

This is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

Citizen Science: An Opportunity for Learning in the Networked Society

Ornit Sagy, Yaela Golumbic, Hava Abramsky, Maya Benichou, Osnat Atias, Hana Manor, Ayelet Baram-Tsabari, Yael Kali, Dani Ben-Zvi, Yotam Hod, Dror Angel

Introduction

One key benefit of the networked society is connectivity between people and communities that might otherwise have little interaction. Seeking to promote science communication, civic engagement and informal education, citizen science is a genre of research that connects scientists and non-scientists around projects involving science. Two recent issues of the *Journal of Science Communication* referred to citizen science as “one of the most dramatic developments in science communication in the last generation” (Lewenstein, 2016, p. 1) that plays a role in “environmental science, public health, physics, biochemistry, community development, social justice, democracy, and beyond” (Bonney, Cooper, & Ballard, 2016, p. 1). On the one hand, citizen science has been around for a long time (Cooper & Lewenstein, 2016), such as the work of Frank Chapman, who initiated an annual Christmas bird count in 1900 (Silvertown, 2009). On the other hand, research on citizen science is still in its infancy (Bonney et al., 2016; Bonney, Phillips, Ballard, & Enck, 2015; Lewenstein, 2016). Although citizen science projects have grown extensively in number and quality, especially during the past decade, much of the knowledge so accumulated is diffuse (see Golumbic, 2015; Pettibone et al., 2016).

This chapter consolidates different research strands dealing with citizen science by providing a new conceptual framework that can advance our understanding of this genre of research.

We start with a quick glimpse into *the making of science* and the role that citizen science plays in this context. After briefly describing the benefits to scientists who initiate and take part in citizen science projects, we focus our attention on non-scientists. Specifically, we examine how theoretical frameworks in the fields of science communication, science education, data science education and learning communities can shed light on participants’ learning processes.

The Making of Science and the Role of Citizen Science

This is a pre-print of: Sagy O., Golubic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 1 -

It is helpful to think of citizen science in the greater context of the scientific endeavor, specifically—big science and little science. Most scientific advances in the current era have been achieved by participants in *big science*—professional scientists working at scholarly institutions who communicate mostly through journals and conferences. In comparison, *little science* is advanced through personal interactions of diverse participants (Lievrouw, 2010). Darwin, for example, made immensely significant contributions to science as an unpaid ship’s naturalist, advancing his ideas through letter writing and discussions with friends (Silvertown, 2009).

Advances in information technologies that gave birth to the networked society have contributed to public engagement with both big and little science, blurring the differences between them (for their affordances and challenges, see Baram-Tsabari and Schejter in Chapter 5 of this book). They offer opportunities for the public to participate in scientific activities such as data collection (Del Savio, Prainsack & Buyx, 2016), increase the accessibility of data, tools and communication methods to the public (Aristeidou, Scanlon & Sharples, 2013; Bizer, 2009; Teacher, Griffiths, Hodgson & Inger, 2013) and enable communities of amateurs to engage in science as a serious leisure activity (Stebbins, 1997).

Citizen science projects may be classified as *global*, often representing big science, or *local*—often largely manifesting the characteristics of little science. Global projects include initiatives such as eBird, that involves people in identifying and reporting observations of bird species (ebird.org), or Galaxy Zoo, in which the public classifies galaxies (galaxyzoo.org) and assists science by gathering and interpreting data on a global (or even cosmic) scale. Local projects are represented by endeavors such as the Shermans Creek Conservation Association—a community effort to monitor and protect a creek in Pennsylvania (facebook.com/ShermansCreekConservationAssociation), with scientists providing answers to citizens’ concerns (Irwin, 1995) and engaging in dialogue with the public through social media (Bonney, Phillips, Ballard, & Enck, 2015).

Potential Benefits of Citizen Science

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 2 -

Potential beneficiaries of citizen science can be divided into three major groups: Those whose job it is to advance knowledge (i.e., scientists); those who participate on an individual basis (i.e., the public, amateurs) and those situated in formal educational settings (i.e., teachers and students).

Potential benefits to scientists

The contribution most often mentioned for science and scientists concerns scientific discoveries and consequently the vast number of publications resulting from them, i.e., those that use citizen science data (Yoho & Vanmali, 2016). In 2015 alone, 402 peer-reviewed articles were published that addressed or used such data. The figures are increasing exponentially (Kullenberg & Kasperowski, 2016), as scientists' motivations for participating in citizen science often include promoting scientific research, obtaining prestigious funding and publishing scientific papers (Golumbic, Baram-Tsabari, & Fishbain, 2017). Personal communication with other scientists has indicated some less obvious motivations as well: "Scientists stand to gain a lot from citizen science: Humility, the need to be more accurate" (personal communication, 2018).

Potential benefits to participating citizens

Contribution to individual participants in citizen science include enjoyment, community building, acquiring new skills and knowledge and hands-on understanding of scientific processes (Brossard, Lewenstein, & Bonney, 2005; Dickinson et al., 2012; Raddick et al., 2009). In some cases, especially when projects address environmental hazards (such as pollution or contamination), participants gain important information about their local environment (Golumbic et al., forthcoming). In some cases, participants can take action, get involved in nature protection and conservation activities and influence policymakers to institute change. One example is provided by eBird participants, who used the eBird database for protecting local parks and nature sites and preventing further development of altered landscapes (Sullivan et al., 2017).

