Enhancing Informal Learning Through Citizen Science – Background Literature

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Introduction

Citizen science has grown significantly as an area of activity around the world with many different models of practice and forms of participation. Citizen involvement in science can be seen as part of a long history of the role of the amateur in science. Research in the USA and UK suggests that citizen science has a powerful potential to support participation in and the learning of science. Increasingly, research has sought to explore and measure the development of 'science literacy', science identity and learning outcomes through citizen science. The scale, focus, and organisation of projects have been demonstrated to influence who participates in them, the scientific achievements, and what contributors learn. Such work has led to Phillips *et al* (2014) *User's Guide for Evaluating Learning Outcomes From Citizen Science*. This builds upon earlier work, which identified various learning outcomes associated with different approaches to citizen science - contributory, collaborative and co-created. The Guide describes empirically defined outcomes for citizen science, such as behaviour and stewardship, skills of science inquiry, knowledge of the nature of science, interest in science and the environment, self-efficacy and motivation.

This paper attempts to locate the work on learning through citizen science within the wider literature on science education, informal learning and science capital. Such a review is inevitably partial and should be seen as a starting point for further exploration rather than as a definitive statement on learning through citizen science.

Research on attitudes to and participation in science education and careers

There has been around 50 years of research into the attitudes of children and young people in relation to science and school science, much of it derived from survey data in the English-speaking community. The attitudes to science have to be distinguished from the development of scientific attitudes (Gardner 1975). For some (e.g. Bonney *et al*. 2009a), scientific attitudes and dispositions have been displaced by the notion of scientific literacy as an alternative way of framing research. It is also important to remember that different sub-constructs have been used in relation to the overall construct of 'attitudes to science' (Osborne *et al*. 2003). While there are differences in the ways in which the research has been framed, a reasonably consistent pattern of findings emerge from these studies.

Attitudes to science are generally positive among young people, although such views are usually based upon stereotypes of scientists as white, male and wearing white coats (Barman 1997), rather than embracing the full range of professional and entrepreneurial identities and careers pursued by those educated in the sciences. In England and Wales, these positive attitudes are not translated into enrolments in science education programmes, where there has been a steady decline in participation in the core disciplines (Osborne *et al*. 2003). While not all science is necessarily taught within the core disciplines, it would appear that attitudes to science are not therefore necessarily translated into attitudes towards school science.

In wealthier countries, there is little interest among young people, especially girls, in becoming a scientist (Sjoberg and Schreiner 2010). While the destructive elements of science are recognised, the capacity to make a difference and help others through science is significant in terms of positive views. Interest in science outside of school decreases between aged 10 and 16 and there is limited watching of science programmes on television or reading about science among young people (Bennett and Hogarth 2009). The importance of peers in supporting behaviour and attitudes is significant (Osborne *et al*. *2003*). Different sciences are viewed proportionally by gender, with girls tending to associate biology with care and physics with war (Jones *et al*. *2000*). While both boys and girls in Jones *et al*. study perceived science as important, their more detailed views of science were gendered. There is also some evidence that studying science subjects in some countries can be seen as limiting career opportunities and to be culturally less valuable than a more 'liberal' education (Osborne *et al*. *2003*).

Attitudes to school science tend to be positive at the upper end of primary schooling but decline through secondary school education (Barmby *et al*. *2008*). Interest in science would seem to be eroded by school science post-11, with increasing questions of the relevance of the latter. Physics and chemistry are the least popular school subjects post-14 in England. Certain older studies suggest school science is seen as too demanding, while more recent studies indicate it is seen as undemanding or 'dull' (Osborne *et al*. *2003*). There is a mismatch between the school science curriculum, which emphasises the 'great men' of science and their discoveries, and the scientific issues of interest to young people, particularly in wealthier countries (Sjoberg and Schreiner 2010). Rather than learning science, young people are often learning the history of science.

Pedagogy also impacts upon attitudes, with young people most positive when they have a high level of involvement, very high level of personal support, strong positive relationships with classmates, and a variety of teaching and learning strategies is in use (Myers and Fouts 1992, Osborne and Collin 2000). Young people like the practical aspects of science, opportunities for investigation and discussion, but these are not reflected so fully in the curriculum and pedagogy of school science, in particular, secondary school science (Osborne and Collins 2000). Lack of specialist knowledge by teachers and understanding of diverse approaches to teaching can impact upon attitudes (Sparkes 1995, Turner-Bisset 1999). Teachers and their approaches to teaching can make a difference to young people's attitudes (Bennett and Hogarth 2009). Studies show that, towards the end of compulsory schooling, while science is considered important, school science is considered 'boring' (Ebenezer and Zoller 1993). These attitudes impact upon educational and career choices post-16.

