Minh Duong,[1*] John B. Luchansky,[2] Anna C. S. Porto-Fett,[2] Caitlin Warren[3] and Benjamin Chapman[4]

[1]North Carolina State Dept. of Food, Bioprocessing, and Nutrition Sciences, Raleigh, NC 27606, USA
[2]United States Dept. of Agriculture, Agricultural Research Service, Wyndmoor, PA 19038, USA
[3]Souderton Area High School, Souderton, PA 18964, USA
[4]North Carolina State Dept. of Agricultural and Human Sciences, Raleigh, NC 27606, USA

PEER-REVIEWED ARTICLE

Food Protection Trends, Vol 39, No. 5, p. 387–397

6200 Aurora Ave., Suite 200W, Des Moines, IA 50322-2864

Developing a Citizen Science Method to Collect Whole Turkey Thermometer Usage Behaviors

ABSTRACT

Citizen science is a unique data collection method in which non-scientists gather and interpret data in collaboration with professional scientists. The purpose of this study was to identify thermometer usage behaviors through a different process for data collection. Most thermometeer usage studies happen through self-reported, quantitative studies. Recently, some studies have used qualitative data such as videos, picture quantitative data has been used to supplement it. A food safety lesson on minimum internal temperature and correct thermometer usage was conducted with high school biology classes in Pennsylvania and family and consumer sciences classes in both North Carolina and Pennsylvania prior to the schools' Thanksgiving break of 2016. As homework, students inputted data into a web-based form on thermometer usage and endpoint cooking temperatures for whole turkeys. Students were asked for picture evidence of how/where the temperature of the turkey was taken. If a photo was provided, students were asked how they knew the turkey was "done." Four types of thermometers were used: dial (n = 22), pop-up (n = 13), digital (n = 11), and liquid (n = 1); two thermometers were of an undetermined type. Of respondents, 31.5% (18 of 57) reported an internal endpoint temperature of 165°F, and 7.01% (4 of 57) reported endpoint temperatures of less than 165°F. Respondents submitted photos showing different thermometer placements, with 53.1% (17 of 32) placing the thermometer in the breast, 35.3% (12 of 34) in the thigh, and 14.7% (5 of 34) undetermined. Our data confirms that citizen science is a viable method of collecting unbiased data obtained by providing participants with tools to collect information from a primary and a photographically substantiated source of information rather than relying on self-reported data alone.

INTRODUCTION

Foodborne illness is a global public health problem. In the U.S., it is estimated that 31 major pathogens are responsible for 9.4 million foodborne illnesses, 55,961 hospitalizations, and 1,351 deaths annually *(34)*. The economic burden of

*Author for correspondence: Phone: +1 571.215.2128; Fax: +1 919.515.7124; Email: minhd16@vt.edu

foodborne illness in the U.S. is estimated at $77.7 billion annually *(35)*. Of the possible pathogen-food combinations, undercooked and/or poorly handled poultry ranks first for estimated annual disease burden because of its association with *Campylobacter* spp. and *Salmonella* spp. *(3)*. In an investigation of poultry-linked outbreaks, Chai and colleagues identified food handling errors and inadequate cooking as the most common behaviors leading to poultry-associated foodborne illness *(12)*. According to the United States' Foodborne Disease Outbreak System data from 1998 to 2012, 25% of outbreaks (279 of 1,114) were associated with poultry *(12)*.

Many high-profile multistate outbreaks have been linked to undercooked poultry products, especially around U.S. holiday events such as Thanksgiving, highlighting the importance of addressing food handling practices *(8, 9, 11, 26, 29)*. Turkey remains a significant public health problem, being associated with numerous outbreaks. A 1963 outbreak of *Salmonella* infection in Kentucky was traced to undercooking of creamed turkey, resulting in 229 of 441 convention attendees becoming ill *(21)*. Bryan et al. *(7)* also identified preparation practices as a factor in a turkey-linked outbreak of multiple illnesses at a school event. Historic and anecdotal data on consumer preparation of holiday meals in the U.S. have resulted in seasonal-specific messages from the U.S. Centers for Disease Control and Prevention targeting turkey handling and cooking, as well as promoting thermometer use to determine doneness *(10)*. The National Turkey Federation (NTF) estimates that 88% of Americans consume turkey at Thanksgiving, accounting for some 46 million turkeys *(27)*.

Campylobacter is commonly present in poultry products. A study conducted at two turkey processing plants over a one-year period found that *Campylobacter* spp. were highly prevalent in carcasses, at 34.9% (841 of 2,412), while a survey by the Minnesota Dept. of Health found that 88% (80 of 91) of retail chicken products harbored *Campylobacter* spp. *(24, 40)*. Another study reported a *Campylobacter jejuni* recovery rate of 98% (49 of 50) in retail broiler carcasses *(41)*. Zhao and colleagues *(47)* assessed the prevalence of *Campylobacter* spp. and *Salmonella* serovars in retail meat and poultry products and recovered *Campylobacter* from 91% (84 of 92) of the samples, while *Salmonella* was present in 3% (3 of 92) of retail samples. Mazengia and colleagues *(25)* conducted a year-long market survey in Seattle, Washington and found that 11.3% (150 of 1,322) of chicken and turkey products were contaminated with *Salmonella* serovars. Yang and colleagues *(45)* reported that the prevalence of *Salmonella* in raw poultry at the retail level in six provinces and two cities in China was 52.2% for 1,152 total chicken carcass samples.

A survey published in 2008 reported that 47% of the number of consumers polled believed the food they eat is very safe *(5)*. However, only 36.9% of 4,000 consumers surveyed around 2016 cooked foods to a temperature sufficient to kill harmful pathogens *(41)*. A U.S. national survey by Kosa and colleagues *(22)* found that 62% of 1,504 consumers reported owning a food thermometer and that participants were more likely to use a thermometer on larger cuts of meat, like whole turkeys, rather than in foods such as ground turkey. Moreover, preparers of poultry reportedly believe that they are unlikely to become sick from eating chicken prepared within their home, believing instead that they are more likely to get sick from eating at a restaurant *(6)*. A self-reported survey conducted by Redmond and Griffith asked consumers how much control they think they have over food safety during food preparation, compared with other consumers. Respondents believed they had more control than others *(30, 31)*. Consumers also underestimate the likelihood that the unsafe food-handling behaviors are associated with microbial risk *(30, 31)*. Fewer than 5% of 120 poultry preparers surveyed used a thermometer to record the temperature of their chicken, and of the ones that do, 40% use a thermometer but cook poultry products to less than the minimum recommended internal temperature of 165°F *(6)*. The 2016 IFIC survey on "Food and Health" provided self-reported consumer data on food thermometer usage and safe endpoint cooking temperatures for meat and poultry products. The survey showed an increase from 49% (494 of 1,007) to 66% (662 of 1,003) between 2015 and 2016 in consumers cooking food to safe endpoint temperature *(19)*.