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 3 -

Potential benefits to teachers and students

Besides the benefits described above, illustrating the individual contribution of citizen science to participants, additional benefits may apply with respect to educational settings. These include various new opportunities for scientific education, enabling students to engage in hands-on authentic research and learn about science from a broad perspective (Bonney et al., 2014). Research evaluating student learning outcomes in several citizen science projects revealed an increase in content knowledge, heightened awareness and an intensified understanding of the scientific research process following student participation (Ballard, Dixon, & Harris, 2017; Golumbic et al, 2016; Kountoupes & Oberhauser, 2008; Silva et al., 2016). Moreover, students involved in the Lost Ladybug Project expressed a sense of pride in their research products and a sense of belonging and connection because they are working on something of major significance (Sickler & Cherry, 2012). Although these outcomes are optimistic and inspiring, the evidence is sparse and few studies have evaluated broad learning outcomes in a systematic manner. Much work is still needed to understand student learning outcomes in citizen science and to better design learning environments and pedagogical guidance to maximize these outcomes. Recently, several initiatives, such as the BSCS Science Learning Workshop on Designing Citizen Science for Both Science and Education (Edelson, Kirn, & workshop participants, 2018), the Board on Science Education within the National Academies of Sciences, Engineering, and Medicine Report on Designing Citizen Science to Support Science Learning (https://sites.nationalacademies.org/DBASSE/BOSE/CurrentProjects/DBASSE_178572) and the new Taking Citizen Science to School Research Center (www.tcscs.center).

So far, we have reviewed benefits on an individual level, but citizen science has the potential for making science itself more relevant and open for active participation, while rendering society more democratic and providing citizens with the ability to influence and promote freedom of expression (see Kidron, Tirosh, Kali and Schejter's notions on democracy in a networked society, Chapter 7).

While most citizen science projects are targeted at advancing science, many have additional goals of supporting science education, science communication and evidenced-based decision making (Golumbic,

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 4 -

2015; Golumbic et al., 2017). Public participants also have their own goals for taking part in the initiative. Some of them align well with the goals of the scientists, as in ecological data collection projects, but some far less, such as in Foldit, in which scientists are interested in identifying protein folding structures. Numerous participants may be interested only in game playing, enjoyment and internal competition (Curtis, 2015). Unfortunately, many projects primarily address the goals of one party (Barron, Martin, Mertl, & Yassine, 2016; Bonney et al., 2015). For example, projects may be oriented to benefit scientists who engage the public in collecting data, with only minimal profit to those who contribute the data (see Galloway et al., 2015). Other projects, such as S'cool – Students Cloud Observations On-line (scool.larc.nasa.gov, now part of Globe: www.globe.gov/web/s-cool/home/participate) or the EarthEcho water challenge (worldwatermonitoringday.org), are oriented towards education or local activism and may have little value for advancement of science (see Andújar et al., 2015). Although citizen science projects indeed engage diverse participants, benefits are not always equally distributed among stakeholders.

Mutualistic Ecology of Citizen Science

To address the interactions among diverse participants in citizen science and their many potential benefits, we conceptualize citizen science and its myriad stakeholders as an ecology. Environments with multiple reciprocal interactions invite this metaphor, as it describes study of the complex interplay among organisms and between them and their habitat. This analogy has been used previously in contexts such as psychology (Kulikowich & Young, 2001), learning (Barron, 2006) and knowledge and innovation (Benkler, 2006). Relationships between parties within the citizen science ecology refer to interaction among scientists, project participants, educational institutions, policymakers, etc. Indeed, participants' interactions have been shown to affect others' participation as well. For example, Cooper and Lewenstein (2016) report a case in which data contributed by a citizen spawned a new research direction that led to novel paths of public participation.

While the ecology metaphor reflects the complexity of multi-party interactions, it does not yet address benefits to participants. Additional metaphors available from biological ecosystems to represent

relationships among parties within this ecology could include mutualism, commensalism, or parasitism, that respectively provide benefit for both parties, affect one party beneficially with no effect on the other, or benefit one party while adversely affecting the other. Consequently, we complement the ecology metaphor with the term *mutualism* to express our desire for interactions in which all parties benefit from their involvement (Bronstein, 1994). With these two metaphors in mind, we propose a Mutualistic Ecology of Citizen Science (MECS) as an analytic framework for characterizing citizen science endeavors, with the ideal of maximizing benefits to *all participants*. This ideal of mutualism is consistent with Hoadley and Kali's notion of eudæmonic learning (Chapter 1), in which learning in a networked society is conceptualized as a component of how individuals and society mutually develop each other (in this case, participants in citizen science can be viewed as a society).

MECS as an analytic framework can potentially contribute to both conceptualization and design of citizen science projects. To operationalize this framework, we use four lenses, spanning several disciplines that allow us to look at potential benefits to different participants. Seeking to contribute to scholarship on *Learning In the Networked Society*, we focus our characterization on benefits associated with learning, i.e., personal growth or advancement of knowledge. In the following section, we elaborate the four lenses that provide us with ways to examine the benefits to different participants—scientists, the general public and those in formal education settings: (1) The learning communities lens illuminates learning opportunities and challenges that may be relevant for all types of participants in different settings; (2) science communication focuses on interactions between scientists and the public and thus highlights related potential for growth; (3) statistical education and data science education aim at supporting the development of data literacy, that may be required and enhanced for citizen science participants, with emphasis on those in formal education; (4) science education is another lens mostly relevant to formal education, as it concerns promotion of scientific literacy.

Learning Communities

Citizen science projects, by design, engage various types of participants whose multiple goals and needs are not necessarily aligned. Many can be thought of as members of different *communities of practice* (Wenger, 1998), defined as groups of people who share a craft and/or profession. This can apply to groups of scientists, citizens focused on a specific socio-scientific issue or a particular scientific topic, educators, students, and so forth. Communities of practice are characterized by a combination of three elements: (1) A collective understanding of what the community is about; (2) mutual engagement that reflects shared norms and trusted relationships; (3) a shared repertoire of communal resources, such as language, routines, artifacts, stories, styles, etc. Wenger (2000) refers to communities of practice as the “basic building blocks of a social learning system, because they are the social ‘containers’ of the competences that make up such a system” (p. 229). Viewing citizen science projects as a mutualistic ecology in which all communities of practice benefit from the interaction is an extension of Wenger’s conceptualization. Instead of focusing on one community of practice, mutualistic ecology focuses on the interaction among such communities.

