Citizen Science: A Learning Paradigm for the Smart City?

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Abstract. Developments in Information and Communication Technologies (ICTs) have revolutionized learning; likewise, they have given a renewed impetus to Citizen Science in recent years. Promoting learning in a variety of dimensions has always been a primary objective of Citizen Science. Yet in practice, combining learning and citizen science activities is problematic for a variety of reasons, not least due to a lack of suitable tools. This paper illustrates the potential of the Citizen Observatory as a novel and innovative construct for enabling the adoption of citizen science thus enabling the promotion of; formal, informal and service learning, in a range of contexts. Such a development has clear ramifications for learning in the smart city amongst other scenarios. The paper is concluded with a case study outlining how one perspective of a Citizen Observatory is being harnessed in a traditional learning environment

Keywords: Citizens' Observatory, Citizen science, Smart city, Formal learning, Informal learning, Service learning

1 Introduction

Formidable challenges exist when incorporating a diverse community, be they lay people, students, community activists and so forth, into a cohesive unit such that a citizen science project may be successfully undertaken. As well as defining appropriate scientific protocols for the study in question, a scientist may be called upon to act as recruiter, project manager, educator, and even Web master amongst others. Clearly many scientists would be ill-equipped to undertake all of these roles. In contrast, a teaching professional may possess a deeper understanding of the educational possibilities; nonetheless, they may well encounter difficulties persuading faculty, parents and students that engaging in citizen science activities is a useful endeavor from a learning perspective.

Growth in Information and Communication Technologies (ICTs) is well documented; education and science are not immune to these developments and the challenge is how best to harness them for their mutual benefit. One common problem is a lack of appropriate tools that can be quickly harnessed to launch a citizen science initiative. Many useful tools do exist of course; however, a holistic and integrative approach is lacking particularly at the data collection and management stage. One potential solution to this is that of the Citizen Observatory[1], a framework for the definition, collection, and management of data that seeks to lower the barrier for those who seek to harness Citizen Science but without comprising scientific best practice. Though the primary use of a Citizen Observatory is for scientific purposes, the framework is sufficiently flexible to simultaneously support other uses, including education.

Citizens' Observatories ordinarily seek to enable citizens to adopt a key role in the stewardship and management of their environment, whatever form that environment may take. This demands the availability of ICT platforms that can be quickly deployed, configured and used by non-technical users. Such platforms are not currently available; conventional Citizen Science platforms, though offering a useful role model, nonetheless, do not incorporate this degree of generality, either technically or functionally. How this can be achieved in practice remains to be seen, and one interpretation will discussed in Section VI. Through such a platform would offer great potential for citizen engagement in environmental governance for example, other uses are also envisaged, including educational. From a smart city perspective, this would contribute to the resolution a particular conundrum, that of effectively ensuring an alignment between top-down and bottom-up visions and practices albeit within appropriate contexts.

This paper is structured as follows: Section II introduces the citizen science paradigm. Section III reflects on formal and informal learning paradigms. A state-of-the art in the use of citizen science within formal education is presented in Section IV. Thereafter a high level description of the Citizen Observatory concept is presented in Section V. An exemplar functional architecture is described in Section VI, illustrated through a use case in Section VII, after which the paper is concluded.

2 Citizen Science

The growth of interest in citizen science has, in recent years, been phenomenal [58], leading to suggestions that it be treated as a distinct discipline in its own right [34]. However, citizen science is a relatively old concept, contrary to popular belief. Indeed, many of the pioneers of science, for example, Franklin and Da Vinci, earned their livelihood through other means. Professional scientists are a relatively recent phenomenon, relegating citizen science to the status of a hobby. Nonetheless, there has always been a cohort of amateurs active in a variety of domains, for example, astronomy. In recent years, the possibilities offered by citizen scientists in a variety

[1] http://citizen-obs.eu/Home.aspx

of manifestations - amateurs, hobbyist, NGO, has garnered the attention of the established scientific community.

Two primary reasons have been attributed to the recent surge of interest in citizen science [53]. The first consists of the increasing range of sophisticated toolkits, mainly ICT based, that foster engagement and collaboration. The second concerns the realization amongst the professional scientific community that the public constitutes a free source of skills, labour, and increasingly, independent and verifiable sensing capabilities. It has been noted that widespread monitoring would be impossible without the active contribution of interested parties from the public. The increased adoption of ICTs has meant that the boundaries between other data collection paradigms, namely crowd-sourcing and participatory sensing, become increasingly blurred.

Motivations for engaging in citizen science differ, ranging from a commitment to social justice to active citizenship, and an increased awareness of environmental issues. A critical challenge is to ensure that scientific norms are adhered to, including but not limited to an adequate methodical approach and data validation, but without compromising motivation nor participation. It has been observed, in one case study involving bird monitoring, that the datasets collected by amateurs and professionals actually complemented each other, though a detailed understanding of the amateur dataset was necessary before its potential could be harvested [54]. As will be seen in Section V, this is the kind of problem with conventional citizen science that the Citizen Observatory was conceived to address.