Gender and ethnicity impact upon attitudes to issues in sciences and different sciences and careers (Jones *et al*. *2000*, Osborne *et al*. *2003*). Thus in the USA, while more females than males enrol in post-secondary education, in natural sciences and engineering males predominate. A 10 country study (Kotte 1992) found that attitudes widen on moving from primary to secondary schooling, in particular amongst those aged 10-14, with girls becoming more negative, despite achieving better grades in science classes. This is also found in other studies (Bennett and Hogarth 2009, Jones *et al*. 2000). Some research indicates that gender is less significant in attitudes prior to age 10 (Murphy and Beggs 2005). There is some evidence that girl's negative views may not arise out of antipathy to school science, but because they perceive themselves as better at other subjects (Jovanic and King 1998).

Biology is the one area of sciences where females enrol more than males, linked to caring concerns. The gendered experiences of science are also found in the everyday practices of young people, with boys more likely to visit scientific venues and to read scientific work. In their study of 6^{th} grade US children, Jones *et al*. (2000) found that out-of-school activities were gendered, with boys more likely to engage in activities and with objects associated with the physical sciences and girls more likely to associate with those of the biological sciences. Where girls do take up sciences, it is often based upon an affective link with a family member working in the area and on opportunities to engage with science in the everyday in practice or reading or watching science programme on television, what Archer *et al*. (2013) refer to as enhanced 'science capital'. The view that girls are more likely to study physical sciences in a single sex environment is not sustained by evidence (Sharp *et al*. 1996). Ethnic background impacts upon attitudes to science education and careers and may be more significant than gender (Greenfield 1995, Aschbacher *et al*. 2010). In the UK, young people from Asian ethnic backgrounds are more likely to choose medical science related degrees than their white peers, while Afro-Caribbean students are less likely. Asian students are more likely to take a longer-term perspective on interests and be less individualistic.

The consistency of these findings and responses to them has not stopped declining interest in science education and careers. However, there are limits to existing research:

1. The focus on attitudes describes a situation, but does not explain how those attitudes are shaped, in particular the social and cultural factors influencing attitudes (Bennett and Hogarth 2009).
2. The focus on attitudes does not address the issue of what needs to be done to change practices as attitude change does not necessarily result in changing practices (Osborne *et al*. 2003). A focus on attitudes and the demand-side also requires supply-side measures to make science education and careers more engaging. It cannot be assumed to be a good or valued in and of itself.
3. To examine attitudes to science and science education is to homogenise a huge range of differing science, educational and career possibilities. Science is not a single phenomenon but takes multiple forms.
4. Most studies focus on particular national contexts, and patterns of attitude and practice may vary across contexts.
5. The range of different survey instruments used makes it difficult to draw direct comparisons of findings across different studies (Osborne *et al*. 2003).
6. Similarly, different theoretical approaches inform attempts to explain attitudes and engagement e.g. science capital, science literacies, science identity, making comparison difficult.

Some of these issues are addressed through two major studies – the ASPIRE project, based in the UK, and the Relevance of Science Education (ROSE) project, based in Norway. The former seeks to examine the factors influencing young people's aspirations rather than attitudes over time. The latter conducts cross-national comparisons of attitudes. Both point to the complexity of making different aspects of science education and careers attractive to different populations. However, they also point to the possibilities for engaging the everyday interests, practices and relationships of young people in scientific issues to enhance the attractiveness of science education and careers more generally.

The ASPIRES (2013) study is a longitudinal project focused on aspirations towards science and careers among 10 to 14 year olds in England and Wales rather than attitudes. While the young people studied showed consistently high aspirations in relation to their education across the time span, and recognised the importance of science and school science, only 15% aspired to become a scientist. Families are identified as very influential to attitudes and behaviours and the children of those families with most science capital (e.g. qualification and social networks among those working in sciences) are more likely to consider a scientific career. This points to the importance of intergenerational relationships and learning in the engagement with and learning of science. Most families do not understand the diverse opportunities that arise from studying sciences. This study also found similar issues to previous studies in relation to negative stereotypes of scientists, and gender and ethnic factors influencing aspirations. The study importantly added to existing research by positing the importance of a family's science capital to the aspirations of young people. Science capital is a concept derived from Bourdieu's concepts of social and cultural capital through which specific groups acquire and reproduce their positions in society by building and being able to draw upon certain resources (Archer *et al*. 2015). They identify a number of different dimensions of science capital: scientific literacy; scientific-related values; knowledge about transferability of science in the labour market; consumption of science-related media; participation in out of school science learning contexts; knowing someone who works in a science related job; parental science qualification; talking to others about science outside the classroom. Some of these are capable of being operationalised as interventions to enhance science capital and impact upon engagement and learning.

