HIGH MOTIVATION AND RELEVANT SCIENTIFIC COMPETENCIES THROUGH THE INTRODUCTION OF CITIZEN SCIENCE AT SECONDARY SCHOOLS: AN ASSESSMENT USING A RUBRIC MODEL

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Abstract

Five different citizen science projects have been introduced in eleven secondary schools where class-groups collaboratively worked together. To assess homogeneously the learning performance, we propose a rubric model that includes scientific, communication, and ICT competencies jointly with participation and motivation attitudes. Results highlight that more than 80% of the students developed highest scientific competencies while 81% of them reached top levels regarding motivation and participation attitudes. Results support the idea that citizen science projects allow for a context-based learning and enable students to handle shared concerns related to their own neighbourhood through a hands-on approach.

Introduction

Schools are privileged scenarios to test, improve, perform and upscale Citizen Science (CS) projects. Teachers provide the right instruction, the perfect framework for participation and the necessary assistance regarding data collection (Dickerson, 2016; Rock and Lauten, 1996; Eick *et al.*, 2008). Schools also allow the performance of CS projects over a quite long period of time without having to maintain heavy engagement infrastructures (Dickerson, 2016). The school context also provides a large number of volunteers that can easily participate in a single experiment as, for instance, in the case of mass experiments (Kasperowski and Brounéous, 2016).

However, these compelling arguments are not consistent with the fact that the presence of CS in schools (understood as pre-University levels) is still anecdotal and, to the best of our knowledge, always deal with a single and particular project. These projects, for historical and feasibility reasons, are indeed mostly constrained to biodiversity and ecology studies (Bonney *et al.*, 2009; Zoellick *et al.*, 2012; Phillips, 2014; Eick *et al.*, 2010). Therefore, the described methodology is quite specific to a given project or topic and it is generally not easy to transfer to a wider variety of scientific disciplines.

Similarly, the evaluation of students' learning competencies during these processes is generally scarce and if existing, ismost often qualitative (Dickerson, 2016; Bingaman and Eitel, 2010; Schon *et al.*, 2014). Silva *et al.* (2014) is one of the few exceptions, making a remarkable effort to evaluate the educational and motivational outcomes of their "Cell Spotting" project. However, questionnaires were only delivered after the experiment and they were not compulsory thus in some way limiting the significance of the study.

Perhaps the most interesting perspective is reported by the prescriptive essay "Lessons learned from Citizen Science in the Classroom" (Gray *et al.*, 2012) since it puts the spotlight on the class-group and the positive learning outcomes in a much broader perspective. And, just for the sake of completeness, we can also add that embedding CS in University level (undergraduate) classrooms has shown to be effective for active learning and has enhanced engagement with science (Freeman *et al.*, 2014; Coleman and Mitchell, 2014; Powell and Harmon, 2014). By using both quantitative and qualitative methods, Vitone *et al.* (2016) have found that engagement with science increased thanks to the introduction of the "School of Ants" project in college.

This chapter aims to contribute to the existing literature by presenting empirical results evaluating the impact of introducing CS at schools with up to five different CS projects. We have wanted to do so by proposing a ready-made rubric model that can be generalized to any CS project introduced in formal education. The methodology was identically applied in all five CS projects obtaining data from more than 500 secondary school students (between 12 and 15 years old). When designing the study, we had in mind three different goals. The first goal was to create and test an easy-to-follow methodology, capable of introducing a diverse typology of CS projects at formal education. The second goal was to develop a common strategy to evaluate the impact of the several CS projects in order to obtain a set of homogeneous results ready to be analysed and compared. Finally, the third goal was to harness quantitative and robust results regarding the impact of CS at schools by testing the acquisition of knowledge, skills and attitudes among eleven different schools and through the rubric model proposed.

The five scientific research groups behind the five CS projects belong to different disciplines and are focused on quite different topics. Each class-group was also attached to a different subject and to different parts of the curricula with the CS project they had been working with. Our projects belong to the *b* and *c* categories of public participation in scientific research, namely collaborative and co-created projects, defined by a seminal National Science Foundation report (Bonney *et al.*, 2009). Working the five projects together has only been possible thanks to the Barcelona Citizen Science Office which has acted as an enabler in order to trigger a collective exploration on how CS can be fitted into secondary schools. With the only restriction that schools had to work in urban and peri-urban areas; organisational aspects were also tackled globally. This approach has also allowed us to obtain a bigger sample in terms of student numbers, making it possible to provide robust results, to evaluate differences among the CS projects and even to link the results with the particularities of each the CS projects being studied.

The chapter therefore proposes a rubrics model for CS projects to assess the acquisition of competencies and attitudes in schools. We test the tool in five different CS projects in a common way and present the results of these rubrics. Data of our study is not only analysed by aggregating all five CS projects but also by comparing their rubrics to find differences due to the peculiarities of each CS project. Finally, we provide a general discussion linking the observed impact in students' competencies and attitudes with the methodology used, the intrinsic characteristics of the projects introduced at schools, and the potentiality of CS introduction at school.

Methodology

Background and tools

Within the frame of a given local and shared concern, students as a group needed to explain what was observed, to conduct experiments, to collect and analyse data, to interpret observations, to draw conclusions from data and to communicate findings (Hattie, 2009). The study involved a total of 547 students and 17 teachers from 11 different secondary schools, five scientific research groups and 19 scientists. The methodology chosen to evaluate the pilots was quantitative with pre and post questionnaires addressed to students, teachers and researchers. Rubric tools (Allen and Tanner, 2006) were designed to help teachers to set the goals and to assess homogeneously students' acquisition of competencies and attitudes in the eleven different schools and 5 different citizen science projects. The rubric model is a very common practice for collecting evidence in learning processes of formal education as well as for assessing the performance of students in a standardized and transferable manner. Rubrics also help teachers to give a clear idea about what their expectations are and the level of performance for each competency and how to assess these competencies. In this chapter, we present the results based on a rubrics tool while detailed description of results from questionnaires and materials created by each school will be left for future publications.

Our approach has a very specific motivation in a quite unique scenario in the CS world. In 2012, five different research groups from Barcelona (Spain), and from quite diverse collection of disciplines, founded the Citizen Science Office with the support of the Culture Institute of Barcelona (City Council). This emergent initiative already hosts, in 2016, sixteen projects from different universities and research centres of the Barcelona metropolitan area. This sort of community of practice is understood by all members as a way of aligning strategies, sharing best practices, organising events or even planning common actions in the field of citizen science. One of these actions started in March 2014 and was precisely aimed to explore education by means of a common experimental approach. Since all groups already had experience in running their projects in informal contexts, it was decided to look into schools. The main reason was that formal education was seen by the different groups as a difficult space to be explored by each project on its own.

Citizen science projects description

Each research project was introduced as a pilot at least in two schools (see Table 9.1 for further details on schools and students). Projects introduced into the schools were:

1. *Plant*tes* (or *Urban Flora and Allergies*), by Aerobiology Information Point (PIA) and Institute of Environmental Science and Technology (ICTA-UAB). They offer a protocol to report and geo-tag allergenic plants to improve the quality of life of people suffering from allergies.

2. *Bee-Path*, by OpenSystems Research Group of the Universitat de Barcelona, by Institute of Complex Systems (UBICS), and by Dribia-Data Research. They provide a tool that allows the study of human mobility through a mobile application in a critical and collaborative way.

3. *Mosquito Alert*, a project coordinated by the ICREA Movement Ecology Lab associated with Centre of Advanced Studies (CEAB-CSIC) and Ecological and Forestry Applications Research Centre (CREAF). They offer a platform for participating in research and management of mosquito vectors of disease.

4. *Observadors del Mar* (*Sea Watchers*, in English), by Institute of Marine Sciences (ICM-CSIC). They provide a meeting point between citizens and scientists to investigate the current state of the sea.

5. *RIU.net*, by Research Group Freshwater Ecology and Management (FEM) of the Universitat de Barcelona. They offer an application for mobile phones that allows for an intuitive and easy way to assess the ecological status of a river.