Interestingly, it has been pointed out that, while the potential of datasets collected by the public is significant, a methodology that relied on such datasets would not pass a review board. Furthermore, it has been suggested that scientific papers incorporating volunteer-collected data are not formally reviewed but are treated as outreach or educational contributions [7]. However, it must be stressed that with a valid protocol, supervision and training, volunteers can collect data that is of equivalent quality to that collected by experts [16] and vastly exceeds the volume that can be collected by experts alone.

Many examples of citizen science initiatives have been documented; most of these tend to focus on ecology and environmental science, see for example, [44], [56]. All usually have a primary singular scientific objective; other objectives may exist but these are of lessor importance. EarthTrek [40] is an example of a Citizen Science program exclusively dedicated to collecting data that will be explicitly used for research outcomes; however, this is the exception rather than the rule.

A number of typologies for citizen science have been documented in the literature [66] [8]. For the purposes of this discussion, it is useful to consider that of Craglia & Shanley [12] who propose a classification based on the primary objective of the project:

1) Advance scientific discovery and knowledge;
2) Inform policy and environmental management;
3) Education and awareness raising;
4) Community building.

These four categories are of course not mutually exclusive; education is frequently a cross-cutting objective.

2.1. Citizen Science in the Smart City

Smart cities [36] [69] represent a model of urban development that has garnered significant attention and research in the last decade; nonetheless, no consensus exists as to what constitutes a smart city or what its attributes are [45]. Optimizing the use of both infrastructural assets and human capital is a broadly agreed objective [71]. In the former case, focus is directed for the most part on the public administration function. In the later, fostering innovation might be an objective. One model, that of Giffinger [26], identifies smart economy, smart environment, smart governance, smart living, smart mobility and smart people as the six dimensions through which the performance of a smart city can be assessed. In the case of the people dimension, social and human capital would be included, as would education. A more recent perspective envisages just two essential attributes that could, either individually or in unison, define a smart city - that of ICTs to facilitate the coordination of fragmented urban subsystems, and that of urban spaces where the lived experience enables a new reality [29]. Though various models have been documented, the role of education, either as a dimension or enabler of the smart city, remains to be seen.

How citizen science can contribute to the conceptual definition, design and management of the smart city is open to question. A naive view regards the citizen scientist as a mere data collector, the importance of this task notwithstanding, or service consumer; a more holistic view might envisage the citizen science community as a bridge between governance and the community, and a key enabler of social and knowledge capital. How education and training in the smart city could be augmented through citizen science is a topic that has not been explored to the best of the authors' knowledge.

3 Learning Paradigms

Learning has personal, social, cultural and economic benefits, it is recognized as a form of human and social capital, worthy of investment by individuals, governments and employers. The overarching concept of lifelong learning has evolved over several decades; it has informed and shaped European and national educational policies through a range of reports and strategies. Lifelong learning promotes inclusive learning across the lifespan, and addresses notions of learning that take place in a wide range of settings, that are life-wide including formal, non-formal and informal contexts [30]. The concept of lifelong learning crystallized in the early 1970s, following a period of radical development in the 1960s. At the heart of earlier definitions of lifelong education, was a humanistic call for the development of a learning society that would involve participation of all citizens over their lifespan and enable learning that would lead to social action, potential change and transformation of society.

Fleming describes lifelong learning as complex, contested and subject to reductionism [23]. Jackson sees the concept as slippery, with competing definitions, and varying practices [33]. In recent years there is a growing concern that lifelong learning has been harnessed to support arguments favoring instrumental utilitarian-learning needs, particularly within formal education, providing for economic growth, competitiveness and increased social cohesion. It is argued that a neo-liberal agenda has had an impact on recent developments within lifelong learning, leading to the term being tarnished and in need of being rescued [23].

Since the 1970s with the publication of the Faure report, lifelong learning's star has risen, faded (1980s) and re-emerged (1990s) [72]. Lifelong learning is a means of enhancing human capital, developing social capital, as well as addressing social justice, and inequalities in society. This wide ranging concept is characterized as participatory, transformative, progressive, a social good and encouraging active citizenship. It is also a strategy for maintaining economic competitiveness, ensuring economic prosperity, promoting the knowledge economy, a way to counteract the implications of globalization, providing for the adoption of flexible employment frameworks, social cohesion or social control. Lifelong learning can be a means of reforming and transforming educational systems and structures, a way of recognizing and valuing learning outside of formal education.

One of the key challenges with an expansive concept such as lifelong learning is finding effective ways to implement the vision and deliver on the potential of the ideas as they relate to individuals and society. Through formal, informal and non-formal education, individuals are provided with multiple opportunities for learning which can address the wider transformative goals of lifelong learning.

3.1. Formal Learning

Typically formal learning is associated with compulsory education, that is, learning within schools, primary and post-primary, whilst informal learning is associated with learning outside of formal structures and not bound by traditional curricular concerns or standardized testing. Formal education provides educational opportunities for children, young people and adults. National governments invest in state sponsored educational structures and formative learning activities for children and young people through a range of classroom-based programs. Formal education provides for the delivery of a structured curriculum where standardized testing takes place at key stages. In some instances opportunities for learning outside of the classroom but supported through the curriculum are encouraged, as is the case with service learning initiatives.

