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Social Studies, Science, and Civics: Teacher Education and Citizen Science in the 21st Century

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Citizen science, research in which members of the public actively contribute scientific data, has recently evolved as a means to support scientific inquiry in the classroom, particularly in fields related to ecology and environmental science. Our research focuses on a collaborative project with teacher candidates, a science education professor, and a social studies education professor at a Canadian university. Teacher candidates were engaged in the classroom and beyond as they explored topics related to civics education and evidence-based decision making. Our findings demonstrate the potential effectiveness of a citizen science lens for science, social studies, and generalist teachers.

La science citoyenne, c'est-à-dire la recherche dans laquelle les membres du public contribuent activement aux données scientifiques, a récemment évolué comme un moyen de soutenir la recherche scientifique en classe, en particulier dans les domaines liés à l'écologie et aux sciences de l'environnement. Notre recherche porte sur un projet de collaboration avec de futurs enseignants, un professeur d'enseignement des sciences et un professeur d'enseignement des sciences sociales dans une université canadienne. Les candidats à l'enseignement se sont engagés dans la salle de classe et au-delà en explorant des sujets liés à l'éducation civique et à la prise de décision fondée sur des preuves. Nos résultats démontrent l'efficacité potentielle d'une optique de science citoyenne pour les professeurs de sciences, d'études sociales et les enseignants généralistes.

Citizenship and global citizenship education have been the subject of renewed international attention in the past two decades (Mirra et al, 2013; Pashby & Andreotti, 2015). As Bergen et al (2020) noted, this increase in attention may be attributed to the perceived skills needed to accompany the rise in globalization, political rhetoric in Western democracies, and the neoliberalization of economies. Within this context, the debates concerning what constitutes rigorous civic education in teacher education programs around the world have also increased (Journell, 2013; Torney-Purta, 2002; Yemini, 2017), and citizen science has emerged as one possible avenue for enabling teacher candidates to develop justice-oriented civic education pedagogy. Citizen science engages members of the public in collaborative research projects, where the public collects data, analyzes data, or monitors projects in ways that would otherwise not be possible by scientists alone (McKinley et al., 2017; National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). In schools, citizen science projects can be used to encourage students to ask questions that are of public concern (civic issues), to design and carry out investigations (take action), and to learn the science behind local issues (investigate the root causes of societal problems; Kelemen-Finan et al, 2018; NASEM, 2018). In this article, we discuss the results of a 2-year interdisciplinary research project that introduced citizen science to teacher candidates as a means to develop justice-oriented civic education pedagogy across multiple subject areas.

The project brought together a science education professor, a history education professor, two social studies instructors, and teacher candidates across a wide range of subject areas and teaching levels at a Canadian university. Our aim in the project was to introduce citizen science as an interdisciplinary approach for civic education teaching. The project had two overarching objectives: 1. The engagement of teacher candidates with topics that foster justice-based civic engagement and evidence-based decision making in the classroom; and 2. The promotion of critical and scientific inquiry into the root causes of societal problems through citizen science. We provided opportunities for teacher candidates to discuss socio-scientific issues from various perspectives, supported teacher candidates to develop student-centered activities that encouraged student agency, and guided teacher candidates through the implementation of citizen science approaches that foster inquiry in multiple subjects, including English, social studies, geography, mathematics, and science. The project explored how citizen science approaches might be taken up by teacher candidates to engage students in topics fostering critical civic engagement, scientific literacy, supporting science research, and evidence-based decision making. We also probed how participating in the project affected the teacher candidates' understandings of teaching pedagogies that could enhance justice-oriented civic engagement.

In this research paper, we have two goals. The first goal is to report on the outcomes of our 2-year project, in particular, the characteristics of the lesson plans that were developed by the teacher candidates. The second goal is to explore a fundamental tension in civic education: that it is typically siloed in social studies courses. With this project, we are endeavoring to imagine civic education as interdisciplinary through utilizing the example of the citizen science approach. To this aim, we report on the impact that participating in the citizen science project had on teacher candidates' understandings about interdisciplinary approaches to civic engagement in the classroom. The types of civic education advocated in the teacher candidates' lesson plans, as well as attrition rates in the project itself, speak to the difficulties associated with developing interdisciplinary civic education pedagogy.

Theoretical Background

Our work is situated at the intersection of teacher education, civic education, science education, and citizen science. Teacher education candidates are at a formative stage of their development as educators and are often eager to explore new ways of learning and teaching through courses, practicum placements, professional learning workshops, and community service projects (McLean & Cook, 2016). In many teacher education programs, learning to teach civic education is embedded in social studies methods courses, as this subject is where civic education is most often included in K-12 curricula (Hughes et al, 2010; Losito & Mintrop, 2001). Civic education pedagogy in teacher education programs has also seen a renewed increase in research (Tupper & Cappello, 2012; Wood et al, 2018), yielding important findings about how teacher education pedagogy can shape civic education in schools. However, few of these research initiatives have sought to cultivate an interdisciplinary approach to teaching civic education, democracy, and/or teaching strategies that enable teacher candidates to incorporate civic values into a variety of subjects, including science, geography, and math (in addition to social studies). Our project contributes to the growing body of research that seeks to expose these limitations by profiling an interdisciplinary initiative developed by a team of professors and teacher candidates to address this gap.

Civic Education

Civic education is a field marked by continuous evolution and debate (Osborne, 2010), but broadly consists of particular sets of skills, knowledge, and values that underpin different conceptions of citizenship (Journell, 2010; Llewellyn et al, 2010), and involves varied pedagogical approaches in different subject areas that are thought to best equip students to actively participate in their communities, advocate for change, interrogate the root causes of injustice, and engage in critical self-reflection about one's place in the world (Pashby & Andreotti, 2015). The debates in these two areas are based on fundamental differences in what is thought to be a "good" citizen, and increasingly, a "good" global citizen. On one end of the spectrum are "personally responsible" (Westheimer & Kahne, 2004), "neoliberal" (Shultz, 2007), or "character education" (Journell, 2010) approaches, which often encourage civic participation within existing social, economic, and political structures, including actions such as voting, signing petitions, global travel, or donating to food drives. On the other end of the spectrum are approaches to civic (and global citizenship) education that look at the problems with existing structures, and advocate for critical self-interrogation and actions that change unjust systems. These "justice-oriented" (Westheimer & Kahne, 2004) or "transformationalist" (Shultz, 2007) approaches are critical of the continued overrepresentation of Eurocentric, colonial, and paternalistic approaches to civic education, and instead look to different ways of knowing in their attempts to cultivate ethical relationships and participation across identity groups (Pashby & Andreotti, 2015). It is this justice-oriented end of the civic education spectrum that we sought to engage within our study.