Table 9.1: Distribution of Citizen Science projects among the schools participating in the pilots

Name of the School	Typology	CS Project	Nr of Teachers	Nr of Students	Age (Grade)
FEDAC Sant Andreu (Barcelona)	Private	Urban Flora & Allergies	1	54	12 (1st ESO)
Institut XXV Olimpíada (Barcelona)	Public	Urban Flora & Allergies	1	82	12 (1st ESO)
SI Bosc de Montjuïc (Barcelona)	Public	Urban Flora & Allergies	1	23	12 (1st ESO)
Col·legi Sant Gabriel (Viladecans)	Private	Bee-Path	2	24	15 (4th ESO)
Institut Enric Borràs (Badalona)*	Public	Bee-Path	3	19	15 (4th ESO)
Regina Carmeli Horta (Barcelona)	Private	Bee-Path	2	24	15 (4th ESO)
Escola Garbí Pere Vergés (Esplugues de Llobregat)	Private	Mosquito Alert	2	67	12 (1st ESO)
Institut de Tordera (Tordera)	Public	Mosquito Alert	2	56	12 (1st ESO)
Institut Enric Borràs (Badalona)*	Public	Sea Watchers	3	34	14 (3rd ESO)
Maristes Champagnat (Badalona)	Private	Sea Watchers	1	86	14 (3rd ESO)
Escola Sant Gervasi (Mollet del Vallès)	Private	RIU.net	1	27	15 (4th ESO)
FEDAC Cerdanyola (Cerdanyola del Vallès)	Private	RIU.net	1	51	12 (1st ESO)

* Same teachers were involved in Bee-Path and Sea Watchers projects

Inquiry-based learning approach with community and context embedded

The inquiry-based learning approach fits into the five CS projects since they all build knowledge, skills and attitudes through hands-on learning activities. Students become active learners and improve both students' perceptions and attitudes towards science (Wee *et al.*, 2004; Bingaman, 2010). Following the process established by the National Institute for Health (2005), we were indeed able to differentiate two types of inquiry-based projects in our introduction process of citizen science in schools. Some projects followed a *guided inquiry* while some others an *open inquiry*. The *guided inquiry* learning projects (i.e., *Mosquito Alert*) provided schools with research questions. Students and teachers were responsible for designing and following their own procedures to respond to those questions and deliver their results and findings. Other projects were quite open (i.e., *Bee-Path*) in the sense that students were encouraged to formulate their own research questions, design and follow through with a developed procedure and communicate their findings and results. That is to say that students had to drive their own investigative questions and the CS project was just a tool to enable their tasks. *Open inquiry* projects are only successful if students are motivated by intrinsic interests and if they are equipped with the skills to conduct their own research study (Bell, 2010; Turner and Patrick, 2008). In order to support the experience, learning resources were provided to offer (if needed) guidance to knowledge acquisition (Kirschner *et al.*, 2006) to teachers. However, only upon request were teachers aided by researchers in the process of identifying and better shaping the research questions for each school project.

An important factor that has been incorporated in our study is the relation of CS projects to the community's concerns. In that sense, we have also wanted to respond to those claims asserting that CS does not go far enough to resolve the concerns of communities and environments. Along these lines, those claims also consider that CS practices need to be considered holistically, by including many non-scientific aspects in the project and without restricting the activity to data gathering and data delivery to scientists (see for instance Mueller *et al.* (2012)). Schools in our study were challenged to observe and question real phenomena from their own neighbourhood and thus respond to shared concerns at a very local and situated level (Callon, 2009). The results and scientific conclusions raised by each school were therefore aimed to be materialised as argued proposals to improve the quality of life in their neighbourhood from different perspectives. We believe that community concerns need to be incorporated into the equation on how CS practices can be part of the existing list of innovative mechanisms in science, technology, engineering and mathematics (STEM) education. This is how our approach includes multidisciplinarity and even transdisciplinarity in an organic manner.

Recruitment and engagement

From October 15th 2015 to November 5th 2015, a call was opened to teachers to participate in one of the five projects. The announcement included requirements described in detail in a microsite exclusively designed for this purpose (https://cciutadana.wordpress.com, in Catalan). The microsite explained in detail the project as a whole and all CS projects enrolled. A link to each project website, in case teachers needed further information, was also included jointly with a list of possible activities related to each project within the current Catalan school curricula (see below for more details). All enquiries related to the call were made through a single and centralized mail account.

It is also important to stress that the relationship with schools was solely established through teachers. In a deliberate manner, we did not ask for the participation of any upper level institution, nor any representative such as school directors. The call was made using our own mail lists from previous experiences and other generic mail distribution lists. Teachers were able to freely participate with their own students and class groups but they did not receive any reward. In doing so, only fully committed teachers were enrolled in the pilots.

Our commitment with schools was to offer an authentic scientific research experience with relatively mature CS projects. The open call stressed the fact that teachers had to use projects, results and conclusions for improving the quality of life of their own school and its surroundings. Teachers were invited to participate in a two-hour training session to fully inform them of the phases of the pilots and offered them the opportunity to share the experiences with all students in a final event at Cosmocaixa, a science centre located in Barcelona.

We received a total of 24 applications mostly from the Barcelona metropolitan area. Applicants had to fill in an online questionnaire with basic information: school, teacher name, project chosen (three ordered options), and few lines to explain why they would like to participate in the mentioned CS project. However, we could only afford to implement eleven school proposals which correspond to between two and three school-projects for each of the five citizen science projects.

The selection criteria were based on:

1. the school and teacher commitments to citizen science philosophy,

2. their potential to work around the school with the chosen CS project, being related to a local concern (i.e., *Sea Watchers* shall be hosted by a school close to the coast and *RIU.net* in a school nearby river),

3. a proper balance in a number of schools and type of schools (school size, number of class groups per school, private versus public schools) in general but also across the five CS projects being offered,

4. different ages (in secondary schools, between 1st and 4th grades of the Spanish ESO, between 12 years old and 15 years old) in and across the five CS projects,

5. being able to be adapted to different subjects between and across the five CS projects,

6. the availability of each CS project to travel to the chosen school.

Students' profile and dynamics of the pilot studies

Secondary school students, from 1st to 4th of ESO (mostly from 12 years old to 15 years old, 13 years old on average) were specifically chosen for this study as it is a life stage when Spanish students decide whether to orient their studies to scientific and ICT careers. We thought that this was the most adequate life stage to promote scientific careers by actively engaging students into real scientific processes able to raise their own concerns as citizens. The choice is also supported by some studies which, at this life stage, report a decline in science motivation in students (Potvin and Hasni, 2014) and in both academic performance and science self-concept (Grabau, 2016). Table 9.1 synthesizes data related to students jointly with other information. Gender balance is quite strong for each group-class with the aggregated proportion of girls around 54%.

All experiences aimed to follow very similar dynamics: between two or three months in duration and amounting to between 10 to 20 hours. Since all group-classes wanted to go further and study their projects in greater depth, they generally dedicated more time to them. The pilots sought collaborative work and the empowerment of the group-class with autonomy so as to learn to function with specific and limited support from researchers. Students were encouraged to explore, design and analyse research questions and become active participants in the scientific inquiry process rather than being passive learners.

Specifically, all pilots followed an identical sequence:

1. A scientist, being an expert, introduced the specific CS project in the classroom (about an hour). In most of the cases, this was the first time students learned about the concept of citizen science and found out about the tasks to be done on the specific CS project that they will work on during the coming months.
2. Students and teachers worked together autonomously. Some of the tasks were distributed within the group-class in a way that some of the students took more responsibility in some tasks than in others. Tasks during this phase were:
    a. To define experiment(s), their location and what is the output that the group-class wants to reach. This included in its first step a process of shaping the research question. The group had in mind the final presentation, their own scientific questions, and their shared concerns related to their own neighbourhood. This discussion was, only if the teacher needed to or wanted to, shared and complemented remotely through e-mail and web conferencing tools with scientists. Some conversations were naturally established to better focus the research question and to adjust the necessary logistics for succeeding in the experiments and the fieldwork. All these

activities were done in the classroom except in the case of Enric Borràs school (*Sea Watchers* and *Bee-Path*) in which they preferred to work in the playground to have a less formal space. Teachers not only wanted to enhance discussion in this way but also to have a larger space to work with larger groups of students.

b. To run fieldwork based on a given research question and with a given experiment. In some cases, an *open inquiry process* was followed (*Bee-Path* and *Allergies and Urban Flora*) while a *guided inquiry process* was followed in the rest of cases. The purpose was in any case to collect data and this task was always done at a walking distance from the school. This activity is done outside the school, except in the Escola Garbí Pere Vergés case (working with *Mosquito Alert*) which has been done in their very large garden. The fieldwork was sometimes assisted by scientists but scientists did not interfere with the work performed and decided by the group-class. In *Bee-Path* experiments, some students acted as experimental subjects while others as supervisors and designers of an experiment, interchanging the roles.
c. To analyse data collected and discuss results in the classroom. Some resources are supplied by scientists to optimize this part of the work. Open source tools such as *Carto* and *Open Street Maps* jointly with *Google Maps* have been explored. GPS data filtering in *Bee-Path* human mobility experiments have been done by scientists. *Allergies and Urban Flora* supervised the photos taken to validate identification of species and their flowering status.
d. Results and conclusions took shape in different ways. These forms were decided by the group-class. On a local level, some of the forms were as follows: Tordera school invited the Mayor to the class in order to brief him on the results about the Tiger mosquito (*Aedes albopictus*) in their small town, Pere Vergés Garbí delivered a surveillance map of *Aedes albopictus* and *Aedes aegypti* for the school gardens, while Enric Borràs school presented their results with the *Sea Watchers* project in public spaces such as food markets of the city of Badalona. There was also a public presentation in Cosmocaixa where all schools shared their results in two different formats: about 5-10 minute talks (which included photos, videos and even performances as to the case of *RIU.net)*, and a poster session (where each school had a table, in front of which the students of each school explained their experience informally). There was some media coverage by the national press.