Much of what is known about food handling in the home relies on self-reported data *(2, 6, 20)*. Self-reported data can be unreliable because of social desirability bias, which is the tendency of respondents to answer with what they perceive to be socially desirable or acceptable behavior/responses instead of socially undesirable ones *(22, 42, 49)*. Consumers' self-reported practices differ from their observed behavior *(2, 20)*. Anderson and colleagues *(2)* observed participants in their homes preparing an entrée and salad, followed by completing a food handling survey, and discovered that although many consumers demonstrated knowledge of food safety, this knowledge did not correspond to their behaviors in preparing food. Jay and colleagues *(20)* investigated practices in home kitchens in Melbourne, Australia, in which participants' food handling practices were monitored and compared to their responses on a food safety questionnaire they completed prior to being observed: significant variations were noted between stated and observed food handling practices. Because of the limitations of self-reported data, food researchers have increasingly sought alternative data collection methods, including ethnography and observation, to provide a more accurate and robust data set *(13, 14, 16)*.

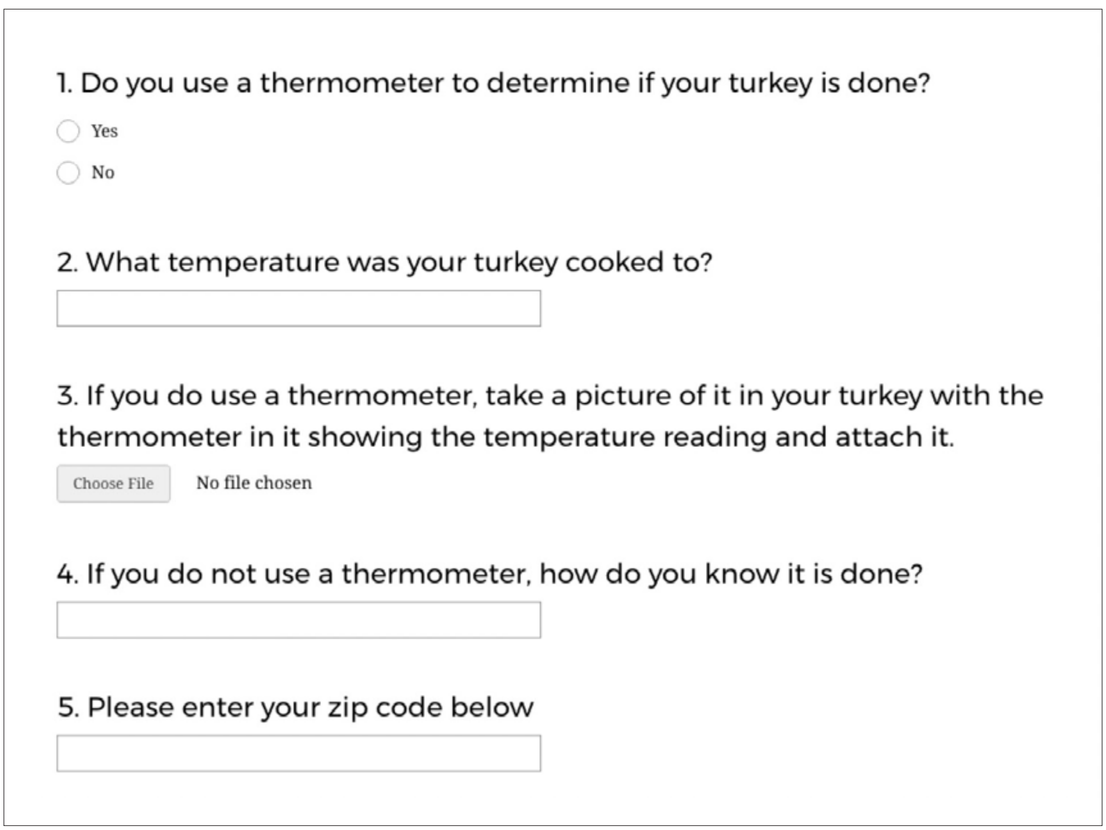
Over the past decade, with the rise of internet connectivity and increased use of smart phones, researchers have exploited electronic modalities for data collection and crowd sourcing to generate more accurate, less biased raw data through citizen science. Citizen science involves the use of volunteers to collect and/or analyze data as part of a scientific inquiry *(36)*. Although not trained as scientists, citizen scientists can quickly and efficiently gather data that cannot otherwise be obtained, particularly if resources are limited *(4)*. Citizen science provides a platform for collecting data that can be expanded on a large geographic scale and over a long duration, while conserving resources *(4)*. Citizen science overcomes the potential biases associated with self-reporting of data by using pictures as a verification method for self-reported data. This method also provides ways for non-scientists to become involved in the process of knowledge generation. To build transparent and trustworthy relationships between a scientist and a data collector, citizen science empowers data collectors and engages them in a deliberative process to support and acknowledge their actions, decisions, and achievements *(32)*. The methodology has been used widely in ecology and environmental science, in which over 600 Web of Science categories exist for these two fields *(23)*. This approach has not, however, been employed by many food safety researchers, appearing in the literature only as a method to track fish toxins *(18)*. As data are collected by volunteers who have no (or little) experience in, and scant background about, the subject matter being researched, concerns have been raised about the reliability as well as the quality of the data collected and analyzed by these individuals *(39)*. However, despite the concerns about reliability, a recent review article provides a foundation for how the methodological strategy can be used in agricultural and food research to gather data that can supplement data collected by other approaches *(33)*. The goal of this study was to investigate the applicability of a citizen science approach to data collection for consumer food safety practices. Study objectives included pilot testing a data collection instrument, recruiting citizen scientists through high school biology and family and consumer sciences classes in Pennsylvania and North Carolina and biology classes in Pennsylvania, and evaluating the usability of the resulting data.