The communities of practice in the context of citizen science can also be characterized as learning communities. These involve learners with diverse expertise and the common objectives of continuously advancing collective knowledge and mechanisms for its distribution (Bielaczyc, Kapur, & Collins, 2013). Engaging in such communities usually requires its members to move out of their comfort zone and adopt new identities, perceptions and ways of doing things (Bielaczyc, Kapur, & Collins, 2013; Penuel et al., 2015). Brown (1994) describes this exchange of roles in a classroom community of learners:

In our program, although we assuredly aim at conformity on the basics (everyone must read, write, think, reason, etc.), we also aim at nonconformity in the distribution of expertise and interests so everyone can benefit from the subsequent richness of available knowledge (p. 10).

The process of developing collective community identity and practice in an ecosystem comprising distinct communities of practice can be challenging (Akkerman & Bruining, 2016; Penuel et al., 2015).

While acknowledging the complexity, Wenger (2000) points out the opportunities that such interactions can potentially yield:

There is something disquieting, humbling at times, yet exciting and attractive about such close encounters with the unknown, with the mystery of “otherness”: a chance to explore the edge of your competence, learn something entirely new, revisit your little truths, and perhaps expand your horizon (p. 233).

The most prominent reason for which we suggest the communities context as a lens for highlighting growth opportunities of diverse citizen science participants lies in the contribution of boundary crossing to learning (Akkerman & Bakker, 2011). Barron (2006) highlights border crossings as an important component of learning ecologies, while Azevedo (2013) suggests tracking such crossings as a means of analyzing learning trajectories. To understand this potential, we examine Wenger’s (1998) distinction among three types of boundary interconnections between communities. The first is called *boundary encounters*, when members of one community engage in activities with members of another community. The second boundary interconnection is represented by the role of *brokers*—members who join two or more communities and bridge among them by facilitating the translation, coordination and alignment of perspectives and meanings. In the context of citizen science, participating citizens may work together and form small groups (Kountoupes & Oberhauser, 2008) or collaborate after attending training workshops (Crall et al., 2012) in which the facilitators may potentially act as brokers. Finally, *boundary objects* are artifacts (tools, documents, models), discourses (common language across boundaries) and processes (routines and procedures) that support the connections among different communities of practice (e.g., scientists and science amateurs). These are exemplified by the online gaming platform of the Foldit Project or the Facebook page that serves as a joint platform for sharing ideas and engaging in a mutualistic discussion in Sensing the Air (sensair.net/map.php). In these cases, aspects of the project design serve as boundary objects. Another context in which the three boundary interconnections can work together is citizen science in formal education. We envision boundary crossing (Akkerman & Bakker, 2011) as an inherent part of a citizen science learning community that includes both teachers and students.

In summary, the notion of learning communities is a powerful means towards understanding the many cultural and interactional processes that occur in citizen science projects. As such, it supplies us with powerful tools for analysis, thus enriching our understanding of the notion of mutualism in these contexts and providing us with better design ideas for MECS.

Science Communication

The field of science communication addresses the study of public processes of understanding and engaging with science as it examines its interactions with society (Bucchi & Trench, 2014). Models of science communication can be roughly divided into two subgroups: Those emphasizing knowledge transfer, such as Public Understanding of Science (PUS, also referred to as the Deficit Model), and those emphasizing public dialogue, such as Public Engagement with Science (PES). Both are relevant for the study of citizen science projects, while emphasizing different objectives and leading to diverse outcomes (Haywood and Besley, 2014). While PUS focuses on educational outreach and learning opportunities for the public, PES aims at democratizing science, determining public desires and needs, encouraging transparency and achieving collective decision making. Science communication also offers theoretical constructs to examine the benefits of citizen science for scientists, as well as processes of trust building.

Although citizen science projects share goals and potential outcomes with other science communication initiatives, few studies have investigated the relationship among them. The majority of studies on citizen science have not emphasized the approach of science communication, but rather focused on scientific or educational approaches. Nonetheless, many successful citizen science projects incorporate science communication ideas within them and benefit from implementing science communication theories.

As a field that promotes collaborations and relationships between citizens and scientists, citizen science can go beyond the deficit and dialogue models discussed above. Indeed, Trench (2008) proposed an analytical framework of science communication that includes three levels of science communication, maintaining the traditional meaning of PUS as the deficit model and dividing the PES model into dialogue

and participation (see Table 1). In this framework, dialogue is considered communication between scientists and their representatives, aiming either to find out how science could be effectively disseminated or to consult regarding specific applications. Participation refers to communication with with diverse groups, based on the notion that all can contribute and all have a stake in the outcome of the deliberations and discussions (Trench, 2008).

Table 1. Science communication models and meanings

Science communication models	Trench (2008)	Meaning
Public Understanding of Science (PUS)	Deficit	Science transmitted by experts to lay audiences
Public Engagement with Science (PES)	Dialogue	Communication between scientists and public representatives for specific applications or consultation
	Participation	Communication with diverse groups on the basis that all can contribute and all have a stake in the outcome of the deliberations and discussions

Considering Trench's (2008) framework, a natural place for citizen science would have been within the participation model, that orients both scientists and the lay public towards taking part in shaping the issue, setting agendas and negotiating meaning. Citizen science projects are diverse, however, often varying in their level of inclusion (Bonney et al., 2009; Haklay, 2013). Hence, they may in fact align with all three science communication levels (deficit, dialogue and participation), depending on their level of inclusion. For example, contributory projects that are initiated and managed by scientists and involve participants only in simple tasks of data collection (Bonney et al. 2009), can be seen as using the public as manpower with no knowledge or ability to make any additional contribution to the scientific process (Haklay, 2013). Consequently, such a project could be aligned with the deficit model, that assumes

audiences to be deficient in awareness and understanding of science. Alternatively, co-created projects that involve the public in all stages of the research process, including initiation and planning, could be aligned with the participation model, that considers all partners involved as equal stakeholders.

Each science communication model benefits citizen science participants, as each is directed towards different outcomes. By focusing on educational and learning opportunities, the deficit or PUS model highlights citizen science aspects of public outreach. Participants are introduced to a great deal of scientific information through citizen science projects at levels that range from layman content knowledge to more sophisticated theoretical ideas (Sullivan et al., 2014). These are available through projects, blogs, forums, Facebook pages etc. (Jackson et al., 2016). Participants can learn this information as they study the scientific background and findings of the project at hand. Similarly, through active participation in data collection and analysis, participants can learn about the nature of science and inquiry processes (Bonney et al., 2009) (for more information about learning in citizen science, see the Science Education section of this chapter).