Learning activities and educational resources

Each school could choose the CS project in which they wanted to be involved. For each of the projects, a proposal of learning activities and a set of educational resources were publicly available in the study website (https://cciutadana.wordpress.com, in Catalan). Each project description also included the specific parts of the educative curricula in which the project can be circumscribed. These parts belonged to subjects such as Science, Biology and Geology, Physics and Chemistry, Maths, Arts or Social Studies. However, the final decision on the educational approach was left to teacher interests and school constraints. Teachers also decided in a quite spontaneous way to work with other colleagues at his/her own school. Some schools worked on natural and physical science courses, others in technology or maths, some even introduced the projects in visual arts, social science or humanities.

The learning support tools offered were:

1. Activity proposals: goals related to courses and to research process.
2. Activity developments: a proposal of activities for each of the sessions.
3. Learning resources: videos, apps, learning guides, created *ad-hoc* for each project.
4. Curricula: selection of points of the formal curricula that are linked to the activities.
5. Optional activities.
6. Requirements for the school: localisation of the school (next to a river, to the sea, etc.), devices needed, and practical recommendations.

Pilot evaluation

Each teacher received the same rubric model to analyse the acquired competencies of their class-group. Competencies and attitudes being evaluated are applicable to all the five CS projects and for the eleven schools. The tool was designed to provide:

1. Indicators of learning acquisition. Prior to the learning process in November 2015, as the researchers and observers of the whole process, we defined the whole rubrics matrix. The existence of the rubrics was mentioned to teachers before they got enrolled in the pilots and their contents were briefly discussed.

2. Assessment support tools for teachers. After the learning process and starting from February 2016, each teacher was required to fill in the rubrics and evaluate their own class-group. Data gathering was done in an aggregate level and no individual data was taken.

3. A quantitative, homogeneous, transferable and standardized approach to analyse data. The rubrics model delivered to teachers follows the standards established by both the Catalan and Spanish Education Law and curricula regarding knowledge, skills and attitudes of ESO students of science, communication, and technologies. Different grades and different projects are quantified using the same rubrics, being at least valid from 1st to 4th of ESO (from 12 to 15 years old). Rubrics are however general enough to be applied to at least other European countries since they have very similar standards.

4. A guarantee that inquiry-based learning process is being followed. Process includes creating questions, obtaining supporting evidence to answer those questions, explaining the evidence collected, connecting explanations to existing knowledge and to social contexts.

The rubric model provided scaled levels of achievement for a set of quality criteria and for a given type of performance (Huba and Freed, 2000). We selected communication, ICT and scientific competencies. We also included the *Participation and Motivation* attitudes as a crucial aspect in formal education, inquiry learning and CS (Jenett *et al.* 2016, Rotman *et al.* 2012). We generated four rubrics, one for each competency and for the attitudes. For each case, we provided a set of subcategories and each of them provided a scaled level of achievement with three level quality gradation. Level 1 assesses the acquisition of basic competencies, level 2 increases the requirements, while level 3 acknowledges reaching an excellent acquisition of the evaluated competencies.

The descriptions of the competencies and attitudes, the subcategories and the three levels for each category of performance were sufficient for an appropriate judgment. The rubrics were indeed used by the teachers themselves as a self-reflection tool to evaluate the experience of the pilots. Besides this, we added the motivation attitude regarding participation as is seen in literature as a crucial aspect in relation to engagement with CS projects (Rotman et al. 2012; Jenett *et al.* 2016,). These are the categories of analysis of the rubrics:

1. Scientific Competencies: necessary for a critical analysis of the reality that surrounds us based on scientific methods and scientific methods.
2. Communication Competencies: necessary to communicate on different channels and at different levels and contexts.
3. ICT Competencies: necessary for the safe and critical use of technology, including different purposes.
4. Participation and Motivation attitudes: necessary to evaluate engagement within the CS project.

Table 9.2 shows the English version of the rubrics which includes in detail the items being evaluated. This is the version that teachers had to fill in.

Table 9.2. Rubrics provided to teachers.

	Scientific competencies		
	Level 1	**Level 2**	**Level 3**
#1	He/she explains the aim of the scientific research project in which he/she has been involved.	He/she explains and justifies the aim of the scientific research project in which he/she has been involved.	He/she explains and justifies the aim and repercussions of the scientific research project in which he/she has been involved.
#2	He/she lists the steps needed to collect data.	He/she lists the steps needed to collect data and justifies their relevance.	He/she lists the steps needed to collect data and justifies their relevance and asks questions that improve this process.
#3	He/she shows the results obtained.	He/she analyses and provides an explanation of the results obtained individually (or in a group).	He/she analyses and provides an explanation of the results obtained individually (or in a group) and participates in the analysis of results obtained by other groups.
#4	He/she identifies the results as part of a larger project.	He/she identifies and locates the results as part of each citizen science research project.	He/she identifies and locates the results as part of each citizen science research project and analyses them taking into consideration the rest of the projects.
#5	He/she understands the social significance of the results obtained.	He/she understands and defends the social significance of the results obtained with arguments.	He/she understands and defends the social significance of the results obtained with ideas on how to improve the context/environment based on the analysis of the results.
#6	(If applicable): He/She presents graphs from data.	(If applicable): He/she elaborates and explains graphs from data.	(If applicable): He/she elaborates and explains graphs from data and uses them as a basis for their arguments.
#7	Lists the steps of the scientific process in which he/she was involved.	Lists the steps of the scientific process in which he/she was involved and clearly identifies in which step is in at every moment.	Lists and describes the steps of the scientific process and participates actively in the design of some of them.

	Communication Competencies

	Level 1	Level 2	Level 3
# 1	The final product explains the purpose, steps taken and data collection.	The final product explains the purpose, steps taken, data collection and offers a data analysis from data obtained.	The final product explains the purpose, steps taken, data collection and offers a data analysis from data obtained. Furthermore, the final product offers possible actions to be taken based on the analysis of data.
# 2	The wording of the text does not contain misspellings.	The wording of the text does not contain misspellings and uses subordinate clauses correctly.	The wording of the text is impeccable.
# 3	(If applicable): oral explanations are understandable.	(If applicable): oral explanations are understandable and convincing.	(If applicable): oral explanations are understandable and convincing and defend authority.
# 4	(If applicable): The artwork is sufficient and respects intellectual property rights.	(If applicable): The artwork is remarkable and respects intellectual property rights.	(If applicable): The artwork is remarkable and respects intellectual property rights and has been edited previously and appropriately.

	ICT Competencies		
	Level 1	**Level 2**	**Level 3**
# 1	He/she uses digital tools for collecting data sufficiently.	He/she uses digital tools for collecting data autonomously and safely.	He/she uses digital tools for collecting data autonomously and safely and offers explanations about its functioning to colleagues who request it.
# 2	He/she uses digital tools for presenting the final product sufficiently.	He/she uses digital tools for presenting the final product autonomously and safely.	He/she uses digital tools for presenting the final product autonomously and safely and offers explanations about its functioning to colleagues who request it.

