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Usability Engineering For Successful Open Citizen Science

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ABSTRACT

Do-it-yourself construction kits for sensor stations is a novel approach for citizen driven sensor networks. In this paper we present the development of SenseBox, a toolkit for open source sensor applications. We provide manuals and open source toolkits for hardware makers to establish a large scale sensor network in Germany, and additionally for schools to teach secondary school students programming in a playful and simple way based on open source microcontrollers. All collected data is open and being published on OpenSenseMap, our platform for open sensor data. After a test phase where we equipped citizens with construction kits for continuous measurements we discovered that most of the stations were disconnected after a few weeks. Following from that we performed a user study to reveal possible error sources during the wiring process, software installation and online registration on OpenSenseMap. Missing general computer skills led to larger problems than wiring of hardware parts.

1. INTRODUCTION

Citizen science can be explained as the engagement of non-professional scientists in collecting data, analyzing data, developing technologies and the publication of these on a voluntary basis. In a majority of citizen science projects, the data to be collected by citizens is geospatial and is being presented on maps. If the data is about environmental observations, this approach is often referred to as participatory sensing (Burke *et al*. 2006).

Our novel approach in this field is to equip citizens with do-it-yourself (DIY) environmental sensor stations to establish citizen driven sensor networks. This approach leads to a better data coverage but also contains motivational aspects, as the citizens build up their own devices and are therefor exposed to sensor technology as well. Most existing DIY sensor stations are not entirely open in terms of source code, data collection, hardware, educational documents or extensibility for other platforms (Uckelmann *et al*. 2011). In conclusion, user groups who are interested in the data or citizens who want to understand the algorithms are excepted from certain levels of those projects, even if they are willing to contribute.

In that context, the SenseBox project started at the Institute for Geoinformatics, University of Münster and is an ongoing open citizen science project. Based on open source hardware and open source software components citizens build their own Web of Things enabled sensor stations to collect environmental data about values of interest such as temperature, humidity, air pressure, loudness, illuminance and intensity of UV-light. The data is then being published as open data and visualized on a web based platform, the OpenSenseMap (OSeM). An educational edition of the SenseBox including hardware parts and didactical material are being introduced into secondary schools, where school students learn to code, measure environmental phenomena and work scientifically. The whole source code and all hardware components are open source, instructions are being published as open educational resources (OER) and models for a 3D-printed waterproof cases are available under open source licenses as well.

During a test deployment of around 50 SenseBox stations, we encountered a leak of reliability in terms of continuous data collection. In this paper we want to investigate, if usability problems were the cause of the low success rate and how the motivation of citizen scientist can be preserved to ensure a long-term data collection.

In the following, we give an overview on related work (Section 2) and introduce our development of SenseBox and OSeM (Section 3). After that, we present potential risks during different states of the development process and present a user study we performed (Section 4). Finally, we bring our approach in context to related work presenting a conclusion and an outlook to future work (Section 5).

2. RELATED WORK

The SenseBox development is closely related to the research field of Internet of Things (IoT), where physical objects and embedded devices are connected to the Internet and made uniquely addressable (Gershenfeld *et al*. 2004). In the Web of Things (WoT), the real world objects become accessible by an URI using REST principles and HTTP protocols (Guinard, Trifa, 2009). A connected world enables application scenarios of smart home and smart city. A major part for these fields are sensor networks, enabling the intelligent control of the environment. WoT enabled sensor stations are intelligent objects that are able to sense the environment, act on incidents or communicate with other sensor nodes or things (Bröring 2011).

Successful, large scale citizen science projects like Galaxy Zoo (Raddik *et al*. 2010) or eBird (Sullivan *et al*. 2014) have shown the power of the creative community as toolkit for science in different domains. In particular large scale projects were pioneers in this field, which enhanced prestige in the scientific community and awoke more interest in mainstream media. Sullivan *et al*. (2014) made aware that these projects vary in their quality of contribution for science, conservation and private policy. In their paper they present a novel approach of building cooperative partnerships in citizen science to increase participation by meeting community needs. Shirk *et al*. (2012) conceptualized a model for public participation in scientific research based on degree and quality of participation. They define the degree of participation as the influence of participants on the research process they are involved in. Formally, that can be expressed by the number of participants, duration of involvement or research effort. They consider key components for a high quality of participation as credibility, trust or responsiveness, which are important subjective factors. Their model about “public participation in scientific research” categorizes conceptual, contributory, collaborative, co-created and collegial projects. It is meant to identify the range of potential outcomes over the interactions between scientific and public interests.

