Technology in Society 75 (2023) 102404

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

Remote experiments for STEM education and engagement in rural schools: The case of project R3

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ARTICLE INFO

Keywords:
STEM education
Rural education
Rural schools
Remote experimentation

ABSTRACT

Rural schools tend not to have enough laboratory and experimentation equipment, which can be an obstacle that hinders student learning in Science, Technology, Engineering, and Mathematics (STEM) areas. Moreover, this loss of competencies can reduce their employment opportunities while society itself is deprived of that human capital. Remote laboratories have emerged as a way of countering the effects of insufficient investment in equipment or the inability to acquire the latter. By way of example, the goal of Project R3, which is presented in this article, is to reduce the absence or shortage of laboratories in the rural world via the use of remote experimentation. Specifically, this article presents the experience, the results, and the main conclusions of Project R3 during its first year of life. It is worth noting that Project R3 has been deployed not only in rural but also in urban environments, making it possible to compare learning results and satisfaction levels for students in both spheres and identify those experiments that provide the best learning experience and are most popular among pupils and teachers. The main objective is that from the local analysis (the Project has only been conducted in Spain) it might be possible to draw conclusions of a global nature that might be extrapolated to other countries in the European Union with similar socio-demographics. Initial results are in the direction of certifying that student achievement and satisfaction are higher in rural than in urban environments.

1. Introduction

Promoting Science, Technology, Engineering and Mathematics (STEM) disciplines among students is a fundamental task that is addressed from very diverse perspectives: via communication, via education, via technology [1]; etc. It is considered necessary, or at least interesting, for children to be attracted by these knowledge areas, since they will (and do) include work of quality, and this activity will also be one of the pillars of future societies [2]. The report suggests that from an initial analysis, one can conclude that scientific vocations are formed at an early age, have a major impact upon the rural world and largely depend upon educational programmes and the teaching staff.

Although interest in STEM was previously believed to develop in pupils during secondary education, a number of studies show that this vocation actually develops earlier, i.e., when pupils are still at primary school [3]. According to Ref. [4] before the age of 14, the pupil's vision of STEM, whether positive or negative, is already shaped. Which is why there are different projects that connect primary education with STEM, such as European SchoolNet's "Integrated STEM Teaching for Primary Schools"[1] or Project R3, presented in this article. To the question, "How can we stimulate a scientific mind?" [5] the literature offers different answers, such as that offered by Ref. [6]: "*Most teachers agree that primary school pupils enjoy learning science, yet many studies have shown that by the age of 10, interest in science begins to wane, and this becomes much more evident when pupils move on to secondary school. It is therefore imperative to foster scientific vocations in early childhood*". However, the results of some studies appear to suggest that this decline might be avoidable (Dewitt et al., 2013) by means of specific interventions and resources in the classroom.

Meanwhile, in Spain, as in other European countries such as Finland

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[1] https://www.europeanschoolnetacademy.eu/courses/course-v1:STEAM_IT+IntegrSTEM_Primary+2020/about.

https://doi.org/10.1016/j.techsoc.2023.102404
Received 11 February 2023; Received in revised form 13 October 2023; Accepted 15 October 2023
Available online 25 October 2023

or Estonia (see Fig. 1), the problem of depopulation and isolation in rural strongholds is increasingly evident. Focusing on Spain, where 6 % of students are outside urban areas, rural zones, also known as “Empty or emptied Spain”,[2] have a very low density of population, which means that there are not enough rural schools and that their low budgets results in them having insufficient experimentation equipment and information and communication technology [7]. According to Ref. [8]; “*Principals in urban schools tended to report better resources for the science department than principals in rural schools*”. This situation is being reversed in Spain by means of the rural development projects aligned with the Sustainable Development Goals (SDG), specifically with number four,[3] with the creation of more rural schools suitably equipped with teachers and Information Technology (IT) resources with a view to maintaining the current population and recovering, as far as possible, the lost population. However, this is a lengthy process and short-term actions are required for today’s pupils.

Paradoxically to the aforementioned situation of need is added the fact that students in rural settings evidence superior digital and scientific competences to those of students elsewhere. In other words, they are better able to take advantage of the digital tools available to them than their peers in urban areas (see Fig. 2). A more detailed description of the situation can be found in the 2019 PISA Report [9] which studies academic performance in rural zones. This report states that “rural schools in Spain, Estonia, Finland and Lithuania can offer their students more added value than urban schools” [10]. Or, to quote a headline in the La Voz de Asturias newspaper in December 2018: “Rural pupils overtake their urban counterparts” [11] in reference to the analysis performed by the Principality of Asturias in 2018, which concludes that in Asturias, an autonomous community of Spain, “Rural pupils tend to compensate with their performance the differences of resources with regards to the urban counterpart” [12]. In similar vein [13], affirm that “rural schools in Spain obtain good academic results, even better than in urban areas”. Thus, returning to the PISA Report [9]; “some of the characteristics of rural education, such as their low student-teacher ratios, the abundance of social capital and the emergence of new technologies, open real opportunities for rural schools.”. It is the use of new technologies that forms the backbone of Project R3.

Finally [14], studies “Why young Spaniards reject the study of science and technology”. In response to this question, pupils point to “the limited offer of subjects related to technology, and their teachers’ insufficient training in these areas”. In its conclusions, the report proposes two measures: 1) Bringing technology closer to students through education; and 2) Training teachers in the STEM field.

On the basis of all these premises (engagement from primary education, rural environment and training teachers in STEM culture), Project R3 addresses this challenge by means of remote experimentation. Remote experimentation turned 27 in 2023 [15] and is an established technology [16]. With this technology, a student connects to a remote experiment via a web interface and performs experiments or activities that are real, not simulated or virtual, as a remote experiment is a real experiment conducted via the Internet, i.e. the experience is real, even if the student is not using laboratory equipment. In the words of Spanish researcher Jesús del Álamo from Massachusetts Institute of Technology (MIT): “If you do not come to the lab, the lab will come to you” or employing the slogan coined by American pioneer in remote experimentation Carisa Bohus: “Second Best to Being There” [17]. For instance, the student moves and observes a real pendulum to learn the laws of its movement, or observes the behaviour of a planarian in different beverages but these experiments which are in front of the pupil are in fact located in Spain, Costa Rica, USA., Brazil or South Africa. In essence, the student accesses them via the Internet and the experiments run physically in their remote locations. Remote experimentation is an open door to the democratisation of access to science and technology for all, in such a way that rural schools can clearly benefit from this technology, since they usually have good IT equipment and connection to the Internet, in Spain at least.[4]

By way of summary, the aforementioned situation presents a shortage of scientific infrastructure in Spanish rural schools that may affect these students’ STEM vocations when they have sufficient. Therefore, Project R3 addresses some research questions listed below that seek to support and reinforce previous findings in the field of digital competences in the rural world [18]; but in this case, with remote laboratories. (i) Is it appropriate to use remote experimentation as a vehicle to promote STEM and provide scientific-technological training?; (ii) Does the use of remote experimentation have a positive and satisfactory effect upon student learning?; and (iii) Does the use of remote experimentation have better effects upon students in rural than in urban areas?; Moreover, this article seeks to examine and figure out the directions of the following two research question: (i) What is the driving force of teachers upon the exploitation of tools provided to improve STEM competences? (ii) Is it possible to draw conclusions applicable in other countries or similar situations or in marginalised collectives?

The article is structured as follows: the next section offers an overview of the most relevant projects and programs on training in STEM skills in the rural world. Chapter three presents the project and its relationship to remote laboratories with the LabsLand company. Chapter four presents the statistical side of the project, underpinning the results presented. Chapter five discusses the results, and the final chapter returns to the essence of the research and provides hints for its future extension.

2. Background

The problem already commented upon in the previous section has been addressed by different teachers and research groups in reviewed literature. Most of the results are to be found in the USA, where the NSF (National Science Foundation) finances different projects. The EDC (Education Development Center) Project[5] in the USA addresses the problem of teaching STEM disciplines in rural areas with poor internet quality during the pandemic. The NebraskaSTEM Project[6] aims to train teachers who can help rural teachers successfully to employ STEM teaching. In Tennessee, the TSIN (Tennessee STEM Innovation Network) initiative[7] organizes an annual professional development program for teachers throughout Tennessee with a view to ensuring that rural students have access to high quality STEM learning opportunities, exposing them to 21st-Century Skills and local professional careers in STEM. In Arkansas, there is a project to improve STEM teaching in rural schools that focuses on DIY (Do It Yourself) and on the use of buses with different experiments that travel around the State.[8] In more systematic fashion, (Harris, 2018) studies the STEM problem in rural schools in the USA and reaches the conclusion that there is a need to analyse the results of STEM training in the rural world in a more specific way.

