Research Article

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The Infinite Learning Chain. Flipped Professional Labs for Learning and Knowledge Co-Creation

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Abstract: Nowadays universities and other classical research institutions are changing their role in knowledge creation. In general terms we can characterize this transition as the path from "Closed Science" to "Open Science" as a part of a deeper and structural phenomenon known as "knowledge democratization", where different stakeholders as students, makers and other tech and science enthusiasts are able to create knowledge learning from the researchers and cooperating with them.

In this process, science engagement of these new actors is a key point to stimulate their creativity, get some important research skills learnt directly from the researchers and be able to apply these skills teaching others in a continuous "learning chain".

In this article, we introduce some main features and preliminary results of an experiment called "The infinite learning chain" done in cooperation with Arduino, focused on sensing science and based in a real research project of Group of Atmospheric Science (GAS) called Luleå Environmental Monitoring Stations (LEMS). We debate some interesting questions related to the impact of the format in terms of science engagement, STEM skills acquisition and cooperative learning involvement. We used as "learning ecosystem" a professional Lab, the INSPIRE Lab a complete multidisciplinary facility for space and environmental research and exploration.

Keywords: Fab Lab, Maker Space, flipped learning, learning co-creation, knowledge co-creation, Open Software, Open Hardware, Project Based Learning, Sensing Science, Citizen Science, STEM, Open science, Open Source.

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1 Introduction

We have an excellent – hierarchical – science and technology system in Europe but it is not still connected with its economic, social and cultural horizontal background. Solving this tension requires a fundamental move to an Open Science approach. In 2016 the European Commission unveiled a new strategy and vision for Europe in terms of innovation and knowledge creation:

"The year is 2030. Open Science has become a reality and is offering a whole range of new, unlimited opportunities for research and discovery worldwide. Scientists, citizens, publishers, research institutions, public and private research funders, students and education professionals as well as companies from around the globe are sharing an open, virtual environment called The Lab." (European Commission, 2016).

In this new vision the two spearheads that are speeding up the evolution to the Open Science paradigm are: 1) The digitalization as the main new technology infrastructure – Lab in your smart phone – and 2) the open living lab as the most suitable learning ecosystem[1] to host a completely new way for research; the knowledge co-creation. The days of the lab considered as a closed environment populated by professionals in white coats, located in university departments or behind corporate walls are numbered. This lab concept is being substituted very quickly for another one characterized by a more decentralized and open features as end-to-end architecture, peer to peer networks, open standards and platforms, or learner-centered approaches.

The aim of "The infinite learning chain" was exactly this one; to transform a "classical" research space in a

1 "Learning ecosystem" understood in terms of life-long learning, life-wide learning and life-deep learning (Barron & Bell, 2015).

learning and knowledge co-creation ecosystem using as a starting point a real research project – LEMS – introduced to the students by the researcher in charge – GAS PhD scholar Thasshwin Mathanlal. To this starting point we will try to add progressively new stakeholders in the learning process building a new collaborative, sustainable, open and digitally-based co-research network (Wulf, 1989). The network permits to flip the roles of the students who participate in the experience; the first time they do as learners, the second time as trainers and mentors for new learners.

2 Open Sensing Science With a Learner-Centered Approach

The Infinite Learning Chain is based on the project Environmental Monitoring Stations (LEMS), a research project of the Group of Atmospheric Science (GAS) which includes sensing capabilities to collect data from the environment. In this regard, it is important to consider that there are key differences between traditional Information and Communication Technologies (ICT) and the more novel IoT and sensing technologies. While personal computers and mobile phones are pervasive in everyday life, smart objects and contents are still novel and largely unfamiliar to most people. This unfamiliarity with the technology and lack of skills to operate them causes an impact on how effectively people engage with them and through them. Following participatory approaches to design novel digital and sensing technologies can foster their acceptance and adoption. That was a key point from the beginning for our experiment.

The Infinite Learning Chain will use co-creation methods in order to increase the sense of ownership among project participants – university students, boost sustained engagement and ensure that any tools and processes that are designed within the activity, mainly different kinds of atmospheric sensors, address the needs and interests of the people who will use them. The principle of co-creation is the process of creating new features, interaction modalities and services with people and not for them. This method offers the possibility of capturing “people insights”, thus moving closer to people and their needs; eventually co-designing with them the core principles. In fact, co-designing is changing the roles of the designer, the researcher and the person formerly known as the “user” in the whole process.

2.1 Background and previous research

The general topic of learning environments has been faced both from a theoretical and methodological perspective by Mara Balestrini and other authors (Balestrini et al., 2017) proposing a framework for running inclusive, community-driven projects that make use of technologies to address social issues. Other specific question that has been researched and should be kept in mind is the kind of factor that contributes to citizen engagement in participatory sensing and data technologies (Balestrini, Diez, Marshall, Gluhak, & Rogers, 2015). The user-centered ICT approach has been applied to different fields as heritage preservation using digital technologies and storytelling (Balestrini, Bird, Marshall, Zaro, & Rogers, 2014) or to design technological interventions that tackle the challenge of a growing ageing population in urban areas (Righi, Sayago, & Blat, 2015).