MATERIALS AND METHODS

This study was pilot tested with thermometer usage for whole turkeys as a more reliable and accurate way to collect data related to endpoint cooking temperatures and thermometer placement practiced by consumers. Citizen scientists for this study were high school students in grades 9–12 in Pennsylvania and North Carolina.

Data collection instrument development

The survey questions *(Fig. 1)* were developed on the basis of information and recommendations in the USDA-FSIS'


1. Do you use a thermometer to determine if your turkey is done?

Yes

No

2. What temperature was your turkey cooked to?

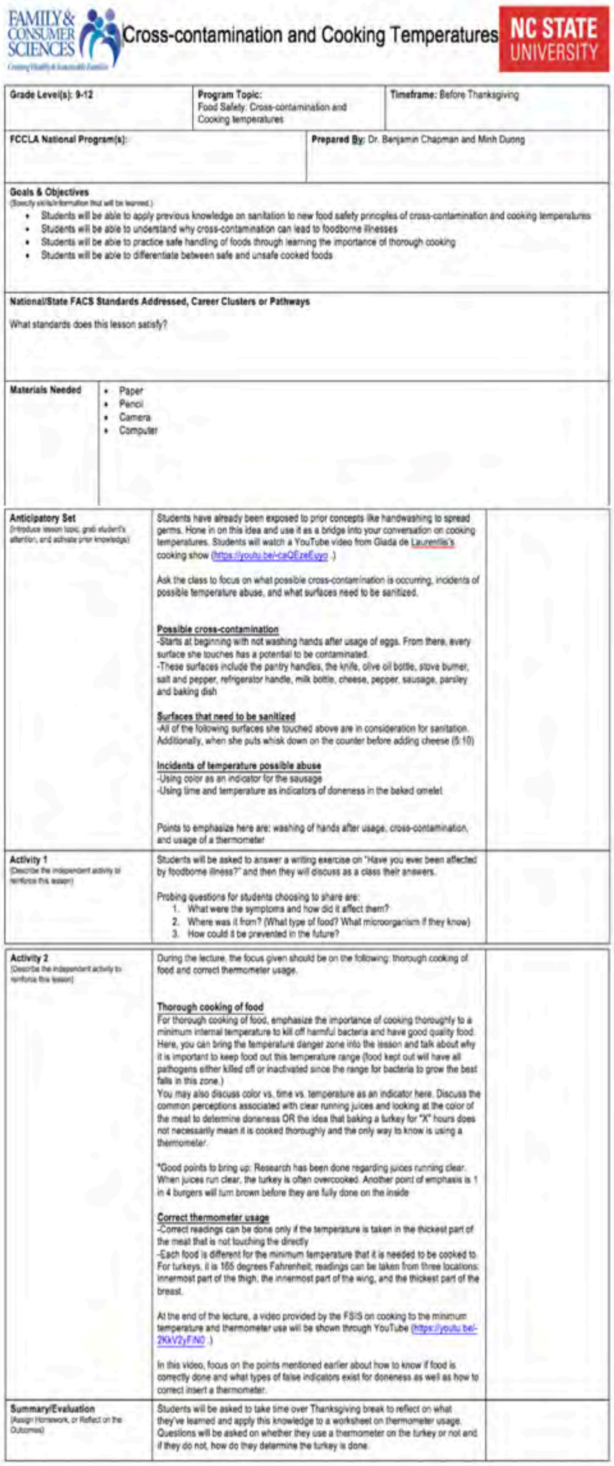
3. If you do use a thermometer, take a picture of it in your turkey with the thermometer in it showing the temperature reading and attach it.

Choose File No file chosen

4. If you do not use a thermometer, how do you know it is done?

5. Please enter your zip code below

FIGURE 1. Thermometer usage data collection instrument for citizen scientists in home kitchens.



FAMILY & CONSUMER SCIENCES

Cross-contamination and Cooking Temperatures

NC STATE UNIVERSITY

Grade Level(s): 9-12	**Program Topic:** Food Safety: Cross-contamination and Cooking temperatures	**Timeframe:** Before Thanksgiving
FCCLA National Program(s):	**Prepared By:** Dr. Benjamin Chapman and Minh Duong	

Goals & Objectives
(Specify skills/information that will be learned.)

- Students will be able to apply previous knowledge on sanitation to new food safety principles of cross-contamination and cooking temperatures
- Students will be able to understand why cross-contamination can lead to foodborne illnesses
- Students will be able to practice safe handling of foods through learning the importance of thorough cooking
- Students will be able to differentiate between safe and unsafe cooked foods

National/State FACS Standards Addressed, Career Clusters or Pathways

What standards does this lesson satisfy?