In Europe, the ERASMUS + KA2 Rural School Cloud Project[9]

[2] https://www.ine.es/dynInfo/Infografia/Territoriales/index.html.

[3] https://www.un.org/sustainabledevelopment/.

[4] According to data available from the Ministry of Economic Affairs and Digital Transformation, fibre optic coverage in Spain at speeds of over 100Mbps already reaches 88 % of the population of our country, although the deployment of this connection is uneven depending on the Autonomous Communities. On the other hand, it is known that 95 % of the population has access to an internet connection of at least 30Mbps, a percentage that drops to 88 % when talking about 100Mbps.

[5] https://www.edc.org/rural-stem.

[6] https://research.unl.edu/blog/stem-project-to-benefit-rural-elementary-schools/.

[7] https://www.tsin.org/.

[8] https://www.edweek.org/leaders/2022/a-diy-approach-to-boost-stem-engagement-in-rural-schools.

[9] https://e-learning.cesga.es/rsc/about-the-project/.

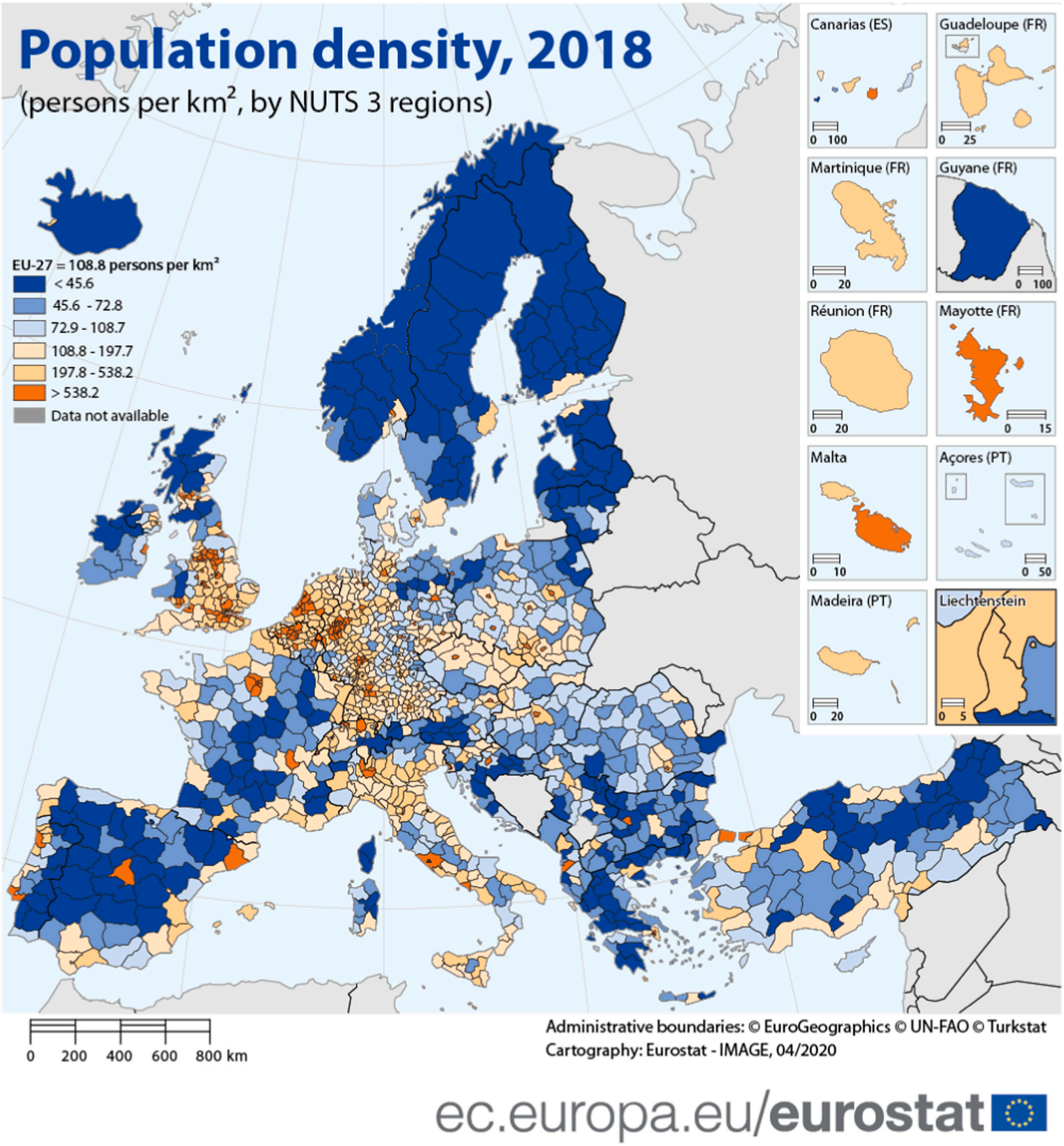

Fig. 1. Population distribution in Europe in 2018 [source: Eurostat].

approaches this problem from the perspective of TICs, and its main goal was to train teachers and administrative staff in the correct use of different digital teaching/learning tools. In addition, it should be noted that European SchoolNet[10] is particularly interested in the development of the STEM discipline in rural areas. Similarly, the Education Development Center (EDC) advocates rural education and the promotion of STEM in its development programs, with special emphasis in the wake of the COVID-19 pandemic[11] as some scholars emphasise the digital divide it produced in some educational centres [19]. In this sense, the long-term lockdown particularly affected certain sectors of the population, such as young girls in marginalised communities, the Romany population, displaced people, the disabled and inhabitants of rural

[10] http://www.eun.org/.

[11] https://www.edc.org/rural-stem.

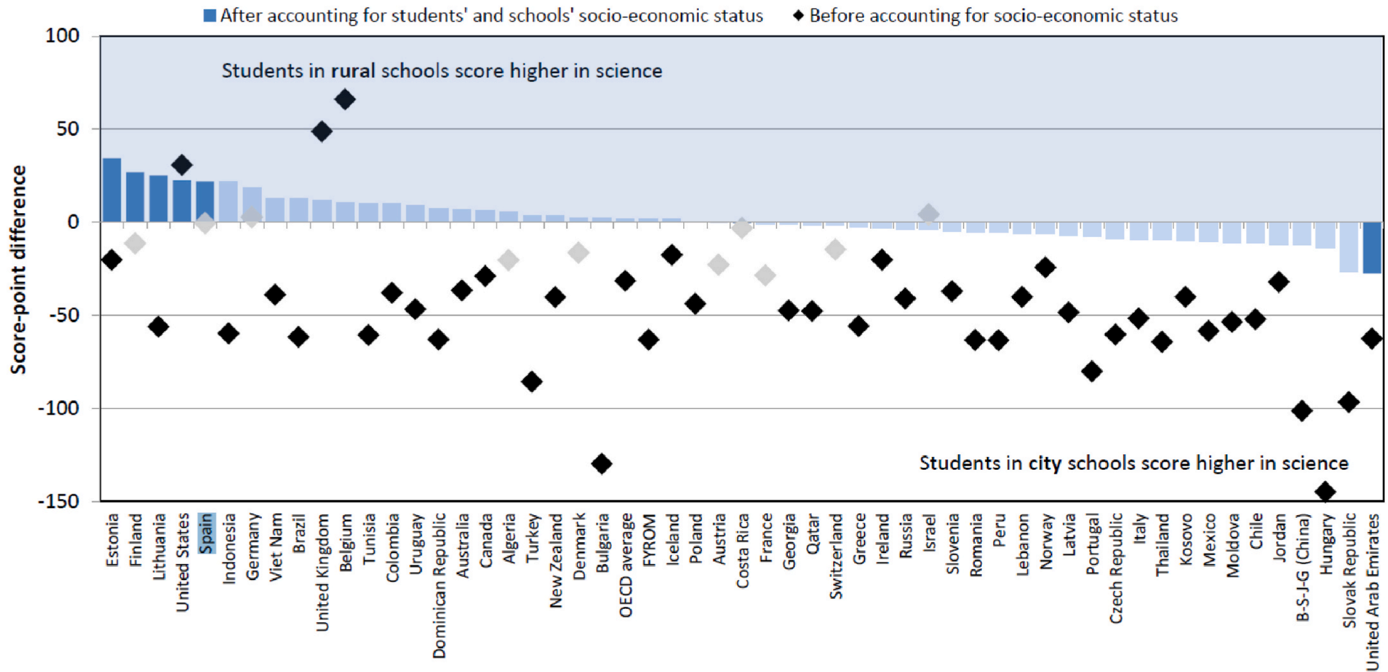

Fig. 2. The Rural-Urban gap in science performance (Echezarra and Radinger, 2019).

areas. In short, according to UNICEF [20] these groups of people suffered from a higher education dropout rate.