Science and technology learning is a complex process. In our experiment, and following STEM approaches, we moved inside the Constructivists framework. We know that students involved in the project are not “empty containers to refill”. They come with their own previous learning experiences and prior knowledge that shape what they know, their skills, their interests, and their motivation. We spent a lot of time and effort on interacting with them to be well aware of this critical aspect. They also are active in the learning process constructing their own understanding of the world and being able to transmit what they have learnt to others (National Academies of Sciences, Engineering, and Medicine, 2018). As the research about relationship between learning and engagement has demonstrated clearly when people are interested in a subject area they are more likely to attack challenges, use effective learning strategies, and make appropriate use of feedback (Csikszentmihalyi, Rathunde, & Whalen, 1993; Lipstein, & Renninger, 2006; Renninger, & Hidi, 2002).

Moreover the learning process is contextual. It doesn’t occur in a kind of “vacuum”. Labs can be a good learning context, a whole environment to make learning possible. But as Bevan explained recently the kind of initiatives as ours requires more than coordination and collaboration of partnerships. It requires building layered networks of social connections that can make possible pathways towards, with and through science visible, inspire interest in them, and help broker them (Bevan, 2018). At the same time we need to take care about converting STEM learning approach from a “theory of whatever” that justifies any kind of outputs that occur inside a Lab into a “maker mode”. As Maria Xanthoudaki reminded us recently for the nowadays STEAM style the words should be matched with real key points as strategic objectives and definitions, but also with research and structured reflection (Xanthoudaki, 2017). In that sense The Infinite Learning Chain is a real learning STEM-based experience focused on students' interest and capabilities, self-realization and prioritized specific science and technology learning goals. It is a reflection on a practice that is nowadays "on stage".

The transformation of professional labs in open learning ecosystems based on knowledge co-creation is something more and more present in classical research infrastructures to change them from inward to outward oriented and from top-down to bottom-up. The Horizon2020 SISCODE Project is a good example of this new approach (SISCODE, n.d.). It is aimed at stimulating the use of co-creation methodologies in policy design, using bottom-design-driven methodologies to pollinate Responsible Research and Innovation, and Science Technology and Innovation Policies in different stakeholders. The co-creation labs focus on experimentation, and this is a key element that is spreading around Europe. The way to do it is by selecting a challenge to tackle with local stakeholders in order to find solutions together. The Infinite Learning Chain is a knowledge co-creation project based in a real atmospheric sensing project led by researchers and involving engineering university students.

Our project is also placed in the specific area of Co-creation and Climate Action, and is specially focused on how people can have an impact on climate adaptation and mitigation. Sensing science is very near to this topic. In that sense, a European Project that has been considered a reference point for research co-creation applied to climate action is TeRRIFICA (Territorial Responsible Research and Innovation Fostering Innovative Climate Action) (TeRRIFICA, n.d.), a network of six partners led by WILA Bonn to seek for best practices and identify the approaches that are already in place to mitigate climate change and help us adapt to its effects. We kept in mind some of the outputs of TeRRIFICA in the design phase of the experiment: importance of the storytelling, closeness of the researchers, real research projects as a framework etc.

2.2 GAS Science Communication strategy

The Infinite Learning Chain is an experience included in a more general science communication strategy of the Group called "From laboratory to the audiences and return" based on learning and knowledge co-creation with different kind of target audiences as university students, children, families, educators, journalist, company staff, institutions, deprived groups and minorities etc.

The experiment includes a set of strategic and specific goals with different indicators to be measured following the contents summarized in Table 1. Our baseline hypothesis for the experiment was built according to strategic and specific goals with their own indicators for impact measurement.

The key elements to building the experiment have been:

– A previous strategy: "From laboratory to the audiences and return".
– A methodology: Participatory Action Research and Learning-Centered approach.
– A research project: Environmental Monitoring Station for Luleå (LEMS).
– A researcher involved: GAS PhD. Students Thasshwin Mathanlal.
– A target audience: LTU students interesting in sensing and programming.
– A reputed partner with experience on education and technology: Arduino.

2.3 LEMS as knowledge co-creation project

The Urban Environmental Monitoring Station for Luleå was one of the projects awarded within the Luleå University of Technology's call Enabling ICT, intended to gather ideas which can serve as pilots for the further implementation of novel systems to drive cities smarter by taking advantage of the Information and Communication Technologies. The LEMS prototype was developed within this project.

The project relates to one of the main problems in modern cities: the degradation of the environment due to human activity with the loss of quality of life it entails for their inhabitants. "Smart cities" are expected to provide solutions to this increasing concern. The project for designing and installing these stations to monitor emissions from vehicles and industries in and around Luleå will provide the first opportunity to assess their effects on the environment which in the long run can affect snow albedo and precipitation, ultimately affecting the local climate and hydrology.