	Participation and Motivation Attitudes		
	Level 1	**Level 2**	**Level 3**
#	He/she listens carefully to the explanations.	He/she listens carefully to the explanations and	He/she listens carefully to the explanations and intervenes

1		intervenes with pertinent questions.	with pertinent questions and clarifies some of their questions to classmates.
# 2	He/she collects data following instructions and without interfering with the work of the rest of the classmates.	He/she participates actively in the data collection.	He/she participates actively in both data collection and in its planning.
# 3	He/she participates in data analysis passively.	He/she participates in data analysis actively.	He/she participates in data analysis actively coming from his/her team and the rest of the groups.
# 4	He/she shows respect, but little participation.	He/she is actively participating, respecting turns and the opinions of classmates	He/she is actively participating, respecting turns and the opinions of classmates. His/her opinions are respected and most times accepted by the rest of the class.
# 5	He/she passively participates in the elaboration of the final product	He/she is actively involved in the preparation of the final product (brainstorming and proposing improvements).	He/she is actively involved in the preparation of the final product (brainstorming, proposing improvements and assuming different tasks, etc.).
# 6	He/she fills in the forms required for the pilots.	He/she fills in the forms required for the pilots. The composition of his/herLaboratory notebook is adequate.	He/she fills in the forms required for the pilots. The composition of his/her Laboratory notebook is exhaustive.
# 7	He/she participates passively in the final discussion.	He/she participates actively in the discussion, listens and supports ideas from colleagues.	He/she participates actively in the discussion, listens and supports ideas from colleagues discussing it, and so is respectful of others.

Results

Student participation and engagement

The CS activities allowed students to actively participate in all the steps that define a scientific investigation and in some cases the activity was entirely designed by the students. The activities carried out in schools were very diverse, since they depended on the design by teachers and, in many cases, by the students themselves. The degree of intervention of the students also varied in each case.

In all cases, the students were involved in the collection and analysis of data. Some of the groups also took part in the choice of the main question (how would people move in pursuit of specific goals? how is the tiger mosquito breeding in our school/in our town?); in the design of the experiment (how will we explain to the participants what they need to do? how will we collect data? what will we consider a positive point?), in the definition of the hypothesis, etc. There were groups directly involved in all the steps of their scientific investigation. For example, through the use of Bee-Path, some students designed a mobility study in an urban environment, while others decided to use it in the study of the pattern of mobility of people pursuing specific goals. In the case of Mosquito Alert, one school decided to focus its analysis on their buildings, while another one extended the analysis to his entire town. All of these decisions were taken between the teachers and their students.

In this sense, these citizen science projects were not used (or even viewed) as a"closed" experiment, but as tools to use in their own designed experiment. Moreover, some groups of students decided to communicate their results to their communities and administrations, taking on the role of science communicators and activists. For example, a group decided to develop a mobile panel to increase the awareness of their neighbourhood about beach pollution; other students decided to invite the Mayor and his team to their classroom and show them the tiger mosquito breeding sites map they have developed, so that the administration could communicate this data, and evaluate appropriate actions to reduce the presence of this invasive species.

Global evaluation results

The rubrics provided a set of subcategory elements to assess homogeneously the learning performance of the 547 students, of eleven schools and 5 research projects. As stated in the methodology, the competencies analysed were related to science, communication and ICT. Motivation and participation attitudes have also been evaluated. Data provided by teachers in the rubrics showed that all students successfully fulfil the acquisition of the competencies and attitude analysed although some sub-categories did not apply to some of the class-groups as outlined hereafter.

Table 9.3: Averaged values among all students participating and over all different subcategories. Subcategories averages allow us to estimate the Standard Error of the Mean (SEM) for each competence/attitude. Empty cell corresponds to errors that cannot be computed due to lack of statistics.

Population (in %)						Weighted level											
Level 1	SEM*	Level 2	SEM*	Level 3	SEM*	Urban Flora	SEM*	Bee-Path	SEM*	Mosquito	SEM*	Sea Watchers	SEM*	RIU.net	SEM*	Average	SEM*
17%	3%	44%	4%	39%	5%	2,18	0,06	2,49	0,08	2,10	0,19	2,41	0,16	1,89	0,09	2,21	0,12
23%	3%	46%	3%	30%	5%	2,27		2,35	0,10	2,15	0,19	2,18	0,19	2,33	0,12	2,26	0,04
14,4%	0,4%	36,3%	0,1%	49,3%	0,4%	2,15	0,07	2,00	0,27	1,97	0,30	2,27	0,10	2,04	0,28	2,09	0,06
19%	3%	38%	2%	43%	2%	2,44	0,04	2,15	0,04	2,21	0,09	2,20	0,07	2,56	0,09	2,31	0,09
18%	2%	41%	3%	40%	5%	2,26	0,08	2,25	0,12	2,11	0,06	2,27	0,06	2,21	0,17	2,22	0,03

The mean scores, considering the sum of all the projects and the sum of all the competencies or attitudes are presented in Fig. 9.1. The radar chart shown in Fig. 9.1 provides the proportion of student (in %) that have reached levels 1, 2 and 3 in four different axes (Science, Communication, ICT and Participation and Motivation). Lower values are placed in the centre of the plot while higher values are displaced to the extremes of each axis. Figure 9.1 shows that, for Scientific and Communication competencies, the most frequent level reached is level 2 whereas for ICT competencies and Participation and Motivation attitudes, the most frequent level reached is level 3. In all cases, level 1 represents a minority of students of no more than 20% for all the types of competencies/attitudes. This finding demonstrates the overall really good results of the CS projects when introduced in formal education. Similarly, averaging all types of competencies/attitudes, most of the students tended to be more in level 2 (41% of students on average) and 3 (40%) rather than the basic level 1 (19%). See Tab. 9.3 for further details.

If we look at each of the projects, we can also observe from Tab. 9.3 that Allergies and Urban Flora (159 students) has a 2.26 averaged level, Bee-Path (67 students) has a 2.25 averaged level, Mosquito Alert (123 students) has a 2.11 averaged level, Sea Watchers (120 students) has a 2.27 averaged level, and RIU.net (78 students) has a 2.21 averaged level. This latter finding demonstrated that there are not important disparities in-between the projects, in that all of them have received a very good global evaluation.

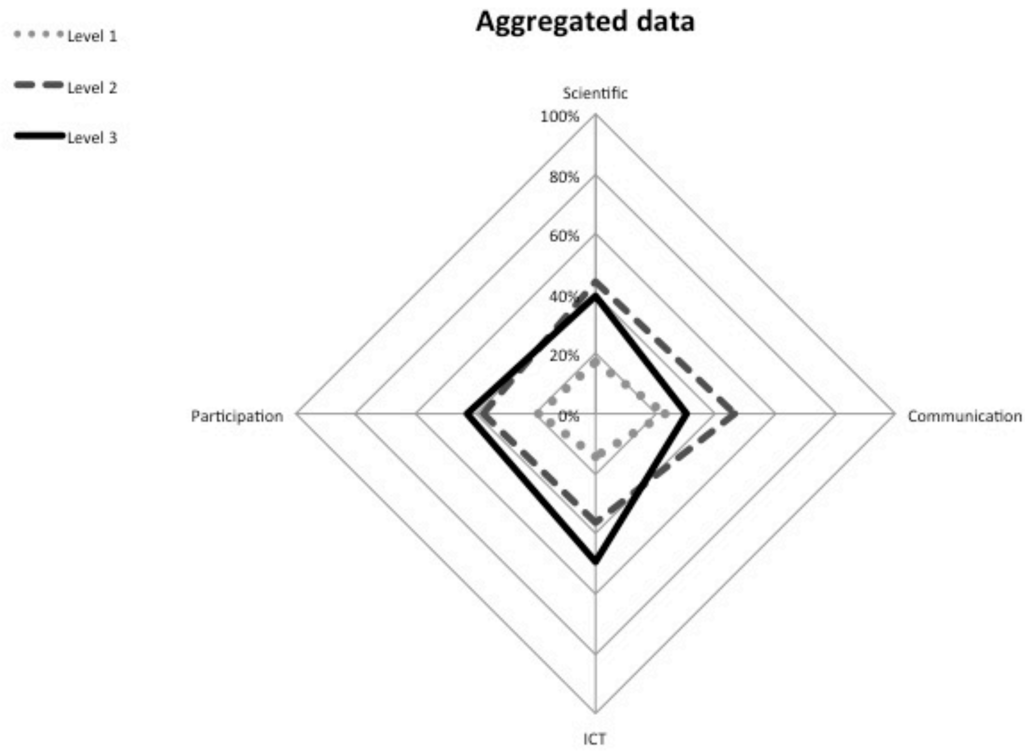

Figure 9.1: Mean scores (sum of all projects) by type of competencies and/or attitudes.