All the aforementioned projects approach STEM vocations in the rural world in global or holistic fashion, and the focus on rural schooling or the rural world via programs financed by public and/or private entities. Project R3, meanwhile, aims towards offering direct support to interested teachers by means of specific scientific activities and experiments. Thus, the results are more easily measurable and deployable with other teachers in the same sphere or a similar situation. As far as the authors are aware, no projects specifically address experimentation in the world of rural schooling via remote experimentation relying on the teacher's intervention as the learning facilitator in the classroom. The authors of this manuscript believe the conclusions obtained by the Project R3 in Spain will be applicable to other countries or regions with similar conditions.

2.1. Remote labs: LabsLand

Before describing Project R3 in detail and its results throughout the first year of application, it is appropriate to explain what a remote laboratory is, how it is provided via LabsLand[12] and which experiments were performed in Project R3, and to provide a brief description of what is offered by each experiment.

LabsLand is a spin-off of a Spanish University and is currently the only company in the world that offers access to remote experiments as a service [21,22]. LabsLand designs and deploys remote laboratories, but overall, seeks to offer remote experiments already designed by other universities and research centres to offer them via its network. Its ideal spin-off is to be a marketplace that offers teachers and students access to high-quality remote experiments, both didactically and in terms of quality of service: waiting time, malfunctions or outages, access problems, etc. At the moment, LabsLand offers more than 50 remote experiments provided by 17 countries on every continent. **Annex 1** of this article lists a set of remote laboratories that were used in Project R3, such as the planarian, the pendulum, robot with Arduino, freefall or Archimedes' Principle.

2.2. Characteristics of a remote experiment

The main advantages and disadvantages of a remote laboratory, and the characteristics of the latter, are presented next. The main advantage is that teachers and students can access the experiment at any time without restrictions; furthermore, the status and maintenance of the experiment are not the teacher's responsibility, but LabsLand's. From the economic point of view, its use is not only free in Project R3 (and very inexpensive in others), but is also sustainable, as the same experiment is shared by various schools without problems of scalability or latency. Didactically, the main advantage is that teachers and students can learn to experiment focusing less on the set-up of the experiment or hardware and more on the experiment itself and/or on the scientific method. Moreover, as the experiment is the same, different teachers can share experiences and materials with other colleagues. For a primary school teacher, it is very important to foster the sense of security in the development and conclusions of an experiment, since this may not be a comfortable situation for them owing to unfamiliarity with the laboratory material or the result of the experiment. The main disadvantage is the fact that to access and control a remote experiment one needs a stable and good quality internet connection. Another, minor, disadvantage, is the sensation of immersion or reality that the remote experiment produces in students, as this conditions the degree to which they benefit from it: the greater the immersion, the greater the learning [23].

With regard to the characteristics, a professional remote experiment such as those of LabsLand can be accessed from any device (laptop, PC, tablet, smartphone …) with any kind of operating system or browser and without compromising the school's network security. Thus, accessibility, universality and security are guaranteed for any student, teacher or centre. As important as accessibility is knowing the didactic value of the remote experimentation, and a question arises: does the use of remote experimentation have a positive effect on the student's learning? The answer given by various researchers is affirmative. To this end [24], and Ma and Nickerson) (2006) published meta-studies in which they reviewed hundreds of published works and arrived at the conclusion that remote experimentation had a positive effect on learning, the same conclusion reached by Jong et al. (2013) in relation to online laboratories. Similarly [25], conclude that, for the remote analogue electronics

[12] www.labsland.com.

VISIR experiment, the Cohen's effect size for learning results is 1, i.e., a high effect size close to that attributed to feedback or to the effect of the teacher.

3. The case of R3 project: Methodology

Project R3 was initially intended for rural schools at every level. In fact, the original objective was to deploy remote experiments in 20 rural areas. However, the COVID-19 pandemic had a two-fold impact upon the Project. On the one hand, many schools had to tackle different organisation problems that left many rural teachers without time or energy. On the other hand, many teachers from different latitudes (rural and urban) expressed an interest in online tools that would enable them to improve their teaching. While both impacts seem to be controversial, they were both helpful for the Project as it will be shown in this Section.

Some centres argued that, although they were neither rural nor affected by the problems intrinsic to a rural school, they did have other kinds of problems (uneven educational level and motivation and student adaptation to the new post-COVID circumstances) and believed that Project R3 would help them. R3 took advantage of this situation to widen the project's participants diversity, which in turn contributed to better analysis of the results. For example, it made possible to study the differences between rural and urban schools, something not initially contemplated when the Project was conceived.

The following sections provide a description of the research methodology employed to respond to the main research questions posed in the introduction.

3.1. Project advertisement and recruitment

First, the R3 project was disseminated in different areas (social networks, specialised websites, twitter, institutions …), attracting about 200 teachers. These 200 teachers were invited to an online session explaining the project, 60 teachers expressed their interest in the project, so they were followed up with a special session about the project. The special session consisted of a hands-on workshop where the teachers were introduced to the remote laboratories. After the workshop, 40 teachers maintained the interest and 32 from 26 schools out the remaining sample created teaching materials associated to the labs. Table 1 shows the distribution of the 26 schools involved in Project R3 thanks to the activities of 32 teachers who wanted to participate in the initiative. Of these 26 schools, 13 were rural (9 primary schools and 4 secondary schools) and 13 were urban (1 primary school and 12 secondary schools). Of the 32 teachers, 16 were from rural schools and 16 from urban ones. And of the 621 students involved, 325 were rural and 296 urban. In Project R3, during the academic year 2021–2022, the schools involved belonged to the Basque Country, Aragón, Asturias, the Valencian Community and Castilla la Mancha, all of them Provinces of Spain.[13]

Table 1
Distribution of schools that participated in Project R3

	Rural Primary Schools	Urban Primary Schools	Rural Secondary Schools	Urban Secondary Schools	Total
Schools	9	1	4	12	**26**
Teachers	12	2	4	14	**32**
Students	136	19	189	277	**621**

[13] https://academickids.com/encyclopedia/index.php/Provinces_of_Spain.

3.2. Teachers' training

Once a teacher joins Project R3 and, before using remote experiments in the classroom, they must participate in some online training consisting in three 2-h modules:

Remote experimentation module: In this module, the teacher learns what a remote laboratory is and its main advantages and characteristics. The main objective of this module is for the teacher to understand which tool they are going to use and its technical and conceptual basis.

Remote experimentation module and scientific method: In this module, the teacher learns how to use different remote experiments with a scientific approach. This module is particularly important for primary teachers, as in general they tend not to have extensive training in science and technology. The main goal of this module is for the teacher to choose which remote experiment they are going to use in class with their students and how to do so from a methodological and pedagogical point of view.

Module of deployment of the remote experiment in the classroom: In this module, the teacher learns how to deploy the experiment in the classroom using the LabsLand platform and a Learning Management System (LMS), for instance, with Google Classroom, Moodle, Sakai, etc. The objective of this module is for the teacher to provide students with access to the remote experiment and observe how they use it.

Upon conclusion of the training, teachers evaluate its quality and satisfaction using the instrument provided in **Annex 2** of this article.

3.3. Evaluation plan

Project R3 has been evaluated from different angles, as is indicated in the results section that follows. On the one hand, Labsland provided to the Project managers the amount of use made of its laboratories per school and per experiment. This information was used to measure successful use of the R3 experiencer. Meanwhile, teacher satisfaction with the training received (see **Annex 2**) and with Project R3 as a whole (see **Annex 3**) were also evaluated. Both questionnaires are designed as unidimensional and include a final open question which is not considered in the analyses. Teacher training satisfaction questionnaire includes seven questions to be answered in a five-point scale, from 1 (bad) to 5 (excellent). Teacher global satisfaction questionnaire has 14 five-point-scale questions; questions 1 to 5 are satisfaction scales, from 1 (very unsatisfied) to 5 (very satisfied), while questions 6 to 14 are five-point Likert scales, from 1 (I totally disagree) to 5 (I totally agree). These are combined to compute the satisfaction score.