Materials Needed	• Paper • Pencil • Camera • Computer

Anticipatory Set (Introduce lesson topic, grab student's attention, and activate prior knowledge)	Students have already been exposed to prior concepts like handwashing to spread germs. Hone in on this idea and use it as a bridge into your conversation on cooking temperatures. Students will watch a YouTube video from Giada de Laurentiis's cooking show (https://youtu.be/-caQEzeEuyo .) Ask the class to focus on what possible cross-contamination is occuring, incidents of possible temperature abuse, and what surfaces need to be sanitized. **Possible cross-contamination** -Starts at beginning with not washing hands after usage of eggs. From there, every surface she touches has a potential to be contaminated. -These surfaces include the pantry handles, the knife, olive oil bottle, stove burner, salt and pepper, refrigerator handle, milk bottle, cheese, pepper, sausage, parsley and baking dish **Surfaces that need to be sanitized** -All of the following surfaces she touched above are in consideration for sanitation. Additionally, when she puts whisk down on the counter before adding cheese (5:10) **Incidents of temperature possible abuse** -Using color as an indicator for the sausage -Using time and temperature as indicators of doneness in the baked omelet Points to emphasize here are: washing of hands after usage, cross-contamination, and usage of a thermometer	
Activity 1 (Describe the independent activity to reinforce this lesson)	Students will be asked to answer a writing exercise on "Have you ever been affected by foodborne illness?" and then they will discuss as a class their answers. Probing questions for students choosing to share are: 1. What were the symptoms and how did it affect them? 2. Where was it from? (What type of food? What microorganism if they know) 3. How could it be prevented in the future?	
Activity 2 (Describe the independent activity to reinforce this lesson)	During the lecture, the focus given should be on the following: thorough cooking of food and correct thermometer usage. **Thorough cooking of food** For thorough cooking of food, emphasize the importance of cooking thoroughly to a minimum internal temperature to kill off harmful bacteria and have good quality food. Here, you can bring the temperature danger zone into the lesson and talk about why it is important to keep food out this temperature range (food kept out will have all pathogens either killed off or inactivated since the range for bacteria to grow the best falls in this zone.) You may also discuss color vs. time vs. temperature as an indicator here. Discuss the common perceptions associated with clear running juices and looking at the color of the meat to determine doneness OR the idea that baking a turkey for "X" hours does not necessarily mean it is cooked thoroughly and the only way to know is using a thermometer. *Good points to bring up: Research has been done regarding juices running clear. When juices run clear, the turkey is often overcooked. Another point of emphasis is 1 in 4 burgers will turn brown before they are fully done on the inside **Correct thermometer usage** -Correct readings can be done only if the temperature is taken in the thickest part of the meat that is not touching the directly -Each food is different for the minimum temperature that it is needed to be cooked to. For turkeys, it is 165 degrees Fahrenheit; readings can be taken from three locations: innermost part of the thigh, the innermost part of the wing, and the thickest part of the breast. At the end of the lecture, a video provided by the FSIS on cooking to the minimum temperature and thermometer use will be shown through YouTube (https://youtu.be/-2KkV2yFIN0 .) In this video, focus on the points mentioned earlier about how to know if food is correctly done and what types of false indicators exist for doneness as well as how to correct insert a thermometer.	
Summary/Evaluation (Assign Homework, or Reflect on the Outcomes)	Students will be asked to take time over Thanksgiving break to reflect on what they've learned and apply this knowledge to a worksheet on thermometer usage. Questions will be asked on whether they use a thermometer on the turkey or not and if they do not, how do they determine the turkey is done.	

FIGURE 2. Food safety curriculum template for teaching thermometer usage during cooking in home kitchens.

Food Safety Information Sheet on Kitchen Thermometers *(42)*. The resulting web-based survey was designed to be used over Thanksgiving break as a way for students to collect data on behalf of their families and the primary meal-preparers in their homes. Data was collected through the end of December 2016. Through their biology or family and consumer sciences classes, students were provided basic instructions on how to submit a picture of what their Thanksgiving turkey looked like and were asked to provide a view that showed the thermometer. No additional information related to intervening in practices was provided, so as to keep the approach open ended and without specific direction, in the hope that this would provide a real-world look at turkeys and thermometer usage in cooking turkeys.

Fifty-seven high school students volunteered to complete the survey over Thanksgiving break. Volunteers were recruited through biology and family and consumer sciences classes at Souderton Area High School, Souderton, Pennsylvania, and through family and consumer sciences (FCS) classes in North Carolina. Classes in North Carolina were emailed the curriculum outlined in *Fig 2*. containing the survey through the family and consumer sciences listserv, an application that allows for distribution of messages to subscribers on a mailing list. Souderton Area High School was recruited through partnerships and connections through previous collaborative work. The 57 participants of this study constitute a convenience sample. A five-question survey was created using SurveyMonkey (San Mateo, CA) focusing on the food safety topics of thermometer usage, minimal internal endpoint cooking temperature, and indicators of doneness for whole turkeys *(Fig. 1)*. Teachers were provided the survey as part of the lesson plan. The survey was distributed to students as a homework assignment to be done over Thanksgiving break as a way for them to reflect on what they had learned from the classroom lesson.

Recruiting citizen scientists through a high school food safety lesson

A food safety class lesson was developed using North Carolina State University's family and consumer sciences lesson template that focused on cross-contamination, minimum safe internal temperature to which to cook meats, and correct thermometer use. The template consisted of the following components: the topic, the goals and objectives, the materials needed, the grade level of the target student volunteers, the time by which the lesson needed to be completed, and the activities to be completed during the lesson *(Fig. 1)*. The objectives of the lesson were for students to (i) apply previous knowledge on sanitation to new food safety principles such as cross-contamination and cooking, (ii) understand how and why cross-contamination can lead to foodborne illness, (iii) practice safe handling of foods as the result of learning about the importance of thorough cooking, and (iv) differentiate between safely and unsafely cooked foods. The anticipatory

FIGURE 3. Sample of pictures provided by data collectors in home kitchens to validate self-reported data.

section, or "warm-up activity," consisted of YouTube video of a Food Network chef; students were asked to list and describe all occurrences of cross-contamination portrayed in the video. Teachers and students discussed the instances of cross-contamination and temperature abuse, as well as the surfaces that needed to be sanitized by the chef in the video. Emphasis was placed on washing of hands after touching raw meat, the concept of avoiding cross-contamination and proper use of a thermometer.

After the warm-up activity, students performed a writing exercise in which they answered the question, "Have you ever been affected by foodborne illness?" and shared their answers with their classmates and teacher as part of a discussion on foodborne illness. Probing questions about the type of symptoms experienced, the possible origin of the foodborne illness, and the future prevention of the foodborne illness were provided to teachers to promote further discussion in class. A lecture was developed with content from USDA-FSIS' food safety information on kitchen thermometers *(42)*. Concepts taught to students were cooking throughout to a minimum internal temperature to kill bacteria, color as a poor indicator of doneness, and how to correctly use a thermometer.

Analyses and evaluation of data

Data collected on thermometer use through Survey Monkey were obtained as a text response, as well as a pictorial response if students stated that they had used a thermometer. Analyses of the survey responses were performed via Microsoft Excel Office 365 (Redmond, WA). Responses were downloaded from Survey Monkey and each was individually cleaned to remove unnecessary information such as survey response times and Internet Protocol addresses. Responses were coded using both the text and pictures provided by participants. Some data were obtainable only through text such as indicators of doneness if a thermometer was not used, whereas other data were obtainable only through pictures, such as thermometer placement in the turkey. Specific information on thermometer type (e.g., dial or digital) were collected through respondents' pictures only, not text. If a picture showed multiple thermometers (e.g., dial and pop-up) in a single turkey, each thermometer was coded separately *(Fig. 3D)*. Thermometer usage and internal temperature data were obtained through text responses and verified pictures. Thermometer placement data were collected for dial, digital, and glass thermometers, but not for pop-up thermometers.