These system's novelty consists in the periodical sampling of the air and the measurement of the precipitations' pH, collecting in this way not only data for the amount of emissions and the allocation of their main sources, but also a direct estimation of the consequences of these emissions for the

Table 1: The Infinite Learning chain experience main goals

STRATEGIC GOAL	THE INFINITE LEARNING CHAIN SPECIFIC GOAL	INDICATOR
To guarantee a minimum quality of science content (science background standard)	To develop a new science learning methodology based on learning by doing	Surveys with values from 1 to 5, items referring to quality of science included in outreach actions, values from 4
To work with several GAS members at the same time to do different things to do outreach actions		70% of all the GAS outreach actions should involve at least 2 or more GAS members
To open GAS facilities to different kind of audiences as students, families and tech fans	To reinforce GAS visibility and relevance in LTU community. To open INSPIRE Lab to the university audience	Develop 9 people Arduino's projects (3/year) based on GAS own Research Projects
To consider the feedback of the audience strategically crucial to do better research	To show and inspire target audience as LTU students how GAS use Arduino in their main research projects (using for that occasion LEMS Project) To promote the personal meeting between LTU Students and researchers To engage LTU students in a cooperative work with researchers to develop a scientific instrument for their field campaign	Achieve a repetition of the activity two times by the same researcher. Tracking of the audience feedback in the research work of the scientist.
To develop cutting-edge innovative learning experiences using new technologies	To cooperate with an important GAS technology partner as Arduino	A set of different learning objective indicators to demonstrate more effectiveness in learning experience and process related to space and environment in school curriculum.
To develop new outreach formats	To develop an easy FIKA-Arduino activity with students. To get multimedia resources to use in a specific News (have a News impact).	Develop at least 1 outreach activity per year of each of these profiles: learning, social, gender, business and reputation. Work at least once per year with each one of these target audiences (children 7-11), teachers, teenagers and young adults, women, families, university students (all levels), researchers and professors, local community, people with special needs, entrepreneurs, journalists.

environment, allowing us to look for the best way of controlling them and palliating the related degradation. The ICTs will play a crucial role in the real-time release of the data, so that appropriate measures can be adopted immediately in order to counteract any undesired effects.

The main objectives of LEMS are:
- To develop environmental monitoring stations with enabled ICTs for real-time data dissemination capabilities.
- To measure the air and precipitation quality.
- To monitor the evolution of the snow pH as a quality controller of air quality.
- To suggest policy measures for improving the long-term environmental sustainability, so that a clear socio-economic impact can be foreseen.

LEMS is a "live" project that has covered three main phases:
- First phase: PES1 and S3ME2. A perpetual environmental station (PES1) as a device able to monitor a series of critical environmental parameters and provide a steady flux of real time measurements to be analyzed. PES1 was conceived as an instrument which can work autonomously for long periods of time, (eventually, during an unlimited period), and which can be applied to a variety of studies. S3ME2

started its course with a 0 version (formerly Perpetual Environmental Station – PES), which was tested in July 2016 in Iceland during a field site campaign. During the initial test, the feasibility of the idea and the expected performance of the prototype could be initially checked. PES1 was improved to a new version S3ME2 programmed to get insights into the investigations of earthquake precursors, apart from providing information for the further development of the device itself. S3ME2 is composed of six modules, containing a particular type of sensors each, which are mounted in a linear assemblage along a central bar to be inserted into the ground, from where they get the pertinent measurements.

– Second phase. LEMS as more complete station for city environment. The unit now includes air quality monitoring sensors (e.g., carbon dioxide, carbon monoxide, sulphur dioxide, ozone, particulate matter and volatile organic compounds) with an environmental sensor package of temperature, relative humidity and pressure sensors coupled with a precipitation pH monitoring system to measure the air emissions along with the pH of precipitation (both rain and snow). All the data from the LEMS nodes will be stored in a computer cloud from where a further study will be performed.
– Third phase. SWASDAG Campaign. A "Swiss Army knife" smart weather station. The new environmental stations are an improved, compact version of LEMS developed by GAS including a very complete set of scientific instruments and atmospheric sensors such as a High Accuracy Barometer and Altimeter, a GPS, a Real Time Clock, an accelerometer and compass, a High Accuracy temperature / Humidity sensor, an Infrared Temperature Sensor / Camera, a soil moisture and a high temperature probes, a multichannel gas sensor to measure CH4, NO2, H2, NH3, O2, CO and a multi-channel digital light sensor to measure UV index and detect UV-light, visible light and infrared light. This kind of scientific installation is very unique in the Himalaya region. The gathered data will be fundamental not only in terms of glaciers retreat research but also to relate the information with environmental problems as pollution. The new stations monitor the pollution in these remote environments at different elevations. These new measurements, allow to evaluate the role of the increasing global pollution and black carbon concentration on the rapid melting of natural glaciers in the region.

The four main aspects initially considered as fundamental to choose LEMS as target project to use it a as a learning co-creation experience were:

– The social impact of the project. LEMS is closely related with climate change local impact. The entire co-design process had a fundamental added value, especially in the engagement of students aware of this problem and in the sustainability of the experiment.
– A target audience: university students interested in acquiring the kind of open technology skills we would like to offer them.
– It was an "Open source" project made with Arduino Software and Hardware, in particular Arduino Nano microcontrollers applied to the environmental sensors used for data acquisition.
– The cooperation of a researcher – Thasshwin Mathanlal – a very motivated and previously trained in science communication to guide the activity and solve problems during the session.

3 Hypothesis, Materials And Methods

3.1 Hypotheses

According to the strategic and specific goals, we selected the main aspects of the three baseline hypotheses to be measured with our evaluation tools:

1. Improvement of the project. The knowledge co-creation process will permit the students involved to start a dialogue with the researcher which will provide him with new data, new ideas or new approaches that can be applied to the project to make it more complete, more efficient or more suited to his scientific goals.
2. Skills acquisition in sensing programing with Arduino. The students will be trained in a very hands-on way in weather sensing using and testing real sensors based on LEMS. The explanation will be provided by Thasshwin Nathanial duign both sessions. During the second session he will be supported by one of the students who attended the first workshop, Mattis Johansson.
3. Engagement of the students in order to be mentors for the new students involved in the second workshop. The engagement will be based on an initial good experience, some training and the capability to involve new students as new learners.