Parental attitudes and the encouragement of science in everyday family life, such as activities, television, books, topics of conversation, and social networks, impact upon aspirations (Archer *et al*. 2012), although this is not straightforward (Atherton *et al*. 2009). This is something also found in PISA data (OECD 2012), which indicates a link between participation in extra-curricular science activities and positive attitudes to science education. Archer *et al*. (2013) produced a typology of different family relationships to science:

1. 'Science Families'- families in which science is strongly embedded with a pro-science child (all White and/or South Asian families, predominantly upper-middle/middle class).
2. 'Doing it for the Kids'- families with no pre-existing science interest, but who have taken up science and embedded it in the family to support strong the child's interest (mostly White/English and middle class).
3. 'Pushing Science'- Families: strong family science interest/capital, lesser child interest (predominantly White middle-class, minority ethnic (ME) working class/middle class).
4. 'Pragmatic Persisters'- child has no particular interest in science but a plan to continue with it in order to actualize a particular aspiration (minority ethnic families).
5. 'Raw'/'Unrefined'Interest- an enthusiastic child with a high personal interest in science, but whose family has low science capital and/or interest (mostly White, working-class families).
6. 'Doing not being'/'Interested but… '- families in which there is some interest and capitals in support of science and the child has strong interest in science and engages for pleasure in own time, but does not want to be a scientist or does not aspire to continue with science in the future (range of ethnicity, class, and gender).
7. 'Science as Peripheral'- families and children with some interest in science, but it is weakly embedded and weakly supported by capitals (mostly White and Black working class).

8. ‘Science as Irrelevant’- families and children with little or no interest or engagement in science (all White working-class girls).

From a small sample of 14 year olds, Archer *et al*. (2014) also identified sources of influence on young people’s aspirations, which included: family member/s with same job, family friend or neighbour with same job; family push/steer (no direct contacts); interest developed through hobby/out of school activity; television; school; general interest (no specific direct experience); and money (job perceived to be well paid).

The implications drawn from this study are:

- Current approaches on raising aspirations in general or interest in science are not working.
- Interventions are needed in primary school, while most tend to focus on secondary school.
- Interventions need to be with families and not simply aimed at young people in order to make science education and careers more ‘thinkable’ within the family habitus, recognising the diversity of family type and the need to address inequality (Archer *et al*. 2012). This suggests the focus and organisation of specific interventions require tailoring to different groups.
- The notion that there is a straightforward link between learning science and being a scientist needs to be replaced by the idea that learning science can lead to many different careers.
- Careers education for young people and families need to be improved.
- Stereotypes need to be addressed and challenged by all involved, including the media.
- Science capital, drawing upon the everyday interests, practices and relationships of young people and their families need to be built to enhance engagement and identification with science education and careers. Engagement with science may be extrinsic i.e. linked to other goals, rather than intrinsic i.e. arising simply from an interest in science.
- Post-school opportunities for studying sciences within a wider range of programmes needs to be explored.

The ROSE project is a 40 country collaborative study of attitudes to science of those aged up to 15, based upon the use of shared instruments (Jenkins and Nelson 2005, Sjoberg and Schreiner 2010). Not all sampling was consistent. Overall, there is recognition of the importance of science and technology to society by children. However, there is more negativity and scepticism about the benefits of science among young people than adult populations in the richer countries and also among more girls than boys. In wealthy countries, young people are not enthusiastic about school science, especially girls, and are less interested in learning science topics than young people in poorer countries. Topics often on school curricula are of less interest to young people in richer countries. Environmental issues are important for all, but more so for girls.

Drawing from the existing research:

1. There is consistent concern that declining numbers taking science programmes in many countries results, despite the economic and cultural importance assigned to science education and careers, in a self-fulfilling prophesy, as there are less

graduates and less able graduates to become teachers and researchers in science. This contributes to the lack of attractiveness of sciences to young people. There is a need for school science and careers to be more effectively promoted across society, which may entail focussing on the opportunities lost as well as the more positive gains of studying sciences (Simpson and Oliver 1990). However, this needs to take account of the need to address different audiences, including different family types.