RESULTS

Of the 57 high school students who participated in this citizen science project, 78.9% (n = 45) reported their family used a thermometer to determine turkey doneness. The majority of families, 48.9% (22 of 45), used a dial thermometer, defined as having a dial display and containing a probe that expands when heated because of the presence of coils of two different metals *(37)*. Pop-up thermometers were used by 29% (13 of 45) of participants, sometimes in conjunction with other thermometers. Pop-up thermometers were defined as a single-use, disposable cooking device made of food grade nylon that has an inside with a stainless-steel spring and organic firing material that will spring, or "pop up," at a specific predetermined temperature *(37)*. No survey questions were asked on whether the pop-up thermometer was inserted by the manufacturer or by the participant. Some respondents answered "yes" to thermometer use but did not provide a temperature, instead providing a picture of a pop-up thermometer rather than a dial, digital, or liquid. Only pictorial responses of pop-up thermometers were coded. Digital thermometers, used by 24% (11 of 45) of families were defined as having a digital display and being thermistors, meaning they have a resistor within a temperature-sensitive tip *(37)*. One participant reported using both a digital and pop-up thermometer, while two other participants reported using both a dial and pop-up thermometer. One participant preferred a liquid thermometer *(Fig. 2D)*, which was defined as having metal or glass stems that were filled with a colored liquid *(37)*. Figure 4 provides a full composition of each thermometer type. Thermometer type was recorded as "undetermined" when pictures were not submitted or a thermometer was not present in the picture.

A safe internal temperature was defined as 165°F, that being the minimum internal temperature recommended for turkey by USDA-FSIS *(42)*. Of participants using a thermometer, only 9% (4 of 46) undercooked their turkey to an internal temperature of less than 165°F. More than half (65%; 30 of 45) of all participants cooked their whole turkey to an internal temperature of 165°F or higher. Figure 5 provides a full breakdown of recorded internal temperatures by cited scientists. Results were recorded as "undetermined" for the internal temperature of the turkey if: (i) the text response provided an oven temperature instead of the turkey's internal temperature, or (ii) if the picture provided was inaccessible or the temperature could not be determined by looking at the picture.

Participants preferred to use either the breast region (17 of 32) or thigh region (12 of 32) for checking the internal temperature of their turkey *(Fig. 6)*. No participants measured the temperature with a thermometer in the drumstick or wing. Five samples were undetermined because of an inability to establish thermometer placement with a picture, if the picture was inaccessible or if a picture of a pop-up thermometer was given instead *(Fig. 3)* from pictures uploaded. Letter A in *Fig. 3* indicates a dial thermometer that measured the specific temperature of the turkey at the breast region. Letter B indicates an example of a digital thermometer that measured a specific temperature; however, the specific measurement region here was not discernable. Letter C indicates an example of two thermometers being used in the same turkey. Letter D indicates an example of a liquid thermometer.

DISCUSSION

Although citizen science as a data collection method has appreciable merits, it can benefit from improvements related to the data collection instrument and to the recruitment and training of citizen scientists. Such improvements will, in turn, increase the usability of the resulting data. Source *(39)* stated that specific protocols easily understood by and designed for citizen scientists must be developed and then tested for reliability. In addition, training participants on equipment before use will help citizen scientists collect actual numbers rather than ranges of numbers. By comparing the results to those obtained by someone who was "pair-trained" (an individual who will assist in checking accuracy of the results), the results can be tested for reliability. Students in the study were trained by being taught correct thermometer placement and the minimal internal temperature; however, the lesson was used to varying degrees in the classroom; some teachers used the lecture on correct thermometer usage and placement, while others did not, so all citizen scientists did not receive the same training. Training was not provided on the data collection instrument of the survey; as a result, certain responses to questions were unusable because they provided the wrong information. For example, when asked for the internal temperature of the turkey, some students provided oven temperatures instead. Training could also benefit clarifying from and specifying specific details of the questions, such as specifying that participants should provide a picture of their turkey only if they used a thermometer or that participants should provide internal temperatures of turkeys only if this information is associated with a thermometer and a picture.