Internationally, civic education can be either a stand-alone subject or embedded in social studies and history courses. In Canada and the United States, Kindergarten to Grade 12 (K–12) curriculum is developed by provincial and territorial or state Ministries of Education, respectively, and can vary dramatically from region to region (Bergen et al., 2020). Some provinces, territories, and states include civic education or citizenship in their social studies courses, and others have optional civics courses as stand-alone subjects. Teacher candidate training is not coordinated across provinces, territories, or states in either country. In Canada, a variety of approaches have been used to train teachers to teach civic education, including service-learning placements, infusing Indigenous content into courses, and looking at structural power dynamics within society (Bergen et al., 2020). Similarly, in the United States there are diverse initiatives that aim to prepare teacher candidates to teach civic education—these initiatives include service-learning experiences in multicultural education courses (Cone, 2012), more critical service-learning experiences (Sulentic Dowell, 2008; Tinkler & Tinkler, 2013), and participation in social action curriculum projects (Shultz & Baricovich, 2010; Stenhouse & Jarrett, 2012). The latter typically task teacher candidates with identifying a problem in conjunction with a community, brainstorming solutions, implementing actions, and reflecting on their learning.

Science Education

Science education can be re-conceptualized as an instrument of civic engagement through activities addressing societal, local, or environmental problems (Vesterinen et al, 2014), as well as activities examining more general socio-scientific issues (Pedretti & Nazir, 2011), to social justice initiatives, especially if students have agency in deciding the goals and procedures of their projects (Eilks & Hofstein, 2014; Sadler, 2011). Science education that is relevant to the individual student, as well as to society, can highlight the relationship between society and science, and bring issues crucial for citizenship education to the forefront (Falk, 2001; Sadler, 2011; Tolppanen, 2015), including systemic issues such as climate change, the impacts of settler colonialism, and economic inequality. Recent studies have found that youth are interested in participation and political engagement, particularly in actions that emphasize self-expression and self-actualization (Kahne & Westheimer, 2006; Quintelier, 2007). Educational researchers have argued for a sustainable development approach to science education for decades (Bybee, 1987; Hurd, 1970). Still, there is no "single, widely accepted view of sustainability education" (Pedretti & Nazir, 2011) and science education in today's classroom is largely detached from societal contexts (Gilbert, 2006).

The emphasis placed on the importance of education for sustainable development has led to numerous models on how to incorporate its central tenets inside the classroom (Bonney, Cooper, et al., 2009; de Haan, 2006; McKeown et al, 2002). Although each model varies, Eilks and Hofstein (2014) summarized the most essential traits as follows: 1. Interdisciplinary approaches must be adopted; 2. Societal issues must be implemented; and, 3. Pedagogical methods must be changed. One criticism of school science that has been posited as the main reason for students' continuing disinterest (e.g., Jack & Lin, 2017) is that science is often depicted as decontextualized and dehumanized (Hodson, 1998). Teaching science in a more humanistic way (Aikenhead, 2006) can contextualize science and help students to better understand the processes of science rather than to merely acquire science content knowledge. According to Eilks and Hofstein (2014) one of the best approaches to contextualize education is to build socio-scientific issues (SSI) into the science curricula (e.g., Sadler, 2011), and to involve students in citizen science projects (Jenkins, 2011). Similar to social action curriculum projects in civic education, providing students with the agency and autonomy to decide the goals and procedures of their projects as they seek to contribute to their communities is key (Stuckey et al, 2013).

Although various science education programs exist that seek to encourage students to take action (Hodson, 2003; Pedretti & Nazir, 2011), few studies in science education have focused on students' sociopolitical actions (Sternäng & Lundholm, 2011). Other studies have failed to measure involvement in community development projects (Boyes et al, 2009; Sternäng & Lundholm, 2011; Zsóka et al, 2013), were based on quantitative analysis only (Zsóka et al., 2013), or focused primarily on students' reasoning and perspectives on a specific issue (Sternäng & Lundholm, 2011). Science educators also find incorporating societal issues into science education to be difficult (Tolppanen, 2015). Research conducted in schools indicates that even though teachers are mindful of a need for activities that address local and global problems and decision-making processes, they sometimes worry about their lack of competence to implement such approaches (Kahne et al, 2013; Pedretti et al, 2008). Lack of time and resources, assessment issues, the coupling of science and ethics, and the politicization of science are barriers to the design of comprehensive activities that foster students' skills, knowledge, and critical thinking about socio-scientific issues (Aikenhead, 2006; Hughes, 2000; Pedretti et al., 2008; Tsai, 2000).

One way to address these barriers is to deliberately take up discussions of anticipated benefits and challenges during teacher education programs.

Citizen Science

Citizen science, when considered most broadly, engages members of the public in scientific research activities, where citizens actively contribute to collaborative research projects through participatory data collection, analysis, and project monitoring (Nugent et al, 2015). Despite the lack of a single definition (Fazio & Karrow, 2015), and concerns over narrow definitions (Auerbach et al., 2019), citizen science projects do possess common characteristics (NASEM, 2018), although varying in goals, design, and outcomes. Seven characteristics commonly seen across projects are active learning of participants; participant engagement with data collection, analysis, and interpretation; a systematic approach to research (often, but not always, scientific in nature), primarily non-scientist participants; the advancement of knowledge on a public rather than individual scale; meaningful benefits to participants, including a sense of satisfaction; and communication of results to an authentic audience (NASEM, 2018). Ballard et al (2017) also advocated for ensuring rigorous data collection, disseminating scientific findings to authentic external audiences, and investigating complex social-ecological systems.

Citizen science has been adopted by teachers who want to incorporate socio-scientific issues in their science or social studies curriculum, because many citizen science projects (although not all) can encourage students to ask questions that matter (real-world issues), to design and carry out investigations (engage or act), and to learn the science behind local issues (investigating root causes of problems; Green & Medina-Jerez, 2012; Mueller et al, 2012). Citizen science projects can support civic education student learning because they are an authentic scientific endeavour, they provide a real-world context for learning, and can engage students in action (NASEM, 2018). Teachers can implement citizen science projects to support civic learning in three ways (NASEM, 2018): having students participate in projects that were initially designed to support civic learning goals (e.g., http://tomatosphere.org/); adapting projects that were conceptualized without specific learning goals, but that include significant engagement opportunities (e.g., https://ontarionature.org/programs/citizen-science/), or involving students in action opportunities that spring from citizen science projects (e.g., https://www.inaturalist.org/projects). Although not all citizen science projects have similar goals, designs, or outcomes, students who have the opportunity to be citizen scientists are likely to have increased confidence in making informed choices and advocating for others—not just humans—and a higher civic responsibility (Mueller et al., 2012).