2. Everyday and extra-curricular activities impact upon attitudes and practices in relation to science, science education and careers. In particular, there is a need to address the gendered opportunities and cultural socialization experienced by children at an early age.
3. Family and peer relations are significant, if complex, factors in young people's attitudes to and participation in science education. In making sciences more attractive to young people, there is a need to involve families, primary aged children and support informal and formal learning in and across generations as part of building scientific capital (Archer *et al*. 2012) and identities.
4. There is a disjunction between the scientific interests of young people and school science, which results in the relevance of the latter being in question. School science needs to be more prospective/exploratory and less retrospective/historical. Learning *to do* science needs greater emphasis than learning *about* (the history of) science. This suggests a need to emphasise practical pedagogies in learning science, based upon the practices of science in developing scientific know-how. There is also the need to differentiate between different forms and foci of science. Focussing on environmental issues is more likely to be of interest to girls than boys.
5. The innovative teaching of science needs to be underpinned by expertise and enthusiasm in the subject, engagement with its relevance to society and the economy, and expertise and enthusiasm in the teaching of young people. There are no shortage of curriculum initiatives and interventions to address this situation, but little that is generalizable in relation to attitudes and aspirations has emerged (Simpson *et al*. 1994, Osborne and Dillon 2008).
6. Examining the issues in relation to science as a totality is not helpful. There is a need for more refined studies into particular aspects and possibilities for different areas within the sciences. For instance, the approach of simply encouraging more women into science is not the most effective. This entails more context specific studies and methodologies (Osborn *et al*. 2003).

Informal Science Learning and Informal Learning

There has been a significant interest in informal science learning as a way of engaging people with the sciences more broadly and as a support for the more formal provision of science education. Many institutions and organisations other than educational institutions try to provide opportunities for people to learn science and also support, in particular, schools and teachers in their teaching of science. The bulk of this activity is focussed on young people.

The interest in informal science learning has been accompanied by increasing research. However, in recent reviews to synthesise existing knowledge funded by the Wellcome Trust (Lloyd *et al*. 2012, Falk *et al*. 2012) significant gaps and limits were identified. Lloyd *et al.* (2012: 2) surveyed providers of informal science learning and identified a number of characteristics of this activity:

- It takes place outside of the formal curriculum, is non-compulsory and is not formally accredited, and while capable of reinforcing formal learning, this is not its core purpose
- It can take place in a range of settings outside of school, although not exclusively – including in museums, science centres, individual's homes and public spaces
- It can inspire, stimulate interest in, encourage positive attitudes towards and lead to a more thorough understanding of science
- It features learning that can be unstructured, unguided and led by the interests of the individual
- It can feature 'learning by stealth', a concept that was mentioned frequently throughout the study and described as "audiences learning without being actively aware of what they are doing".

However, fundamental to this review was the finding that most providers of informal science focus more on making science enjoyable and interesting, and inspiring a general interest in and engagement with science than they explicitly focus on learning. In other words, ways of framing practice are in terms of engagement more than learning (Bell *et al*. 2009). In focussing on the providers of informal science learning, we might therefore identify a participation approach (i.e. audience development, awareness-raising, changing attitudes) and a learning approach (i.e. learning about science, learning scientific facts, learning to do science). While the two are inter-linked, the particular emphasis and approaches adopted will impact on the possibilities for participation and learning.

Falk *et al*. (2012) also show how young children and adults are attended to less than older children by providers of informal science learning, when the recent work on science capital would point to the need to precisely focus on cross-generational groupings as a basis for enhanced participation and learning. In addition, they argue that the informal science learning community, while largely adopting an apprenticeship approach to learning, often has an under-developed theory of learning informing practice. In other words, there is no authoritative body of learning research and theory informing the practices of informal science learning; 'for a system which aims to support learning as one of its primary goals, there was little evidence of any deep understanding of contemporary ideas about learning' (Falk *et al*. 2012: 52). This may hardly be surprising given that most activities engaged in out of educational institutions are not for the purposes of learning. As Lloyd *et al*. (2012: 30) point out in relation to teenagers in the UK, 'learning was not a conscious driver of the activities tweens chose to undertake outside of school, but some boys like to collect "facts" and this is a motivator to watch television programmes such as *QI* and to read non-fiction books'.

This mismatch between the purposes of those providers of informal learning opportunities and the motivations of those involved in such activities may help to explain why the notion of learning by stealth was identified as a way of addressing this situation. It may also be unhelpful to refer to informal learning providers as a system given that there is no formal structure or curriculum to which different organisations contribute. Informal learning by participants takes place regardless of what is organised and designed as activities for them, although what is learnt and how varies and can be more or less effective depending on the implicit and explicit pedagogies adopted. Practices to support learning through enabling more effective participation in and contribution to the activities that motivate people's interests would seem a key strategy to enhancing science learning in such contexts. This is an approach that has been adopted elsewhere in education where there has been a focus on enhancing literacies for learning, drawing on the everyday reading and writing practices of students, rather than focussing on teaching literacy (Ivanic *et al*. 2009). These draw upon theories of learning through participation in practices and pedagogical approaches developed from them (e.g. Lave and Wenger 1991, Chaiklin and Lave 1996, Engestorm et al. 1999, Fenwick *et al*. 2011).