3. BACKGROUND

In 2011 the SenseBox project was initiated during a study project at the Institute for Geoinformatics, at the University of Münster. The developed prototype was an WoT enabled sensor station. It focused on a generic and flexible approach for modular sensor setups in outdoor environments (Bröring *et al.* 2011). The core of the station was based on open source hardware Arduino microcontrollers. It was flexible in terms of sensor setup and application areas. The advantage of using Arduino as a basis, is the large and constantly growing community of DIY hardware prototype makers, organized in blogs, magazines and community meetings. Potential non-professional users can take advantage in the DIY community as they are not limited to specific tutorials and documentations. Currently, the SenseBox project offers two versions. Each of them is designed for a specific user group. Both of them are aiming to establish a large scale sensor network of open environmental data, collected by citizen scientists. In the following, we describe the current state of our project.

3.1 SenseBox Home: A DIY sensor station for citizen scientists

The SenseBox Home is a low cost starter kit for a DIY environmental measurement station, allowing non-professionals to collect and publish their own sensor data. Detailed construction manuals are available including descriptions for setting up the hardware, installing required software and registering the station on OSeM. As a core, the setup consists of an Arduino Uno microcontroller, a network adapter and the Arduino-compatible SenseBox Shield. The latter is designed for an user friendly setup of the four basic sensors, consisting of barometer, luxmeter, UV-light sensor and a combined temperature and humidity sensor. Because of its open source character, the basic setup can be enhanced with additional sensors and modules to cover as many application scenarios as possible. Mobile data logger as well as air- and water-quality sensor upgrades are currently in development. The aim is to set up and deploy a reliable sensing station which is pushing measurements to the a server continuously. Because of the motivational aspect, the DIY character of the construction kit is highlighted when supplying SenseBoxes to the citizens. Additionally we created a 3D model for a waterproof case, which is freely available on the Thingiverse platform[1] and can be 3D printed. On the left in Figure 1 below, an illustration of the 3D model is shown. The lamellae are used as sensor protection against raidiance. On the right, the assembled case without cover to show the wiring.

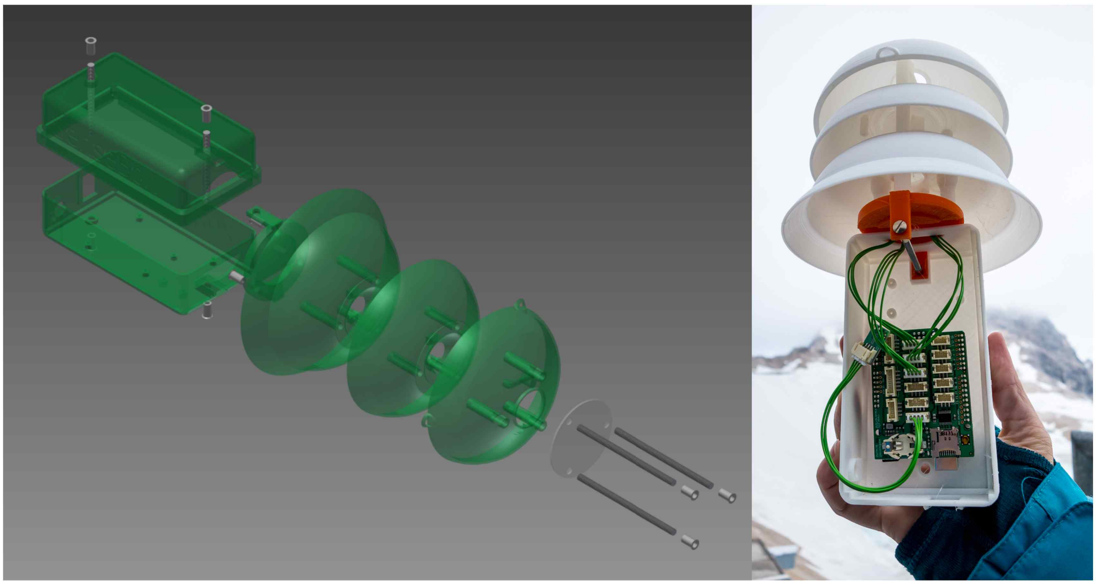

Figure 1. Our open 3D model can be used as casing for environmental sensors .

