their teachers. In the words of one girl, they could speak with the scientists '*as adults*'. In this regard, they claimed that many of their teachers would need to change their attitude towards students in order to increase students' interest in science. Specifically they suggested that teachers should avoid dominant relationships, show interest towards students' comments or ideas, value what they can learn from students, learn to listen them, recognize students' reasoning ability, and improve their explanations of complex issues to make them understandable.

Changes beyond performing science within the ICIL project. Changes in perception of science, skills and self-confidence seemed to result in changes in attitudes beyond the frame of the scientific project differed among students. Three students perceived the scientific method to be useful to deal with their daily problems in an organized and systematic way whereas the other five acknowledged to be unaware of that possibility because they used to ask their parents for solving their problems. Finally, students expressed different opinions regarding the impact of the ICIL project in their future political behavior. While they recognized that they were generally more interested in social debates as a result of their participation in the project, half the group felt they were still not ready to be actively involved in social movements in the near future (Table 1).

DISCUSSION

The results presented above suggest that students are more interested in scientific research and feel more confident when dealing with science than they were and did before participating in the ICIL project. They have also enriched their understanding of the research practice, They gained first-hand experience with how people socialize in the academic community, its normativity and ambiguity. Even though they have experienced the frustration and complexity of research (e.g. failed experiments), they have also become aware that they are part of the scientific process and are necessary to achieve accurate research results. Students have also improved their self-confidence and collaboration among themselves and with scientists. Importantly, students have been able to reflect upon their own experience in this project, identifying the attitudes and skills they developed through the project, and wrote an article to share their experience with their peers, in a peer-reviewed journal (Andújar et al., 2015). Through such a situated, inquiry-based and collaborative approach, we argue that the ICIL project has empowered students to behave as autonomous learners and to critically think about their actions and decisions regarding the scientific practice. Most of these skills and attitudes (e.g., critical thinking, individual responsibility, ability to work as part of a team) have been identified elsewhere as important for citizens to acquire in order to participate effectively in scientific research but also in their daily life activities (Blanco-López et al., 2015). We discuss here how the ICIL project has led to such transformation in science learning and how the formal education context has both enhanced and undermined such process.

Some key elements of the NCS citizen science approach

In the learning experience developed through the ICIL project, we identified three key elements that have significantly contributed to such transformative process.

First, as in this project, relationships were characterized as *transparent and trust building*, and were elective, not imposed. In the ICIL project, scientists, students and the teacher participated voluntarily in all the stages of the project. It was not advertised as a blueprint solution to foster students' interest in science, rather the pros and cons of their involvement were clearly explained. For example, students were told it was possible they would not find an immediate answer to their research question; they acknowledged the challenge and decided to continue in the project, probably motivated by such challenge. Transparency also engaged students and scientists in a collaborative process based on the establishment of a horizontal interaction, which is far away from traditional teaching-learning approaches at school that limit students' involvement in knowledge building. Such authenticity seems to have provided trust among ICIL participants, which in turn might facilitate learning and transformation among them.

Second, participants were engaged in a continuous *deliberative process* about the meaning and rationality of their actions, decisions, achievements or limitations while conducting research. This seems to be crucial for having achieved their empowerment. For ICIL students, and citizens in general, to understand how research facts and values are connected to their lives and to be able to make informed decisions, they need to become active agents in the knowledge building process (Dietz, 2013). Taking part in designing the questions, performing and analyzing experiments, and disseminating the results allowed for such an understanding. Reflexivity among ICIL students was promoted through discussions with scientists as well as during focus groups and other meetings without them (including follow-up focus groups of this study). We suggest that such deliberative process allowed students to discover and develop their own skills and reinforce their motivation. Deliberation may also have the potential to change the frames of reference of students countering some prior cultural, social and political assumptions they hold related to science and themselves as knowledgeable actors in their society.

Third, and based on the philosophy of 'slow science' (Alleva, 2006), the ICIL project was planned on a *long-term, flexible basis* (3 to 10 years), had *no performance targets*, but some task deadlines. Such a long time frame facilitates the meshing of the agendas of both researchers, who often have a dense research agenda, and citizens, who typically pursue their personal and professional lives. It may also allow transformative learning to take place. One cannot expect a full understanding of research values and methods within a few hours of lecture or even the best interactive workshops. Moreover, and contrary that required of most school projects, of the absence imposed research outcomes and deliverables does not means a lack of results, nor of low performance. The ICIL project demonstrates students' engagement in research led to meaningful contributions that are usually restricted to professional, academic research, such as publishing a peer-reviewed scientific article (Andujar et al., 2015) and participation in a researchers' discussion at a departmental seminar (i.e., neuroscience lab at the Bellvitge Hospital in Barcelona). We suggest that independently of whether students' motivation to conduct these activities may or may not result in a direct academic performance at school, they develop greater curiosity about the question posed, increase interest to contribute to find a socially relevant answer and, most importantly, the pleasure of sharing time with people eager to meet each other.

Interaction with the formal educational context

Lack of flexibility of formal educational structures has been a challenge for the development of the ICIL project within the secondary-school environment. ICIL project had to adapt to the school's rhythms, such as exam periods. Divergences also existed between the ICIL project and some teachers' pedagogical approaches and objectives, as mentioned by students (see above). Differently from the transformative learning approach of the ICIL project, scientific learning at the school is generally based on the unidirectional and vertical transfer of expert knowledge, which is in turn decontextualized from young people's reality (Frisk & Larson, 2011). Furthermore, students and teachers may feel sometimes overworked, especially when project activities concentrate on the school exams period. In the case of the ICIL project, some students could 'validate' part of their activity within the ICIL project as a formal school assignment, thereby integrating it in the curricula. It is also worth noting that in the ICIL project, the school itself was an object of research and the origin of the research question (the colors of its walls), thus providing the initial motivation and a space to act on.