PES complements the PUS model in its dialogic nature, focusing on democratizing science and creating mutual relationships. According to this model, citizen science participants are not just scientific data producers, but rather are considered partners who help direct the study. Through dialogue between scientists and citizens, participants can address scientific topics which are relevant to their lives, help form new scientific questions and guide studies towards greater sensitivity to society's needs (Haywood & Besley, 2014).

Citizen science can be seen as a way to integrate the different science communication models. Combining ideas from both PES and PUS may promote both social and educational goals. One example is the citizen science initiative Sensing the Air (air.net.technion.ac.il), a collaboration between scientists and citizens that aims at facilitating air quality research through active involvement of volunteers and through the collection and interpretation of meaningful air quality data. To do so, ideas from all science communication models were considered and implemented in practice during the project.

Features of Sensing the Air that correspond to the PUS model were air quality data dissemination facilitated through an interactive data presentation platform, explanations about air quality concepts and research and examination of learning processes throughout participation in the project. Features that correspond with the PES model were hazard reports submitted to scientists by participants, new research ideas raised by participants, providing opportunities for participants to engage in and conduct their own research—making the science relevant to their everyday life—and responding to public concerns.

While these features align with the two science communication models discussed, in practice, many were in fact implemented as a consolidation of models. This combined practice is illustrated in the data presentation platform. While dissemination of information is a one-way transfer model generally considered part of the PUS model, the platform was designed with a user-centered approach that created dialogue and guaranteed the presentation of relevant information—a key feature of the PES model.

In summary, building elements of all traditions of science communication into citizen science practice and combining them into new practices enables projects to be geared to participants' various needs. Using such practices in the design stages of citizen science projects can support different types of audiences by incorporating multiple opportunities and levels of engagement for the benefit of diverse stakeholders.

Statistical education and data science education

Citizen science projects often involve the collection of large amounts of differential types of data. Data science is the interdisciplinary field that enables extraction of knowledge from such data (Hardin et al., 2015). The growing number of citizen science projects that provide participants with access to accumulating data brings the value of statistical reasoning, thinking and literacy to the forefront. In societies that are becoming increasingly technological, individuals should be able to make educated decisions concerning scientific issues that affect their personal lives (e.g., causes and effects of air pollution and related policy). Such decision making requires statistical understanding of the scientific process. Many studies indicate, however, that adults do not think statistically about important issues that affect their lives (Gal, 1994; Watson, 1997).

Statistical literacy is described as the ability to interpret and critically evaluate statistical information and data-related arguments that people may encounter in diverse contexts. It is also related to the ability to communicate reactions to statistical information and concerns regarding the acceptability of given conclusions (Gal, 2002; Wallam, 1993). These capabilities are grounded in an interrelated set of human knowledge elements, such as statistical literacy, context knowledge, critical skills and dispositional elements (e.g., critical stance, beliefs).

Statistics educators argue that to develop statistical literacy, it may be necessary to work with learners—ranging from younger students to adults—in ways that go beyond traditional instructional methods. For example, the big data collected in citizen science projects often contains large amounts of data collected by a variety of people with a wide range of specialties. Analyzing such data to answer scientific questions requires measures to understand how reliable and representative the data is. Such cases provide authentic grounds for familiarizing learners with “worry questions” (Gal, 1994) regarding data quality and validity. Examples include: “Where did the data come from? Was a sample used? Is the sample biased in some way? How reliable or accurate were the instruments or measures used to generate data?” Asking about and querying such data enables developing a critical stance and supporting beliefs about statistical investigation, including the development of learners’ inquiry skills. This can be accomplished by engaging students in carefully designed, technology-enhanced Exploratory Data Analysis learning environments (Ben-Zvi, 2006; Garfield & Ben-Zvi, 2006). Exploratory data analysis aids can also facilitate learners’ handling of uncertainties involved in making *Informal Statistical Inferences* (Manor & Ben-Zvi, 2011; Pratt & Ainley, 2008), including development of their model-based skills (Manor et al., 2015; Pratt, 2000).

Moreover, although most statistical analysis in citizen science projects is performed by scientists, projects designed with supports that develop participants’ statistical literacy might improve the quality of collected data, while providing an opportunity to engage citizens in the statistical investigative phase of citizen science projects. Scientists in projects that take these features into account may gain more from participating citizens who understand the needs and importance of collecting reliable data. For example,

a citizen who is aware of measurement errors might be more careful while measuring and perform repetitive measurements. As a result, scientists will be able to gradually trust citizens' reasoning and involve them in more intricate parts of the research projects. There may even be cases in which citizens with advanced statistical reasoning skills may propose different methods of gathering data and understand their effect on the analysis and inference processes.

The statistical education lens gives us the ability to analyze the data science literacies needed for participating in different citizen science projects and the extent to which this participation supports the development of those literacies, benefiting those who choose to do so. Furthermore, statistical education informs designers regarding possible scaffolds that may aid in the process of developing the relevant data literacies, benefiting all participants and helping projects become MECS.

Science Education: Scientific Literacy and Socioscientific Issues

As a scientific endeavor itself, citizen science is a fitting and exciting context within which to consider science education. The concept of scientific literacy has different meanings and interpretations of what the public ought to know about science and who that "public" is (Laugksch, 2000). Two visions are most prevalent (Roberts & Bybee, 2014): Vision I is based on the idea of the student as a novice scientist who is expected to master the knowledge of science and its methodologies; Vision II of scientific literacy seeks to cultivate future citizens with the knowledge to take part in rational, democratic decision-making processes regarding science-related issues (Aikenhead, 2005; Bybee & DeBoer, 1994; Roberts & Bybee, 2014).