There are challenges to incorporating citizen science in the classroom, such as misalignments in aims and practices, including outcomes and assessment (Fazio & Karrow, 2015; Glasson, 2015; Shume, 2015), and a lack of resources, including lack of access to scientists and primary literature (Gray et al, 2012). A lack of experience can be another barrier; Fazio and Karrow (2015) pointed out a need for professional learning in order for teachers to adopt citizen science projects—a gap that our study seeks to address.

Conceptual Frameworks

For our research project, we drew upon two conceptual frameworks in order to guide project development and understand how candidates took up the idea of citizen science when analyzing the data. The first framework was a citizen science project framework developed by Bonney, Ballard, et al. (2009), which looks at three categories for considering how a project is designed and who is involved in carrying it out. We refer to this framework as the "3 Cs," because it consists of contributory projects, which are scientist designed, but include the public in the data collection phase; collaborative projects, which are scientist structured, but the public are able to refine project design, analyze data, or communicate findings; and co-created projects, which are fully democratized, with the public actively engaging in all steps of the scientific process. As the project unfolded, based on our analysis of the data, we added a fourth category, classroom-created, where the teacher developed a collaborative project in which the wider community could participate. The emphasis in these projects was on collaborative data collection and analysis rather than on individual inquiry, with the teacher taking on the role(s) that scientists would typically play. This fourth category is in alignment with the apprenticeship possibilities inherent in citizen science projects (NASEM, 2018).

The second conceptual framework that we adopted was a framework for citizenship science education developed by Vesterinen et al (2016), which draws on the work of Westheimer and Kahne (2004). We used this framework, which we called the "3 Ps," as a starting point for examining the student actions that might arise when our participants' citizen projects were implemented. The first category, personally responsible action, sees students engaging in activities that require them to act responsibly toward other people and/or the environment (e.g., recycling), but primarily on an individual level (Vesterinen et al., 2016). The second category, participatory action, sees students taking part in school or community efforts (mentoring students, volunteering in community development groups), which are more collective-based. Vesterinen et al.'s (2016) third category, preparation for future, sees students engaging in activities that are also preparing them for future actions (learning new skills, making new contacts, etc.). However, we eliminated this third category, because we agreed that participating in any citizen science lesson could lead to developing skills for future actions toward making the world a better place. We replaced this category with a new category, possibilities for systemic action, in order to describe projects that investigate the root causes of societal problems, or could overtly lead to possibilities for systemic, justice-oriented changes.

Research Questions

In this paper, we discuss the results of our 2-year interdisciplinary research project that introduced citizen science to preservice teachers as a means to develop citizenship pedagogy. Our goals were to support teacher candidates to develop student-centered activities that could encourage student agency, and to promote the understanding that citizen science approaches can foster inquiry in multiple subject areas. The questions guiding our research were: 1. What do teacher candidates know about citizen science? 2. After participating in our project, what kinds of citizen science activities did teacher candidates plan to implement, particularly with regard to the 3 Cs and 3 Ps frameworks? and 3. What challenges did participating teacher candidates experience when adopting a citizen science approach in planning and teaching?

Methodology & Methods

Our project used a mixed methods case study methodology (Yin, 2014), endeavoring to cultivate an in-depth, detailed understanding of small groups of teacher candidates and their experiences with citizen science. Through the case study, we critically analyzed the experiences of these small groups with the end goal of connecting their experiences to larger trends in citizenship education within teacher education programs in Canada, and internationally. This feature of case studies, the ability to link micro level experiences with macro level structures (Neuman, 2011), was one of the strengths of our research. Case study approaches typically also employ a diverse set of data collection methods in order to generate the most complete understanding of the case as possible, and in order to validate the findings (Merriam, 2001). In our project, we used three data collection methods that allowed us to build a deeper and more comprehensive description of our research participants' experiences than a single collection method would have enabled, and these varied methods allowed for a cross-method validation of findings.

Participants

Participants in this extracurricular professional development project were teacher candidates who were registered in a 2-year, post degree Bachelor of Education program at an urban university with three programmatic focus options: elementary (Kindergarten to Grade 6), intermediate (Grades 7 to 10), and secondary divisions (Grades 11 to 12). Among the participants, approximately one third were from the elementary division and had a previous degree in the humanities (psychology, anthropology, or sociology). Among the intermediate and secondary level candidates, subject specialties included science, history, and mathematics. Although 50 teacher candidates initially provided consent and completed the initial questionnaire, the number of teacher candidate participants dropped after completing the initial questionnaire, with 14 teacher candidates completing the follow up questionnaire, 23 submitting lesson plans, and 12 participating in the exit focus groups.

Project Description

In Year 1, at the beginning of the fall semester, we obtained ethical approval for the study, hosted information workshops, and invited teacher candidates to participate in a study about citizen science. The project formally began with an online questionnaire regarding participants' views of citizen science. Then, during a two-hour interactive workshop, we introduced the concept of citizen science along with the 3 Cs and 3 Ps conceptual frameworks, conducted a group critique of lesson examples to determine what criteria to use in assessing citizen science projects, and explored how citizen science activities could fulfill or complement prescribed science, social studies, or citizenship education curriculum topics. The examples we probed included projects that mapped bird migration patterns as a means for understanding human impacts on the environment, and outdoor rink freezing and melting points that tracked changes in climate. Participants then had the remainder of the semester (11 weeks) to develop a lesson plan that they might be able to implement in their practicum classrooms. Given the range of opportunities and limitations typically provided for teacher candidates on their practicum placements, we did not require that the lesson had to be taught. Throughout the term, the research team was available to provide support, in group follow-up meetings and/or on an individual basis as requested. At the end of the semester, we collected all of the completed lesson plans for analysis, and we invited participants to attend focus groups, where they shared the lesson plans that they had created with their colleagues. Finally, we asked them to complete an online questionnaire that explored their responses to these experiences.

Similarly, in Year 2 of the project, we hosted interactive workshops on citizen science, and invited teacher candidates to participate in the study; three of the Year 2 participants returned from Year 1. We conducted similar collaborative sessions, and offered support for planning. Additionally, based on feedback from Year 1, we created a "Primer" that was used with Year 2 participants to help teacher candidates understand and plan citizen science projects that take a participatory democratic approach (see Appendix A). Participants again had the majority of the semester (10 weeks) to develop a lesson plan that they could possibly implement in their practicum placement. At the end of the semester, we collected completed lesson plans, sent out follow-up questionnaires, and conducted a focus group.

Data Sources and Analysis

The sources of data in this project were two questionnaires (initial and follow-up), teacher candidates' lesson plans, and the focus group transcripts. Each of these data sources is described below, along with the approaches we took to analyze the data that were collected.