Similarly, students also completed a questionnaire measuring satisfaction with the R3 Project (see **Annex 4**). This satisfaction was measured via adaptation of the UX4RL questionnaire [26] for primary and secondary students. It includes nine five-point Likert scales and an open which is not included in the analyses. It is considered unidimensional although the original UX4RL questionnaire has three scales (usability, utility, and immersion).

Satisfaction questionnaires are analysed for reliability using the Cronbach's alpha coefficient. Results are presented as per-question stacked centered bar plots. An estimator of each satisfaction measure is presented by the mean scaled as a percentage; its error estimate is also calculated and presented. For the student satisfaction data, results are compared between experiments and type of schools both graphical and using appropriate statistical tests (ANOVA and Wilcoxon-Mann-Whitney).

Finally, there was an analysis of knowledge prior and subsequent to experiments conducted in the remote laboratories (**Annex 5** include the questionnaires for the "Freefall" and "Pendulum" experiments). These questionnaires are designed to be brief and easy to respond to. They have four and three true-false prompts respectively. Grade is taken as the ratio of correct responses without correcting for chance. For the "Pendulum" experiment, because data are not paired, learning, difference between pretest and post-test, is checked with a Wilcoxon-Mann-Whitney test. Results are visualized on a box plot. For the “Free-fall” experiment, pretest and post-test are paired. A paired Wilcoxon-Mann-Whitney test and a Sankey diagram are used to assess students learning.

In Fig. 3 the overall process for involving teachers and students as well as the evaluation metrics is summarized.

4. Results

4.1. Use of laboratories

As commented above, Labsland provided the number of access to the different materials and remote laboratories. In total, 19 Project R3’s remote laboratories have been accessed on 7187 occasions. Of these, 5714 were in rural and 1473 in urban centres. This difference is due to the fact that, depending on the type of experiment, the number of accesses changes considerably, irrespective of the topic. For example, one access to the pendulum experiment may suffice to establish a competency in physics, but a robot requires dozens of accesses until the student acquires a degree of skill and attains competency in computational thinking. Regarding the use of remote experiments, Project R3 offered over 50, via LabsLand, although several of these were particular to the university environment and therefore of limited use for R3 teachers, therefore only 19 were used (please, note that there is a list of the most commonly used R3 experiments in **Annex 1**).

As is shown in Table 2, the two most used were the planarian experiment (an experiment with a type of worm [27] in eight schools, seven of them rural (6 Primary and 1 Secondary School), the same as the robotic experiment, which was also used by seven rural schools (4 Primary and 3 Secondary Schools). The freefall experiment was used by 7 schools, six of them urban (all of them Secondary school) and one rural. Seven centres also used the buoyancy experiment, 5 rural schools and two secondary schools (one rural and one urban). In short, each teacher selected one or several experiments for their students according to the subject syllabus or the teacher’s preferences.

4.2. Satisfaction

4.2.1. Training

As explained in the previous Section, participating teachers received training in the use of remote laboratories. This training was evaluated in the questionnaire provided in **Annex 2**. AS it can be observed in the Annex, the questionnaire was made up of 7 close questions with a Cronbach’s Alpha reliability coefficient of [0.89; 0.97] (confidence interval for a level of 95 %). The global satisfaction with the training of all the teachers (N = 28) was measured through the evaluation of Q7 (“Global satisfaction with R3 training as a whole”) with an 81.5 % of respondents scoring positively with a typical error of 3.4 %. Fig. 4 shows the answers to the seven questions on the questionnaire that measure satisfaction with the training received on ordinal scales of one (bad) to five (excellent). These confirm that teachers were very satisfied with the training received, as in almost all the items, 80 % of teachers express a positive opinion.

4.2.2. Project R3

Satisfaction with the Project as a whole was evaluated via questionnaires directed at students and staff, as noted in the previous section.

4.2.2.1. Teachers. Teacher satisfaction was evaluated by means of 14 closed questions and one open question in the questionnaire evaluating the classroom experience (**Annex 3**). These 14 questions are divided into two blocks: the first five questions correspond to a satisfaction scale of 5 points (from one, very unsatisfied/to five very satisfied), and the remaining five to a five-point Likert scale (where one represents total disagreement and five, total agreement).

The responses given by the teachers who answered (N = 24) are summarized in Fig. 5, where one can see that their answers are positive in the majority of the aspects of the questionnaire for over 70 % of participants. On the understanding that these questions are a single scale of satisfaction, for a level of confidence of 95 %, Cronbach’s alpha reliability is [0.84, 0.95]. In short, global teacher satisfaction was 83.1 % with a standard error of 3.1 %. The questions that, at a glance, prompted a less satisfactory answer, were “Suitability of the experiments for classroom level” (Q2) and “I would like to participate in the next edition of the Project” (Q10).

4.2.2.2. Students. The results obtained from students (N = 687 valid answers) are shown in Fig. 6. It can be observed that for all the nine questions in a Likert scale, being 1 total disagreement and 5 total agreement (see **Annex 4**), students have a positive opinion in more than 60 % of the responses obtained. The two items with a slightly higher rating are “The remote experiment is real” (Q2) and “I have focused on the tasks” (Q4); both questions address student immersion in the experiment and the sturdy is positive, which consolidates the use of the remote experimentation in Project R3 according to Ref. [23]. Taking the questionnaire as a single satisfaction scale, Cronbach’s Alpha is [0.89; 0.91] (confidence interval for a level of 95 %). Thus, the satisfaction is 72.0 % with a standard error of 0.9 %. The questions with lowest satisfaction rate were: “I used the computer (interface) almost without help, it is very intuitive” (Q5) and “I would like to use a remote laboratory again” (Q7).

According to observations made after data analysis in the implementation of remote experiments in one of the schools, one particularly discordant school was detected. This will be referred to henceforth as School Z. Here, one senses that the satisfaction and conduct of the participants was different from the norm in other participating schools. For this reason, the satisfaction levels of students at school Z have been represented separately (Fig. 7) from the other schools (Fig. 8). This difference is statistically confirmed via a Wilcoxon-Mann-Whitney test (statistical value p inferior to 0.001). It is important to note that the number of students at school Z is not negligible, since it represents half of the sample (349/687). The observed differences between school Z and the rest of the schools are associated with some already-known issues that affected how remote laboratories were presented and used in this specific school. The teacher in this school was the only one who did not complete the training among the 40 teachers who volunteered to participate (which is the cornerstone of the R3 Project); (s)he also decided to use more experiments than recommended (four when commonly teachers decided to only use one or two experiments, which was the organizers’ suggestion). Thus, the students had a more confusing experience and had to answer many more questionnaires than the rest of the participants. A lower satisfaction level in this school (but still passable) is not totally surprising, though. In essence, School Z not only stood out for its high activity and the number of completed questionnaires but also for the low level of experience with the labs, which undoubtedly conditioned the overall satisfaction and performance of the students. In view of these results and the way experiments were used in school Z, the following analyses, which were all about understanding which were the experiments that provided higher student satisfaction and performance, excluded school Z data as they can skew the overall results.