The school context may also have contributed to keep the group together along the years. Indeed the students who left the school within these 3 years also left the project. Maybe this is only due to the loss of the social connection that the school provides among young people of the same generation. After 3 years now, while all members of the group have left for university, they still plan to pursue the project. The school context is thus no longer necessary, while all members still live in two small towns, few kilometers apart.

The challenge of involving researchers

From the perspective of researchers, considering questions from citizens as legitimate and relevant is an attitude that many scientists are still hesitant or even reluctant to adopt. Developing a research project at the margin of their research agenda is challenging for the scientists who feel pressured by the 'publish or perish' rule. Moreover, data gathered from citizen science projects are often perceived by external scientists as lacking scientific validity, which might discourage scientists to be involved in such projects (Riesch & Potter, 2013). While the researchers involved in the ICIL project were hesitant at the beginning they are now advocates of this approach, convinced that it allows to produce socially relevant research[4], that can be valued even in rather traditional approaches to research evaluation (i.e., through publication, public presentations) (Bonnefond *et al.*, 2015). The social relevance was achieved here through a question prevalently defined by citizens and a protocol co-constructed in between citizens and researchers. Indeed, together with students, ICIL researchers have designed a project inspired by students' curiosity that they could not have thought of if they had been staying in their lab. They are now pursuing their collaborations with the group of students (now university students) and plan together a wide neuroscience experiment, involving many participants. The neuroscientists are indeed highly interested by the possibility to perform neuroscience experiment within the natural "ecological" setting of young people who are learning, rather than in the artificiality of research labs.

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4 Redefining social relevance of research through participatory approaches: *https://modelisation.wordpress.com/2014/09/25/redefining-social-relevance-of-research-through-participatory-approaches/*

CONCLUSION

Our study has allowed to characterize the impacts of the transformative learning process experienced by the students involved in the ICIL citizen science project, a first pilot developed within the NCS program. As a result of such involvement, students developed a perception of science as collaborative and full of uncertainty, which strengthened their motivation for and understanding of science. Students also enhanced their self-confidence through designing their own experiments and interacting with professional researchers. The ICIL project has thus had impacts beyond responding to the request from society to researchers, or facilitating citizens to decide which questions should be addressed by scientists. The full participation of the students in the design and implementation of the research project allowed them to appreciate that understanding how the answer is constructed is as important as the findings themselves. It is this reflexive and deliberative research process which empowers: citizens together with researchers can develop tools and skills, take decisions, collectively build knowledge and critically analyse and communicate it. In the ICIL project empowerment was demonstrated through students' reframing not only of their attitudes and perceptions of science, but also towards themselves, as valid, competent and knowledgeable actors.

The ICIL project is still developing, in collaboration with the researchers from the Netherlands. Substantial experiments are being planned. More research will also be done to analyze the impact of this experience, both from the perspective of the citizens and the researchers, on a longer term. Furthermore, the impacts of the NCS approach will be studied based on the other NCS ongoing projects, in different contexts and with different communities.

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APPENDICES

Appendix 1. Description of the roles played by students in the role-playing game.

Cognitive neuroscientist:
You are a cognitive neuroscientist who is doing his/her PhD research in a prestigious laboratory about how colors affect learning. You have been invited to participate for free in an education project with secondary students to whom you will have to explain an experiment that will help them to understand and learn more about your research. You accepted because you like education and communicate your research out of the academic context. But you have never taught secondary students and you are afraid they will not understand academic language. You have spent many nights preparing the experiment. When students arrive at the laboratory you are a bit nervous and tired, but you will have to work hard to try to make students pay attention.

Student participating in the ICIL project:
You are a secondary student who is participating in a science school project which initial research question was how walls' colors at school influence students' learning, if they do. You have been told that you will visit a laboratory where scientists will conduct an experiment related to your project. You are excited about the idea of visiting the laboratory and have prepared some questions to learn more about your research topic. When you arrive at the laboratory, however, some of your classmates complain about the visit and disturb scientists during their explanations and experiments. What will you do in that situation?

Student not involved in the ICIL project:
You are a secondary student who has been told that will visit a laboratory where scientists will conduct an experiment related to your classmates' science school project who are studying something related to colors and learning. You think these kind of scientific projects are not useful and the visit to the lab will be boring. When you arrive at the laboratory, you complain about the visit to your teacher and disturb scientists during their explanations and experiments.

Appendix 2. Semi-structured interview guide designed and implemented by the students.

Name (if the interviewed person gives consent): Date: Place: Interviewer: Audio recording: Yes / No 1. What is the ICIL project about, what are the objectives? 2. Do you think that you have learnt in this project? What? How? (activities, people) - Have you learnt about the scientific method? - And about how to conduct a research? - Did you expect to learn in such a way? - How was the experience of doing an experiment? Would you repeat the experiment in the same way? - How do you have implemented all this learning as a student? 3. Do you think that you would be able to test your hypothesis in another way? (If yes, how; if not, why is important to have conducted this experiment?) 4. Has your opinion about science changed? How? 5. Would you participate again in a similar project?