Questionnaires

The initial questionnaire was a combination of closed-choice and open-ended questions designed to gather information about participants' self-reported levels of knowledge and confidence with a citizen science approach, and to help us to answer our first research question. The questionnaire, which was designed to take approximately 10-15 minutes to complete, contained questions about the participants' current level of knowledge of citizen science and their opportunities to use a citizen science approach in their own teaching.

The follow-up questionnaire was similar to the initial questionnaire, designed to gather information about participants' levels of knowledge and confidence, and containing additional questions that targeted participants' perspectives on pedagogy and resources and that sought feedback on the project itself. This questionnaire was also intended to take approximately 10-15 minutes to complete, and contained questions about how the project had influenced participants' knowledge and confidence to lead discussions on citizen science in their future classrooms and the kinds of additional resources that might help participants feel confident and prepared to teach citizen science.

Analysis of the initial and follow-up questionnaire responses was either a quantitative summation of closed-choice responses, or a qualitative coding of open-ended responses. We took an inductive category development approach to coding (Auerbach & Silverstein, 2003; Hsieh & Shannon, 2005). Responses to open-ended questions were first read through once to gain a sense of the overall sentiments in the responses. Next, answers were read a second time word by word to derive one- or two-word codes that encompassed the main ideas of the answers (Hsieh & Shannon, 2005). Once all open-ended questionnaire responses had been coded, we read responses a third time and grouped codes into categories.

Lesson Plans

Our project provided participating teacher candidates with the opportunity to learn about and practice the skills necessary to create a citizen science lesson plan, and we asked our participants to submit their plans to team members. Subsequently, participants were free to select topics for their lesson plans, although we encouraged the inclusion of scientific inquiry, civic engagement, and evidence-based decision making. Over our 2-year study, teacher candidates were provided with two templates to aid them in developing their citizen science lesson plans. After selecting a lesson planning template that best suited the lesson they decided to develop (including sections on inquiry goals, curricular outcomes, and pedagogical strategies), they had approximately 10-11 weeks to create and submit their plan to the research team.

The lesson plans were coded using the three-phase model developed by Auerbach and Silverstein (2003). In the first phase, we independently analyzed each of the lesson plans, and in the second phase, we met to discuss and debate our findings. We found that most of the initial discrepancies in our individual analyses resulted from limitations of the two conceptual frameworks, and it was then that we decided to amend the conceptual frameworks as described earlier. Subsequently, our two frameworks focused on how the project was designed, who carried it out (Cs; Table 1), and to what end was the project implemented (Ps; Table 2), allowing us to answer our second research question. We were able to reach a nearly unanimous decision about the conceptual framework's fit; at least three of the four authors agreed on the category of Cs and Ps for each lesson plan.

Focus Groups

The focus group discussions at the end of each year explored the citizen science lessons that the participants developed as a result of participating in the project and highlighted the kinds of resources that the candidates needed to feel confident and prepared to teach citizen science, in particular for justice-oriented citizenship. Focus groups were designed to take approximately one hour, and semi-structured questions addressed the pedagogical tools or ideas developed by the participants, the challenges and obstacles experienced by participants, additional resources that

Table 1

The Cs—Lesson Plan Analysis

Conceptual Framework Category	Number of Lesson Plans	% of Total
Classroom-created	8	35%
Teacher conceptualized with citizens/students collecting and consolidating data on local issues		
Contributory	8	35%
Scientist designed, with students undertaking data collection		
Collaborative	1	4%
Scientist structured, with students given freedom to refine project design, analyze data, or communicate findings		
Co-created	0	0%
Fully democratized, with students actively engaging with scientists through all steps of the process		
Did not meet criteria for a citizen science lesson plan	6	26%
Total:	23	100%

Table 2

The Ps—Lesson Plan Analysis

Conceptual Framework Category	Number of Lesson Plans	% of Total
Personally Responsible Action	6	26%
Students act responsibly toward the environment or help people on a personal level (e.g., recycling, giving money to charity)		
Participatory Action	4	17%
Students organize or take part in school/community efforts for making the world a better place (e.g., taking part in charity projects, volunteering)		
Possibilities For Systemic Action	8	35%
Students engage in actions that target systemic/global change (e.g., students design an action plan to reduce the effects of pollution)		
Did not include specific student actions for effecting change	5	22%
Total:	23	100%

might help participants feel confident and prepared to teach citizen science, and participants' overall experiences with implementing citizen science. Transcripts of all focus groups were prepared by a professional transcription service. The transcripts were then coded following Auerbach and Silverstein's (2003) three-phase model, with four main areas of interest that allowed us to answer parts of all of our research questions, but especially our third question: teacher candidates' thoughts about citizen science pedagogy, challenges and obstacles that they faced, resources that would help them to overcome such obstacles, and their overall experiences in the project.

Findings

In the following section we present the results of data collected over the span of the 2-year project. Although the number of participants varied in each year and within each data collection method, by combining our data across years and methods, we were able to understand what teacher candidates knew about citizen science, what kinds of citizen science activities teacher candidates planned to implement, particularly with regard to the 3 Cs and 3 Ps frameworks, and what challenges participating teacher candidates experienced when adopting a citizen science approach in planning and teaching.

Questionnaire Responses

Over our 2-year study, we collected 50 initial questionnaires. Answering a question about their current level of knowledge of citizen science, 45 participants selected the response "My knowledge is limited. Citizen science is not really on my radar." Three participants selected "I regularly incorporate citizen science into my teaching practice, so I feel I have a pretty good level of knowledge," and the remaining two participants selected the response, "I'm a citizen science junkie. I am very confident in my knowledge and could explain the importance of citizen science to others." We also asked about the tools, resources, and/or knowledge that participants thought might help their teaching practice. Participants listed up to three items, and their responses fell into seven categories: unit, lesson, and activity plans (n = 37); a better understanding of citizen science, and science content and curriculum (n = 19); websites and videos (n = 8); books and manipulatives (n = 7); professional development workshops and guest speakers (n = 13); money (n = 5); books and equipment (n = 7); articles and databases related to citizen science (n = 3); and support from teachers and administrators (n = 3). These responses helped us to understand teacher candidates' base-line level of knowledge concerning citizen science, and the responses from Year 1 participants subsequently led us to develop a citizen science Primer (Appendix A) in Year 2 of the project.

We received 14 follow up questionnaires (11 from Year 1 and 3 from Year 2). This time, when asked about their level of knowledge, only five respondents chose "My knowledge is limited", and six respondents selected "I regularly incorporate citizen science into my teaching practice, so I feel I have a pretty good level of knowledge." We also asked whether the workshops influenced participants' knowledge and confidence to lead discussions on citizen science in their classrooms. Five participants selected the response "Yes, I know where to go for tools, resources and support," and nine selected "Somewhat, but I still need more training and tools."