Typically the majority of students transfer to state supported secondary education though there are options for diversification, such as vocational pathways within secondary schools or technical colleges that offer alternatives for young people outside of traditional academic schooling. In many European countries there is a requirement for young people to remain within school or formal education until the age of 16. Further education providers offer a diverse range of education and training options including: vocational programs, return to learning, basic and adult education, as well as sandwich courses linked to Higher Education (HE). Evidence indicates that increasing numbers of school leavers make the transition to higher education.

3.2. Informal Learning

Learning that falls outside of formal education, that is, not accredited or validated by regulatory bodies, is often termed informal learning. Such learning is also linked to categories of non-traditional learning that are work or community based, or form part of adult education. Generally informal and non-formal learning fit within the life-wide learning strand of lifelong learning. Typically informal learning is not bound or regulated by established norms found within formal education, such as standardized examination, set curricula, or learning outcomes. The level of restriction often associated with traditional forms of education or classroom-based learning does not apply to informal learning.

Informal learning can be associated within informal learning networks; it can take place in a range of settings, the work place, museums, galleries and other everyday sites. In some instances informal learning can be casual or unplanned; alternatively it can be organized. Opportunities for informal learning can occur in public spaces in cities and urban environments through networks, gatherings and events that are relational and human-centric. In the emergent field of urban interaction design, there is growing interest in public spaces, how they are used, and how people interact and relate within environments that are technology-enriched.

Opportunities for learning and motivation to learn are central to informal learning. By its very nature informal learning does not fit within recognized forms of established provision, therefore the supply of informal learning opportunities is not well documented or promoted. There are notable exceptions, for instance The Bird House Network informal science project where large numbers of citizens were engaged in supplying data for research purposes to advance an established scientific project. With set protocols and instructional guidelines in place, volunteer participants who are locally based contributed to gathering relevant data, thereby assisting in achieving project goals whilst simultaneously learning through experience, acquiring skills, knowledge and enhancing their scientific literacy [10].

Within the wider lifelong learning concept, informal learning, associated with life-wide learning, is deemed to have been marginalized and, it is argued, is under-valued and under-researched. Furthermore as there is greater investment by governments and industry in formal learning, there is a tendency to overlook and underestimate the potential of informal learning.

3.3. Service Learning

Service learning presents an enthusiastic and progressive model of community participation and active civic engagement for students and young people. Through partnerships with schools and higher education institutions the needs of communities can be addressed. Service learning breaches the boundaries of traditional academic structures encouraging students to actively engage in, and with, communities where experiential learning is provided to students and communities goals are met. Service learning is a pedagogical method that combines meaningful service to the community with curriculum-based learning. Further, it addresses the aspirations of lifelong learning by encouraging young people to engage in civic participation and enhance their learning by doing so.

3.4. Learning in the Smart City

Smart Education is seen by many as one distinct enabler of the smart city [62] [26]; at the time of writing, the degree to which education is fundamental (or otherwise) to the smart city vision depends on one’s preferred model of the smart city. Smart people differentiate a digital city from a smart city [32]; skills, education level and life-long learning are key elements here. Nonetheless, the role of education and educators in the construction of smart cities and the transformation of learners into active citizens remains undefined [3]. Giovannella [27] describes a framework to define and measure the smartness of learning ecosystems, including that of cities. Buchem & Pérez-Sanagustín [11] consider smart cities as spaces for learning, envisaging a dynamic merging of the physical and digital spaces, resulting in augmented, ad-hoc and personalized learning environments. Given that smart cities remain hypothetical sociotechnical artefacts, except in the minds of marketing professionals perhaps, the role of education in their construction and operation remains uncrystallized.

4 Citizen Science in the Educational Landscape

To obtain a snapshot of how citizen science has been harnessed in the broad education sphere, a brief survey of the literature was undertaken. Using the well-known database Academic Search Complete, a variety of research terms were used to search the abstracts & key words of the academic journal entries. Obviously, such a methodology will not result in an exhaustive review; rather it is a snapshot of the state-of-the-art which will serve for the purposes of this discussion.

Three themes emerge when education is considered with a citizen science context. The first theme concerns the broad purpose of citizen science itself from an educational perspective. In the case of adult civic science literacy, it has been demonstrated that through engagement in a non-formal education and experiential learning citizen science program, civic science literacy can be raised [15]. Spellman [55] envisages citizen science as one means of promoting resilience in social-ecological systems. Educational and research goals of a project can conflict; many people engage in projects for a perceived greater good, or social experience, and not to learn. For deep learning, participants must be interested, and the project must allow for practice, working through mistakes and reflection [35]. However, as many citizen science projects are in the broad environmental sphere, there is significant scope for increasing environmental awareness [9].

A second theme considers the issue of participant education prior to engaging in a project. This is perceived as crucial, requiring the preparation of materials explaining background issues, motivation for and theory of the research question as well as protocols for observation recording [19]. In a small survey of citizen science projects (n=19), mandatory training occurred in 63% of cases [24]. In the case of a groundwater education program, a full days training was sufficient [59]; this is probably archetypical.