This brings us to a fundamental issue in the discussion of informal science learning and informal learning more generally; what is the informal aspect of learning. Some have focussed on the issue of informality in relation to the knowledge that is learnt in different contexts. It is argued that formal learning in educational institutions results in the acquisition of abstract and generalizable knowledge which is not context specific – propositional knowledge. By contrast, informal learning outside of educational institutions results in the acquisition of specific and context-bound knowledge – know-how. On this basis, formal and informal learning are entirely separate and there is a value difference inscribed between them. However, as in Colley *et al*. (2003) and others have argued, what is learnt educational institutions is itself context bound to those institutions and what is learnt outside educational institutions can itself be abstract and generalizable. In other words, propositional knowledge and know-how are not entirely distinct, but there is a complex interplay of them in any context. In addition, this notion of informal and formal learning emphasises knowledge at the expense of other aspects of learning in relation to skills, attitudes, values, identities and practices. On this argument, it is not the learning which is informal or formal but the ways in which it is organised and engaged with, which is reflected in the characteristics identified by the providers of informal science learning above.

In the USA there has been much more research and attention focussed on informal science learning than the UK, where the attention has largely been on how informal learning can be drawn upon more effectively for formal learning. However, this has largely focussed on the science learning outcomes to be achieved and assessed. Different frameworks have been developed through which to identify the possible learning outcomes of informal science learning. For instance, Friedman *et al*. (2008) identify learning outcomes in relation to: knowledge, awareness and understanding; engagement, interest or motivation in science; skills related to scientific inquiry; attitudes towards science; and behaviour. The US National Research Council (2009) identified learning outcomes in relation to: understanding; interest; scientific exploration; identity; and skills. Less attention has been given to the processes and practices of learning or the wider learning outcomes of participation in informal science learning. It is also arguable that such outcomes could be identified in relation to any science learning.

Falk *et al*. (2012: 8) argue that, 'rather than assessing the influence of any one experience, whether a school lesson or a visit to a museum, our view is that it is better to see learning as a product of experiences that happen across settings and over time'. A systemic understanding of learning in different contexts across time would be more helpful to enhancing science learning rather than a focus on specific forms of learning – informal/formal – within particular contexts. Yet this more systemic or ecological view is lacking (Bell *et al*. 2009) and indeed hard methodologically to achieve without longitudinal and ethnographic research, although there have been some attempts at this through a focus on the learning lives of people rather than learning in particular contexts (Biesta *et al*. 2011). Learning is both a process and outcome, regardless of context. Thus, in their review of the literature on informal learning, Colley *et al*. (2003, emphasis in original) argued that 'seeing informal and formal learning as fundamentally separate results in stereotyping and a tendency for the advocates of one to see only the weaknesses of the other. It is more sensible to see *attributes of informality and formality* as present in all learning situations'. Bell *et al*. (2009: 47) argue that 'informal environments are generally defined as including learner choice, low consequence assessment, and structures that build on the learners' motivations, culture, and competence'. Drawing upon a range of empirical studies, Colley *et al*. (2003) argue that all learning has attributes of informality and formality, whatever the context and suggest that these can be examined analytically in relation to process, location and setting, purposes, and content. Informality and formality are attributes rather than types of learning and the construct of informal learning as a type is unhelpful.

Falk *et al*. (2012: 37), echoing the recent work on importance of families in science education, point out that 'children's learning experiences in museums were found to be enhanced significantly by parents who interact meaningfully with children and provide "casual explanations" to children's questions'. This points to the issue of science capital in families and the possible role of intergenerational practices to enhance learning. Mannion (2012) identifies four characteristics of intergenerational learning:

- It involves people from two or more generations participating in a common practice that happens in some place;
- It involves different interests across the generations and can be employed to address the betterment of individual, community, and ecological well-being through tackling some "problem" or challenge;
- It requires a willingness to reciprocally communicate across generational divides (through activities involving consensus, conflict, or cooperation) with the hope of generating and sharing new intergenerational meanings, practices, and places that are, to some degree, held in common; and
- It requires a willingness to be responsive to places and to one another in an ongoing manner.

These are broad characteristics and the specific pedagogic practices to be adopted require further learning theory. More work is required also on what is understood by the notion of generation. The study of intergenerational rather than specifically family learning is at an early stage.

When exploring the factors contributing to scientific knowledge, Falk and Needham (2013: 448) found that 'a large amount of out-of-school science learning occurs through on-line resources, reading books and magazines, and through interpersonal relationships among friends, family, clubs, and other groups'. In other words, the learning of science is itself often independent of the explicit providers of informal science learning, with the different components reinforcing each other. However, as with patterns of participation in science more broadly, they found that males currently working in a science or technology related job with a high income were most likely to have the greatest self-reported knowledge of science and technology. And it was adult free choice learning that was most significant in relation to self-reported science knowledge. This suggests the need for a complex interplay of factors to be considered when supporting the learning of science outside of educational institutions; the contribution of adult male parents may be part of the problem of participation in science, but it might also be a bridge to the learning of others.