When reflecting on the biggest obstacles or challenges they faced integrating citizen science lessons, many teacher candidates identified pedagogical issues such as keeping students on task and assessing understanding (n = 5), along with a lack of lesson plans and resources (n = 4). Other barriers were trying to get "buy in" from supervising teachers (n = 2), difficulties finding curricular expectations and topics to address (n = 2), not having sufficient background knowledge (n = 2), still not knowing enough about citizen science (n = 1), and finding time to implement their lesson plans (n = 3). Of the three respondents from Year 2, two reported using the Primer and finding it to be very useful. In response to a question about their overall evaluation of the citizen science education project, one participant wrote, "I'm positive that the project is capable of engaging student interest and making geography learning relevant." Another candidate responded, "I enjoyed the planning of the citizen science lesson … it was great to see that you can link citizen science to the Ontario curriculum in a variety of engaging and fun ways." Another participant noted, "My goal was for students to feel like they were an integral part in gathering data, researching solutions, and in the outreach project … my aim for this assignment was to have students feel engaged civically and for them to feel like their actions can change things if they put the work behind them."

Teacher candidate questionnaire responses echo recent in-school research, which found that even though teachers understand the need to integrate activities that address local and global issues, at times they worry about their lack of competence to implement such an approach in their classroom (Kahne et al., 2013; Pedretti et al., 2008). Despite the lack of competence expressed by teacher candidates in the preliminary questionnaire, some of the participants were able to overcome their insecurities and maintain motivation to support students to become active agents and take responsibility for societal change in the contemporary world. The process of participating in our project activated teacher candidates' understanding of the relevance and importance of citizen science education. As Tolppanen (2015) noted, science education that is relevant to students' lives and society, can bridge the relationship between science and society, and bring issues critical for citizenship education to the forefront.

Lesson Plans

Over our 2-year study we collected 23 completed lessons plans from our participating teacher candidates. Our three-phase analysis and reconceptualization of the framework categories allowed us to make sense of the variation in the plans, as shown in Tables 1 and 2, although categories were not mutually exclusive, and some plans showed characteristics of more than one category. Our newly generated conceptual category, classroom-created, captured eight lesson plans created by the teacher candidates rather than by a scientist. As a case in point, one lesson plan asked students to observe and document the life cycle of local plants and create a chart to record findings. New observations were added to a pool of data from previous years to analyse discrepancies and discuss environmental impacts of climate change on plant growth. One project crafted by a teacher candidate requested that the students track the bee population around the school and then use persuasive writing to influence local homeowners to plant bee friendly flowers. Another lesson plan documented the effects of organic and inorganic waste on our planet and how to proactively manage it. Students not only participated in a litterless lunch initiative, but also collected litter during a monthly Green Sweep and kept a tally of the types of litter collected to learn how to reduce and repurpose waste. Data in this lesson were sent to various eco-friendly waste management initiatives.

The eight lesson plans categorized as contributory projects typically used an existing public research database as a resource for teaching about a particular issue, with students collecting data according to the submission guidelines of the research website. As a case in point, one of the lesson plans involved two types of tomato seeds (one exposed to space or space like conditions and one untreated) for students to investigate, examine, and record the effects of outer space on seed germination, with results submitted to an online database. A second lesson plan involved recording local weather patterns on a daily basis and reporting observations to a national online database, and a third lesson plan drew upon an existing research project and database and submitted the students' findings to the Globe at Night online database. The one lesson plan that we categorized as collaborative was based on a research project about tracking stream biodiversity to investigate the bilateral relationship between living organisms and their environments, designed by scientists but adjusted by the teacher to meet the needs of students and the local community, with students contributing to a public data set. None of the lesson plans were deemed to be co-created. In Year 1, six of the lesson plans based on research projects about dandelion blooming, waste management, river life, growth and changes in plants, biodiversity, and Canadian wildlife did not necessarily meet citizen science criteria, because although they included observation and data collection, they did not include contribution to a public dataset, which as described earlier, is typically a central component of citizen science projects. Based on these results, we developed a "Primer" to support teacher candidates in planning citizen science activities that contribute to a public dataset. In Year 2, all four lesson plans met the criteria for citizen science.

As shown in Table 2, six of the lesson plans required personally responsible action and were framed around individual action plans that engaged students in local learning and sometimes organizational data collection. Responsible actions for change included completing environmental observations checklists to learn to observe and interpret data, keeping track of their personal waste and water use, and taking photos of plants in their community to learn about biodiversity. Of the 23 lesson plans submitted by teacher candidates, four required participatory action on behalf of students. One project was designed to investigate the interdependence of plants and animals on specific habitats, and communities were used in the creation of multimodal information flyers, suggesting that a school or community wide response was involved. A second project introduced students to the topic of light pollution by conducting research on what light pollution is and how it is affecting the planet. Students were assigned to discuss ways they can help prevent light pollution and how to bring these ideas back home to their families to implement. Importantly, a total of eight lesson plans contained characteristics of possibilities for systemic action, as illustrated in the example of a lesson plan on light pollution, which had as an intended outcome, students designing an action plan to help reduce the effects of light pollution. A second lesson plan categorized as possibilities for systemic action had the potential for leading to further global or systemic change. In this lesson, students were invited to explore and learn about food access and related issues of availability in the city by creating a photo essay. The students were to analyze and explore the interdependent relationship between food price and factors affecting costs, and then present findings to the class and broader community. Finally, although five of the Year 1 lesson plans could not be categorized because students were neither taking action nor developing action plans (such as researching and presenting on different birds in the Prairie region), all four of the Year 2 plans met criteria for promoting action.

Focus Group Responses

Over our 2-year study, we conducted two focus groups with 12 participants. Our analysis of transcripts was based on four main areas that would help to answer our original research questions. We were interested in participants' thoughts about pedagogy, challenges, useful resources, and overall experiences in planning and teaching with a citizen science approach.

Pedagogical Tools or Ideas That Were Developed

Teacher candidates reported using or planning to use a variety of tools and approaches, including technology-based resources, pencil and paper approaches, and hands-on activities to determine and build students' knowledge. Technology including blogs, portfolios, websites, and online videos were mentioned, with one particular website on endangered species considered "helpful because it organizes everything the same. Each student has access to the same amount of information and it's all reliable." Teacher candidates used blogs to increase their knowledge and understanding of citizen science and as guides for designing lesson plans that would be "meaningful with [their] own teaching philosophy, and [their] class." Videos were described as having the potential to facilitate student engagement and cultivate, in the teacher candidates' phrasing, a citizen science "mindset." Pencil and paper approaches including posters, tally sheets, and letters were also mentioned during focus groups, as well as "going out in the fields to get [students] the hands-on experience to collect [specimens]." These comments illustrate teacher candidates' growing awareness of multiple ways to integrate citizen science into their curriculum.