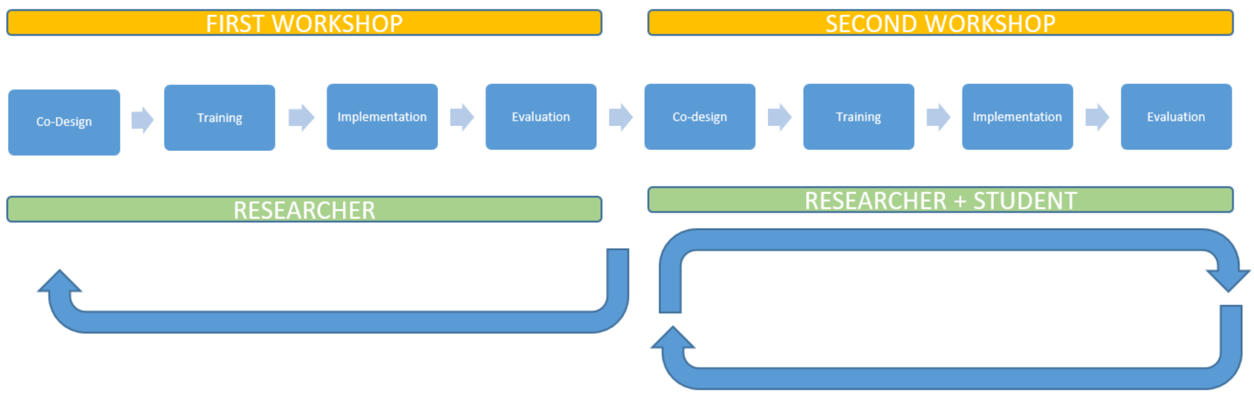

Figure 1: The Infinite Learning Chain path.
Source: GAS

3.2 Materials

The GAS facility used for the workshops was the INSPIRE Lab, a laboratory designed and equipped with all the relevant hardware and software tools to create a multidisciplinary design environment, providing effective communication, data exchange, and engineering tools, so that the team members, mainly Staff, Master program students, and PhD candidates, can work concurrently in the design and development of prototypes for planetary research and exploration.

The main materials for the workshops were sponsored by Arduino – Arduino Uno and Mega – to program and test the same sensors that were used in LEMS:

- High Accuracy Barometer and Altimeter.
- GPS.
- Real Time Clock.
- High Accuracy Temperature / Humidity sensor.
- Infrared Temperature Sensor / Camera.
- Accelerometer and Compass.
- Soil Moisture probe.
- High Temperature Probe.
- Multichannel Gas sensor – measuring CH4, NO2, H2, NH3, O2, CO.
- Multi-channel digital light sensor – measures UV index and detect UV-light, visible light and infrared light.

3.3 Methods

In the theoretical arena we combined the best practice in Participatory Action Research, and draw from User Centered Design and Participatory Design (Carroll, 2000; Sanders, & Stappers, 2008; Muller, Wildman, & White,1993) to support the co-design of sensors that take into account users' requirements and interests in the given context. These methods involve working with university students in a face-to-face manner to collaboratively identify needs and requirements. It also requires co-designing user feedback and prototyping solutions, iteratively deploying them in-the-wild in order to gather feedback to improve the initial sensor designs.

In more specific terms, we co-designed with researchers an iterative process following the path summarized in Figure 4. The first workshop was conducted on May 12, 2018 and the second one on December 15, 2018, with researchers and the student involved previously. See Figure 1.

To evaluate the hypotheses attainment we used three main qualitative and quantitative tools:

- A satisfaction survey to be filled up by the participants immediately after concluding the activity (quantitative approach connected with hypotheses number 2 and 3). See appendix 1.
- A personal interview of some of the attendants immediately after concluding the activity (qualitative approach connected with hypotheses number 2 and 3)[2].
- A satisfaction survey to be completed by the researcher after the activity (quantitative approach connected with hypothesis number 1). See appendix 2.
- A personal interview of the researcher involved in the activity (qualitative approach connected with hypothesis number 1).

Regarding the third hypothesis – student engagement – the evaluation after the first workshop was immediate:

2 See video interviews in Supplementary materials.

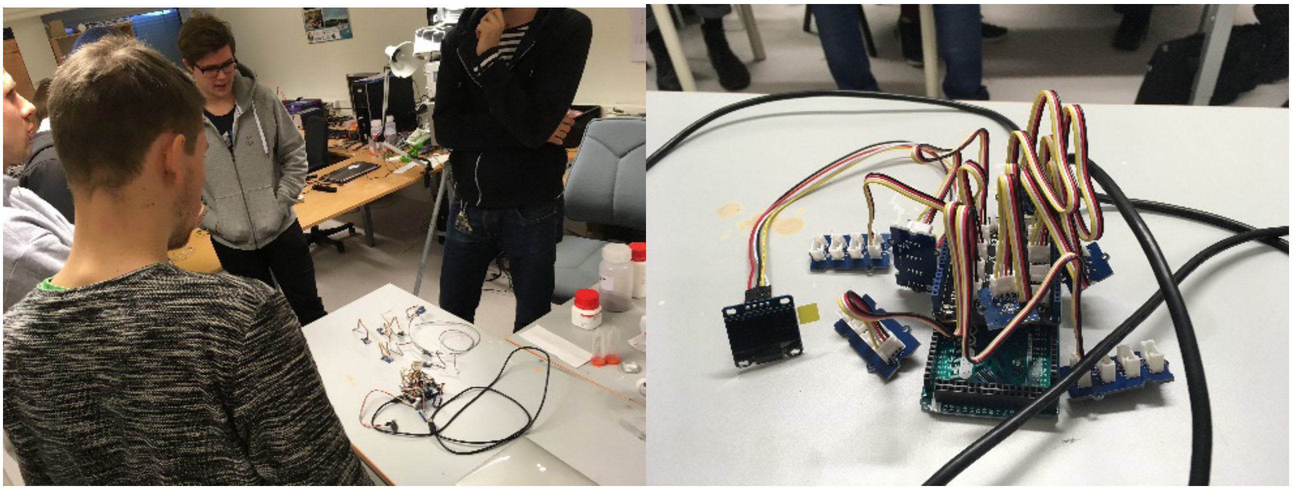

Figure 2: Sensor matching and testing at the end of the second
Source: GAS

to determine whether or not students could be involved in continuing the learning chain within the second workshop. If we were able to achieve this, the learning chain would continue.

Regarding some formal procedures all the personal data provided by the participants were treated and managed using GPDR standards. The participants' images used in GAS website and social media were authorized explicitly by signing an individual image release consent document. Mattis Johansson was the first student engaged as a mentor in the second workshop. He was comprehensively trained before the second workshop was carried out.

4 Implementation

The Infinite Learning Chain was developed in a non-continuous sequence of two interrelated open workshops. The length of each one was approximately two hours and a half. They were carried out on Saturday morning to facilitate the presence of the students.

The structure of the activity was the same in both cases:

- A twenty-minute presentation of the main activity goals, the schedule and the features of LEMS project with some basic training in Arduino sensors programing.
- A quick downloading session to provide all the students with the Arduino software tools needed.
- A one-hour researcher (or researcher and student in the second workshop) guide session to program different kinds of weather sensors. The students could work individually, in pairs or in groups of three or four, etc. Each group developed a specific sensor that would be combined and tested with the rest of the sensors designed at the end of the workshop. The dynamic was based on a progressive presentation of all the steps needed to achieve the final design.
- A cooperative testing part to check the sensors accuracy outside the lab and under real environmental conditions. See Figure 2.
- A final feedback session with questions for future development (individual, in groups or as another workshop).

5 Results and Discussion

According to some of the main statements of the study mentioned above, there is some evidence related with the learning co-creation process. See appendix 3:

- Following the constructivist approaches, we confirmed that previous knowledge of the attendants was fundamental to start the learning process. Students had very different backgrounds, proficiency level, and experience (from people who didn't know anything about Arduino programming to some "expertise"). This was particularly interesting because it involved different simultaneous learning rates and outputs in the same context with some interesting feedback between them. Knowing these previous profiles in detail has been fundamental for the suitable implementation of the experiment.

- As Csikszentmihalyi, Rathunde, & Whalen (1993), Lipstein, & Renninger (2006), and Renninger, & Hidi (2002), have pointed out, interest and motivation are key factors to advance and maintain the learning process especially for this kind of "fast learning formats". The feeling of being an active part of something that is interesting while being able to create and contribute in some unique way is a powerful dimension of the experiment. On the other hand, the time factor should be considered as critical in the engagement process. Pop-up workshops, such as this one, are very attractive and engaging but the effect needs to be maintained over time. This is something we are checking every time we plan and do a new workshop.
- Following Maria Xanthoudaki (2017), the awareness of the use the STEM frame as a "theory of whatever" can justify any kind of output occurring inside a Lab, and help participants turn into a "maker mode". Having a general strategy with specific goals and sub-goals has been fundamental to achieving a good frame for action, orientation, planning and tracking. To have a theoretical and strategic reference to use for contrast and guidance should always be considered a necessary starting point. In this regard, we oppose the anti-theory approach that is widespread nowadays. Students should understand the framework from the beginning to give them some "root", on which they can build their knowledge through observation and experimentation. The expected results were confirmed also with the output of the workshop – students were able to program their sensor and test that it worked well, and with the quality approach of the interviews where students recognized skills acquisition as one of the main outputs of the experience. The hypothesis regarding the skills acquisition in sensors programing with Arduino was confirmed in the two workshops. As a response to "I have learnt some important science concepts" in the first workshop 66.66% of the participants chose the maximum value (5) and the 33.33% chose 4. In the second one the values were 40% for 5 and 40% for value 4. The continuity factor (students continuing the research by themselves and applying what they learned in their everyday life after finishing the activity) is also clear. For the first workshop the results were 33.33% – 5 and 50% – 4 for the first dimension and 33.33% – 4 and 66.66% – 3 for the second dimension. For the second workshop the results were 20% – 5, 20% – 4 and 40% – 3 for the first dimension and 20% – 5, 20% – 4 and 10% – 3 for the second dimension.
- Identity is a key point in learning. We challenge the students not only to learn but also to try to engage others in doing the same. The peer-to-peer effect is something of great importance to the authors. We complemented this approach with a new input: a student can be a learner and a teacher at the same time in a single sequence. The roles are very flexible depending the way they participate in the experience. Even in the same workshop, the same students can be sometimes learning from researchers or other students, and sometimes they can be teachers to others or even researchers with their own goals and achievements. The students who participated the first time in the experiment where responsible both for engaging and teaching other students in the second experiment. We discover that to be an active learning stakeholder is important to consider the learning process design. The engagement of the students in order to be mentors for the new students involved in the second workshop was clear from the beginning. Even the results of the surveys pertaining to activity repetition and volunteer cooperation were positive in the two workshops (50% – 5 and 33.33% – 4, and 33.33% – 5 and 33.33% – 4 respectively for the first workshop, and 50% – 5 and 30% – 4, and 20% – 5 and 20% – 4 respectively for the second workshop). One of the students showed the most engagement– Mattis Johansson – as he became a mentor in the second workshop. Two more students voiced their intention (interviewed at the end of the workshop) to be mentors in the third workshop that is pending. A good point to keep in mind in the discussion is the importance of the involvement dimension of the learning process. The students are not only responsible for other students' learning, they should invite them "to live" the experience, as they did their first time around. Step by step, they build their own networks and communities focusing on different topics, such as Arduino programming, Laser-cutting devices production, 3D print instrumental prototyping etc.