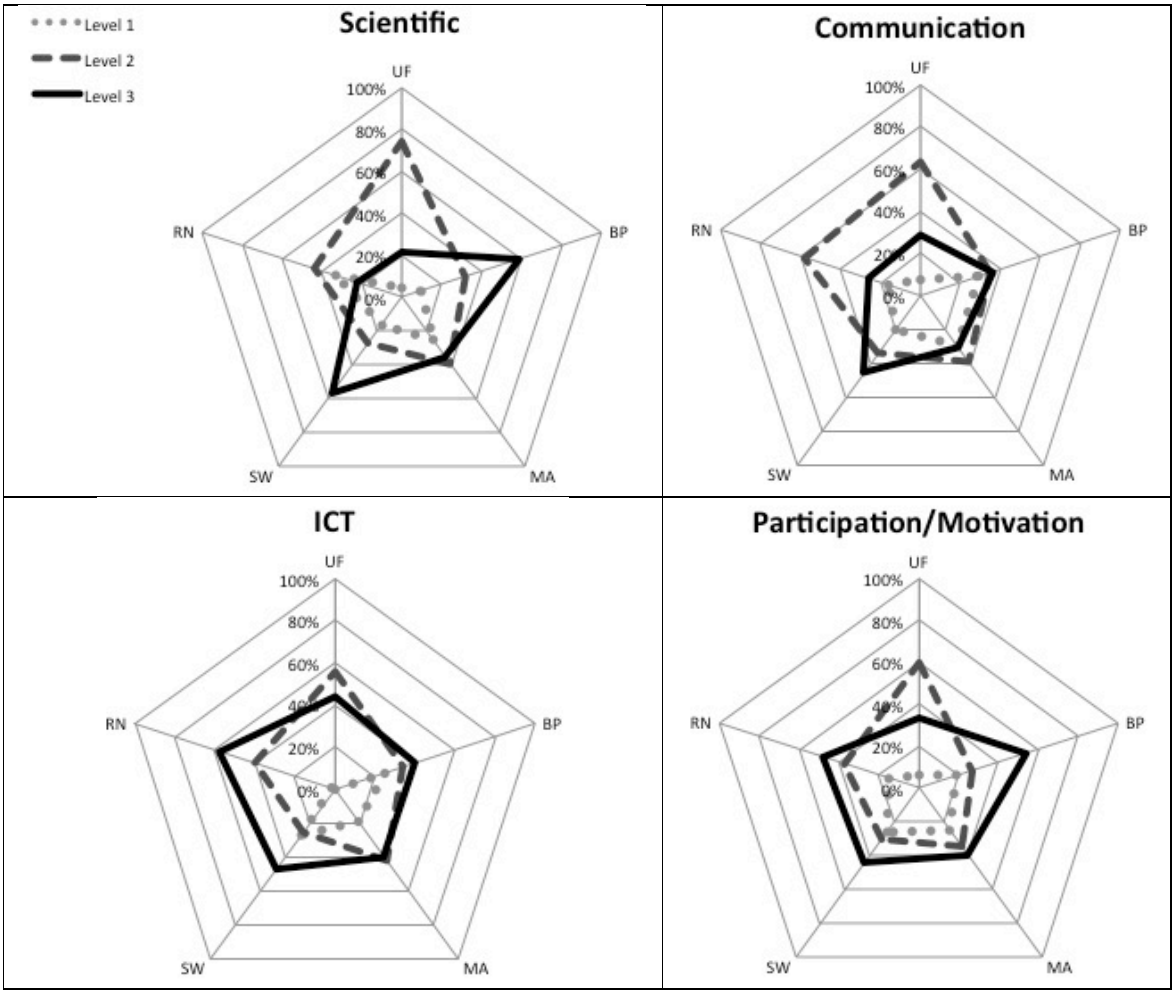

Fig. 9.2: Mean scores by scientific competencies and by CS projects. UF: Urban Flora and Allergies, BP: Bee-Path, MA: Mosquito Alert, SW: Sea Watchers, RN: RIU.net. More details are reported in Tab. 9.3. Number of participants in each project are given caption of Fig. 9.1.

Scientific competencies

The competencies needed for the critical analysis of the reality that surrounds us were divided into seven different subcategories provided in Table 9.2. The weighted level among all class-groups and subcategories is 2.21. It might indeed be stated that 83% of students were able to make a critical analysis of the reality around them and they are able to use scientific methods at a level at least noticeable (summing up levels 2 and 3 in the aggregate of all class-groups) as shown in Tab. 9.3. Moreover, the level of scientific competency has been achieved among all students and 39% of students got the top level in scientific competencies. The standard mean error when averaging all categories fluctuates between 3% and 5% which demonstrates that the categories are robust and provide consistent results among the different items being evaluated.

The averaged results regarding scientific competencies for each CS project are presented in Fig. 9.2 and confirms the outstanding results of *Bee-Path* and *Sea Watchers*, as both projects got an average of Students 3 level of 59% and 57% respectively. *Urban Flora and Allergies* and *Bee-Path* groups also show the larger proportion of students reaching level 2 and 3. Both CS projects might be qualified as *open inquiry* projects and, although the most extreme one shows better results in level 1, it also obtains less homogeneous results among the group as a side effect.

An even more detailed evaluation is presented in Fig. 9.3. The aggregated radar chart highlights that the vast majority of students (91%) acquired in an excellent or very good manner (levels 2 and 3) the competency of analysing results and explaining them in a comprehensive way (subcategory #3, see details in Tab. 9.2). The majority of the students also reached an excellent level (52%) regarding the competencies on how to justify the purpose of the research project (subcategory #3). Besides, some particular projects obtained very high scores for specific competencies. For example, 83% of students involved in *Bee-Path* project reached level 3 of the phases of the scientific project (subcategory #7), meaning that the open inquiry design of the project succeeded in involving the vast majority of students in all research phases. Another interesting result shows that 91% of students of *Sea Watchers* class-groups reached level 3 when evaluating the competencies related to the general aims of the given project (subcategory #1), probably related to the pedagogic efforts of the scientists and the easy to understand purpose of the project when asking to collect and report the presence of plastics on the shore close to their school.

It is also worth mentioning that several schools did not develop the competency of data visualization. This is the case of 2 of the 3 schools participating in *Allergies and Urban Flora* (corresponding to 65 students), 2 of the 2 schools participating in *Mosquito Alert* (123 students), 1 of the 2 schools participating in *Sea Watchers* (30 students), and 1 of the 2 schools participating in *RIU.net* (25 students). We strongly believe that this is an aspect that needs to be included in the rubric model and which has to be improved in the Spanish school curricula given that it is directly related with the difficulties of the Spanish school system to increase ICT competencies (Moreira, 2008).