The above figures provide with a generic idea of the general evaluation of the Project. However, given the diversity of remote laboratories, the existence of different levels of student satisfaction according to the remote laboratory used was analysed. To perform this analysis, satisfaction data was excluded in the case of unidentified schools (on occasions questionnaires from schools that did not include their name were received) and the above-mentioned school Z. Moreover, for this analysis the inclusion criteria was to consider only laboratories with at least

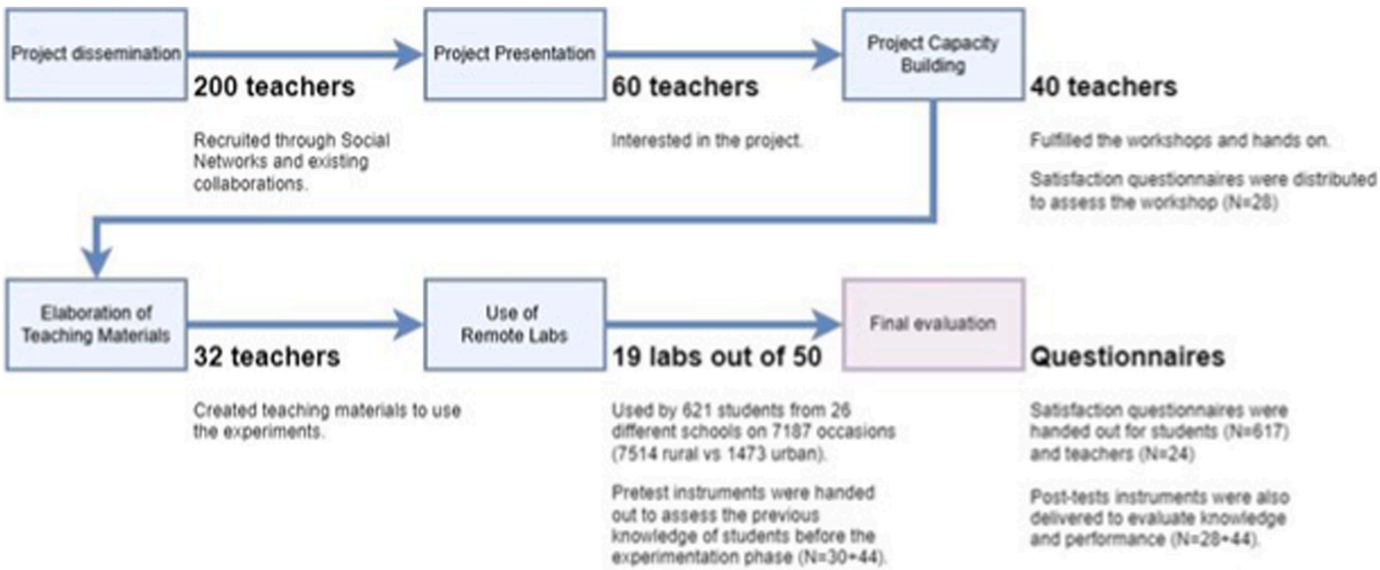

Fig. 3. Sequence diagram with metrics about recruitment, capacity building and assessment.

Table 2
Description of the most frequently used experiments.

Experiment (# of centres)	# Rural Centres Primary + Secondary	# Urban Centres Primary + Secondary	Description
Planarians (8)	6 + 1	0 + 1	The student observes a planarian in different liquids to see how the planarian's nervous system is affected by substances such as sugar, caffeine, ginseng, or taurine. Related to health sciences and healthy lifestyles.
Robotics (8)	4 + 3	0 + 1	The student learns to programme a robot by means of a function block language. Related to Technology and Programming.
Freefall (7)	0 + 1	0 + 6	The student observes an object fall onto a plane with different slopes. Related to physics.
Archimedes (7)	4 + 1	1 + 1	The student throws objects of different mass and volume to see whether or not they float and why. Related to physics.

seven answers to the student satisfaction questionnaire: pendulum (Galileo's pendulum), radioactivity, freefall, planarians (planarians and beverages), and basic circuits.

Fig. 9 shows satisfaction levels for each of the eight laboratories. In every case, one observes very high satisfaction, although at first glance the Arduino laboratory receives some lower ratings than the others. To compare these differences between laboratories in terms of average satisfaction, ANOVA analysis was performed on a single factor. A p value lower than 0.001 [$F(7) = 10.586$, $p = 7.415e\text{-}12$] is obtained, indicating that here is statistical evidence between student satisfaction according to the remote laboratory. A post-hoc analysis enables to make two-by-two comparisons. For this, Tukey HSD test and t-type two-by-two tests, applying Holm's correction to all (see **Annex 6**) was applied. The results reveal significant differences between remote laboratories. Thus, the statistics demonstrate that the Arduino laboratory generates less satisfaction than Archimedes, planarians, robotics and VISIR. The same occurs between freefall/cinematics and Archimedes, planarians and robotics. To conclude, the results show that the planarians and robotics generate more satisfaction than the pendulum.

Beyond the statistical results, this test enables the teachers to accurately choose among remote experiments the one that will prove most satisfactory for students and will make it easier for the teacher to establish some competencies. According to the previous results, when hesitating whether using laboratories related to robotics or to teach programming they should go for robotics-based experiments to ensure a higher student's performance and satisfaction, at least in the rural world. In this sense, as well as the differences between remote laboratories, it was studied whether there were differences in student satisfaction according to type of centre (rural and urban) and educational level (primary and secondary) were significant or not.

Comparison using the Wilcoxon-Mann-Whitney test between the different central student satisfaction ratings according to type of school gives a p value lower than 0.001. This value indicates the existence of a significant difference in satisfaction depending on whether the school is rural or urban. Average satisfaction in a rural school is 88.4 % with a standard error of 1.1 %, while average satisfaction in urban schools is 80.4 % with a standard error of 1.3 %. The conclusion is that, during the first year of the Project, there was greater satisfaction and productive use of materials in rural schools.

Comparing student satisfaction according to educational level, using the Wilcoxon-Mann-Whitney test, a p value lower than 0,001 is obtained. This value indicates the existence of a significant difference in satisfaction depending on educational level. Average satisfaction in primary education is 90.0 % with a standard error of 1.0 %, while average satisfaction in secondary schools is 78.8 % with a standard error of 1.3 %.

Ultimately, when comparing student satisfaction vis-à-vis both variables (Fig. 10), it can be observed good satisfaction results obtained in general and particularly in primary and rural schools.

As well as quantitative responses on a Likert scale from 1 to 5, the satisfaction questionnaires included an open question for students and teachers to describe their experience in Project R3. Around 25 % of students included a comment in their questionnaire, mostly positive. For instance, these comments in relation to the planarian experiment: A25) "I enjoyed myself. I have learnt a lot. For example: "We shouldn't consume energy drinks because if you drink a lot you could die." A14) "At first the password didn't work and I became desperate, but when we finally managed to enter, the experiment was better than I had expected. It was fun watching the planarian doing somersaults." A60) "Seeing the

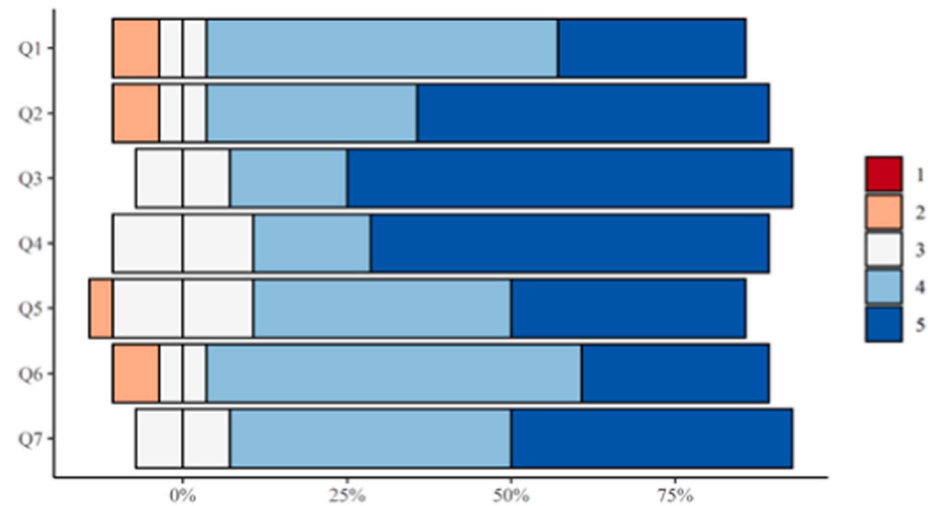

Fig. 4. Teacher satisfaction with Project R3 training.

