Citizen science: An opportunity for learning in a networked society

Introduction

Most scientific advances in the current era, are achieved by participants of "Big science" - professional scientists working in scholarly institutions communicating mostly through professional journals and conferences (Lievrouw, 2010). Communication and information technology enhances public participation as contributors to big science (Del Savio, Prainsack & Buyx, 2016). At the same time, technology increases accessibility of both data and tools to the public (e.g. Bizer, 2009; Teacher, Griffiths, Hodgson & Inger, 2013). This enables and supports science as a serious-leisure activity (Stebbins, 1997), with communities of amateurs working together. Web2.0 which allows multidimensional communication enhances interactions between individual, communities of serious-leisure-amateurs and scientists affords the return of science communication based on personal interactions a.k.a "Little science" (Lievrouw, 2010).

Citizen Science (CS) projects include projects in which citizens assist "Big Science" in gathering and interpreting data (Bonney, Cooper, et al., 2009) as well as projects in which scientists provide answers to citizens' concerns (Irwin, 1995) and engage in dialogue with the public (Bonney, Phillips, Ballard, & Enck, 2015) as in "Little Science". Many projects are targeted at advancing science, but a large portion have additional goals of supporting public science education, science communication and evidenced-based decision making (Golumbic, 2015). The resultant diversity of participants and ways of participation, such as scientists who initiate or aid the research, volunteers, informal and formal education trainers, teachers and students (e.g., Crall et al., 2012; Kountoupes & Oberhauser, 2008) leads to complex relationships and influences of all related parties. We refer to these interactions and relationships as "the ecology of CS".

Participants in the ecology of CS includes, in addition to individual participants, groups of volunteers. Such groups may assemble around a specific project (i.e. cleaning a local body of water) thus forming a task learning community or around a specific interest or hobby as practice based or knowledge building based communities of learners (Reimann, 2008). Based on Elhanati (2007), participants who join practice based learning communities around CS projects as serious-leisure gain recognition and self-representation. However, additional questions arise regarding participant learning processes and outcomes. Do they also learn from the interactions among themselves and with professional scientists? What do they learn from these interactions? Can similar, or different learning happen when CS is brought to schools (Feinstein, Allen & Jenkins, 2013)? Does learning relate or depend on the type of project people participate in?

CS projects are often divided to three categories according to level of engagement (Bonney et al., 2009). Contributory projects generally involve simple contribution of information to established research, while collaborative projects introduce citizens to data analysis and interpretation. Co-created projects involve the public in all aspects of the research process (Bonney et al., 2009). These lines of classification resemble similar typologies suggested in the field of science education. For example, ranking of the development of an inquiry-based science program embraces several different approaches according to the level of students' engagement: structured inquiry, guided inquiry, open inquiry, and learning cycle (Colburn, 2001).

CS projects typically involve the collection of large amounts of diverse types of data (Gould, Johnson, Moncada-Machado, & Molyneux, 2015) involving different types of uncertainties, these large sets of mixed data are referred to as 'big data' (reference?). As the analysis of 'big data' requires the combination of computational with statistical techniques, a new interdisciplinary field named 'data science' has emerged, which enables the extraction of knowledge from big data (Hardin et al., 2015). Data science can be a useful tool if applied in scientific and CS inquiry, as the means to analyse big data. As such, both fields of statistical and science education can be helpful in informing the design of such projects that involve non-experts. Some of the scientific questions raised in CS are associated with controversial social issues, e.g. environmental and public health problems. Teaching and learning science in the context of such issues is in line with the contemporary vision of science literacy which views the aim of science education as promoting future citizens, rather than solely promoting future scientists (Sadler, 2011). Looking at this reciprocal relation between CS and education we believe that education related theories and lines of research may both contribute to and benefit from the study of CS projects. This relationship extends beyond the fields of science, statistical education, learning communities and the design of the learning environment to encompass the development of interdisciplinary understanding and science communication. In this chapter we review current approaches used to study participation in citizen-science projects and examine educational and learning sciences through lenses that may contribute to deeper understanding of CS ecology.