A third theme concerns the education, or learning, that emerges from engaging in a citizen science program. A number of case studies have been documented. Operation Magpie is an example of a citizen science program that was at least partially harnessed in a junior curriculum [1]. Two observations from this study are of interest. The first concerns the need for families to actively support student interests in the home environment. The second concerns the notion of making science central to the curriculum from which other learning areas can be enhanced, for example, literacy, numeracy, higher-level thinking, and so forth, rather than vice versa as is currently the norm. Trautmann et al. [60] describe how students have engaged with a number of well-known citizen science projects, e.g. eBird and FeederWatch, as part of their studies. Operation Spider has been harnessed by teachers to engage students from low socio economic backgrounds so as to increase their capability and inspiration to complete school [48].

Global Learning and Observation to Benefit the Environment (GLOBE) [6], and Open Air Laboratories Network (OPAL) [17] offer support to teachers who are keen to work with them and harness Citizen Science in their curricula. The Communities, Cameras and Conservation (CCC) program, undertaken in collaboration with the Rocky Mountain Cat Conservancy, involved training instructors and students in the monitoring of self-triggering remote cameras, thus bringing real-life research into the classroom [49].

A citizen science program involving the HorseShoe Crab was used as a test case to compare students that studied the crab in a traditional science program with a treatment group that engaged in a citizen science program with a professional biologist [31]. Results showed that authentic fieldwork within a formal setting can improve achievement and Science, Technology, Engineering & Mathematics (STEM) career motivation.

From a formal learning perspective, citizen science should be of significant benefit in developing countries, yet this would appear not to be the case [4]. A case study in India illuminated some of the difficulties when working with the formal education system [51]. Here students, teachers and parents were, for the most part, ambivalent about the process, primarily, it's suspected, as they did not see how it would align with a formal curriculum and contribute to better exam results. It is probable that such a perception is widespread and thus inhibits the potential of citizen science in formal learning.

From an informal learning perspective, many citizen science projects claim to support informal learning; however, in many instances they are structured hierarchically, following a top down approach. Here a Principal Investigator (PI) takes on the leading role in the project, using volunteers not as partners but as an unpaid workforce [22]. Thus it is questionable whether such projects will enable volunteers to have a meaningful impact in the way they would envisage [50]. Crall [14] encourages certification in particular skills as this demonstrates commitment and improves volunteer retention; however, the primary motivation here is the demonstrable improvement in data quality, a perceived weakness in many citizen science initiatives, and a fundamental motivation for developing Citizen Observatories.

Three levels of learning have been identified [37]:

1) Project, that is the science motivating the project;
2) Task, that is the mechanics of making an observation;
3) Community, that is, peer to peer learning.

In terms of learning outcomes, there is limited research. Jordan [35] reports that participants increased their knowledge of invasive species but participation did not affect their understanding of how scientific research is conducted. In general, the process of just making observations tends to increase knowledge [21] [61]. Crall [13] found no improvement between tests administered before and after a one day program; however, improvements in science literacy and knowledge using context-specific measures were found.

Though citizen science harnesses a range of technologies in pursuit of its objectives, it is not necessarily the case that all of the scientific and learning activities take place in a real world environment. There exists significant interest amongst the scientific community in the collaboratory construct [43]; here, scientific researchers can come together to undertake research irrespective of their physical location, and have access to a range of online tools and services to facilitate research and collaboration. Remote laboratories seek to enable similar objectives and may also be used for educational purposes [57]. FieldScope, an online platform for citizen science developed by the National Geographic Society, would incorporate aspects of a collaboratory [52].

5 The Citizen Observatory

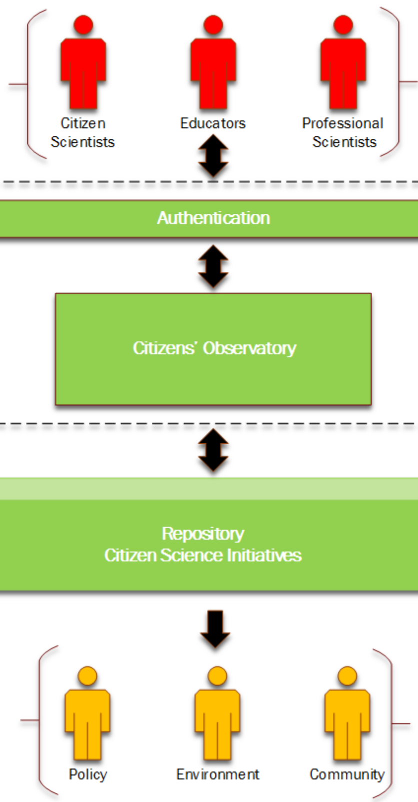

Fig. 1. Abstract model of a Citizens' Observatory

It must be stated at the outset that there is not an agreed definition of a Citizens' Observatory. What follows is a brief description of the salient characteristics as perceived by the authors. For an alternative, though not necessarily conflicting viewpoint, the interested reader is referred to Wehn & Evers [64] and Liu et al. [41]. The term Citizens' Observatory is synonymous with environmental monitoring and governance in many instances including this discussion; however, it should be noted that it can also be used in other contexts including health, security and human rights. Citizens' Observatories are multi-faceted constructs - Figure 1 illustrates an abstract model of just some potential stakeholders. They may be regarded as one interpretation of a Centre for Citizen Science [7] that enables the creation, management and synthesis of repositories of volunteer-collected data. Many projects operate independently, producing datasets that could, potentially, be of great use to a variety of constituencies. The Citizens Observatory enables a framework through which projects could be coordinated and their datasets made publicly available.