However, in the area of knowledge co-creation the results were different:

- Improvement of the project. This hypothesis was not confirmed. Both in the satisfaction survey and in the interview, the researcher observed that the students did not provide any relevant idea, approach or data that can be applied to the weather station in order to make it more complete, more efficient or more adapted to its scientific goals (See appendix 4: Post-activity item "I will apply the feedback of my audience in my own research in some way" and final evaluation item "I will apply the feedback of my audience in my own research in some way"). The experiment was well structured by the researcher in terms of repetition, recommendation and continuation with new projects, such as Cube Sats mentioned in the survey. Some causes that maybe have provoked this lack of feedback could be the short time spent in the workshop setting and the differences in skill levels among the students: some of them were shy trying not bother the beginners with their ideas.

6 Future Research

Based on the results obtained we conclude with some interesting future study areas that will be the object of research in the next experiments:

– How can the knowledge co-creation factor be reinforced in the learning environment? In the end, the students' feedback was not relevant for the improvement of the research project. We can try to change some variables like the duration of the workshop (extending from one morning to a whole day or even a couple of days) or increase its frequency (once each trimester or monthly) to facilitate the interaction with the researcher and provide him with more time to foster a deeper understanding and better interaction.
– It is very important to research with more detail the post-activity phase with *in situ* observations and mid- to long-term tracking: how the participants continue applying the skills acquired in the workshops "outside", in their everyday life environments (university classes, friend meetings etc.), if they engage their friends, colleagues, families etc. in their project (how and why), if they have applied the skills to their formal academic learning (how and why), or the way they teach other stakeholders the skills they learned previously in the workshop.
– One important question to be considered is the mentoring factor. The ratio progress seems to be one mentor for each six students for the next workshop. How can this ratio be improved? It should be further investigated what the most effective mechanisms are for "recruiting" new colleagues to carry out the experiment in the same way they did it. The per-to-peer impact in the knowledge acquisition process should be analyzed in some important variants: emotions, empathy, trust, language and team building.

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Appendix 1

Participants' satisfaction survey template

ACTIVITY NAME	

Gender	☐ *Male* ☐ *Female*
Age	
Job	
City/Town/Place	

COMUNICATION

How did you know about this activity	☐ *Media* ☐ *Social Media/Internet* ☐ *Friends* ☐ *Other*

Please evaluate with 1 as the lowest value and 5 as the highest one

CONTENT					
The content was relevant, interesting and inspiring to me	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
I learnt some important science concepts	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*

I changed my previous conception about the topic	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
After the activity, I will continue researching the topic by myself	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
I will apply the content in my everyday life	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

PEOPLE IN CHARGE OF THE ACTIVITY					
The communication skills were good	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The scientific competence was good	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The people organizing the activity were able to engage me from the beginning	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
They opened my point of view and my curiosity about the topic	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
They used the appropriate language	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

ORGANIZATION					
Previous information about the activity was appropriate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The timing was correct	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The length of the activity was correct	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

The resources and materials used were useful	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
The manners were fine and friendly	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
The space and light was comfortable and adequate	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*

FINAL EVALUATION	
The global experience was positive	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
I will recommend it to my family, friends, colleagues	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
If it is possible, I will repeat the activity	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
I would like to engage with the organization as a science volunteer	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
Besides the topic of the activity and inside space, environment and technology field I liked very much…	
Give us some ideas to do a better activity next time	

Appendix 2

Researcher's satisfaction survey template

ACTIVITY NAME	
DATE	
FORMAT	☐ *Lecture* ☐ *Workshop* ☐ *Interview* ☐ *Other (specify which one)*
RESEARCH PROJECT	

PREVIOUS TO THE SCIENCE COMMUNICATION ACTIVITY	
Before the activity, did you have a good idea about the main characteristics of your audience? *How did you know them? (in person, beforehand…)*	
Did you plan ahead all the resources and materials needed? (including some rehearsals)	
Did you train some outreach skills to prepare the activity? If the answer is yes, which ones?	
How much time did you dedicate to prepare the activity?	
What kind of support was given to you from	

GAS Science Communicator to prepare the activity?	