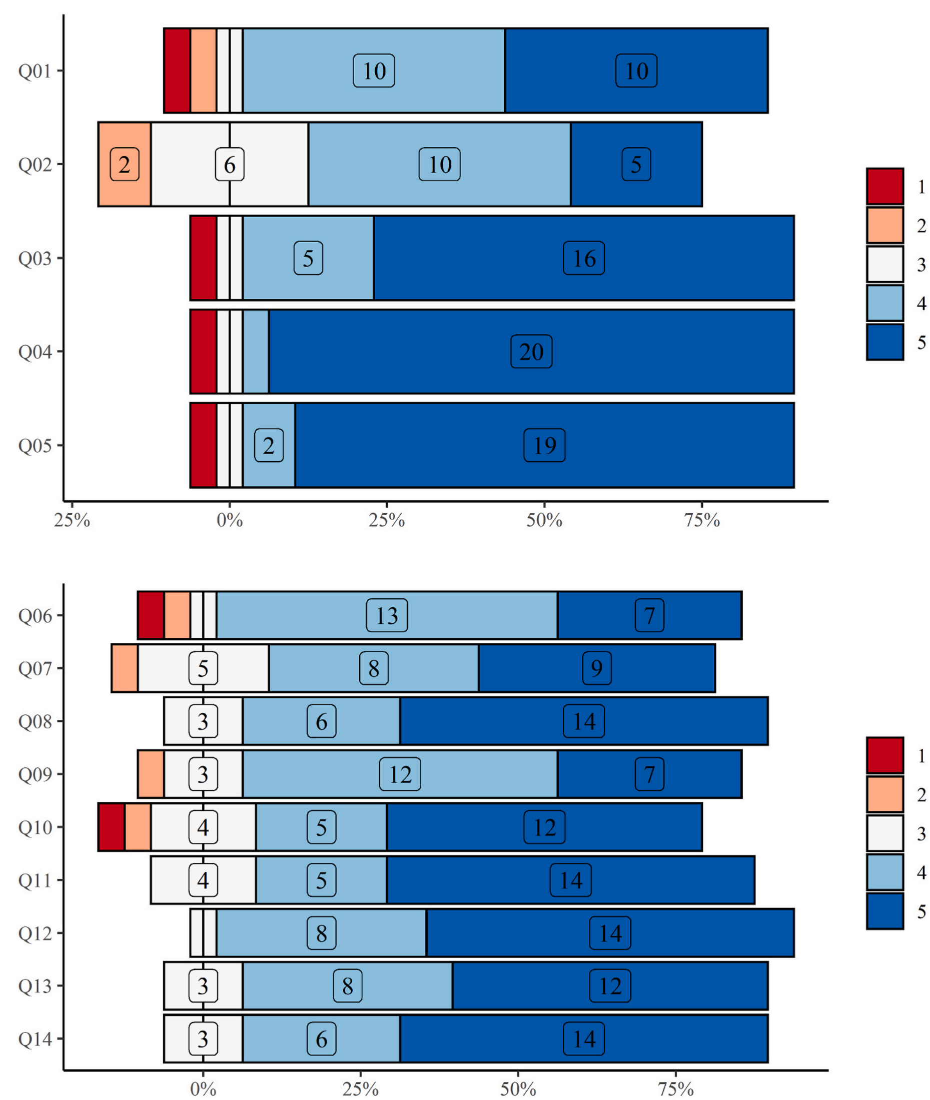

Fig. 5. Teacher satisfaction presented with Project R3. To avoid misinterpretation of results due to a small sample of 24 respondents, the actual number of teachers who responded to the Likert scales is provided along with the percentages. It's important to note that for readability purposes, only the bigger numbers are reported, but the sum of each bar always adds up to 24.

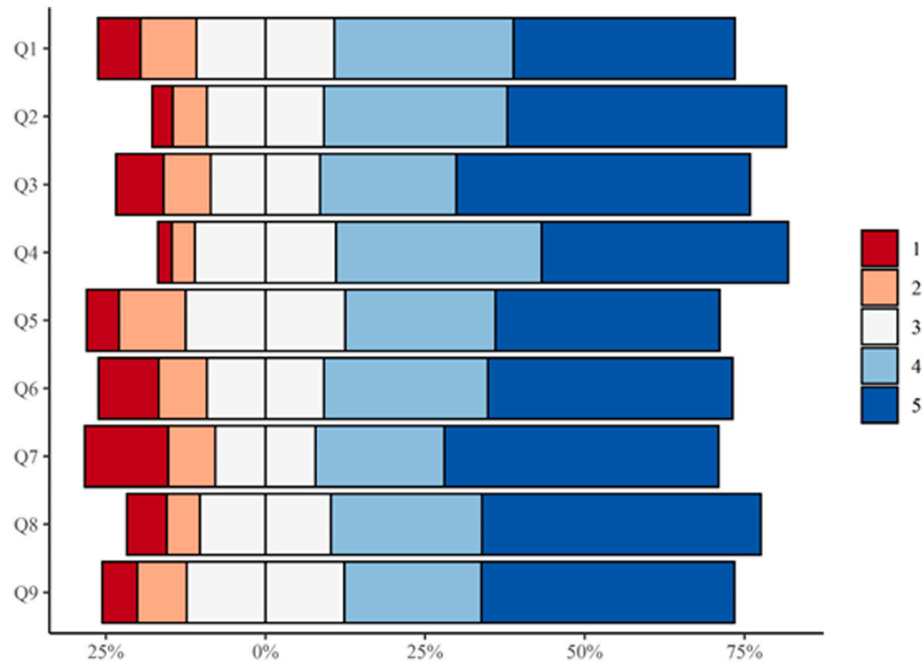

Fig. 6. Student satisfaction with the use of remote laboratories.

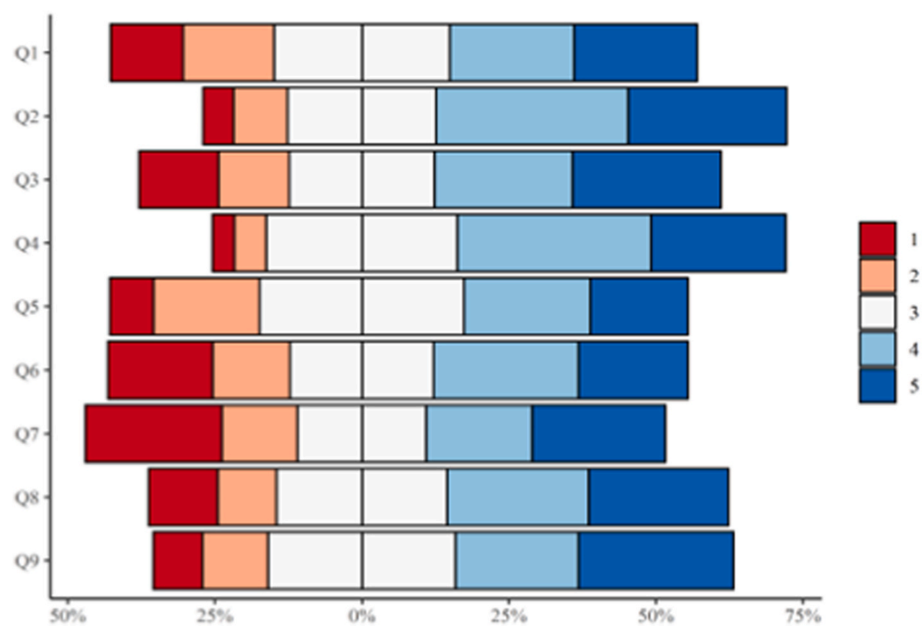

Fig. 7. Student satisfaction with the use of remote laboratories in school Z.

planarian in different substances and the effect upon it has made me reflect upon the fact that taurine kills brain cells."

In the sphere of robotics, one student commented: A21) "I felt like a robot designer". Another robotics student said: A113) "It seems a bit difficult to me, but when you've done it more than once it's easy and fun.". A different message was written by another student: A55) "You have worked hard on this and I respect that". Fig. 11 shows various drawings by students at different schools and a photo of classroom work. As has been noted, many students were primary level and their teachers asked them to draw something related to their experience in Project R3.

4.3. Learning

Learning in remote experiments took place via ad-hoc questionnaires created by the Project teachers and researchers. These had to be brief, so as to interfere as little as possible in teaching dynamics. For the moment, learning has been measured in four rural schools. Two of them used the freefall experiment, while the other two performed the pendulum experiment (see learning questionnaires in **Annex 5**). In one of the schools that used the pendulum, to guarantee the anonymity of participants, there was no association between pretest and post-test, with 30 pretest and 28 post-test answers in the case of the pendulum. However, in the case of the freefall experiment, analysis was pre-and post-test (N = 44).