A Citizen Observatory may also be considered as a Geospatial Cyberinfrastructure [68], a combination of computational resources, geospatial technologies and services that bring people together to undertake science, in this instance citizen science. In this view, it may also be perceived as a kind of portal for citizen science projects, much like other initiatives, for example, GalaxyZoo[2].

5.1. Motivation

The increased proliferation of smartphones suggests they are viable platforms for gathering data for extended periods both spatially and temporally. As such, the potential volunteer base is potentially enormous but how this can be effectively utilized remains to be seen. A second motivation was the realization that resources are usually limited in citizen science initiatives and this invariably involves adopting suboptimal ICT tools. Invariably, the fit-for-purpose of such tools is questionable and may incur hidden costs such as poor usability and limited functionality [65]. A third, and the most important, concerns the notion of active citizenship. Citizen Observatories seek to enable citizens taking an active role in the stewardship of their environments, in conjunction with other interested organizations, including local government and NGOs.

5.2. Objectives

Citizens' Observatories focus on the data collection and dataset publication exercises, but not to the exclusion of analysis, visualization and so forth. The objective is to produce a dataset that enables its genesis to be determined in a multiplicity of dimensions. This addresses a key limitation of many existing projects that labor to produce large and extensive datasets; however, if the provenance and quality of the data records comprising a dataset cannot be determined, it cannot be fruitfully used in environmental governance for example, and its potential use elsewhere is severely compromised. The objective is to deliver a singular platform that encapsulates the necessary functionality to deliver such datasets. At a minimum, such functionality includes user and access management, support for the easy incorporation and

[2] http://www.galaxyzoo.org

conflation of heterogeneous data sources, data management, quality assurance, and data publication. In principle, such functionality could be realized through harnessing a number of technologies - cloud services for example. However, the core objective of ensuring that a Citizen's Observatory can be deployed in as wide a variety of situations as possible does curtail what technologies can be used in practice. Open-source solutions are of course attractive; however, it must be remembered these frequently occur a cost in terms of lack of technical support, limited documentation and so forth.

5.3. Stakeholders

Three key stakeholders must be supported:

1) The Principal Scientist or Investigator is responsible for defining the broad parameters of the study, prioritizing the objectives of the initiative and ensuring that the protocol for data capture by the participating citizen scientist is sufficient to meet these objectives. When a custom-made App is required for example, it is their responsibility to commission it, and ensure it is fit for purpose. Should a study have an educational objective, then a teacher would adopt this role.
2) The Citizen Scientist will volunteer and register for the project of interest to them. Information concerning the project in question, its motivations, objectives, prerequisites for participation and the protocol for engaging must be available. On agreeing, they may download the necessary App or access a protected WWW site, and proceed to contribute. In an educational study, students will adopt this role.
3) External Stakeholders may include scientists, NGOs, government agencies, amongst others. They may have an interest in harnessing the data for a variety of purposes, most of which will not have been envisaged originally. Such a development may of course give rise to additional security, privacy, legal or even ethical issues. It is the Principal Scientist's responsibility to ensure that these issues are addressed satisfactorily within prevailing legal frameworks and comply with the ethical norms of the governing institution.

5.4. Citizen Observatory Projects

Five projects designed to illustrate and validate the Citizen Observatory construct are ongoing (Table I). CITI-SENSE [5] is primarily but not exclusively concerned with health, focusing on the monitoring of air quality in urban environments. WeSenseIT focuses on the crucial issue of water monitoring [38]. CitClops is also concerned with water monitoring but in an ocean context [25]. Omniscientis is concerned with the issue of odour, the second highest cause of complaints in France and Belgium, but one that cannot be treated and monitored like a pollutant as it is linked to the human sense [39]. COBWEB [70] focuses on biospheres, ecologically sensitive areas, and is particularly concerned with the issue of data quality [42]. Uniquely, it focuses on delivering an end-to-end solution from App design through to data quality assessment and finally dataset publication in a public repository.

Table 1. Active Citizen Observatory projects.