Current lines of research

Citizen participants learning is most often examined using quantitative methods based on data mining in projects recorded logs and surveys (e.g., Alender, 2016; Crall et al., 2012; Hiller & Kitsantas, 2014). Recently education research methods such as design based research (e.g. Aristeidou, Scanlon & Sharples, 2013; Thompson, Gouvea & Habron, 2016) case studies (e.g. Ballard, Dixon & Harris,2016) start to emerge in relation with CS projects. These are mostly used examining particular groups of participants, mostly students and youth engaged in CS projects as part as their formal or informal education.
[This section will be expanded]

Lines of research stemming from learning sciences and education

Learning communities and networks of practice as frameworks for exploring CS ecologies

There are many types and models of learning communities, all involving learners with diverse expertise with shared objectives and mechanisms of sharing (Bielaczyc, Kapur, & Collins, 2013). Brown and Duguid (2000) refer to the interactions between geographically distant local communities and introduce the notion of *networks of practice*. They recognize the differences between distant communities in terms such as dispositions, attitudes, and knowledgeability and the mechanism of knowledge diffusion among these networks. Cobb and McClain (2006) identify three types of interconnections involved in the process, involving: a) boundary encounters,b) brokers, and c) boundary objects. Boundary encounters take place when members of two or more communities engage in activities together. In other cases, there are members that belong to more than one group and act as brokers among them. The third form - boundary object - is an activity or resource that bridges between networks and communities. In the ecology of CS such encounters can be recognized in the community of scientists collaborating with citizen-participants when the design of the project serves as a boundary objects (e.g., the processes that take place in the Foldit Project, 2015).

Participating citizens may work together and form small groups (e.g., Kountoupes & Oberhauser,2008) or collaborate after attending training workshops (e.g., Crall et al., 2012), in which trainers may act as brokers. In the context of formal education we envision, in addition, learning communities of teachers working together (Reimann, 2008) and then having boundary encounters with their students.

Science literacy and engagement in socio-scientific issues

Some of the scientific questions involved in CS are associated with controversial social issues. Such issues are referred to as *socio-scientific issues* and include, for example, environmental and public health problems. Teaching and learning science in the contexts of socio-scientific issues is in line with the contemporary vision of scientific literacy, which views the aim of science education as promoting future citizens, rather than promoting future scientists (Sadler, 2011). Some researchers (e.g., Hodson, 2003) have taken this concept further, arguing that science education should prepare the individual toward socio-political action. Hodson (2003) proposes four levels of scientific literacy in which the highest level is anticipating and preparing to take action. Hodson defines feelings of ownership and empowerment as central keys needed for translation of knowledge into action. Following Hodson's claims, it is likely to assume that higher levels of engagement and participation in CS projects will promote the development of scientific literacy and active citizenship.

Interdisciplinary understanding

Preparing students to take informed positions on complex problems through critical evaluation is considered an important aspect of scientific literacy (Sadler & Zeidler, 2009; Roberts, 2007). In approaching contemporary problems, the ability to understand and position oneself in interdisciplinary issues is essential (Boix Mansilla & Duraising, 2007).

In recent literature, the pedagogical framework of socioscientific issues (SSI), which integrates science concepts and their social significance, involving students in a community of dialogue, discussion, and debate, has been established as effective for students to develop their reasoning with the types of issues described, as well as content knowledge (Sadler, 2009; Zeidler, Sadler, Applebaum, & Callahan, 2009). The goals of the SSI movement overlap significantly with those of university educators as well as K-12 teachers to help students learn to integrate disciplines to responsibly approach real problems. Much of the literature on SSI has concentrated on decision making for citizenship, however, fluency in discussing socioscientific issues and integrating perspectives from different disciplinary fields will be especially important for those entering fields that will tackle problems like climate change and epidemics (Thompson Klein, 1990). More research is needed into effective learning contexts for developing socioscientific reasoning and integration of different perspectives into decision making.