There is a sense in which the research on informal science learning sometimes reaches out and sometimes echoes the wider research on science education, informal learning and broader learning theory, but that the links are not as systematic as they might be, thereby reducing the achievement of educational goals in relation to participation in and contribution to science. Informal science learning does appear to be treated mostly as a type of learning and could helpfully be reframed as attributes. There is also the potential to draw more explicitly on the wider range of learning theories and associated pedagogical possibilities. In that respect, we have already made reference to some situated learning theory, activity theory and intergenerational learning, all of which can be identified as forms of experiential learning with different aspects and degrees of informality and formality associated with them and pedagogic roles (see Fenwick 2001).

Learning through citizen science projects

To date, the impetus behind citizen science projects has been in relation to the contribution of volunteers to science. However, increasing attention has been given to the informal learning of innovative, responsible and ethical scientific attitudes and practices as part of research into what in the US is referred to as public participation in scientific research (e.g. Bonney *et al*. 2009a and b, Phillips *et al*. 2014). While there is long-standing research on citizen participation in science policy and the public understanding of science and technology (e.g. Fiorino 1990; Lengwiler 2008; Bogner 2012), citizen science offers new ways to engage in scientific research, new ways though which to engage the public in this research, and new possibilities for learning.

Citizen science projects take many different forms, using different types of engagement and encouraging participation of different groups. Some are more local, and some, increasingly mediated by computer technologies, are more global. Some target and involve specific groups, such as school children, while others are more open, increasingly using crowdsourcing and other forms of technology. Some are disciplinary based, while others are more problem focussed and multidisciplinary. Although referred to as citizen science, a lot focus on environmental and ecological issues and engage volunteers in field science. While most are instigated by professional scientists working in both public and third sector organizations, there is increasing interest in more collaboratively developed and citizen initiated projects. Their importance is reflected in the increasing support citizen science projects have from government organisations, third sector groups, and other public bodies, including schools, colleges and universities, and the guidelines produced on how to develop projects (e.g. Tweddle *et al*. 2012). To date there has been limited involvement of employers and commercial companies in such initiatives.

There has been a significant growth in citizen science projects over the last three decades and there is evidence they are making important contributions in many areas of science (Roy *et al*. 2012). With these projects has come some research on:

- the motivation to participate in these project as volunteers (e.g. Raddick *et al*. 2010);
- the interactions of professional scientists and citizens and possibilities of undermining the professional status of the former through the amateur participation of the latter (Brabham 2013);
- the validity of the scientific work undertaken (e.g. Trumball *et al*. 2000; Wiggans *et al*. 2011, Shirk *et al*. 2012, Dodge and Kitchin 2013),
- the effects of training on scientific literacy (e.g. Cronje *et al*. 2011)

- the practices and technologies of interaction; and
- the effects of such work on attitudes to science (e.g. Brossard *et al*. 2005).

Increasing attention has been given to researching who contributes to these scientific projects, the forms of knowledge and expertise they draw upon in making their contributions, the knowledge practices in which they engage (Edwards 2014), what is learnt through participation in such projects, and the ways in which these could enhance participation in science education and careers more broadly. In other words, increasing research is focussing on the educative potential of citizen science, both in relation to specific projects and wider attitudes to and participation in science. The potential to make more of the educational potential of citizen science is a point highlighted in a recent report for the European Commission DG Environment (Science Communication Unit, University of the West of England, Bristol 2013) and is also evidenced in a recently published *User's Guide for Evaluating Learning Outcomes in Citizen Science* (Phillips *et al*. 2014).

In examining the features of citizen science projects, different areas have often been the focus of attention, in particular, their organizational structure - expert led/contributory, peer/collaborative, community-defined/co-created – and the scientific contributions of volunteers – e.g. defining questions, gathering information, developing hypotheses, designing the study, data collection, analysing samples, analysing data, interpreting data, drawing conclusions, disseminating results, discussing results and asking new questions. In their attempt to produce a typology of citizen science projects, Wiggans and Crowston (2011, 2012) explored approximately 80 facets - project demographics (e.g. age, geographic range, research discipline, stated goals), organizational features (e.g. affiliations, funding sources), participation design (e.g. task types, skills or tools required), educational features (e.g. informal learning resources, curricular materials), outcomes (e.g. publications, protocol revisions, innovations), technologies (e.g. communication tools, web site features), processes (e.g. data validation, volunteer management, communication) and data management (e.g. data sharing, ownership, stewardship). From their clustering of projects, they identified five types of citizen science project:

- Action projects - volunteer-initiated participatory action research to encourage participant intervention in local concerns.
- Conservation projects - natural resource goals, involving citizens in stewardship.
- Investigation projects - focusing on scientific research goals in a physical setting.
- Virtual projects - similar goals to Investigation projects, but entirely ICT-mediated and differ in a number of other characteristics.
- Education projects - education and outreach as primary goals.