3.2 The SenseBox Edu: an educational toolkit

After the implementation of the hardware infrastructure described above, the SenseBox was used in practical workshops of ifgi's GI@School lab, providing secondary school students with a toolkit for learning to code with open source hardware. Evaluations of our

1 http://www.thingiverse.com/thing:728592

workshops have revealed that microcontroller programming implies a simple and playful way to teach children the basics of coding. The haptic feedback of intelligent I/O circuits controlled by microcontroller software is highly motivating for them when dealing with the complex topic of structured code writing. Construction kits for single projects, e.g. a weather station based on the SenseBox concept for schools, were developed afterwards. Beginning from scratch, in approximately four hours working with the SenseBox, small groups of two pupils are already able to program a car traffic counter with integrated data logger, controlled by ultrasonic sensors. In Figure 2 below, two school students are preparing a traffic counter in one of our workshops.

Figure 2. Pupils wiring and programming a traffic counter during a SenseBox workshop.

During the procedure of setting up the wiring and programming the microcontroller, they are instructed to use our construction manuals in combination with the online community as a support and therefor not only learn about how to code, but to solve technical problems using the knowledge of a creative community in the web.

After numerous hack events in our school laboratory and in the frame of project days in local secondary schools we selected experiments and projects developed in our workshops and created educational construction kits enabling a stand alone application in the schools. In that context, teachers can use the SenseBox in mathematics, computer science, natural science and technical related subjects to create interdisciplinary teaching units.

3.3 OpenSenseMap: A standard for collecting and sharing open sensor data

One result of the deployment of sensor station construction kits was the upcoming need of storing and sharing measurement data. Consequently, we developed an online web platform for that purpose: the OpenSenseMap. By analogy with OpenStreetMap where volunteers are mapping the environment by hand to fill blank areas with information, participants in our project are doing so by deploying and registering a new sensor station at a fixed location. In Figure 3 below, the map interface of OSeM is displayed with an example sensor station selected. Different colors of location markers are indicating different types of sensor setups.

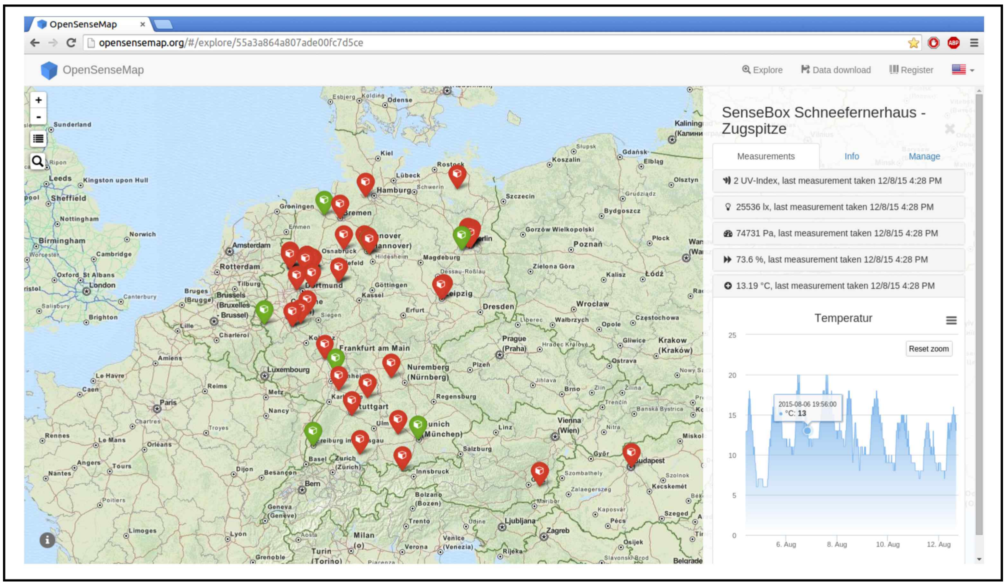

Figure 3. Screenshot of the OpenSenseMap interface.

The OSeM server application is based on a RESTful service architecture and has a document based database integrated. That allows data storage of any structure and makes the database highly scalable (Pfeil *et al*. 2015). Its open API is designed for simple access, enabling the storage of any possible measurement data. In addition, it is possible to subscribe to one ore more stations over the API or to download the datasets as CSV or GeoJSON. In a lightweight registration, SenseBox stations as well as custom stations can be instantiated in the database. As unique feature, we provide automatic software sketch generation for sensor stations based on open source Arduino microcontrollers. Primarily we want to establish a large scale, high resolution sensor network in Germany, driven by school projects and citizen scientists. The vision of OSeM is to become a standard for citizen science open measurement data.