Name	Topic	URL
CITI-SENSE	Air Quality, Noise	http://www.citi-sense.eu
WeSenseIt:	Citizen Observatory for Water Quality	http://www.wesenseit.eu
Citclops	Water Quality: Coast, Ocean	http://www.citclops.eu
OMNISCIENTIS	Odour	http://www.omniscientis.eu
COBWEB	Biosphere Monitoring	http://cobwebproject.eu

5.4. The Citizen Observatory in the Smart City

When discussing smart cities, a topic that recurs in the literature is that of top-down versus bottom-up approaches. A top-down approach is synonymous with local government and administration, envisaging a suite of technologies harnessed for the efficient management of the city. Top-down would generally be perceived as techno-centric; a weakness of this approach is that it can tend to ignore what is happening on the ground. In contrast, a bottom-up approach is citizen-centric, and enables the delivery of solutions that address local issues. As articulated by Wolf et al. [67], for a bottom-up approach to become a reality, citizens must possess the skills to capture, interpret and exploit urban data that continuously increases in quantity and complexity.

Though technological artefacts, Citizen Observatories can contribute effectively to both top down and bottom-up approaches. As citizen-centric, they are a particularly apt solution in bottom-up scenarios where they can enable citizens gather data in a scientifically verifiable way thus informing local decision making in a transparent and credible fashion. For local government, sponsoring citizen observatories offers an effective means of monitoring the policies they pursue; it allows them, in a verifiable fashion, to assess what is actually happening on the ground. In this way, the Citizen Observatory can at least partially contribute to the grand challenge identified by Giovannella et al. [28] in that it can enable a fusion of the functionalist top-down approach with that of the more people-centric bottom-up approach. In this way, motivated and sustainable Knowledge Building Communities [46] can be enabled.

6 Design & Implementation of a Citizen Observatory

The Citizen Observatory inherits many of the advantages (and disadvantages) of learning through the citizen science paradigm, and the scope for learning is only limited by the nature of the project itself. Nonetheless, a number of advantages could potentially accrue from using an observatory-based approach. In particular, it is possible to engage students at the early stages of the process where the all-important definition and validation of the scientific protocol will be undertaken. Significant scope for learning exists here, and it may serve as an opportunity to introduce students to the broader area of ethics and legal frameworks, amongst others. From an ICT perspective, scope exists for enabling students design, implement, test and document their own Apps, as well as exploring sensor technologies. For an educator, the potential to expose students to small but practical longitudinal studies also exists.

The following discussion is influenced by the authors' experience as part of their engagement with The Citzens' OBservatory WEB (COBWEB)[3] one interpretation of a Citizen Observatory that specifically seeks to address the needs of those resident in, visiting or managing biospheres. Focus is directed on one aspect of this endeavor, namely, how a sensor network deployed as part of an Observatory may be harnessed in a formal learning context.

6.1. Background

In brief: biosphere reserves are geographic areas that seek a sustainable balance between biodiversity, economic development and cultural activities. Reserves are designated by UNESCO; at present, the World Network of Biosphere Reserves (WNBR)[4] comprises 651 reserves in 120 countries. Biospheres consist of three zones: a core zone comprising a protected ecosystem; a buffer zone that surrounds or adjoins the core zone; and a transition zone that fosters sustainable economic and human development. Conservation, Development and Logistic support are the three pillar inter-connected functions of an arbitrary biosphere. Training and education activities come under logistic support, and occur in the buffer and transition zones. Human activity is fundamental to sustainable biosphere management and development; biosphere designation is not meant to curtail human activity nor does it place additional constraints on such activities. However ensuring sustainable development invariably demands education and training for residents of the biosphere in the first instance.

Biospheres are synonymous in many people's eyes with rural and remote geographical regions; this is a misconception. Urbanisation affects biodiversity in many ways; consider that many cities are located near coasts or major river systems. Inevitably, land cover changes are the predominant influence in biodiversity. Many biospheres include urban areas or are located near major cities. Urban biospheres [63] were conceived in response to the realization of the need to foster the development of urban ecosystems and improve environmental governance. Yet the biosphere construct is an evolving one and, within city contexts, may be regarded as a tool for sustainable urban management [20]. Education and training are fundamental. Values and ethics are also indispensable components; however, these can be seen as advocacy rather than educational making their incorporation into formal curricula potentially difficult [2].

6.2. COBWEB – Functional Design

Figure 2 illustrates the generic functions undertaken within a Citizens' Observatory, and of course COBWEB. Each of these is now briefly elucidated.

1) Survey Definition: Fundamental to citizen science is the notion of a survey, what it is that a particular project is concerned with, for example, species

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[3] https://cobwebproject.eu

[4] http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves

sightings. Characteristics of a survey must be defined including its geographic range, data management policies, participant selection and so forth.