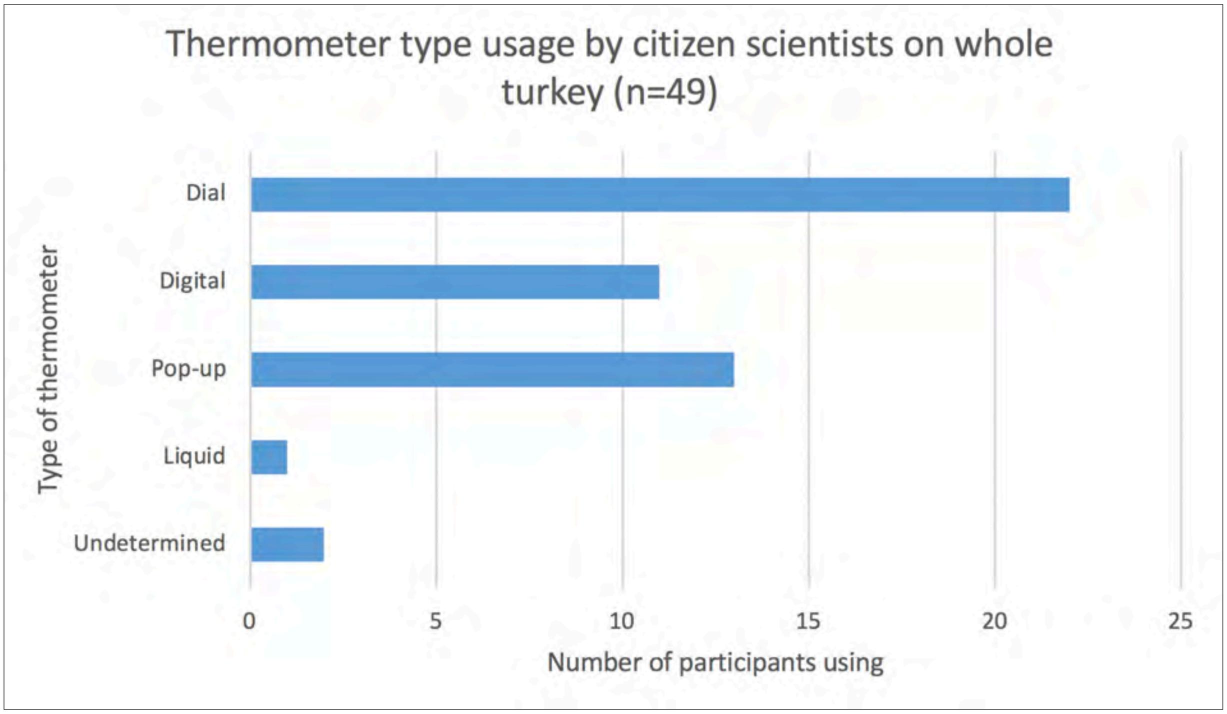


FIGURE 4. Thermometer type usage on whole turkey by citizen scientists.

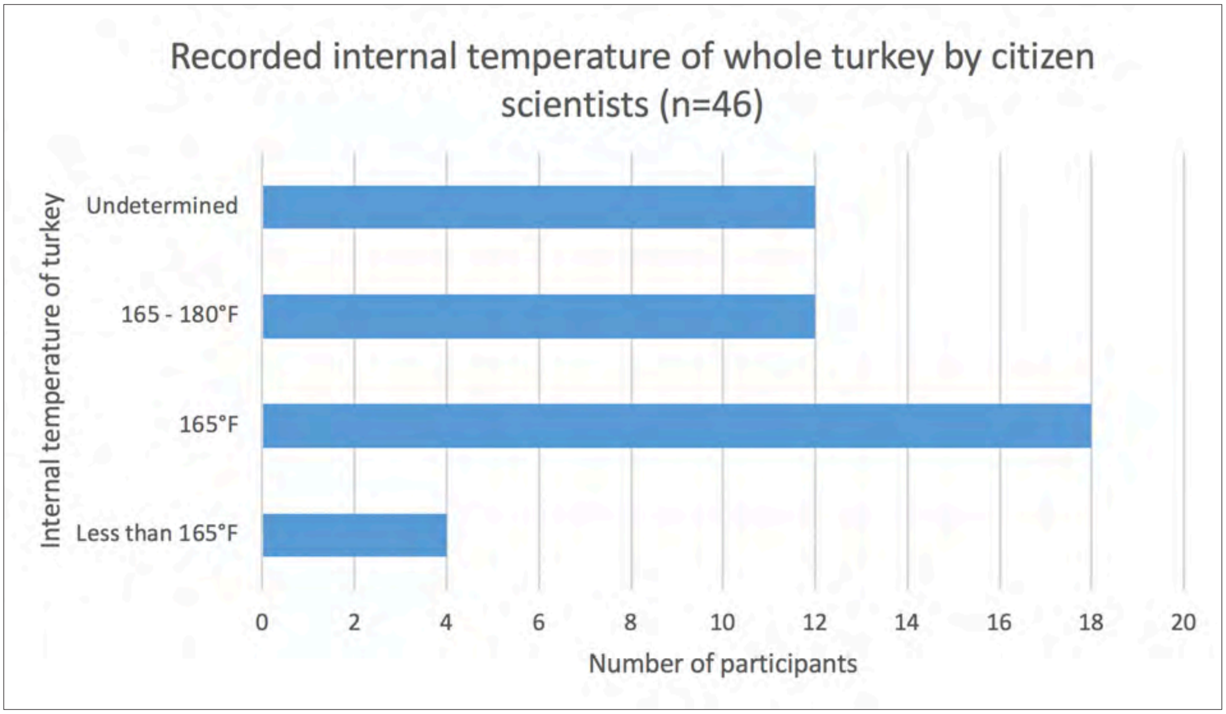


FIGURE 5. Recorded internal temperature of whole turkey by citizen scientists.

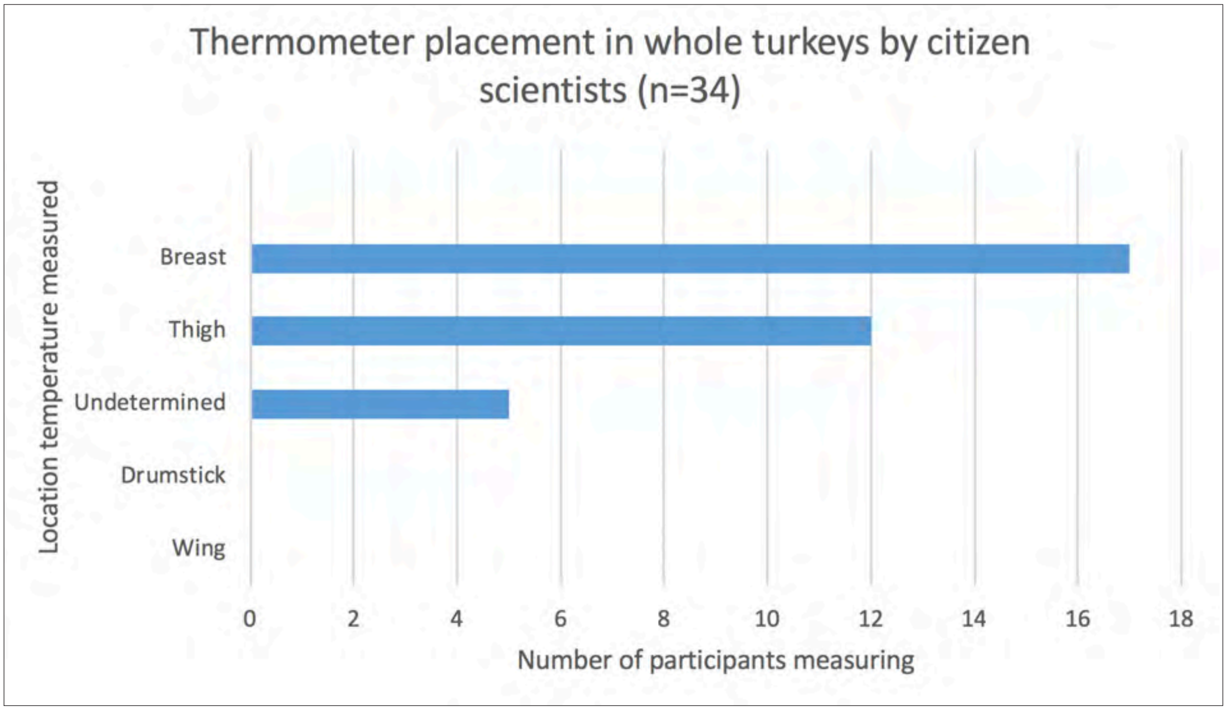


FIGURE 6. Thermometer placement in whole turkeys by citizen scientists.