Challenges and Obstacles That Were Faced

Participants differed in the extent to which they were able to apply new ideas about citizen science in classroom contexts. For example, one teacher candidate found it challenging to pursue interdisciplinary approaches and "fit these cross curricular ideas into the set curriculum," and another participant struggled to develop content that would be "accessible and relatable" for all students. Most teacher candidates commented upon wrestling with implementing their lesson plans due to a shortage of time, absence of confidence, and lack of flexibility in their practicum placements.

Additional Resources That Might Lead to Confidence in Teaching Citizen Science

Participants identified co-planning opportunities, additional workshops, and access to cross-curricular resources for wide grade ranges as additional resources that might help them feel confident to prepare a lesson plan. One teacher candidate requested offline resources "because a lot of [students] don't have access to the Internet at home." One respondent described how it was difficult to implement the lesson plan because they "didn't really have a lot of support within the schools" and suggested that the research team write an introductory letter to practicum supervisors to ease the process of implementation. Teacher candidates also suggested a peer review session to discuss their lesson plans prior to implementation might be helpful.

The Overall Experience of Implementing Citizen Science

Teacher candidates reported enjoying planning and teaching through an approach that they stated was "different than textbook work." In particular, teacher candidates valued observing nature in the schoolyard and taking field trips to explore environments beyond the confines of school. Some teacher candidates experienced a broadened understanding of their role as science educators. As one participant explained, "We're not just educating [students] about the science or the social sciences, but just in general how to be better, in the world, citizens." The hands-on experience of introducing students to what one participant called "real-world consequences that are going to affect them down the road" was considered one of the most valuable aspects of the project.

Similar to Tolppanen's (2015) findings, the teacher candidates in our study found it difficult at times to incorporate societal issues into science education. Teacher candidates struggled to implement a citizen science approach for reasons that echo recent literature, such as a lack time and resources, the politicization of science, assessment issues, and the coupling of science and ethics, which all serve as barriers to the design processes that foster students' knowledge about socio-scientific issues (Aikenhead, 2006; Hughes, 2000; Pedretti et al., 2008; Pedretti & Nazir, 2011; Tsai, 2000).

Despite challenges and constraints to implementing a citizen science approach, teacher candidates reported that they were motivated to create citizen science lessons because they were able to select relevant and interesting topics that would not only combine science and societal issues, but also would be fascinating and relevant to them and their students' life worlds. Some scholars are concerned that although students might be able to identify courses of action, this knowledge does not always lead to acting (Grace & Ratcliffe, 2002). However, in their focus group responses, participating teacher candidates described citizen science lessons as providing opportunities for deep and transformative learning that could facilitate empowered student agency and responsibility to take action on issues. As the literature reminds us, science education is reconceptualized as a tool of civic engagement when society and science interact to support students' development of personal contributions to social justice initiatives (Vesterinen et al., 2014), particularly when students have agency to decide the procedures and goals of their projects (Eilks & Hofstein, 2014).

Based on their experiences, a teacher candidate stated that, "[citizen science] is a great way to help [students] … pursue things that they care about in the future," and commented upon witnessing student agency as students discovered that they had some control over what they were learning. Students were also described as taking more pride in their work. The benefits of citizen science are captured in this teacher candidate's description:

> It was awesome because it took students a couple of classes to finally realize that this is not just for fun, their data's actually going to be sent to the agency itself, and it's real. They're putting their observations and their knowledge to use for researchers and astronauts and things like that.

Discussion

Our aim in this project was to introduce teacher candidates and their students to an interdisciplinary approach to local issues to foster civic education and engagement with evidence-based citizen science lessons. Returning to our research questions, we wanted to learn what teacher candidates already knew about citizen science, how they might go about implementing citizen science in their own placement classrooms, and what challenges they reported facing. Our results allow us to provide some insights into how teacher candidates conceptualized citizen science to develop their civic education pedagogy and engaged students in scientific inquiry and evidence-based decision making. Moreover, we offer examples of how participating in this project provided teacher candidates with perspectives on interdisciplinary approaches to civics education that lent themselves to the more justice-oriented end of the civic education spectrum. We also identify some of the benefits and challenges that can be associated with developing citizen science pedagogy. By participating in this interdisciplinary project, teacher candidates came to view citizen science as having the potential to support students in becoming justice-oriented citizens, with the knowledge and skills needed to critically interrogate contemporary systemic problems, as evidenced by their lesson topics and propensity towards systems-level actions in our 3 Ps conceptual framework and collaborative data collection and analysis in our 3 Cs framework.

Our analysis of the lesson plans that were created by the teacher candidates contribute to debates concerning what constitutes rigorous civic education in teacher education programs (Journell, 2013; Torney-Purta, 2002; Yemini, 2017). The lesson plans that were created by the candidates considered how a project is designed and who is involved in carrying it out and covered a broad variety of topics related to ecology, geography, and environmental and social sciences, and many of them addressed systems-level or social justice issues, such as drinking water availability, food insecurity, light pollution, river water quality, waste management, climate change, declining bee populations, water consumption, and sustainable ecosystems. However, given the number of Year 1 lesson plans that did not meet the criteria for citizen science, (failing to contribute to a public data set or omitting student actions), in Year 2 we provided a Primer to help teacher candidates develop lesson plans for citizen science projects, with the result that all Year 2 lesson plans met citizen science criteria according to the 3 Cs and 3 Ps.

Although research has found that teacher candidates feel under equipped to teach about controversial issues or democratic content in their specific disciplines (Chikoko et al, 2011), after participating in our study, most teacher candidates experienced an increase in confidence and competence to teach citizen science within their respective disciplines (corroborated by their changed survey responses). Teacher candidate lesson plans were based in a collaborative-inquiry approach, which according to Nugent et al. (2015) engages members of the public in scientific inquiry and encourages citizens to actively contribute to research projects through participatory data collection and analysis. Teacher candidate lesson plans were also based on personal, community, school, or government level initiatives that were applicable to real-life situations, which according to Tolppanen (2015), is the most effective approach to support students to grasp the relationship between society and science, and to usher relevant citizenship education discourses to the forefront of education. Through their lesson plans, teacher candidates highlighted their ability to design and implement strategies for collaborative inquiry, participatory data collection, and change. As Stuckey et al. (2013) noted, enabling students to activate their autonomy to decide the procedures and goals of their projects, and to develop personal ways to contribute to their communities are vital to citizen science education.