2) Data Conflation: Data can frequently be conflated with other data to make it more valuable. One example is that of conflating an observation made by a citizen scientist with the prevailing weather conditions near the time of observation. Prevailing contextual data can be linked to a citizen's observation in a transparent manner. Likewise, using GPS data to augment an observation is a frequent occurrence in citizen science Apps; however, ethical, privacy and security issues must be considered in this, as in all cases.
3) Quality Assurance: This allows for the augmentation of data with a quality metric. All observations can be assessed using a range of techniques, and a cumulative metric calculated that gives an indication of the quality of the recorded data [42]. The degree to which Quality Assurance can be undertaken will be specific to the survey in question. However, it must be stressed that a lack of quality assessment means that the data is of limited use to third parties, and renders it unfit for registration in public catalogs of datasets.
4) Access Control: A federated approach [18] to security is adopted in COBWEB. This allows citizen scientists to work in different biospheres or on different projects within the same biosphere using the same credentials. In some categories of project, knowing who made an observation is of crucial importance as their identification, and implicitly expertise, can be fundamental is assigning a quality metric to an observation.
5) Multi-resource Data: COBWEB supports the integration of third-party Apps as well as the definition of custom Apps for an arbitrary survey. However, it also comprises protocols for the capture of data from physical sensor networks as well as from social media streams.
6) Data Publication: Fundamental to Citizen Observatories is the understanding that the resultant dataset will be made publicly available for visualisation, consultation and consumption by other interested parties (including educational establishments). Exceptions include datasets concerning species that are protected by law. Datasets will be made available via GEOSS[5], the Global Earth Observation Systems of Systems.

[5] http://www.earthobservations.org/geoss.php

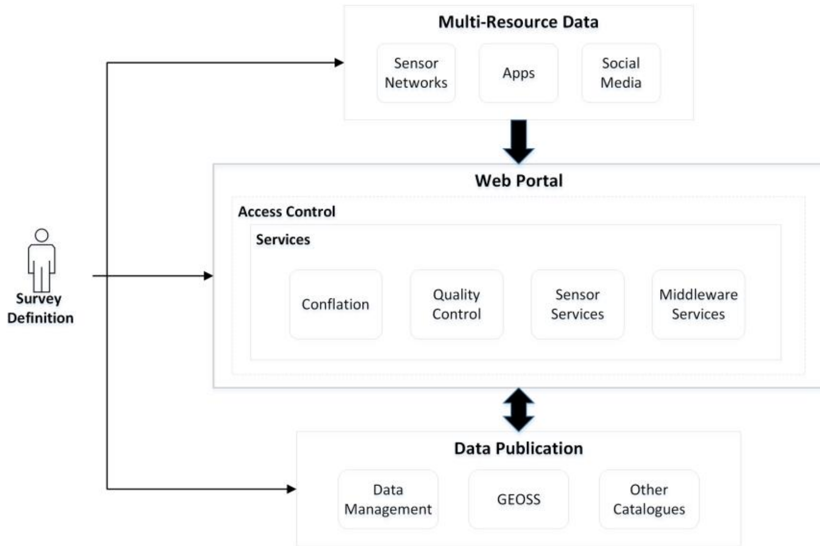

Fig. 2. Functional Architecture of a Citizen Observatory

6.3. Implementation

COBWEB is realized as a web portal where both the definition and management of surveys is undertaken; the portal also incorporates a suite of services that deliver the functionality described in the previous section. A variety of technologies, including open-source frameworks have been harnessed. For example, GeoNetwork[6] is a key enabler of portal functionality, and SIXTH [47] has been adopted as the sensor middleweight platform. Where appropriate, Open Geospatial Consortium (OGC)[7] web services are being harvested, including the Sensor Observation Service (SOS)[8] for data publishing, and the OGC catalog service (CSW)[9] for publishing search and querying the associated metadata.

7 Enabling Learning through a Citizen Observatory

At the time of writing, COBWEB is being validated in the Dyfi biosphere in Wales. A number of local amateur science groups have been given access to the COBWEB platform and asked to use it in the definition, monitoring and management of their own citizen science initiatives. Feedback from this endeavor will drive a subsequent iteration of design and development as part of a co-design process. As this is partially a testing exercise, data is not being released into the public domain via the COBWEB protocol though of course it may be in the future.

[6] http://geonetwork-opensource.org
[7] http://www.opengeospatial.org
[8] http://www.opengeospatial.org/standards/sos
[9] http://www.opengeospatial.org/standards/cat

Part of this validation exercise involves the deployment of a sensor network throughout the biosphere. This network has been designed in consultation with a range of local groups who are active in monitoring a variety of ecosystems in the biosphere. It consists of a range of sensor platforms, most of which are connected via telemetry to the internet. A suite of weather stations constitute the core of this network, and these are augmented with a variety of other sensors including, for example, some for salinity and water depth measurement.

7.1. Ysgol Bro Hyddgen

Ysgol Bro Hyddgen is a bilingual school in Machynlleth in the heart of the Dyfi biosphere. It has engaged with COBWEB as part of its educational and community outreach mission. In the former case, the emphasis is on STEM activities and how material discussed in the classroom can be applied in the real world; in the latter case, seeking to ensure the sustainability of the biosphere going forward is of utmost importance. Habitat monitoring is a common activity across the biosphere and students collaborate with local groups in this endeavor. Specifically, they use Apps developed as part of COBWEB to gather data, under the supervision of their teachers and in collaboration with experienced citizen scientists. This data is subsequently analyzed in the classroom. The strategic location of the school makes it ideal for hosting one of the weather stations that comprise part of the COBWEB sensor deployment. The station is connected to the internet via the school WiFi network (Figure 3). Staff and students have access to data via a local console display, an embedded web server and the internet. Data can be downloaded in a variety of formats by staff and students. The model hosted by the school is a Davis Vantage Pro2 Plus model[10]. It consists of a solar powered range of sensors for measuring rainfall, temperature, humidity, wind speed and direction, UV and solar radiation. Such data can obviously be used in a wide variety of teaching scenarios, and in cross curricular contexts. It also allows topical subjects such as global warming be considered from a practical perspective. Capturing such data over extended time periods and harnessing it in lessons. Initial feedback indicates that live, localized weather data can be particularly useful for those students who may struggle with reading and understanding graphs.