Statistical education

CS projects often involve the collection of large amounts of diverse types of data. Data Science is the interdisciplinary field which enables extracting knowledge from such data (Hardin et al., 2015).

The growing number of CS projects that involve scientific inquiry, brings to the forefront the value in statistical reasoning. People are not always aware of the benefits they can gain from vast amounts of available data. Furthermore, when Data Science is applied in CS inquiry, handling various sources of uncertainty due possibly to sample size or repeated measurements is inevitably involved. Such uncertainties might lead people to doubt the reliability and validity of scientific inferences. In societies that become more and more technological, individuals should be able to make educated decisions related to scientific issues that affect their personal lives (e.g. causes and effects of air pollution and related policy). Making such decisions requires statistical understanding of the scientific process.

Statistical educators have focused recently on students' Informal Inferential Reasoning and on fruitful pedagogical approaches to assist learners handling the uncertainties involved in making Informal Statistical Inferences (Colleagues & AuthorB, 2011; Pratt & Ainley, 2008). Research suggests that engaging learners in carefully designed Exploratory Data Analysis learning environments develop their inquiry skills (AuthorB, 2006; Colleagues & AuthorB, 2011) and that model-based learning can assist learners in quantifying uncertainties that are involved in the process of making inferences from data (AuthorM et al., 2015; Pratt, 2000). Statistics educators and researchers (e.g., Garfield & Ben-Zvi, 2009) also recommend the use of several key features of the statistical reasoning learning environments, such as: Investigating an authentic and meaningful phenomenon and integrating the use of appropriate technological tools.

CS projects typically involve big data (Gould, Johnson, Moncada-Machado, & Molyneux, 2015) characterized with large amounts of diverse data that is rarely collected through random sampling and therefore may involve different types of uncertainties. These uncertainties challenges current pedagogical approaches, which will have to be refined in order to assist and develop citizens' inferential reasoning in the context of explorations of scientific data sets.

Most of the statistical analysis in CS projects is done by scientists, however engaging citizens in the statistical investigative phase provides an opportunity to develop participant statistical reasoning. Building bridges between two areas of research: CS and statistics education might be an important step in understanding the statistical skills needed for participating in CS projects. Identifying pedagogical key ideas that supported the development of students' uncertainty reasoning while taking into account the unique characteristics of data involved in CS projects will lead to the development of fruitful ways for developing statistical reasoning in educational CS projects.

Design research

Previous studies have shown that collaboration between scientists and citizens is difficult to obtain (Mueller et al., 2012), especially as their interests and goals may not be conveniently aligned (Zoellick et al., 2012). Louv & Fitzpatrick (2012) describe the tension between different objectives of a CS project as a tradeoff: allocating more weight to one objective (e.g., advancing science) necessarily reduces the weight given to others (e.g., providing science education). In ecological systems such a win-lose relationship is called competition, which is hardly the desirable effect for a CS project. A more productive model would resemble mutualism, an ecological relationship in which each participant benefits from the activity of the other. While few CS projects seem to achieve "mutualism" (e.g., Gray et al., 2012), many fall short of this goal or work around it (e.g., Zoellick et al., 2012). According to Alender (2016), taking into account the interests of participants when designing a CS project may lead to higher quality of participation while encouraging larger quantities of participants thus accounting for scientists interests (Shirk et al. 2012) and achieving "mutualism".

Design plays a major role in education (Goodyear 2015, Laurillard 2012) leading to the development of the design based research (DBR) methodological approach. DBR is a research paradigm that is gaining more and more interest in education and the learning sciences, specifically when innovative design is involved. Sandoval describes the goal of design research as "to create novel conditions for learning that theory suggests might be productive but are not common or well understood" (Sandoval, 2014, p. 22). Studies based on this paradigm commence with a theoretically grounded design of an innovative learning environment, followed by iterations of intervention, in which the design is enacted in a naturalistic setting, and refined, based on analysis of data collected during the intervention. Thus, DBR is contextual, interventionist, iterative and is committed to a dual purpose - advancing theory while improving practice (Barab & Squire, 2004; Collins, Joseph, & Bielaczyc, 2004; Kali, 2008; McKenney & Reeves, 2012).