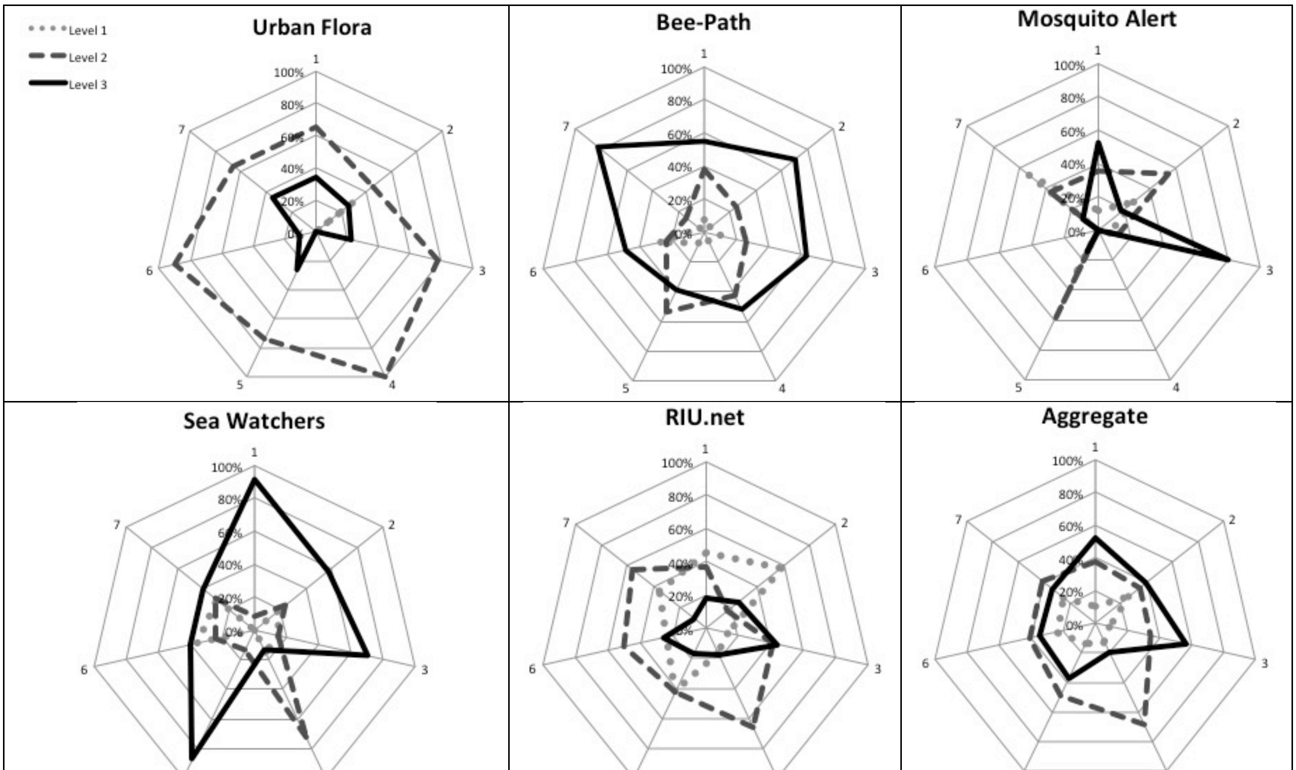

Fig. 9.3: Detailed scientific competencies, for each 5 CS projects and when all projects are aggregated. All subcategories and their numbers are reported in Tab. 9.2.

Communication competencies

Communication competencies are those related with the skills to express ideas and interact orally, written or visually through different channels. We assessed four different subcategories regarding communication competencies which are explicitly described in Tab. 9.2. Several students were not evaluated on some of the categories mostly due to lack of time for completely developing the project as a whole. *Allergies and Urban Flora* schools just considered one category ("Generation of the report" in 2 schools with 136 students, corresponding to subcategory #1; and "Oral presentation" in the third school with 23 students, corresponding to subcategory #3. See Tab. 9.2 for the full description of competencies. One of the three schools with 24 students participating in *Bee-Path* was able to evaluate all four categories; another one with 24 students was unable to work on the "Visual presentation in a final report" (subcategory #3), while the third one with 19 students was only evaluated through the "Generation of a final report" (subcategory #1). In the case of *Mosquito Alert* and *Sea Watchers*, one of the schools was susceptible to be evaluated with all categories while the second one limits the evaluation to the category of "Generation of a final report" (subcategory #1) with respectively 67 and 34 students. Finally, the two school-groups working with *RIU.net* almost respond to all categories (except in the case of "Oral expression" in one of the two schools, subcategory #3 which corresponds to 27 students).

However, we still find the results interesting when they are carefully analysed (see Tab. 9.3). The level established to measure communication achievements were acquired for all students and even 76% of them were able to communicate in different contexts and channels in a good manner (that is: summing up level 2 and 3 and all categories). The aggregate shown in Fig. 9.4 furthermore reveals, that 39% of the kids were able to represent data in an excellent manner (subcategory #4). The level of writing (subcategory #2) was solid in 67% (between level 2 and 3) of students, and the remaining 33% were able to write without misspellings. Error behind the aggregated data from all four categories is again small, between 3% and 5%, thus showing once again the robustness of the rubrics being proposed. As shown in Fig. 9.4, *RIU.net* reaches a good level of communication competencies for each of the four competencies, the number of level 2 students being always in-between 56% and 67%, This could be linked to the important effort by the scientists to explain their projects clearly and their accurate use of several resources. *Sea Watchers* also shows excellent results in generating the final output (subcategory #1) and this can be attributed to their really well focused objective: to raise awareness about the tremendous amount of plastics across the seafronts of the cities of the schools.

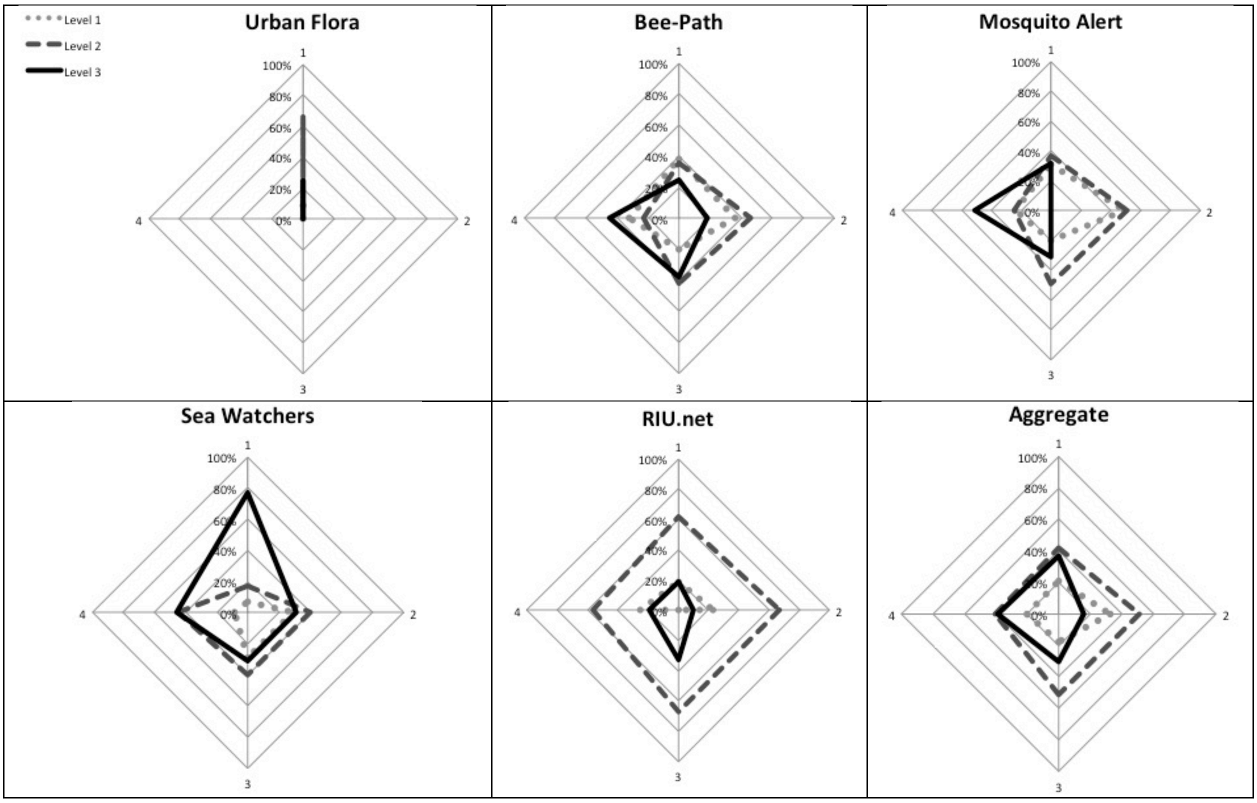

Fig. 9.4: Detailed communication competencies, for each 5 CS projects and when all projects are aggregated. Results of Urban Flora and Allergies that cannot be seen properly for subcategory 1 are: 9% (level 1), 66% (level 2), 25% (level 3). All subcategories and their numbers are reported in Tab. 9.2.

ICT competencies

The Information and Communication Technologies (ICT) competencies are necessary for a safe and critical use of technologies for different purposes as described in Tab. 9.2. All school-groups developed tasks related to these categories with the exception of *Bee-Path* (with 19 students) and *Mosquito Alert* (with 67 students); school-groups which did not include the use of ICT in the final product process during their work in class. The results in these two categories are very similar when averaged among the different school-groups.