Participants' thermometer usage behaviors was higher with citizen science than with self-reported data *(19, 22)*. In the present study, 78.9% (n = 45) of participants reported using a food thermometer through text or pictorial response. In comparison, 30% (n = 1,003) of respondents reported thermometer use to check doneness of meat and poultry items in IFIC's 2016 Food and Health Survey, while 73.2% (1,101 of 1,504) of consumers self-reported using a thermometer to specifically check the internal temperature of whole turkey in a study by Kosa and colleagues *(19, 22)*. A dial thermometer was the preferred thermometer among 48.8% (n = 22) of participants. Compared with digital thermometers, dial thermometers can provide less accurate and lower measurements of the internal temperature of hot food because although the tip and stem must be inserted to the immersion point on the stem, some consumers think that only the tip should be inserted into the food *(39)*. Insertion of the thermometer about 1/2 inch into a food gave a temperature reading that was 10 to 48°F below the temperature of the center portion of the food *(38)*. Calibration is sometimes required for dial thermometers to ensure that they are accurate *(41)*.

Thirty-four participants provided a usable temperature value through text or picture, while twelve participants provided unusable data that was categorized as "undetermined." Of the participants who provided usable data, 66.7% (n = 30) cooked their turkey to the required internal temperature of 165°F or higher *(43)*. This percentage is higher than IFIC's data, which indicated that 66% (n = 1,003) of consumers cooked their meat and poultry items to the required temperature of 165°F *(19)*. Most participants correctly placed thermometers in their turkey. Only four participants (8.9%) undercooked their turkey. Citizen science participants were exposed to educational materials on the importance of thermometer use, of cooking turkey to a safe internal temperature, and on correctly placing a thermometer in food. However, the results could be influenced by participants' responses to the educational materials. The Theory of Planned Behavior (TPB) contains three variables: perceived behavioral control (PBC), attitudes, and subjective norms *(1)*. PBC is a person's perception of ease or difficulty when performing an intended behavior, attitudes are a person's favorable or unfavorable evaluation of the behavior, and subjective norm is the perceived social pressure caused by the expectations of others *(1)*. Exposure to the food safety lesson may have influenced students' thermometer use; students could have developed positive or negative attitudes toward thermometer usage from the lesson and/or been influenced by their peers' attitudes on thermometer use *(10)*. These factors could have affected whether students used a thermometer or not and whether they completed the survey.

The "undetermined" category for recorded internal temperature of turkeys was high, accounting for 26% (n = 12) of the samples in that data set. Poor quality data is a potential weakness of citizen science, since the data are dependent on the training, knowledge, and expertise of the contributor *(17)*, although, in this study, knowledge and expertise were not specifically measured. Ratnieks and colleagues *(28)* quantified the effectiveness of training methods during their collection of data on insects and flowers and found that training method has a significant effect on accuracy of the results, to the point that correct identification of honeybees and social wasps could be changed. Limitations were related to not training the teachers or others charged with providing citizen science instruction. Levels of information taught from the curriculum and training done were not compared between participants exposed to food safety material and those who were not. The training method in this citizen science study was a food safety lesson developed for high school classes that focused on correct thermometer usage, achieving a safe internal temperature, and correctly placing the thermometer in the turkey. Those who provided the instruction were not trained on the protocol for delivery or evaluation of the lesson, and they used the lesson to varying degrees; some used the material fully, some used it partially, and some did not use it at all. At Souderton Area High School, family and consumer science classes utilized only the survey, and biology classes used the lesson to varying extents, depending on whether a lesson on food safety was taught earlier in the year. Some teachers have a school, county or state curriculum they need to follow to prepare students for standardized tests, and this may have affected their ability to use the lesson fully as intended. The food safety lesson is heavily science-based and may fit better in a biology class curriculum or teaching schedule than in a family and consumer sciences class.

The quality of data collected by citizen scientists depends on how well the data fits its purpose. Wiggins and colleagues *(44)* describe it as a "multifaceted evaluation of states such as completeness, validity, consistency, precision, and accuracy." In this study, everything from recruitment through data collection and evaluation was important to collecting data that was accurate, and the lack of complete implementation may have altered the study outcomes. Council and Horvath offer tools for citizen science recruitment, citing resources such as community partnerships through local science museums or libraries, social media such as Twitter and Facebook, or recruitment through classroom engagement *(15)*. Future recruitment of potential teachers and students as citizen scientists could include social media components to gain a wider geographic range of approaches or through local partnerships that will provide science communication.

Classroom engagement in this project involved 57 participants but may increase with a tool Council and Horvath used, which involved inviting scientists researching particular topics related to the project into classrooms so that they could interact with students *(15)*. The effect of engaging partnerships was noticeable when examining the geographic region results; 45 of the 57 participants were from Souderton Area High School (SAHS) – the only school sampled in Pennsylvania – and only 12 were from North Carolina (NC). Teachers at SAHS were provided the food safety curriculum with the help of individuals who had previous involvement with NC State's researchers on a previous project, which made engagement with the classes from this school easier. Teachers from NC were provided the lesson through a listserv of two-hundred-plus classes where no follow-up was done.