3.4 Promoting the project

It is a crucial part for a project with public involvement to meet the corresponding user groups. Community meetings are focused on a specific user group and offering the possibility to draw attention on the project for potential users. Depending on size and publicity, exhibitions have the further advantage to reach people nation- or even worldwide. In our case the most important fairs we attended were the following three: Didacta, which is the most prominent educational fair worldwide with over 72000 visitors. Hannover Messe, which is the world's leading trade fair for industrial technology with over 220000 visitors (70000 of them from outside Germany). And at least the Maker Fair, which is a hot spot for hardware prototyping enthusiasts with more than 10000 visitors. On site, we presented the SenseBox on a stand, where we offered information material and simple interactive experiments to interested visitors. An indicator for the publicity are recorded sessions on our project website, shown in Figure 4 below.

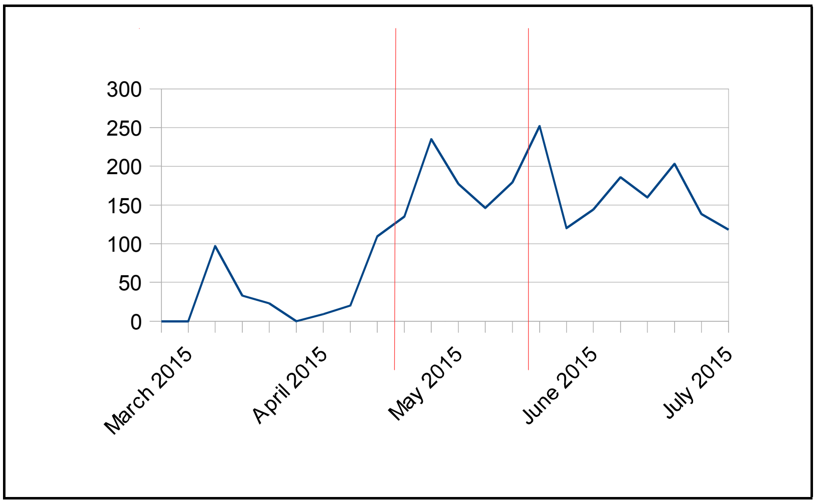

Figure 4. Number of weekly sessions on our project websites. Participations in community meetings are indicated as red lines.

3.5 Networking and funding

To reach more potential users for citizen science projects, an information network should be established to inform citizens about development state and product updates (Sullivan *et al*. 2014). The name of the project should be promoted and emphasized in online and offline media. As an example for the importance of mainstream media, an article about the deployment of a SenseBox station at a scientific station on the Zugspitze, which is the highest mountain in Germany, reaches 35000 readers of the Make Magazine as hard copies and many more online.

In Germany, a new citizen science era started with the establishment of the official Citizen Science platform *Bürger schaffen Wissen* (*Citizens Create Knowledge*)[2], established by the scientific community *Wissenschaft im Dialog*[3], in April 2014. Beginning with ten starter projects on their platform, there are now over 30 projects promoted. The platform has become the place to go for both, Citizen Science projects that want to become popular and interested parties which want to participate. SenseBox was one of the ten promoted starter projects and has become the most clicked project on the platform.

An important supporter in our network is the Federal Ministry of Education and Research (BMBF), which is particularly interested in the establishment of a nationwide sensor network of light measurmements for Germany within the scope of BMBF's “Make Light” initiative. Their funding enabled us to finalize our SenseBox prototypes and enhance our server infrastructure during the last months. As a state institution, they have connections to a large number of related institutions in Germany and access to events, like the three fairs mentioned in the last subsection. As a partner of the BMBF, we also draw additional attention in public media and gained a professional outward appearance in the public.

4. ENHANCING USABILITY OF DIY SENSOR STATIONS

In a first project phase, around 50 fixed SenseBox Home stations were deployed to citizens and schools distributed over Germany. Some participants had problems in the building and registration process of the SenseBox, others disconnected their SenseBox after some time. Even though, the number of registered stations increased constantly, the uploaded

2 http://www.buergerschaffenwissen.de/en
3 http://www.wissenschaft-im-dialog.de/en/about-us/

measurements did not (Figure 5).