Twenty-first century citizens are often required to take an active stance and make decisions concerning socioscientific matters—controversial social affairs involving science, such as environmental or public health issues (Sadler, 2011). The quality of those decisions, mostly made by lay people, is of major significance in a democratic society (Kolstø, 2001); the decisions reflect the four tenets of democracy, as described in Kidron and colleagues (Chapter 7): Active participation, free movement of

voices, equal and just expression and ability to influence. In line with these understandings, contemporary views of scientific literacy emphasize Vision II and identify the goal of science education as supporting the development of future citizens, rather than promoting the education of future scientists (Vision I). These views describe scientific literacy as the insights and abilities that empower citizens to confront, negotiate and make decisions in life situations involving science (Bybee, McCrae & Laurie, 2009; Sadler, 2011). Some researchers (e.g., Hodson, 2003) have taken this concept farther, arguing that science education should prepare the individual for sociopolitical action and that a sense of ownership and empowerment is essential for translation of knowledge into action.

The study of science in the context of socioscientific issues can serve as an effective means to support Vision II science education goals (Zeidler, 2015). Instruction based on socioscientific issues has also been shown to promote students' learning of the content and nature of science, both constituents of Vision I, although the empirical base to support this conclusion is limited (Romine, Sadler & Kinslow, 2016; Sadler, Romine and Topçu, 2016).

Local citizen science projects, such as the Shermans Creek Monitoring Program (Wilderman, 2004) or Sensing the Air often involve socioscientific issues related to conflicting agendas concerning local resources (e.g. nature preservation vs. economic growth). Following Hodson's (2003) claims (see above), it is reasonable to assume that higher levels of engagement and participation in such citizen science projects will promote the development of Vision II and of active citizenship. Indeed, citizen science has been suggested as a platform for encouraging public dialogue on socioscientific issues and as a means to engage the public in decision-making processes (McKinley et al., 2016; Mueller et al., 2012; Stilgoe et al., 2014). Current research examining the feasibility of these ideas is lacking, but some work has been accomplished that does display promising results. While several researchers have shown that participation in citizen science projects has failed to change participants' attitudes towards science in general and environmental issues in particular (Brossard et al., 2005; Crall et al., 2012), other citizen science projects have indeed increased local environmental awareness (Evans et al., 2005). Recent research has addressed this problem by formulating specific design elements. For example, Bonney and colleagues (2015)

suggested adding reflective steps to enhance learning by helping participants understand their own role in the scientific process. Ballard et al. (2017) conceptualized a citizen science framework that integrated science education, skill improvement and personal development, aimed at empowering youth participating in citizen science projects and inspiring behavioral change.

Participation in citizen science initiatives is associated not only with Vision II, but also with an enhanced version of Vision I with greater emphasis on the realms of scientific thinking (Evans et al., 2005), understanding the scientific process and related skills (Brossard et al., 2005; Bonney et al., 2009) and improving knowledge of scientific subject matter (Brossard et al., 2005). Given the evidence for the educational potential of practicing authentic science, citizen science initiatives such as monitoring a section of a sandy beach or measuring water quality at home have been introduced recently into formal education settings. The results appear optimistic in terms of building students' capacity to take part in present and future conservation campaigns and the promotion of a positive perception of science and scientists (Ballard, Dixon, & Harris, 2017; Redondo, Manzanares, & Navarro, 2018), thus achieving some of the benefits citizen science embodies for students taking part in such projects.

Several leading reports concerning contemporary directions for science education—such as the NRC Education for Life and Work Report (2013), the Framework for K-12 Science Education (NRC 2012) and the Next Generation Science Standards (NGSS Lead States, 2013)—have been published over the past few years. These reports emphasize shifting from coverage of isolated facts to focusing on the construction of a rich network of connected ideas and interrelated concepts that can be used to explain phenomena and solve problems by engaging in science and engineering practices (Krajcik et al., 2014; Reiser, 2013), declaring that learning must be practiced within the context of relevant and authentic activities (Sadler, Foulk, & Friedrichsen, 2017). These reports, as well as science education in general, refine the tools to promote and evaluate such learning. As such, the science education lens contributes framework evaluation tools to the MECS that provide insights into the extent to which citizen science projects promote the development of scientific literacy and into the manner in which such supplementary benefits may be incorporated into their design.

Summary

At the new Taking Citizen Science to School Research Center (www.tcss.center), we recently proposed an example for a MECS model based on the four lenses described above (Atias et al., 2017). The new model, Students as Citizen Science Ambassadors, integrates a citizen science program in a K-12 school as part of its formal science curriculum. Scientific researchers worked closely with educational scholars and teachers to co-design boundary objects, such as curricular resources and student activities. These were used to advance communication with citizens and engage them in their communities. The various players were encouraged to exchange roles and identities by becoming brokers at different phases in the learning process. Educational researchers bridged between scientific researchers and teachers; teachers mediated between researchers and students, while students—when interacting with other citizens—negotiated between their own community and scientists. The model follows the ideas of Vision II discussed above, where science education practices are used as a means to promote active citizenship among students. Activities designed to advance science and data literacies involved learning about the research subject, thereby gaining proficiency in scientific inquiry and data analysis tasks. Most importantly, students assume an advocacy role, communicating information and designing and executing project-related activities for their close community.

This model is expected to intensify the mutualistic nature of citizen science; the students gain data and science literacies, as well as science communication skills, while being empowered to promote change in their own community. The community gains access to relevant scientific information and an option to contribute to scientific research. The scientists benefit from the students' acting as agents promoting public participation in their research, producing increased capacity for data collection and analysis, along with a well-informed, attentive audience.

The four lenses enable us to utilize the unique analytic framework of MECS to enhance our conceptualization of learning in citizen science projects, as well as their design. Specifically, the MECS

framework helps focus on the various potential benefits within each of these lenses for the different participants involved. The learning community lens provides a means for examining cultural and interactional processes involved in citizen science, with an eye on those interactions that promote learning and growth. Science communication reveals the power of citizen science as a vehicle to enhance the general public's understanding and engagement with science, thereby supporting mutualism between citizens and scientists. Statistics education and data science education address the ubiquitous need to make educated decisions related to scientific issues that affect people's personal lives, possibly supporting the advancement of science at the same time. Finally, science education empowers citizens to take more control of their lives by making informed decisions regarding their active involvement in society, thereby potentially producing benefit for citizens and society alike. The four lenses combined operationalize the MECS analytic framework, enabling a critical stance for both analysis and design. Understanding the different ways citizen science projects benefit diverse participants is a vital step towards designing effective MECS that contribute to all who are involved in them.