Over the span of the project, the experience of creating a citizen science lesson plan also enhanced teacher candidates' awareness of obstacles to creating and implementing civic education lessons. As one respondent explained, "I enjoyed the process, but … I think it could have been more beneficial for me to … have it reviewed by peers so I could adapt it." Despite constraints, many of which were typical issues such as lack of access to resources and limited time or lack of support for their efforts, participants reported that they were motivated to create lesson plans using citizen science because they were able to choose topics that would be relevant, current, and interesting to them and their students. The candidates' comments reinforce the observation by Stuckey et al. (2013) regarding the importance of relating issues to society to help students grasp the relationship between society and science. This finding is important, given that science educators often find it difficult to incorporate societal issues into science education (Tolppanen, 2015), and citizen science provides one way of meeting both civic education outcomes, and incorporating issues of interest to students.

In their questionnaire responses and in focus groups, teacher candidates profiled the positive aspects of the citizen science project and, as noted by participants above, came to understand that citizen science could provide opportunities for collaborative-based, deep and transformative learning, facilitated student responsibility, and empowered student agency. The emphasis on student agency is another important finding for our study. As noted previously, although various science education programs that seek to encourage students to take action already exist (Hodson, 2003; Pedretti & Nazir, 2011), few studies in science education have focused on students' socio-scientific or sociopolitical actions or behavior (Sternäng & Lundholm, 2011).

Limitations

One of the limitations of our project was the high attrition rate that we experienced. Although we had high rates of responses for some data collection methods, in Year 1, only nine participants completed all stages of the project, and in Year 2, only one participant completed all data collection methods. We observed similarly high attrition rates in other events that were planned within the teacher education program and, rather than a lack of interest, our participants commented on the difficulty of finding time to create lesson plans that were outside of regular program requirements. In fact, we were pleased to have such committed participants, who persevered despite demanding schedules. The high degree of commitment, though, does mean that the positive views of citizen science came from participants who found the approach was beneficial for them and for their students.

Concluding Remarks

In this project, we explored teacher candidates' planning of citizen science projects. The results are promising; our findings indicate that teacher candidates were eager to learn more about citizen science and to experiment with strategies for civically engaging students in their own classrooms. Participants were able to develop lessons that included a range of characteristics of citizen science, as shown in Tables 1 and 2, and readily conceptualized projects with social justice goals. This study also added new categorial perspectives to the conceptual frameworks previously described in the literature, including classroom-created in the 3 Cs, and *possibilities for systemic action* in the 3 Ps. Our new frameworks are versatile, and can be applied to a wider range of lessons and activities, while capturing a more nuanced sense of teacher intentions for citizen science pedagogy.

As a means for cultivating pedagogical approaches with teacher candidates that will engage their future students in justice-oriented civic education, our study confirms that citizen science can offer one such approach. By uniting important subjects in teacher education, civic education, social studies education, and science education, the project provided opportunities for teacher candidates to learn about citizen science, and harmonized learning about civic and scientific issues, offering scientific investigations as means for civic action, and investigating the root causes of societal problems through scientific lenses. Our project also led to the development of a "Primer" to support teacher candidates in planning citizen science activities. Finally, the data suggest that through participating in the project, teacher candidates developed confidence in their abilities to plan and implement interdisciplinary citizen science activities that would enhance critical thinking and underscore evidence-based decision-making skills in their future students, and these results contribute to discussions of pedagogical approaches that foster civic engagement while engaging students in real world contexts.

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Appendix A: Citizen Science Planning Primer

Civic Engagement and Evidence-Based Decision Making Through Citizen Science: Developing a Project

C. D. Tippett, L. R. McLean, J. Baroud, & J. Bergen

What is Citizen Science?

Citizen Science is a form of participatory democracy—citizens actively take part in research collaborations with scientists and other experts, with the end goal of fostering civic engagement and evidence-based decision making. Citizen Science as a teaching approach involves interdisciplinary projects that build upon the underlying assumption that democratizing science education is vital to fostering students' understanding of how science is relevant to their lives. When education includes participatory democracy, students are more likely to make informed choices, think critically, and believe they can make a difference (Mueller et al., 2012). Citizenship education can have an effect on students' engagement in societal issues, and concepts of sustainable development are often included in curricula around the world (Vesterinen et al., 2016).

Why Teach Through Citizen Science?

Students have opportunities to:

- Ask questions that matter, design and carry out investigations, and learn the science of community issues
- Collaborate with community professionals, teachers, and scientists
- Develop confidence in making informed choices and advocating for those who need it
- Demonstrate civic responsibility

Citizen Science approaches involve multiple subject areas, including but not limited to:

- English (reading, writing, oral communication, and media literacy)
- Social studies (citizenship/civics education)
- Geography (patterns and trends)
- Science (analytical thinking and scientific inquiry)
- Mathematics (calculations and problem solving)

Identifying a Citizen Science Project

The following checklists will help you to identify Citizen Science projects that engage students in their local community while providing developmentally appropriate opportunities to develop critical thinking skills.

Criteria 1: The Cs (adapted from Miller-Rushing et al., 2012)

A Citizen Science project must exemplify one of the following designs:

- ❑ **Classroom projects**: teacher designed, involving data collection and subsequent actions
- ❑ **Contributory projects**: scientist designed, with the public often relegated to simple data collection
- ❑ **Collaborative projects**: scientist structured, with citizens given freedom to refine project design, analyze data, or communicate findings
- ❑ **Co-created projects**: fully democratized, with the public actively engaging with scientists through all steps of the scientific process

Criteria 2: The Ps (adapted from Vesterinen et al., 2016)

A Citizen Science project must include one or more of the following actions:

- ❑ Personally responsible action: Students act responsibly toward the environment or help people on a personal level (helping friends in need, recycling, giving money to charity)
- ❑ Participatory action: Students organize or take part in school/community efforts for making the world a better place (mentoring fellow students, taking part in charity projects, volunteering in community development groups)
- ❑ Possibilities for systemic action: Students engage in social justice aspects of an issue (designing a plan to reduce the effects of pollution)

Criteria 3: Inquiry Indicators (Ontario Ministry of Education, 2007, 2008a, 2008b, 2013a, 2013b)

A Citizen Science project involves the element of inquiry. Whether contributory or co-created, leading to personally responsible or participatory actions, Citizen Science projects should include one or more of the items in each of the four categories below.