Table 9.3 shows that almost all students (85%) achieved the necessary skills for the safe and critical use of ICT for different purposes and that almost the majority of students reached level 3 in relation to data collection (50%) and data presentation (49%). Figure 9.2 also easily shows how this competency is the one that gets better results for the highest level (level 1). Therefore, the results are overall very satisfactory and can be related to the compulsory use of ICT tools in some phases of all CS projects included in the current study. For example, in *Allergies and Urban Flora*, geo-located pictures had to be taken; in *Bee-Path*, an App had to be used, data treatment and data visualization undertaken with sophisticated tools; in *Mosquito Alert* and *RIU.net*, the data collection was done through an App installed on smartphones. If one looks closely at Fig. 9.5, one can see that *RIU.net* gets the best result concerning the use of ICT for the final output/product of the CS (subcategory #2), and this can be clearly attributed to the fact that this project has a very robust App with a very clear protocol which provides an automatic evaluation of the river based on the different questions that the App formulates to participants. However, if one looks closer at the use of ICT for data gathering (subcategory #1), *Mosquito Alert* and *Sea Watchers* get the best scores. Both work in a very easy manner in geo-locating observations.

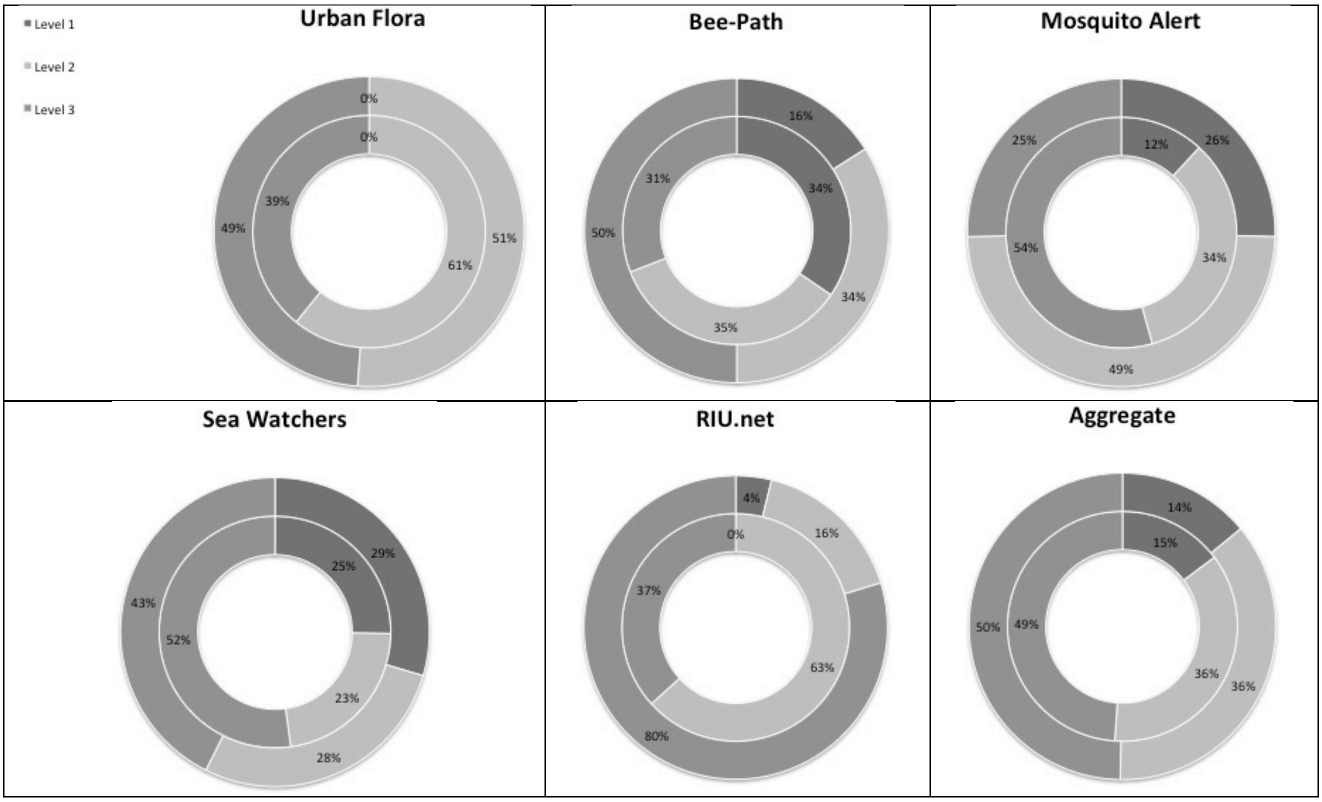

Fig. 9.5: Detailed ICT competencies, for each 5 CS projects and when all projects are aggregated. Inner circle corresponds to subcategory #1 and outer circle to subcategory #2 (see Tab. 9.2).

Participation and motivation attitudes

Attitudes of participation and motivation also reach very high rates in level 3, behind the results obtained for ICT competencies (see Tab. 9.3 and Fig 9.1). 81% of the students appeared as being very motivated and participative (level 2 and level 3) as shown in Tab. 9.3. Errors when averaging over all categories are very small (around 3%) thus showing again that rubrics are also robust when evaluating participative and motivated attitudes. Regarding motivation, collecting data reached the highest rate (48%) jointly with data analysis (51%) as shown in the aggregate radar chart from Fig. 9.6. It is also worth mentioning that 41% and 46% of the students had respectively shown an excellent attitude in the discussion sessions with a high level of participation. The comparison in-between projects provided by Figs. 9.2 and 9.6 shows that *Bee-Path* reached outstanding results with a majority of level 3 students for all competencies. This can be related to the good scores obtained in scientific competencies and with the *open inquiry* design of the pilots, allowing the students to have a high level of freedom during the whole process.

Finally, the categories not been evaluated by all groups are those related to a final reflection (subcategory #7, see again Tab. 9.2) and to discussion when working with results (subcategory #5) but in very few cases. Subcategory #1 evaluation is only absent in the class-groups working with *Allergies and Urban Flora* (with 159 students) while subcategory #5 is only absent in one class-group of *Mosquito Alert* (with 67 students).