The integration of design and research to improve instruction, occasionally takes place in higher education contexts. Instructors in these cases (typically education researchers), design and research their own courses using a DBR approach (e.g., Bergroth-Koskinen & Seppälä, 2012; Kali & Ronen, 2008; Sagy et al., 2016) or other research methodologies (e.g., Barak & Dori, 2009; Ellis, Goodyear, Calvo, & Prosser, 2008; Hod & Ben-Zvi, 2014). In K-12 settings teacher-researchers (e.g., Cochran-Smith & Lytle, 1999) and teacher-designers (Shamir-Inbal et al., 2009) practices are gradually becoming more common, but normally, teacher-designers do not systematically study the enactments of their own designs. Still there can also be found cases in which teachers customize TEL environments based on systematic exploration of their students' data that is automatically recorded by the technology (e.g., Gerard, Spitulnik, & Linn, 2010), or cases in which the design is enacted as part of an academic research (e.g., Tal, Kali, Magid, & Madhok, 2011).

When looking at CS projects that view education as an important aim, DBR may prove useful for studying the learning while refining the design of the project. Indeed there are a few studies in this approach. Thompson, Gouvea & Habron (2016) use the method to study the activity of learners in an interdisciplinary setting. Aristeidou et al. (2013) are using DBR to explore "Inquiring Rock Hunters" a project combining CS with inquiry-based learning. As this is a new trend, most of these studies have not yet been published.

Science communication

Providing scientific information, exchange of knowledge and experience and engaging the public in science, stand in the bases of science communication field. The models of science communication can be typically divided into two sub-groups: models emphasizing knowledge transfer, and models emphasizing public dialogue. These two sub-groups are fundamental for the research of citizen science projects and will further be described as Public understanding of science (PUS) and Public engagement with science (PES), respectively.

According to Haywood and Besley (2014), elements of these two theoretical traditions have influenced citizen science while emphasizing different objectives and leading to diverse outcomes in citizen science projects. PUS focuses on educational outreach and learning opportunities for the public. PES aims at democratizing science, determining public desires and needs, encouraging transparency and encouraging collective decision making. Although citizen science projects have similar goals and potential outcomes as many science communication initiatives, few studies have investigated the relationship between the two fields. Furthermore, the majority of studies published under the subject of citizen science, have not emphasized the approach of science communication, but rather scientific or educational approaches. Nonetheless, many successful CS projects incorporate science communication within their platforms and provide participants with scientific information in the form of blogs, videos, newsletters or reports (Golumbic, 2015). This form of transferring information from scientists to the public, referred to as PUS, was traditionally thought to increase positive attitudes towards science (Brossard & Lewenstein, 2009). However, this was not empirically proved (Bauer, 2009) nor has it shown to induce behavior or attitudes change (find ref!).

CS is more than a transfer of information. CS projects aim to involve many people in structuring new scientific knowledge. Although participant are not necessarily involved in all stages of the research, they make a huge impact on the construction of scientific knowledge. Participants can also direct the study to new destinations and detect rare phenomena (e.g., species or unexpected findings) that might have been overlooked by scientists (Dickinson et al., 2010). An example for this, is the discovery of new astronomical objects named "green peas" by volunteers in galaxy zoo

(Clery, 2011). Thus, CS is contributing to public engagement in science, and creating a dialogue between scientists and the public. Applying the PES approach in CS projects may therefore benefit both scientists and public, as it assists in creating useful, valuable and relevant contributions to scientific discussions and decisions (McCallie et al., 2009).

Combining elements of all traditions of science communication into CS practice, can achieve both social and educational goals as project outcomes and expand the benefits of all participants of the CS ecology.

Additional lines of research that may be relevant

זה המקום העיקרי בו נשמח לתרומות

Summary

How CS can benefit from the wealth of research lenses and how can CS contribute to these fields of study

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