Wiggans and Crowston (2012) suggest these are mutually exclusive types, but this seems hard to accept, given the educational dimensions, in particular, informal learning, associated with any such projects. Their sample of projects was relatively small and overwhelmingly US-based.

While recognizing the diversity of practices, a major UK review of citizen science in relation to the environment and natural history (Roy *et al*. 2012: 10) defines such projects as involving 'volunteer collection of biodiversity and environmental data which contributes to expanding our knowledge of the natural environment, including biological monitoring and the collection or interpretation of environmental observations'. The report explicitly identifies environmental education as well as environmental research and wildlife recording as integral to citizen science projects in this area. The review identified a number of different forms for projects: simple local projects, thorough local projects, simple mass participation projects and thorough mass participation projects. Most projects were established by professionals and then invited volunteers to contribute, although some are more collaborative or co-created. While national and international projects in scope have the highest profile, many projects are local in scale. Roy *et al*. identified the use of technology as increasingly important to citizen science, extending access to participation in such projects and increasing their spatial scales.

Roy *et al*. (2012) also identify a number of drivers for increasing numbers of citizen science projects: the limitations on volume of data collected if reliant on professional scientists; increased confidence in the validity of volunteer generated data; and the possibilities of technologies. Motivations for contributing to these projects vary, but the intrinsic worth of the activity and the usefulness of what they are doing both rate highly among volunteers, as does being in the natural environment. Roy *et al*. also point out the particular demographic profiles of participants, with black and minority ethnic groups and lower socio-economic groups participating less than others, reflecting more general demographic trends in volunteering.

While motivation to contribute to citizen science among volunteers remains an important focus of interest, less is known about who contributes, their educational backgrounds and the learning arising from participation. Research on learning by young people in citizen science is particularly sparse. As indicated above, where the latter has been studied, the focus has largely been upon learning outcomes – what is learnt – rather than learning processes – how that learning occurs. Phillips *et al*. (2014) have produced a framework for evaluating the learning outcomes of citizen science project focussed on: interest in science and the environment; self-efficacy; motivation; knowledge of the nature of science; skills of science inquiry; and stewardship and behaviour. While such frameworks are helpful in evaluating the learning outcomes of projects, they give limited information on the processes of learning, and also might exclude outcomes that do not sit within these categories, but which are important nonetheless for the volunteers involved. In using such formal frameworks for evaluating learning outcomes, important aspects of informal learning may be overlooked.

In their surveys of one large global astronomical citizen science project, Raddick *et al*. (2010, 2013) focused on volunteers' motivations for contributing to the project and their educational backgrounds to a limited extent. In the earlier article, Raddick *et al*. (2010) identified through grounded theory twelve major motivations for contributing to Galaxy Zoo. While making a contribution was the top motivation, the next two related to education; learning and discovery. Contributing to the project also enabled people to learn and discover new and different things and this was a key part of the motivation to become involved. The later article (Raddick *et al*. 2013) reports on an online survey of project volunteers that explored motivation and also collected certain demographic data.

Over 82% of respondents to the survey were men, which probably reflects the nature of the particular scientific project – astronomy – and the existing gender distinctions within sciences. In terms of age, there is a fairly consistent pattern of contribution between 30 and 60, with the older adults more likely to be men. As an international project, contributors from 118 countries and territories were identified. However, two countries (the USA and UK) were home to 65% of volunteers and 25 countries accounted for 95% of volunteers. The largest numbers of volunteers came from countries with higher levels of per capital gross national product. The survey asked volunteers about their level of education and the more qualified were more likely to contribute. Over a quarter of volunteers had a bachelor's degree and just over 17% identified themselves as school, college or university students. However, while we are able to identify the level of educational qualifications of contributors, there appears to be no data on what they might have previously studied or currently be studying. In other words, we do not know if there is any relationship between previous content of education and their contributions to Galaxy Zoo. In particular, is astronomy something contributors previously studied formally or is it additional to their formal education and qualifications? We also do not have data on what they have learnt through participation in the project, nor how it might have changed their attitudes to and participation in science more generally.