7.2 Implementation

A number of surveys have been designed and the corresponding App implemented by school staff. These are then hosted on school devices and given to students before field trips. Using the COBWEB infrastructure, data collected by each student is stored and can be subsequently visualized and analyzed by the students on school workstations. A detailed description of the COBWEB infrastructure is beyond the scope of this discussion and the interested reader is referred elsewhere [50]. The sensor case study is compact and can be elaborated on briefly.

Sensors, such as those deployed at Ysgol Bro Hyddgen, are made accessible to the COBWEB Data Conflation and Quality Assurance sub-systems through the use of SIXTH Adaptors. SIXTH offers a middleware solution for the management of sensor networks that are inherently heterogeneous. SIXTH Adaptors mitigate the

[10] http://www.davisnet.com

issue of heterogeneous sensor devices, and simplify the process of adding additional arbitrary sensors to support the observations occurring within the biosphere. Heterogeneity can occur in multiple dimensions, for example communications, power source, operating system, data protocol and so forth. It is noted in passing that, from a SIXTH perspective, a person carrying a mobile device is regarded, conceptually and technically, as a mobile sensor platform. Adaptors are a popular software engineering approach to countering the problems that arise due to heterogeneity. They enable a homogenous view of data at a higher layer in the software stack. This data homogeneity then allows for the development of small SIXTH applications/components to expose and export data to the subsystems using standards such as the OGC Sensor Observation Service (SOS) and JavaScript Object Notation for Linked Data (JSON-LD). The Davis Vantage Pro2 Plus model is attached to a Meteobridge[11]. This acts as a local Base Station, routing data via a router to the internet. Data is imported into the COBWEB framework via a middleware service (SIXTH). It is also streamed to the Weather Underground[12] and in this way, made available to the local community.

The weather station used in this instance is a relatively sophisticated model chosen for a variety of technical and scientific reasons. It must be observed that there is a range of weather stations available in hobby outlets, many of which have been used by weather enthusiasts and which could also be harnessed for educational purposes. These and other sensor platforms have come down in price in recent years and are within the budget of many schools and citizen science communities.

7.3. Ongoing Developments

At the time of writing, sensor deployments are ongoing in the biosphere and testing of the COBWEB toolkit is ongoing. Integrating legacy sensors, which are available via public and documented APIs, is an ongoing process. In the case of the school deployment, it is envisaged that it will be augmented with an additional sensor platform, possibly one dedicated to monitoring air quality. For many, sensor technologies remain somewhat esoteric and are the preserve of the professional scientist. In line with ICTs in general, costs continue to decrease making sensing technologies increasingly affordable. However, many of the tools supporting sensors and sensor networks do require a degree of expertise on the part of the user. A Plug and Play approach to sensor technologies is still some way off although developments in the Internet of Things (IoTs) may result in a long term sustainable solution. Going forward, standardization issues will become of increasing importance; requirements such as interoperability, extensibility, scalability and so forth must be supported. Preliminary work is being undertaken by the Open Geospatial Consortium (OGC)[13] in developing a profile for citizen science; however this work must accelerate in the near future and involve additional standardization organizations.

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[11] http://www.meteobridge.com

[12] http://www.wunderground.com/cgi-bin/findweather/getForecast?query=52.591373,-3.853940

[13] http://http://www.opengeospatial.org

Monitoring of staff and student activities from a teaching, curricular and extra-curricular perspective, as influenced by both the school and biosphere sensor deployments, will continue over the coming academic year. It is envisaged that new opportunities for integrating citizen science into curricula will emerge. Furthermore, it is hoped that a more sustainable approach to education with the biosphere though more formal service learning approaches will be enabled. Identification of best practice principles for the harnessing of Citizen Observatory frameworks for educational purposes will have implications for all other biospheres in the world network, inclusive of urban biospheres.

Fig. 3. Weather station node located within school grounds.

8 Conclusion

Though Citizen Observatories are novel constructs aimed primarily at citizen science communities, nonetheless, significant potential exists in the broad education sphere. Up to now, case studies demonstrating the successful integration of citizen science into a formal curriculum are limited. Citizen Observatories offers an infrastructure that can be harnessed in formal education, enabling a formal, structured and scalable environment for incorporating citizen science into mainstream curricula.

From a smart city perspective, citizen observatories can act as validators for top-down approaches and enablers of bottom-up designs. More research is needed to assess how Citizen Observatories can best support educational activities, as the construct itself remains fluid. Pedagogical challenges remain - a participatory pedagogical approach, possibly involving a service learning component, would seem a promising option in this regard.

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