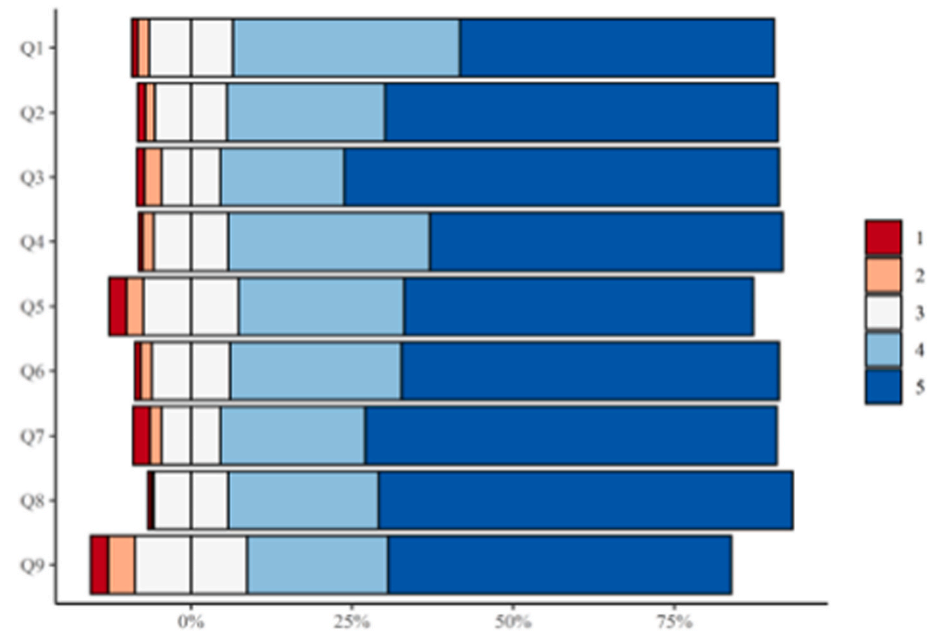

Fig. 8. Student satisfaction with the use of remote laboratories in the remaining schools.

Fig. 12 summarises the results in the pre & post-test for the Pendulum experiment. Bearing in mind that not all the data is associated, results are shown by means of boxplots for pretest and post-test. One observes that results (scaled from 0 to 1) improve with the use of the remote laboratory. A Wilcoxon-Mann-Whitney test on this data confirms this improvement in the central value of results (p value equal to 0.02).

The Sankey diagram (Fig. 13) summarises the results obtained scaled from 0 to 1) in the pre- and post-test for the freefall experiment. There is also an improvement in the results, especially in the lowest pretest values. The Wilcoxon-Mann-Whitney test for paired data evidences an improvement in results (p value equal to 0.04). Remember that it could not be possible to present the same graph for the pendulum because in this case the questionnaires were anonymous, and it is not possible to record an increase or reduction in competencies.

5. Discussion

5.1. Satisfaction and learning

In view of the results presented in the previous section, it is clear that the use of remote laboratories in rural schools has a significant impact in terms of competencies acquired, satisfaction level and use in the classroom. Similarly, it has seen how, in some cases, the use of the remote experiment is at least as effective as that of a real experiment [24,28] and enables students to consolidate knowledge impossible to obtain without experiencing scientific research. Both findings are related to the two initial research questions that were proposed in the Introduction Section. In the light of those findings, similar to what is reported by Ref. [23] or [29] in their fieldwork, it is worth noting that the remote experiments offered by LabsLand are agnostic. This means that the student, upon access, finds the experiment interface and some instructions regarding its use, but no information about the experiment itself, since it is the teacher who must provide the latter.

5.2. The role of the teacher

This is the major difference between the R3 proposal and other experiences analysed in the background section. Most of the studies documented there have to do with programs to promote STEM culture where the focus is normally on the student, with teachers removed from the equation (even substituted on occasions by external teachers). However, in Project R3, the teacher is at the centre of training, and (s)he is the leading character who can attract pupils to the remote labs and experiences. It is the teacher that first confronts the remote experimentation tool and learns how to use it after various training sessions. It is the teacher that, in subjective fashion, decides the number and diversity of laboratories to be used throughout the academic year, without there being guidelines in this respect. They decide which are the labs with (s)he feels most comfortable with and/or those that (s)he expect students will most benefit from (the results of this article offer some clues as to the experiments that generate most satisfaction). Ultimately, the authors of this manuscript believe that successful use of remote experimentation in rural areas depends on the teachers that opt to participate in the project understand the pros and cons of LabsLand and introduce it into the classroom as a tool to consolidate STEM skills (please, recall how a low involvement experience from the teacher in school Z might influence the students' performance and overall satisfaction levels). All of this contributes to answering the third research question set out in the introduction section.

5.3. Rural vs. urban pupils and disadvantaged groups

In response to the last two questions stated in the Introduction section regarding the differences vis-à-vis the urban environment and the generalisation of the results, the answer is clear. Results in the previous section show that Project R3 is equally valid in an urban context. However, data concerning the benefits of training (as in the PISA Report), and student satisfaction are better in a disadvantaged environment than in those that have larger budgets and find it easier to equip laboratories. In view of these differences, it might be more interesting to clarify whether the use of remote laboratories in rural schools is similar to the use made by other disadvantaged collectives such as conflictive suburbs of large cities, or the disabled, as UNICEF notes in its report. In the same line of discussion of tangential themes (socio-economic and demographic in the main), it is worthwhile opening a debate on the importance of having better-equipped rural schools to promote scientific culture and STEM skills, among others. The authors of this article, based on the evidence reported by reviewed scholars, maintain, and agree that the existence of rural schools helps to consolidate the population and generates entrenchment which was already in a prior study of [30].

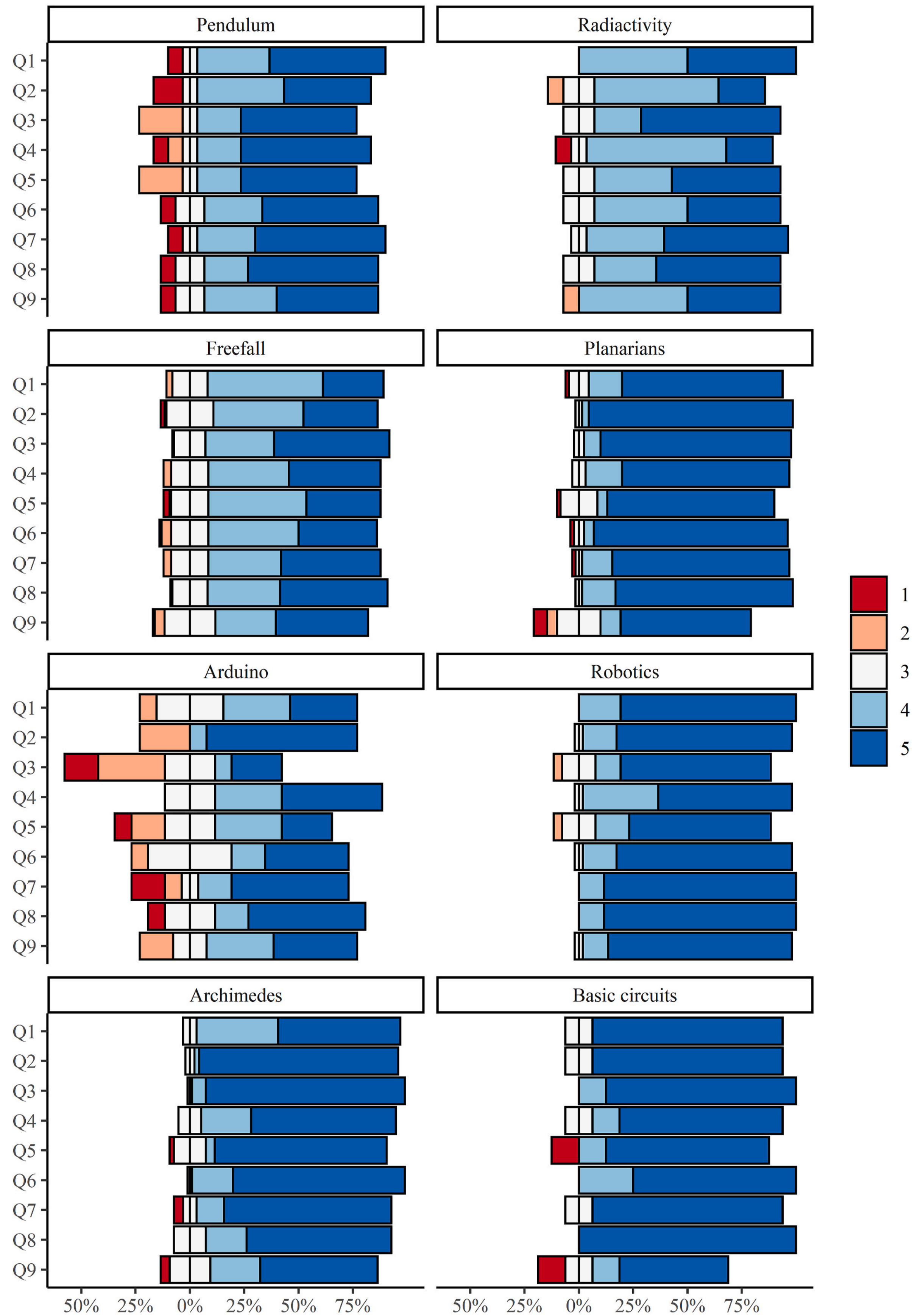

Fig. 9. Student satisfaction according to remote laboratory.