Epilogue

Insights that emerged during the writing of this chapter have been further developed and are currently being carried out and explored as part of the Taking Citizen Science to School Center (www.tcass.center), as exemplified by the Students as Citizen Science Ambassadors model. Leveraging the interdisciplinary approach at the LINKS Center (see Chapters 1, 2 and 3), the TCSS Center involves researchers from five STEM education disciplines: Mathematics, and statistics education, biology, earth science and environmental education. The principal theoretical perspectives guiding TCSS research span learning sciences, science communication and public engagement with science, informal and outdoor science education, learning communities, data sciences and technology-enhanced learning. As described in the current chapter, we believe that these theoretical perspectives, embedded within the notion of MECS and

This Is a pre-print of: Sagy O., Golubic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 18 -

operationalizing it as an analytical framework, hold great promise for further conceptualization, as well as design of citizen science endeavors.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 19 -

References

- Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, 81(2), 132-169.
- Akkerman, S., & Bruining, T. (2016). Multi-level boundary crossing in a professional development school partnership. *Journal of the Learning Sciences*, 25(2), 1-44.
- Aristeidou, M., Scanlon, E., & Sharples, M. (2013). A design-based study of citizen inquiry for geology. In *Proceedings of the Doctoral Consortium at the European Conference on Technology Enhanced Learning, Co-located with the EC-TEL 2013 Conference* 7-13. CEUR.
- Atias, O., Sagy, O., Kali, Y., Angel, D., & Edelist, D., (2017). *Jellyfish and people—a citizen-science collaboration with mutual benefits to citizens and scientists*. Poster presented at the American Educational Research Association Conference, San Antonio, Texas, April.
- Ballard, H. L., Dixon, C. G., & Harris, E. M. (2017). Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation. *Biological Conservation*, 208, 65-75.
- Barak, M., & Dori, Y. J. (2009). Enhancing higher order thinking skills among inservice science teachers via embedded assessment. *Journal of Science Teacher Education*, 20(5), 459-474.
- Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development*, 49(4), 193-224.
- Barron, B., Martin, C. K., Mertl, V., & Yassine, M. (2016). Citizen science: connecting to nature through networks. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series, vol. 16 (pp. 257-284). New York: Springer.
- Bauer, M. W. (2009). The evolution of public understanding of science—discourse and *Comparative Evidence*. *Science Technology & Society*, 14(2), 221-240.
- Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. New Haven and London: Yale University Press.
- Bielaczyc, K., Kapur, M., & Collins A. (2013). In C. E. Hmelo-Silver, C. A. Chinn, C. Chan, & A. M. O'Donnell (Eds.), *International Handbook of Collaborative Learning*. New York: Taylor & Francis, Inc.
- Bizer, C. (2009). The emerging web of linked data. *IEEE Intelligent Systems*, 24(5), 87-92.
- Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). Public participation in scientific research: Defining the field and assessing its potential for informal science education. A CAISE Inquiry Group Report, (July), 1-58.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 20 -

- Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A *Developing Tool for Expanding Science Knowledge and Scientific Literacy*. *BioScience*, 59(11), 977-984.
- Bonney, R., Phillips, T., Enck, J., Shirk, J., & Trautmann, N. (2014). *Citizen Science and Youth Education*. Washington, DC: Research Council Committee on Out-of-School Time STEM.
- Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2015). Can citizen science enhance public understanding of science? *Public Understanding of Science*, 25(1), 2-16.
- Bronstein, J. L. (1994). Our current understanding of mutualism. *The Quarterly Review of Biology*, 69(1), 31-51.
- Brossard, D., & Lewenstein, B. V. (2009). A critical appraisal of models of public understanding of science. In L. Kahlor & P. Stout (Eds.), *Communicating science: New Agendas in Communication* (pp. 11-39). New York: Routledge.
- Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, 27(9), 1099-1121.
- Brown, A. L. (1994). The advancement of learning. *Educational Researcher*, 23(8), 4-12.
- Bucchi, M., & Trench, B. (2014). *Routledge handbook of public communication of science and technology*. Abingdon, UK and New York: Routledge.
- Bybee, R., McCrae, B., & Laurie, R. (2009). PISA 2006: An assessment of scientific literacy. *Journal of Research in Science Teaching*, 46(8), 865-883.
- Cochran-Smith, M., & Lytle, S. L. (1999). The teacher research movement: A decade later. *Educational Researcher*, 28(7), 15-25.
- Colburn, A. (2000). An inquiry primer. *Science Scope*, 23(6) 42-44.
- Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research : Theoretical and methodological issues. *Journal of The Learning Sciences*, 13(1), 15-42.
- Cooper, C. B., & Lewenstein, B. V. (2016). Two meanings of citizen science. In D. Cavalier & E. B. Kennedy (Eds.), *The rightful place of science: Citizen science* (pp. 51-62). Tempe, AZ: Consortium for Science, Policy & Outcomes.
- Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., & Waller, D. M. (2012). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science*, 21(1), 1-20.
- Curtis, V. (2015). Online citizen science projects: an exploration of motivation, contribution and participation. Ph.D. dissertation submitted to the Open University (United Kingdom).