The level of student contribution to this project may also have impacted upon the motivations of people, as one might anticipate that students would be looking to learn as much as possible from their involvement in a project of this sort. However, the analysis of the data removed students when it came to exploring motivation to contribute. It is highly noticeable, therefore, that in this second piece of research, while making a contribution (39.8%) remained the prime motivation for people, and discovery remained the third most important motivation, but only at 10.4%, learning was only identified by 1.6% of volunteers as a motivation for participation. In other words, while informal learning may result from participation in citizen science, it is not necessarily a significant motivation for contributing to such projects. Making more explicit the educational aspects of citizen science project may therefore not make them more attractive and may even make them less so. Overall, Raddick *et al*. (2013) conclude cautiously that 'a greater number of volunteers are motivated by identification with project goals and interest in scientific content and are less motivated by learning science and participating in a social community'. However, as Shirk *et* al. (2012) indicate, this may be the result of the design and focus of the project, as much as any inherently negative attitudes towards science in general.

In a further study, Wiggans *et al*. (2011) surveyed the ways in which citizen science projects sought to ensure the validation of the data collected. Once again, based upon a small sample of mostly US based citizen science projects, they identified the usage of different approaches - expert review: 77%, photo submissions: 40%, paper data sheets submitted along with online entry: 33%, replication or rating by multiple participants: 23%, training programme: 22%, automatic filtering of unusual reports: 18%, uniform equipment: 15%, validation planned but not yet implemented: 8%, replication or rating, by the same participant: 3%, rating of established control items: 3%, none: 3%. Seventy five per cent of projects used up to five methods, with expert review being the core. Questions of validity remain important in relation to ensuring accuracy and developing scientific attitudes. Although accuracy rates can be high, it is suggested the monitoring and training of participants by experts remains necessary (Brandon *et al*. 2003).

For Shirk *et al*. (2012) it is the degree and quality of volunteer participation that defines different types of project. In terms of the degree of participation, they identify five types:

- Contractual projects - communities ask professional researchers to conduct a specific scientific investigation and report on the results;

- Contributory projects - generally designed by scientists and for which members of the public primarily contribute data;
- Collaborative projects - generally designed by scientists and for which members of the public contribute data but also help to refine project design, analyze data, and/or disseminate findings;
- Co-Created projects - designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all aspects of the research process;
- Collegial contributions - non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals.
-

A slightly different typology in provided by Haklay (2012), who identifies four levels of participation:

- Crowdsourcing – citizens as sensors
- Distributed intelligence – citizens as interpreters
- Participatory science – citizens as contributing to problem definition and data collection
- Extreme science – citizens collaborating in problem definition, data collection and analysis.

For Shirk *et al*. (2012), the quality of participation is evaluated in relation to a number of areas - inputs, activities, outputs, outcomes, and impacts. Overall, they suggest this provides a framework for the design of particular projects. They also point out that different models have strengths and limitations. For instance, contributory projects are more likely to produce robust scientific research outcomes, while co-created projects are more likely to affect policy decisions. One crucial aspect of collaborative models is their development of social capital, which is linked to the development of science capital.

The desire to have both scientific and educational outcomes from citizen science is in line with Bonney *et al*. (2009a), who identify scientific outcomes as measurable by, for instance:

- Numbers of papers published in peer-reviewed journals
- Numbers of citations of results
- Numbers of researchers publishing citizen science research papers
- Numbers and sizes of grants received for citizen science research
- Size and quality of citizen science databases
- Numbers of graduate theses completed using citizen science data
- Frequency of media exposure of results.

Meanwhile the educational outcomes can be measured by, for instance:

- Duration of involvement by project participants
- Numbers of participant visits to project Web sites
- Improved participant understanding of science content
- Enhanced participant understanding of science process
- Better participant attitudes toward science
- Improved participant skills for conducting science

- Increased interest and participation in science education and science as a career.

The link between the design of the citizen science project and its capacity to enhance educational outcomes is clearly demonstrated in Brossard *et al*. (2005). Evaluating a single ornithology citizen science projects with adults, they found that while it produced enhanced scientific knowledge in relation to the birds studied, it did not impact upon general attitudes to science and the environment in any statistically significant ways. They argue for the need to develop measurement tools that can be used across multiple projects and the general population to compare their effectiveness.

Conclusions

While it is too early to make strong conclusions from the existing research, it is clear that citizen science does provide an important range of practices through which to support the learning of science by contributors. However, the extent to which this is a prime motivation for participating is open to questions. The extent to which learning goals become a structured part of the design of citizen science projects and the impact this may upon participation and participants are clearly questions, given specific forms of education are differentially valued by different groups and individuals. The need to engage with the wider research on education and learning is also apparent, given the interest in the citizen science community to both engage a wider range of the public and also contribute to science learning, science education and careers.

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