Please evaluate with 1 as low value and 5 as highest one

ACTIVITY					
During the activity I was able to explain all the contents as I had planned	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
During the activity I was able to apply all the outreach skills I had learnt before	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
During the activity I received good feedback from my audience to apply my research	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
There is a correspondence between my plan for the activity and the real one	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
I felt comfortable with the audience's attitude towards me	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
I used the materials and resources as planned	☐ *1*	☐ *2*	☐ *3*	☐ *4*	☐ *5*
How much time did you dedicate to do the activity?					

POST ACTIVITY	
I followed up the results of my activity to keep in mind for the next time	☐ *Yes* ☐ *No*
I followed the media and social media impact of my activity	☐ *Yes* ☐ *No*
I will apply the feedback of my audience in my own research in some way	☐ *Yes* ☐ *No*
I want to maintain the contact with my audience after the activity	☐ *Yes* ☐ *No*
Thanks to this activity I found contacts, funding, partners, new projects… Which ones?	☐ *Yes* ☐ *No*

FINAL EVALUATION	
The global experience was positive	☐ *1* ☐ *2* ☐ *3* ☐ *4* ☐ *5*
I will repeat the activity again. Why?	☐ *Yes* ☐ *No*
I will repeat the activity again with other GAS colleagues	☐ *Yes* ☐ *No*
I consider this activity out of my “outreach comfort zone”	☐ *Yes* ☐ *No*
This activity has changed my perception about my own research. Why?	☐ *Yes* ☐ *No*
This activity has changed my perception about science communication. Why?	☐ *Yes* ☐ *No*

I have found interesting feedback to include in my research work to improve it	☐ *Yes* ☐ *No*
I will recommend this experience to another researcher. Why?	☐ *Yes* ☐ *No*
The activity has changed my perception about the audience. Why?	☐ *Yes* ☐ *No*
My advice to other researchers is…	
For the next time to do better, I consider it important to keep in mind…	

Appendix 3

Participants' satisfaction survey results May 12, 2018

Reference data

· 6 surveys filled out by 6 attendants (100% of the total audience) Statistical value.

· 2 females/4 males

· Age: from 20 to 33 years old.

· Job: Students

· Way to know the activity: 3 (other), 1 (social media), 2 (friends).

CONTENT	
The content was relevant, interesting and inspiring to me	83.33% – 5 16.66% – 4
I learnt some important science concepts	66.66% – 5 33.33% – 4
I changed my previous conception about the topic	50% – 3 33.33% – 2 16.66% – 1 Keep in mind that the activity was the first contact with Arduino for half of the students who attended the activity. This result is coherent with that situation.
After the activity, I will continue researching the topic by myself	33.33% – 5 50% – 4 16.66% – 3
I will apply the content in my everyday life	33.33% – 4 66.66% – 3

PEOPLE IN CHARGE OF THE ACTIVITY	
The communication skills were good.	**66.66% – 5** **16.66% – 4** **(One questionnaire not filled out)**
The scientific competence was good	**83.33% – 5** **(One questionnaire not filled out)**
The people organizing the activity were able to engage me from the beginning	**50% – 5** **33.33% – 4** **(One questionnaire not filled out)**
They opened my point of view and my curiosity about the topic	**50% – 5** **33.33% – 4** **(One questionnaire not filled out)**
They used the appropriate language	**50% – 5** **33.33% – 4** **(One questionnaire not filled out)**

ORGANIZATION	
Previous information about the activity was appropriate. To improve	**16.66% – 5** **16.66% – 4** **50% – 3** **(One questionnaire not filled out)**
The timing was correct.	**16.66% – 5** **33.33% – 4** **33.33% – 3** **(One questionnaire not filled out)**
Activity length was correct.	**33.33% – 5** **33.33% – 4** **16.66% – 3** **(One questionnaire not filled out)**
The resources and materials used were useful.	**50% – 5** **33.33% – 4**

	(One questionnaire not filled out)
The manners were fine and friendly	83.33% – 5 (One questionnaire not filled out)
The space and light was comfortable and adequate	50% – 5 33.33% – 4 (One questionnaire not filled out)

FINAL EVALUATION	
The global experience was positive	66.66% – 5 (One questionnaire not filled out)
I will recommend it to my family, friends, colleagues	50% – 5 16.66% – 4 16.66% – 3 (One questionnaire not filled out)
If it is possible, I will repeat the activity	50% – 5 33.33% – 4 (One questionnaire not filled out)
I would like to engage with the organization as a science volunteer	33.33% – 5 33.33% – 4 16.66% – 3 (One questionnaire not filled out)
Besides the topic pf the activity and inside space, environment and technology field I liked very much…	The friendly atmosphere. I did not feel stupid. I think everything that has to do with electronics and things like that is very fun. It's nice to see a practical application of sensors.
Give us some ideas to next time a better activity	I will think of something right now. The opportunity for people (like me) with no previous experience to read information before the workshop. Maybe invite more people, even form other programs than aerospace. Increase the time of the activity.