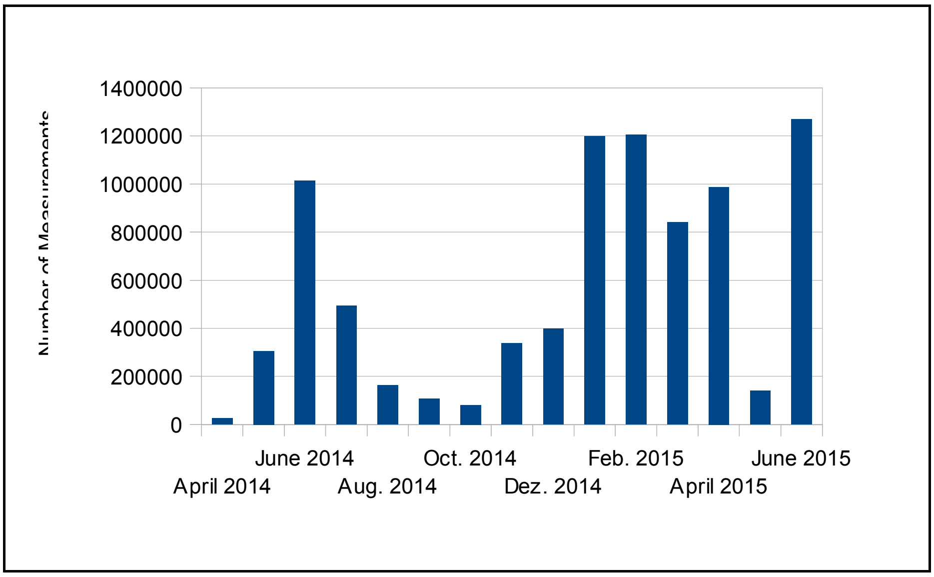

Figure 5. Uploaded measurements from SenseBox stations to OSeM per month.

Following from that, we looked for volunteers to perform a user study to find gaps and error sources of our approach. In this section of the paper we describe our methodology for selecting an appropriate user group and the results of the user study we performed at our institute.

4.1 Focus on user group(s)

User groups are varying depending on the domain of the project. In Section 3 we explained the two types of the SenseBox and their application areas in detail. Following from that, we focus on a user group of young teachers that are interested in technical project work for their classes (1) and on a user group of citizens that are in touch with DIY hardware prototyping or WoT development (2). In our case both of the user groups are interested or involved in geosciences, as we place special emphasis on the aspect of environmental sensing.

Table 1. Overview about personal information of the study participants.

ID	Age	Gender	Job	Area
A	33	Male	Teacher	Sports
B	29	Male	Student	Geography
C	27	Male	Student	Human Sciences
D	21	Female	Student	Geoinformatics
E	22	Female	Student	Maths / Geography
F	26	Female	Student Teacher	Human Sciences
G	33	Male	Teacher	Maths / Sports

H	27	Male	Student	Maths / Geography
I	21	Female	Electrician	Devices and Systems
J	28	Male	Student	Geoinformatics
K	25	Male	Student	Geoinformatics

Besides personal information stated above, we asked the participants in how far they are interested in the topics of DIY hardware, environmental monitoring, citizen science and the Web of Things. On a scale of 1 (no interest) to 5 (high interest) one volunteer was only partly interested (scale of 2) in one of the topics, the others were not less than interested (scale of 3) in at least two of the fields.

4.2 User study

We conducted the user study in a controlled environment at the Institute for Geoinformatics, University of Münster. The goal of the study was to reveal possible error sources in our documentation material, that was used in the initial testing mentioned above. We focused on non-professionals, that were at least interested in DIY hardware or in the domain of geosciences. In total, 30 volunteers were informed about our project. They were asked for participation if they showed interest for our topic. Finally, we chose 11 of them to further conduct in our study, which is enough for determining significant test results (Nielsen 1993). Each study took 45 minutes and as an inducement for participation, we randomly selected one out of the pool of volunteers and provided the person with a SenseBox Home construction kit worth ~100€. Personal information of the test subjects were anonymized, user names and e-mail addresses used for online registration, were deleted after each test run in the presence of the test subject.

The task of the study was to construct a SenseBox station (1), install all the required software (2), and integrate it into our sensor network by online registration on OSeM (3). All instructions were given in form of a printed version of our construction manual. Step 1 was video and sound recorded by a table top camera, in step 2 and 3 we captured the screen of the test computer used by the volunteers. A passive observer was present in our laboratory during the study and made notes about the subject's behavior during the test. In case that a volunteer was not able to continue because of wrong hardware handling, errors in software installation, or inappropriate handling of the construction kit, the observer intervened, solved the problem and noticed it. After the study the volunteers filled out a questionnaire, containing questions about personal information, background knowledge and interest. In addition three standardized NASA Task Load Index (TLX) forms were filled out for each of the construction steps, for subjective workload assessment (Hart, 1988).