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 21 -

- Del Savio, L., Prainsack, B., & Buyx, A. (2016). Crowdsourcing the human gut. Is crowdsourcing also “citizen science”? *Journal of Science Communication*, 15(3), 1-16.
- Dickinson, J. L., & Bonney, R. (Eds.). (2012). *Citizen science: Public participation in environmental research*. Ithaca, NY: Cornell University Press.
- Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., ... Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, 10(6), 291-297.
- Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen science as an ecological research tool: challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics*, 41(1), 149-172.
- Edelson, D. C., Kirn, S. L., & workshop participants. (2018). *Designing citizen science for both science and education: A workshop report*. (Technical Report No. 2018-01). Colorado Springs, CO: BSCS Science Learning.
- Ellis, R. A., Goodyear, P., Calvo, R. A., & Prosser, M. (2008). Engineering students’ conceptions of and approaches to learning through discussions in face-to-face and online contexts. *Learning and Instruction*, 18(3), 267-282.
- Feinstein, N. W., Allen, S., & Jenkins, E. (2013). Outside the pipeline: reimagining science education for nonscientists. *Science*, 340(6130), 314-317.
- Gerard, L. F., Spitulnik, M., & Linn, M. C. (2010). Teacher use of evidence to customize inquiry science instruction. *Journal of Research in Science Teaching*, 47(9), 1037-1063.
- Golumbic, Y. N. (2015). What makes citizen science projects successful, and what can we learn from them for future projects? THE Technion Literature Review of Citizen Science Projects. Technion Citizen Science Project (TCSP). Haifa, Israel: The Technion—Israel Institute of Technology.
- Golumbic, Y. N., Orr, D., Baram-Tsabari, A., and Fishbain, B. (2017). Between vision and reality: A case study of scientists’ views on citizen science. *Citizen Science Theory and Practice* 2(1), 1-13.
- Golumbic, Y. N., Baram-Tsabari, A., & Fishbain, B. (2017). Why and how should we facilitate scientific information to the public [in Hebrew]. *Ecology and the Environment*, 8(3), 5-6.
- Golumbic, Y. N., Fishbain B., & Baram-Tsabari, A. (Forthcoming). User centered design of a citizen science air-quality monitoring project.
- Goodyear, P. (2015). Teaching as design. *HERDSA Review of Higher Education*. 2(2), 27-50.
- Gould, R., Johnson, T., Moncada-Machado, S., & Molyneux, J. (2015). Modeling with “Big Data” in secondary schools: An exploratory study. In *Proceedings of the Ninth International Research Forum on Statistical Reasoning, Thinking, and Literacy* (SRTL9) (pp. 176-188). Paderborn, Germany: University of Paderborn.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 22 -

- Gray, S. A., Nicosia, K., & Jordan, R. C. (2012). Lessons learned from citizen science in the classroom. a response to “the future of citizen science.” *Democracy and Education*, 20(2), 14.
- Haklay, M. (2013). Citizen science and volunteered geographic information—overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing geographic knowledge: Volunteered geographic information (VGI) in theory and practice* (pp. 105-122). Berlin: Springer.
- Hardin, J., Hoerl, R., Horton, N. J., Nolan, D., Baumer, B., Hall-Holt, O., Murrell, P., Peng, R., Roback, P., Temple Lang, D., & Ward, M. D. (2015). Data science in statistics curricula: Preparing students to “think with data.” *The American Statistician*, 69(4), 343-353.
- Haywood, B. K., & Besley, J. C. (2014). Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. *Public Understanding of Science* (Bristol, England), 23(1), 92-106.
- Hiller, S. E., & Kitsantas, A. (2014). The effect of a horseshoe crab citizen science program on middle school student science performance and STEM career motivation. *School Science and Mathematics*, 114(6), 302-311.
- Hod, Y., & Ben-Zvi, D. (2014). A group psychotherapeutic perspective on transforming participation in a learning community. *Instructional Science*, 42(6), 949-970.
- Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education*, 25(6), 645-670.
- Irwin, A. (1995). *Citizen Science. A Study of People, Expertise and Sustainable Development*. New York: Routledge.
- Jackson, C., Østerlund, C., Maidel, V., Crowston, K., & Mugar, G. (2016). Which way did they go? Newcomer movement through the Zooniverse. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (pp. 623-634). New York: ACM Press.
- Kali, Y. (2008). The Design Principles Database as means for promoting design-based research. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of design research methods in education* (pp. 423-438). New York: Routledge.
- Kali, Y., & Ronen, M. (2008). Assessing the assessors: added value in web-based multi-cycle peer assessment in higher education. *Research and Practice in Technology Enhanced Learning*, 3(1), 3-32.
- Kolstø, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education*, 85(3), 291-310.
- Kullenberg, C., & Kasperowski, D. (2016). What is citizen science?—A scientometric meta-analysis. *PLOS One*, 11(1). URL: <https://doi.org/10.1371/journal.pone.0147152>.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 23 -

- Kountoupes, D. I., & Oberhauser, K. S. (2008). Citizen science and youth audiences: Educational outcomes of the Monarch Larva Monitoring Project. *Journal of Community Engagement and Scholarship*, 1(1). URL: <http://jces.ua.edu/citizen-science-and-youth-audiences-educational-outcomes-of-the-monarch-larva-monitoring-project/>.
- Kulikowich, J. M., & Young, M. F. (2001). Locating an ecological psychology action for situated methodology. *Journal of the Learning Sciences*, 10(1-2), 17-26.
- Kullenberg, C., & Kasperowski, D. (2016). What is citizen science?—A scientometric meta-analysis. *PLOS One*, 11(1). URL: <https://doi.org/10.1371/journal.pone.0147152>.
- Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, 84(1), 71-94.
- Lievrouw, L. A. (2010). Social media and the production of knowledge: A return to little science? *Social Epistemology*, 24(3), 219-237.
- McCallie, E., Bell, L., Lohwater, T., Falk, J. H., Lehr, J. L., Lewenstein, B. V., ... Wiehe, B. (2009). Many experts, many audiences: Public engagement with science and informal science education. A CAISE Inquiry Group Report, (March), 1-83.
- McKenney, S. E., & Reeves, T. C. (2012). *Conducting educational research design*. London: Routledge.
- Mueller, M. P., Tippins, D., & Bryan L. (2012). The future of citizen science. *Democracy and Education*, 20(1), 2.
- Penuel, W. R., Allen, A. R., Coburn, C. E. & Farrell. (2015). Conceptualizing research-practice partnerships as joint work at boundaries. *Journal of Education for Students Placed at Risk*, 20(1-2), 182-197.
- Raddick, M. J., Bracey, G., Carney, K., Gyuk, G., Borne, K., Wallin, J., & Jacoby, S. (2009). Citizen science: Status and research directions for the coming decade. Astro2010: The Astronomy and Astrophysics Decadal Survey, Position Paper no. 46. URL: <http://adsabs.harvard.edu/abs/2009astro2010P..46R>.
- Redondo, M. L., Queiruga Dios, M. A., Sáiz Manzanares, M. C., & Juez Navarro, S. (2018). Citizen Science in School. In M. F. P. C. Martins Costa, J. B. Vázquez Dorrió, & J. M. Fernández Novell (Eds.), *Hands-on science. Advancing science. Improving education*. (pp. 194-198). Hands-on Science Network. Braga, Portugal: Copissaurio Repro – Centro Imp. Unip. Lda. Campus de Gualtar, Reprografia Complexo II. URL: <http://www.hsci.info/hsci2018/images/pdfs/eBookHSCI2018.pdf>
- Reimann, P. (2008). Communities of practice. In H. H. Adelsberger, J. M. Pawlowski, & D. G. Sampson (Eds.), *Handbook on Information Technologies for Education and Training*. Berlin and Heidelberg: Springer.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 24 -