Participants' satisfaction survey results December 15, 2018

Reference data

· **10 surveys filled out by 10 attendants (100% of the total audience) Statistical value.**

· **1 females/9 males**

· **Age: from 22 to 31 years old.**

· **Job: Students**

· **Way to know the activity: 2 (others), 7 (friends).**

CONTENT	
The content was relevant, interesting and inspiring to me	40% – 5 10% – 4 40% – 3 10% – 2
I learnt some important science concepts.	40% – 5 40% – 4 10% – 3 10% – 2
I changed my previous conception about the topic.	20% – 5 20% – 4 20% – 3 20% – 2
After the activity I will continue researching by myself about the topic	20% – 5 20% – 4 40% – 3 10% – 2 10% – 1
I will apply the content in my everyday life	20% – 5 20% – 4 10% – 3 30% – 2 20% – 1

PEOPLE IN CHARGE OF THE ACTIVITY	
The communication skills were good.	40% – 5 60% – 4
The scientific competence was good.	60% – 5 40% – 4
The people organizing the activity were able to engage me from the beginning To reinforce	30% – 5 30% – 4 40% – 3
They opened my point of view and my curiosity about the topic	30% – 5 40% – 4 10% – 3 10% – 2 10% – 1
They used the appropriate language	60% – 5 40% – 4

ORGANIZATION	
Previous information about the activity was appropriate.	20% – 5 20% – 4 60% – 3
The timing was correct.	40% – 5 30% – 4 30% – 3
Activity length was correct.	50% – 5 10% – 4 30% – 3 10% – 2

The resources and materials used were useful.	**70% – 5** **20% – 4** **10% – 3**
The manners were fine and friendly	**90% – 5** **10% – 4**
The space and light was comfortable and adequate	**50% – 5** **50% – 4**

FINAL EVALUATION	
The global experience was positive	**40% – 5** **50% – 4** **10% – 3**
I will recommend it to my family, friends, colleagues	**50% – 5** **40% – 4** **10% – 3**
If it is possible, I will repeat the activity	**50% – 5** **30% – 4** **20% – 3**
I would like to engage with the organization as a science volunteer	**20% – 5** **20% – 4** **10% – 3** **30% – 2** **20% – 1**
Besides the topic pf the activity and inside space, environment and technology field I liked very much…	**The enthusiasms of the scientists.** **The possibility to learn other knowledge than my education.**
Give us some ideas to next time a better activity	**Possibility to do something with the data.** **More time to do our own calibration/sensor program/sensor read.** **More time and a little more challenging tasks, for example.**

Appendix 4

Researcher's satisfaction survey results

ACTIVITY NAME	Arduino Day
DATE	15-Dec-2018
FORMAT	☐ Lecture ☑ Workshop ☐ Interview ☐ Other (specify which one)
RESEARCH PROJECT	

PREVIOUS TO THE SCIENCE COMMUNICATION ACTIVITY	
Before the activity did you have a good idea about the main characteristics of your audience? How did you know them? (in person, beforehand…)	Yes. Before the workshop, we had a preview of the students' background.
Did you plan ahead all the resources and materials needed? (including some rehearsals)	Yes. We did all the planning and got the resources ready.
Did you train some outreach skills to prepare the activity? If the answer is yes, which ones?	Yes. Presentation about Arduinos and the activity timing for the workshop.
How much time did you dedicate to prepare the activity?	2 days
What kind of support was given to you from GAS Science Communicator to prepare the activity?	Materials, Planning.

Please evaluate with 1 as low value and 5 as highest one

ACTIVITY	
During the activity I was able to explain all the contents as I had planned	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
During the activity I was able to apply all the outreach skills I had learnt before	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
During the activity I received good feedback from my audience to apply my research	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
There is a correspondence between my plan for the activity and the real one	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
I felt comfortable with the audience's attitude towards me	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
I used the materials and resources as planned	☐ 1 ☐ 2 ☐ 3 ■ 4 ☐ 5
How much time did you dedicate to do the activity?	2 days

POST ACTIVITY	
I followed up the results of my activity to keep in mind for the next time	■ Yes ☐ No
I followed the media and social media impact of my activity	■ Yes ☐ No
I will apply the feedback of my audience in my own research in some way	☐ Yes ■ No
I want to maintain the contact with my	■ Yes ☐ No

audience after the activity	
Thanks to this activity I found contacts, funding, partners, new projects… Which ones?	☐ Yes ☒ No

FINAL EVALUATION	
The global experience was positive	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☒ 5
I will repeat the activity again. Why?	☒ Yes ☐ No
I will repeat the activity again with other GAS colleagues	☒ Yes ☐ No
I consider this activity out of my “outreach comfort zone”	☐ Yes ☒ No
This activity has changed my perception about my own research. Why?	☐ Yes ☒ No
This activity has changed my perception about science communication. Why?	☐ Yes ☒ No
I have found interesting feedback to include in my research work to improve it.	☐ Yes ☒ No
I will recommend this experience to another researcher. Why?	☒ Yes ☐ No Arduino was my strong point in research. Similar workshops can enhance the knowledge of the researchers in their respective fields.
The activity has changed my perception about the audience. Why?	☐ Yes ☒ No
My advice to other researchers is…	To organize similar workshops in their field of expertise.
For the next time to do better, I consider it important to keep in mind…	To have more interesting projects for students, like building a cubesat.