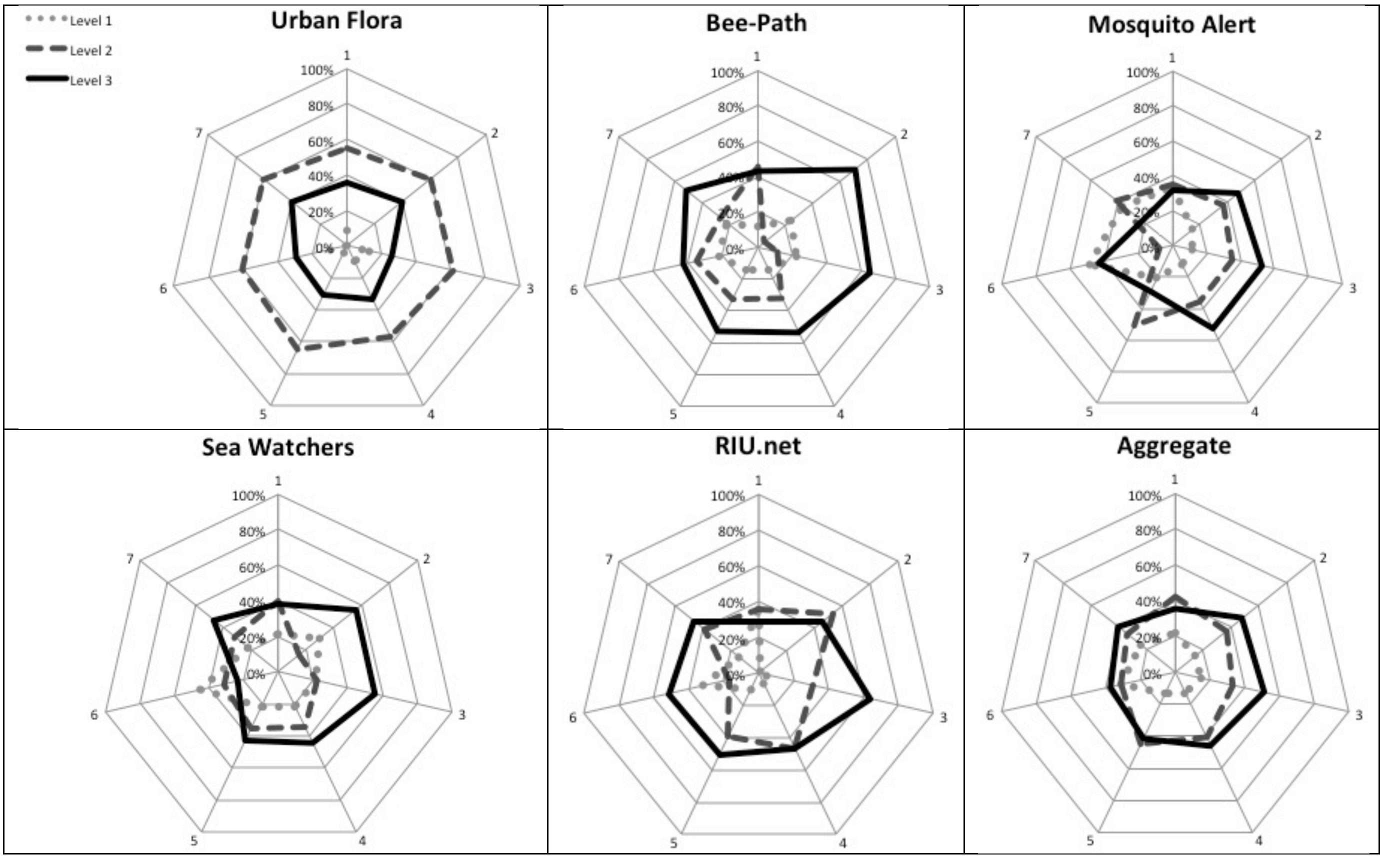

Fig. 9.6: Detailed Participation and Motivation competencies, for each 5 CS projects and aggregated. All subcategories and their numbers are reported in Tab. 9.2

Discussion

Rubrics have allowed us to evaluate in a quantitative manner the very positive impact of the five interdisciplinary CS pilots when introduced to Catalan secondary school classrooms. An identical methodology has been used in the five CS projects to avoid bias and the very positive results obtained can be attributed to the capacity of CS projects to work in a collaborative manner and co-create a real scientific activity within the group-class (Bonney, 2009). Namely, students were considered as central actors of their scientific research, being able to decide or to have an influence on several aspects such as the definition of the research experiment, the protocol used for data collection, the way to report results and the knowledge transfer to the community. Student empowerment acting as citizen scientists (Gray, 2012) and moved by neighbourhood local and shared concerns (Bingeman, 2010; Schon, 2014) was enabled by the methodology design of the pilots. The experience allowed close contact between curious and active students, engaged teachers and fully committed (most of the time junior) scientists with a CS spirit. We firmly believe that all of these factors contributed to the high motivation of the more than 500 students enrolled in the pilots.

We have to especially highlight that 83% of the students achieved a very good level in scientific competencies, and 39% of them even reached the highest level. Best scores in terms of scientific competencies are the explanation of the results (57%) and the understanding of the aim of the research (52%) both in level 3. Based on these results, we can suggest that the introduction of CS in schools has increased the understanding of the purpose of research from a societal perspective. The results obtained for the scientific competencies are very encouraging and clearly proves that the implementation of CS in secondary schools is a powerful strategy to introduce the students to the different aspects of the scientific methods. Students in this way develop cognitive processes that are related to their new ability to think and work as a scientist.

As far as we know, the direct comparison with the evaluation of other CS projects at school is not possible, since this is the first time that rubrics are used for this purpose. One of the closest experiences is probably the one described by Powell *et al*. (2014) that introduced a research experience to 2-year college university students. Their work concluded on the need to mentor students toward a deeper understanding of the complex nature of the scientific process. In our case, this competency was acquired through a “learning by doing” process as the students were directly embedded within the research projects, in that they were independent actors able to take their own decisions in the framework provided by the CS projects.

When we look at the *Communication* competencies, we can highlight that the advantages of the introduction of the CS project in secondary schools overtakes the direct benefits in STEM disciplines and has an additional positive impact in other disciplines where writing, reporting, arguing opinions or exposing are key competencies. We advocate a multidisciplinary approach regarding the introduction of CS at schools. Some of these projects had many different perspectives and could be introduced through visual arts, social science or humanities disciplines as it has been the case in one of the schools working with *Bee-Path* and *Sea Watchers*. Results thus encourage working on CS projects in a multidimensional way as a transversal project that can be explored starting from several subjects of the school curricula.

Together with the very good results on scientific competencies acquisition, we shall also highlight *Participation and Motivation* attitudes since 43% of the students reached the highest level. Those values are very high in comparison to ordinary activities performed in class as highlighted by teachers in the online questionnaires provided after the experience. Seventeen teachers answered the survey where 63% of teachers considered CS projects to be useful as "traditional" activities while over 30% considered them even more than useful. All of them considered that the activity has had a positive impact on students; a 94% rating points to the fact that students have been fully engaged and 71% stated that students were highly motivated. We therefore consider that the high level of attitudes towards motivation and participation is one of the two most striking results of the current study. It contradicts the classical perception that European students are not motivated regarding STEM disciplines (Sjøberg, 2010), however, it is in agreement with previous studies that, using CS as part of regular classroom activities, that an increase in student motivation and a positive impact in their attitudes towards science is observed (Silva, 2016; Vitone, 2016).

The origin of this excellent result concerning participation is probably multi-causal but one can hypothesize that, by participating in CS projects, the students are naturally “forced” to go outside of their comfort zone and act as young activists related to scientific citizenship positioning (Ellan, 2003) and regarding issues affecting their close neighbourhood. In this way, the empowerment of the students is almost immediate as they have the ability to decide from the very early steps in the research project and their participation and motivation is then strongly increased. The close contact with scientists, the perception of their ability to solve important issues for the community and their empowerment as true owners and disseminators of the projects surely do play a key role too.

In this way, we fully support the conclusions made by Gray *et al.* (2012) claiming that creating a dialog with experts and fostering the ability of the public to critique information and evidence are successful factors to be taken into account in order to introduce CS in schools. Our approach and results support this view: an open-minded co-design of the educational activity between teachers, researchers and students led to an increase of intrinsic motivation, the first stone of meaningful learning, as described by Omrod (2014). Once again, the benefits of the CS projects have a wider impact than the STEM disciplines, since an increase of motivation is beneficial for student learning as a whole. Motivation positively affects cognitive processes, leads to increase effort and energy, strengthens persistence in challenges or problem solving activities and enhances performance.

These very good results in *Participation and Motivation* attitudes are especially remarkable in *open inquiry* projects such as *Bee-Path* which contrast with other projects as *RIU.net*, *Mosquito Alert* or *Sea-Watchers* which by following a *guided-inquiry* process get however the best results concerning the use of ICT. This can be clearly attributed to the fact that these CS projects have a robust and easy-to-follow protocol in data gathering or evaluation thanks to the use of user-friendly Apps or web-based digital interfaces.

Conclusions

A rubric model to assess the introduction of CS to secondary schools has been designed and applied to a diverse set of CS projects for secondary schools and formal education using a common strategy. The four types of competencies included were *Scientific*, *Communication*, *ICT* competencies and *Participation and Motivation* attitudes. The rubrics have shown to be easy-to-follow and robust methodology when implemented and tested by 11 secondary schools and with 547 students. We believe that the rubrics proposed are complete and general enough to be valid to evaluate the impact of any CS project.

The strategy to provide a multifaceted experience to students and teachers, not exclusively focused on any specific STEM subject, has been proved to be successful. By asking for a very complete cognitive and organizational effort, students not only acquired very good but also excellent *Scientific* competencies. Thinking and acting as researchers also improved their *Communication* and *ICT* competencies and some of the teachers have also included Humanities and Arts classes into the pilots to enhance reflection and creativity. Despite the fact that all the projects' implementation proved to be successful, some differences were observed in-between the projects, tending to show that the *open inquiry* design facilitates a better acquisition of the different competencies and attitudes,

Based on the results obtained, we advocate the use of rubrics for CS project evaluation, allowing for a multidimensional perspective. We also strongly encourage the aggregation of CS projects and their approach to schools in a coherent manner, for an even more successful introduction of CS in secondary schools. In this way, efforts made on the methodological and organizational aspects would become sustainable and shared by several CS projects. Moreover, a larger number of secondary schools can be involved while reinforcing schools' own interests and special features. By pursuing a context-based learning and moving research to students' everyday life, schools will be able to produce real research and even contribute to reinforce the connections among CS projects, citizenship and democracy within the frame of the so-called *action research* (Stringer, 2013; Mills, 2000). While looking for an impact on local communities close to each of the schools, not only does it increase student motivation and competencies in STEM formal education but it also favours innovation in it. We therefore hope that this contribution enriches the toolbox of those who which to encourage participation and collaboration which can drive social changes and help to face major societal challenges by situating formal education inquiry learning at its core.

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