- Roberts, D. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729-780). Mahwah, NJ: Lawrence Erlbaum Associates.
- Romine, W. L., Sadler, T. D., & Kinslow, A. T. (2016). Assessment of scientific literacy: M. F. P. C. (QuASSR). *Journal of Research in Science Teaching*, 54(2), 274-295.
- Sadler, T. D. (2011). Situating socio-scientific issues in classrooms as a means of achieving goals of science education. In *Socio-scientific issues in the classroom: Teaching, learning and research* (pp. 1-9). Dordrecht, the Netherlands: Springer.
- Sadler, T. D., Romine, W. L., & Topçu, M. S. (2016). Learning science content through socio-scientific issues-based instruction: A multi-level assessment study. *International Journal of Science Education*, 38(10), 1622-1635.
- Sagy, O., Kali, Y., Tsaushu, M., & Tal, T., (2016). The culture of learning continuum: Promoting internal values in higher education. *Studies in Higher Education*. DOI: 10.1080/03075079.2016.1174205.
- Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research.” *Journal of the Learning Sciences*, 23(1), 18-36.
- Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. C., Krasny, M., & Bonney, R. (2012). Public participation in scientific research: A framework for intentional design. *Ecology and Society*, 17(2), 29.
- Sickler, J., & Cherry, T. M. (2012). Lost ladybug project summative evaluation report. Edgewater, MD.
- Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, 24(9), 467-471.
- Stebbins, R. A. (1997). Serious leisure and well-being. In J. T. Haworth (Ed.), *Work, leisure and well-being* (pp. 117-130) London: Routledge.
- Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., ... Kelling, S. (2014). The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation*, 169, 31-40.
- Sullivan, B. L., Phillips, T., Dayer, A. A., Wood, C. L., Farnsworth, A., Iliff, M. J., ... Kelling, S. (2017). Using open access observational data for conservation action: A case study for birds. *Biological Conservation*, 208, 5-14.
- Tal, T., Kali, Y., Magid, S., & Madhok, J. J. (2011). Enhancing the authenticity of a web-based module for teaching simple inheritance. In T. D. Sadler (Ed.), *Socio-scientific issues in the classroom: Teaching, learning and research*. (Vol. 39, pp. 11-38). Dordrecht, the Netherlands: Springer.
- Teacher, A. G. F., Griffiths, D. J., Hodgson, D. J., & Inger, R. (2013). Smartphones in ecology and evolution: A guide for the apprehensive. *Ecology and Evolution*, 3(16), 5268-5278.

This Is a pre-print of: Sagy O., Golumbic, Y. N., Ben-Horin, H. A., Benichou, M., Atias, O., Manor H. B., Baram-Tsabari, A., Kali, Y., Ben-Zvi, D., Hod, Y., & Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. Schejter (Eds.) *Learning In a Networked Society - Spontaneous and Designed Technology Enhanced Learning Communities*. Computer-Supported Collaborative Learning Series, Vol 17 (pp. 97-115). Switzerland: Springer.

- 25 -

- Thompson, K., Gouvea, J., & Habron, G. (2016). A design approach to understanding the activity of learners in interdisciplinary settings: Environment and diversity. *The International Conference of the Learning Sciences*, June 19-24, Singapore, 2016.
- Trench, B. (2008). Towards an analytical framework of science communication models. In D. Cheng, M. Claessens, N. R. J. Gascoigne, T. J. Metcalfe, B. Schiele, & S. Shi (Eds.), *Communicating science in social contexts: new models, new practices* (pp. 119-138). Dordrecht, the Netherlands: Springer.
- Watson, D., & Floridi, L. (2016). Crowdsourced science: sociotechnical epistemology in the e-research paradigm. *Synthese*, 195(2), 741-764.
- Wenger, E. (1998). *Communities of practice, learning, meaning and identity*. Cambridge, UK: Cambridge University Press.
- Wenger, E. (2000). Communities of practice and social learning systems. *Organization Articles*, 7(2), 225-246.
- Wilderman, C. C. (2004). Shermans Creek: A portrait. Technical Status Report. Carlisle, PA: Alliance for Aquatic Resource Monitoring (ALLARM). Dickinson College.
- Yoho, R. A., & Vanmali, B. H. (2016). Controversy in biology classrooms—citizen science approaches to evolution and applications to climate change discussions. *Journal of Microbiology & Biology Education*, 17(1), 110-114.
- Zeidler, D. (2015). Socioscientific issues. In *Encyclopedia of science education* (pp. 998-1003). Dordrecht, the Netherlands: Springer.
- Zoellick, B., Nelson, S. J., & Schaffler, M. (2012). Participatory science and education: bringing both views into focus. *Frontiers in Ecology and the Environment*, 10(6), 310-313.