4.3 Study results

Only four out of eleven subjects completed the study successfully without help of the passive observer. All problems that could not be solved by the participants themselves occurred in step 2, where subjects were asked to install required software and driver components. Even though we provided detailed step-by-step instructions in the manual, 90% of the mistakes happed during copying and unzipping required software libraries into a program folder on the hard disk. One participant was, as he mentioned, “confused” because of the high task load during the study. He overlooked one of the pages in the construction manual and after downloading the pre configured microcontroller code he selected a wrong file in the download folder after the registration in step 3. In Table 2 below, error sources of each participant are and time measurements illustrated.

Table 2. Error sources and construction time of the participants.

ID	Step 1	Step 2	Step 3	Time
A		Copy error	Forgot to upload	40:40
B				36:54
C		Copy error		38:53
D		Copy error		31:51
E	Loose cable			34:25
F		Unzip error		39:47
G		Driver installation error		31:23
H		Driver installation error	Selected wrong software file	34:11
I				38:43
J		Wrong installation sequence		25:17
K		Copy error		20:30

Results of the standart NASA TLX questionnaire underlined the problems occurred during the usabitlity test. On a scale from 0 (low) to 20 (high) the participants rated mental, physical and temporal effort, their own performance, effort in general and frustration. The results are illustrated in Figure 5 below.

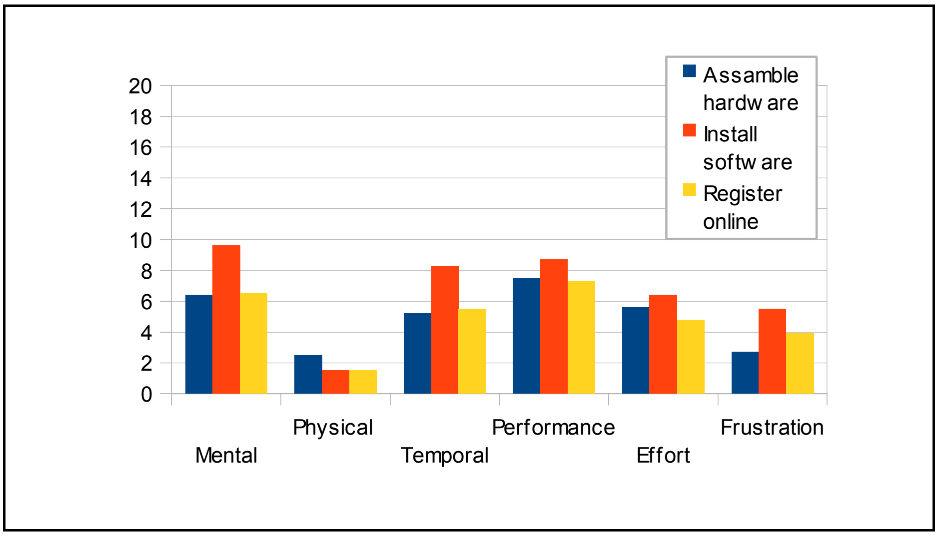

Figure 5. Average results of NASA TLX test of the three steps in the user study.

5. CONCLUSIONS AND FUTURE WORK

We have shown that open source hardware prototyping is a promising approach for environmental monitoring in the field of citizen science and education in secondary schools. In contrast to existing projects, we are aiming to provide introductions for DIY hardware, and microcontroller programming to bring methods of scientific data gathering to the public. We focus on the user groups of school teachers, hardware makers and citizens who want to build up professional stations by themselves to become "professionals". To get an inside look into sensor technology is a important motivation factor for citizens and school students when dealing with environmental monitoring. After less than one year of supplying SenseBox construction manuals, our sensor network grew up to 70 stations in Germany, with over eight million recorded measurements. To identify a user group is crucial to uncover potential risks in an early state of citizen science projects as well as for a high success rate in participation. More than 70 preorders of the educational version of the SenseBox are showing that there is a need for technical project work in German schools besides the citizen science movement. However, our user study showed that the provided documentation material must be complete and understandable for non-experts. We discovered that software and driver installation process are leading to high error rates, while hardware wiring was not a problem, even for beginners. Following from that we are implementing the study results into our construction manuals and develop a one-click software to fill this gap. In a next step we supply around 100 SenseBox stations nationwide in Germany, to proof our enhancements. After that, we are planning to expand our partnership to European level. By enlarging our network throughout Europe we are making a next step for OpenSenseMap to become the standard for sharing open sensor data.

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