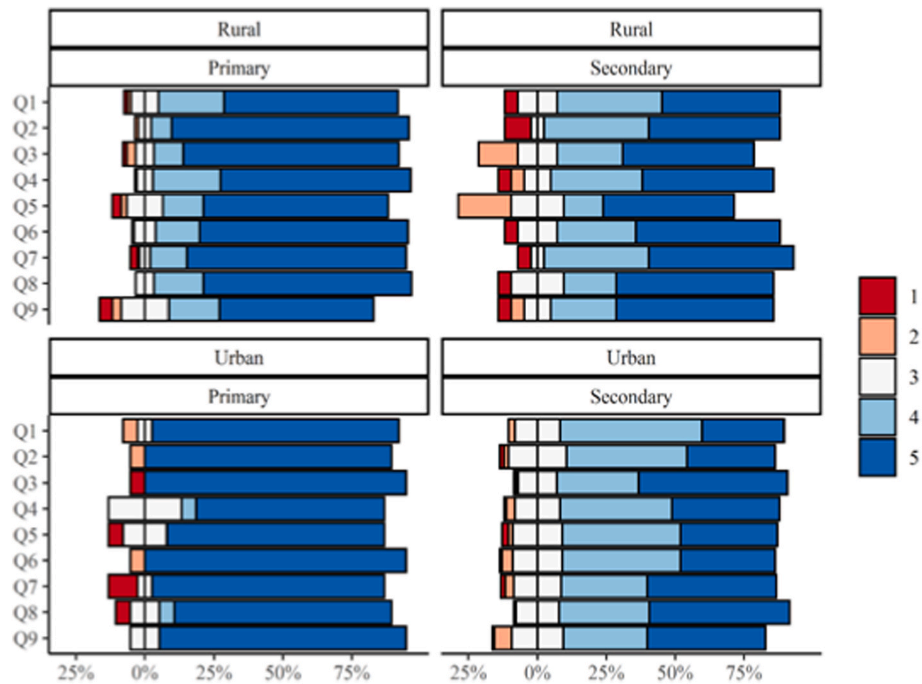

Fig. 10. Student satisfaction according to type of school and educational level.

Fig. 11. Samples of classroom activity in Project R3 (permission from the school and parents was given for dissemination to the Project R3).

Schools are a crucial element of a broad socio-cultural fabric and of a social capital where relations between families and communities are reinforced in the vicinity of the school as a result of friendships between pupils, participation in extracurricular activities or community projects to improve schools. Consequently, better-equipped schools, with a greater capacity to create communities and where teachers and students can make better use of technological resources, as in the case of Project R3, create centres of reference where families in the area opt to educate their children in these spaces rather than in schools in province or county capitals. The advantages in this respect are obvious: (i) there would be more rural schools; (ii) there would be more resources distributed among different schools rather than concentrated in one (county capitals); (iii) the population would increase or be stabilised, as there would be no need for daily displacements of dozens of kilometres; (iv) more families would consider living in rural areas; and (v) educational syllabuses could be created in which STEM training did not end at primary level, but more secondary or vocational training centres were created to respond to the educational needs of the area, improving and digitalising the rural world (see what the European Commission is doing in this respect by means of research projects such as AURORAL[14] [31] or d-RURAL[15]).

6. Conclusions

In this article, the use of remote laboratories in the rural world has been addressed due to its particular idiosyncrasies (e.g., lack of resources, less equipment, less connection with the research and business world). Project R3, which focuses on how to perform scientific

[14] https://www.auroral.eu/#/

[15] https://drural.eu/.

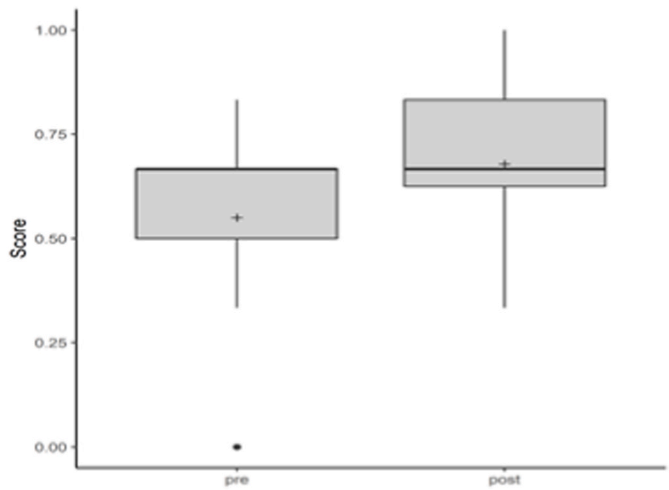

Fig. 12. Results for the pendulum (scaled from 0 to 1).

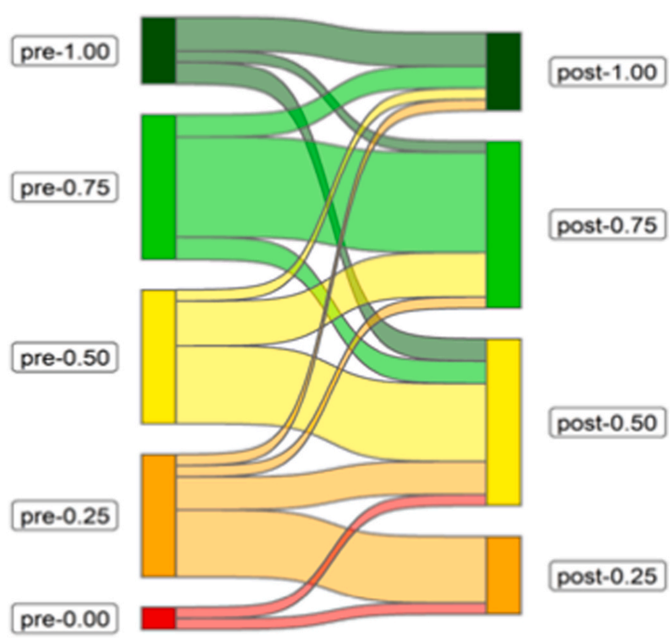

Fig. 13. Results for the freefall experiment (scaled from 0 to 1).

experiments and improve STEM skills in primary schools in rural areas by means of remote laboratories has concluded its first year of development. Positive results have been achieved, both by teachers and students, with 32 teachers deciding to receive training and employ remote experimentation in the classroom with over 600 students. Pre-post studies and satisfaction surveys, as well as qualitative data, have confirmed that remote experimentation is a suitable tool for the development of STEM skills in rural schools and that rural schools can be made more attractive when compared with urban schools in terms of education and facilities. As well as drawing these comparisons, the idea is further to exploring the role of the teacher as the main figure in the educational process, and providing guidelines with regard not only to which laboratories work best but to the type of teacher best prepared to address the shortage of resources in the rural world.

Based on the analysis of the results, remote experiments have been found to be a highly effective, sustainable, and socially impactful technological tool in primary and secondary education. The goal of remote laboratories is to bring about educational equity in all settings, particularly in disadvantaged environments such as rural areas. Therefore, decision-makers such as policy-makers, education departments, and any other institution responsible for education should consider remote experimentation as a means to democratize access to science. It is essential for these decision-makers and teachers to take note of the findings of this article, not only because of its low cost per pupil, ease of maintenance, and lack of technological deployment but also for the reasons stated earlier. Moreover, all that is required to access remote experimentation is a simple browser tab, thus making it possible to bring science education to anyone.

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Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2023.102404.

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