Initiating and Planning / Formulating Questions			
Grades 1–8	❑ asking questions ❑ planning procedures ❑ clarifying problems ❑ exploring events, developments, or issues to identify the focus of an inquiry ❑ determining key concepts relevant to the topic	Grades 9–12	❑ formulating questions or hypotheses ❑ planning investigations to answer questions or test hypotheses ❑ making predictions about ideas, issues, problems, or the relationships between observable variables exploring events, developments, or issues to identify the focus of an inquiry
Performing and Recording / Gathering and Organizing			
Grades 1–8	❑ following procedures ❑ accessing information ❑ recording observations and findings ❑ collecting relevant data, evidence, and/or information from primary sources, secondary sources, and/or field studies	Grades 9–12	❑ conducting research by gathering, organizing, and recording information ❑ safely conducting inquiries to make observations ❑ collecting relevant data, evidence, and/or information from primary sources, secondary sources, and/or field studies
Analyzing and Interpreting / Evaluating and Drawing Conclusions			
Grades 1–8	❑ organizing data (graphic organizers, charts, tables) ❑ reflecting on the effectiveness of actions performed ❑ drawing conclusions ❑ developing criteria for evaluating evidence and information, making judgements or decisions, and/or reaching conclusions	Grades 9–12	❑ evaluating the adequacy of data from inquiries ❑ evaluating the adequacy of information from research sources ❑ analyzing the data or information in order to draw and justify conclusions
Communicating			
Grades 1–8	❑ using appropriate vocabulary ❑ communicating findings (judgements, decisions, conclusions, predictions, and/or plans of action) in a variety of ways ❑ using appropriate forms of documentation for different audiences and purposes	Grades 9–12	❑ using appropriate linguistic, numeric, symbolic, and graphic modes of representation ❑ using a variety of forms to communicate ideas, procedure, results, judgements, decisions, conclusions, predictions, and/or plans of action ❑ using appropriate forms of documentation for different audiences and purposes

General

Consider each of the following questions in turn. For further insights on the compatibility, equity, and adaptability of a citizen science lesson consider the following criteria (McLean & Cook, 2016):

- ❑ Are issues of equity addressed? If not, how can they be?
- ❑ Is the topic of interest to students?
- ❑ Is the age/grade level appropriate?
- ❑ Are required resources available or easy to access?
- ❑ Is the activity feasible? (time and timing, cost, equipment)
- ❑ Do pedagogical approaches support an inquiry approach?

Example Citizen Science Projects

This section profiles two examples. The first shows what primary aged students can accomplish when given the appropriate guidance, support, and independence. The second is an activity for high school students developed by a teacher candidate as part of the Citizen Science Project, Faculty of Education at the University of Ottawa.

Example 1: Blackawton Bees (Blackawton et al., 2011)

This project was instigated by primary school children who were working with a neuroscientist. The project involved science, math, physical education (PE), and literacy. 25 children aged 8-10, decided that they wanted to learn about bees, and specifically they wanted to know if/how bees used colour to locate flowers with nectar. First, the children devised games using PE equipment and practiced solving puzzles. Then a Plexiglas bee hutch was set up, and the students created puzzles for bees using arrangements of salt and sugar solutions (Figure 1). Students ran multiple trials, recorded data (Figure 2), and analyzed results. Then, students wrote up their findings … and published them in an academic journal, *Biology Letters* (Figure 3).

3Cs and 3Ps: This project would be categorized as Co-created, Participatory Action, and Preparation for Future.

Inquiry indicators: Student involvement included all inquiry indicators listed in Criteria 3.

Figure 1
Puzzle (p. 171)

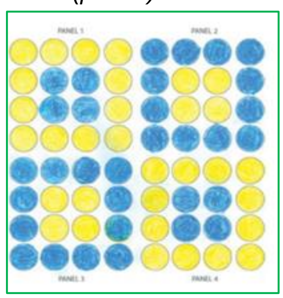
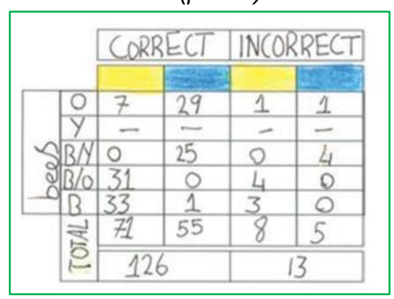


Figure 2
Recorded Data (p. 171)



		CORRECT		INCORRECT	
bees	O	7	29	1	1
	Y	—	—	—	—
	B/Y	0	25	0	4
	B/O	31	0	4	0
	B	33	1	3	0
TOTAL		71	55	8	5
		126		13	

Figure 3
Excerpt From the Published Article (p. 172)

We conclude that bees can solve puzzles by learning complex rules, but sometimes they make mistakes. They can also work together (indirectly) to solve a puzzle. Which means that bees have personality and have their personal 'likings'. We also learned that the bees could use the 'shape' of the different patterns of individual flowers to decide which flowers to go to. So they are quite clever, because they can memorize a pattern. This might help them get more pollen from flowers by learning which flowers might be best for them without wasting energy. In real life this might mean that they collect information and remember that information when going into different fields. So if some plants die out, they can learn to find nectar in another type of flower.

Note. Adapted from "Blackawton bees", by P. S. Blackawton, S. Airzee, A. Allen, S. Baker, A. Berrow, C. Blair, M. Churchill, J. Coles, R. F.-J. Cumming, L. Fraquelli, C. Hackford, A. Hinton Mellor, M. Hutchcroft, B. Ireland, D. Jewsbury, A. Littlejohns, G. M. Littlejohns, M. Lotto, J. McKeown, A. … and R. B. Lotto, 2011,. *Biology Letters, 7*(2), 168–172. https://doi.org/10.1098/rsbl.2010.1056. Copyright 2010 by The Royal Society. Adapted with permission.

Example 2: As Long As the River Flows (Costeira, 2018)

In this project for Grades 11 and 12, students will combine science (chemistry) with geography, history, and citizenship/civics (social studies) to examine issues of sustainability, stewardship, human rights, and access with regard to freshwater in Canada. The purpose is to promote student inquiry and advocacy, and to encourage students to become engaged citizens.

Part 1: What is our local water quality? Students will make several trips to local rivers, lakes, or streams to conduct water sampling and contribute to the Water Rangers citizen science platform, which can be found at htttps://waterrangers.ca

Part 2: What if access to drinking water is not secure? Using primary and secondary sources, small groups will research a specific community that is under a long-standing “boil water” advisory (e.g., https://www.hrw.org/report/2016/06/07/make-it-safe/canadas-obligation-end-first-nations-water-crisis). Students will probe the historical and geographical contexts surrounding the water being declared unsafe to drink, and compile their findings into a research report. Note: students will soon discover that these communities are predominantly Indigenous—a powerful learning opportunity.

Part 3: What are potential solutions? Groups will identify possible ways to address water quality issues and will communicate their findings and potential solutions to relevant political representatives (e.g., MPs, MLAs, MPPs) in the form of a PowerPoint presentation. If possible, the representative would meet with students, online or in person, for a “question period” to discuss what actions have, can, or will be taken to address the issues of water security for all.

3Cs and 3Ps: This project would be categorized as Contributory, Participatory Action, and Preparation for Future.

Inquiry indicators: Students will be assessed on water testing (skills/analysis of results), research report (synthesis of data), PowerPoint presentation (communication of results).

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