The data collected herein via citizen scientists is encouraging, since most respondents demonstrated proper selection, placement and use of a thermometer and cooked their Thanksgiving turkey to a temperature of at least 165°F; this data can be used to supplement results obtained through self-reported survey methodologies as well as observation. This is a one-time case study, in which a single point in time was studied after a treatment that may have caused change. Further studies are needed to more comprehensively develop, refine, and pilot test classroom information and exercises related to proper thermometer use in the cooking of poultry and to expand the demographic and geographic components of the collection of data by citizen scientists within homes. Citizen science provides a viable way to collect reliable and accurate self-reported data from various sources that is useful in triangulating food handling practices. Future steps could include utilizing social media to collect everyday or event-specific food safety information, utilizing citizen science as a component of a mixed-methods study. The methodological strategy on its own provides a snapshot of practices, but coupling it with other data collection methods could provide synergy. The collected data was obtained in two forms, text and picture, allowing for verification of results. Although the current study focused on whole turkeys, citizen science data collection can be applied to other food products of interest.

ACKNOWLEDGMENTS

The authors thank the high school teachers and students of Pennsylvania and North Carolina for pilot testing and for incorporating and/or using this lesson in their classrooms, and the North Carolina Family and Consumer Sciences organization for providing a lesson template. The authors are grateful to the teachers of Souderton Area High School for allowing us to use their classrooms, specifically biology teachers Karen Wolfe, Colleen Hartman, Nick Chiarolanza, Val Ford, and Patrick Murphy, as well as Reno Palombia, Family and Consumer Sciences Education Consultant in North Carolina, for helping distribute the curriculum through email. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number #2012-68003-30155. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

REFERENCES

1. Ajzen, I. 1991. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process* 50:179–211.

2. Anderson, J. B., T. A. Shuster, K. E. Hansen, A. S. Levy, and A. Volk. 2004. A camera's view of consumer food-handling behaviors. *J. Am. Diet. Assoc.* 104:186–191.

3. Batz, M. B., S. Hoffmann, and J. G. Morris. 2012. Ranking the disease burden of 14 pathogens in food sources in the United States using attribution data from outbreak investigations and expert elicitation. *J. Food Prot.* 75:1278–1291.

4. Bonney, R., J. L. Shirk, T. B. Phillips, A. Wiggins, H. L. Ballard, A. J. Miller-Rushing, and J. K. Parrish. 2014. Citizen science: next steps for citizen science. *Sci.* 343:1436–1437.

5. Brewer, M. S., and M. Rojas. 2008. Consumer attitudes toward issues in food safety. *J. Food Saf.* 28:1–22.

6. Bruhn, C. 2014. Chicken preparation in the home: an observational study. *Food Prot. Trends* 34:318–330. Available at: http://www.foodprotection.org/files/food-protection-trends/Sep-Oct-14-Bruhn.pdf. Accessed 13 September, 2017.

7. Bryan, F., T. W. McKinley, and B. Mixon. 1971. Use of time-temperature evaluations in detecting the responsible vehicle and contributing factors of foodborne disease outbreaks. *Milk Food Technol.* 34:576–582.

8. Centers for Disease Control and Prevention. 2013. Multistate outbreak of *Campylobacter jejuni* infections associated with undercooked chicken livers – Northeastern United States, 2012. Available at: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6244a2.htm%0D. Accessed 21 August, 2017.

9. Centers for Disease Control and Prevention. 2013. Multistate outbreak of *Salmonella* Heidelberg infections linked to chicken (Final update). Available at: https://www.cdc.gov/salmonella/heidelberg-02-13/index.html. Accessed 17 August, 2017.

10. Centers for Disease Control and Prevention. 2016. Food safety tips for your holiday turkey. Available at: https://www.cdc.gov/features/turkeytime/index.html. Accessed 12 August, 2017.

11. Centers for Disease Control and Prevention. 2018. Outbreak of multidrug-resistant *Salmonella* infections linked to raw turkey products (Final update). Available at: https://www.cdc.gov/salmonella/reading-07-18/index.html. Accessed 30 April 2019.

12. Chai, S. J., D. Cole, A. Nisler, and B. E. Mahon. 2017. Poultry: the most common food in outbreaks with known pathogens, United States, 1998–2012. *Epidemiol. Infect.* 145:316–325.

13. Chapman, B., T. Eversley, K. Fillion, T. Maclaurin, and D. Powell. 2010. Assessment of food safety practices of food service food handlers (risk assessment data): testing a communication intervention (evaluation of tools). *J. Food Prot.* 73:1101–1107.

14. Chapman, B. J., T. MacLaurin, and D. A. Powell. 2013. Video observation and data coding methods to assess food handling practices at food service. *Food Prot. Trends* 33:146–156.

15. Council, S. E., and J. E. Horvath. 2016. Scientific citizenship. *J. Microbiol. Biol. Edu.* 17:38–40.

16. DeDonder, S., C. J. Jacob, B. V. Surgeoner, B. Chapman, R. Phebus, and D. A. Powell. 2009. Self-reported and observed behavior of primary meal preparers and adolescents during preparation of frozen, uncooked, breaded chicken products. *Brit. Food J.* 111:915–929.

17. Foster-Smith, J., and S. M. Evans. 2003. The value of marine ecological data collected by volunteers. *Biol. Cons.*113:199–213.

18. Guardone, L., M. Guarducci, L. Gasperetti, F. Susini, M. Longo, A Maneschi, N. Davidovich, A. Guidi, and A. Armani 2016. Climate change and food safety: citizen science for monitoring the presence of toxic alien fish species in Italian waters. *Proceedings of the 89th SIBS National Congress on Climate and Life.* Ozzano dell'Emilia, Italy, 2 December 2016.

19. International Food Information Council. 2016. Food and Health Survey. Available at: http://www.foodinsight.org/sites/default/files/2016-Food-and-Health-Survey-Report_FINAL1.pdf. Accessed 13 September 2017.

20. Jay, L. S., D. Comar, and L. D. Govenlock. 1999. A video study of Australian domestic food-handling practices. *J. Food Prot.* 62:1285–1296.

21. Kelsay, R. C. 1970. Food poisoning outbreak in Kentucky traced to creamed turkey. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2031814/pdf/pubhealthreporig01060-0073.pdf. Accessed 13 September 2017.

22. Kosa, K. M., S. C. Cates, S. Bradley, S., Godwin, and D. Chambers. (2015). Consumer shell egg consumption and handling practices: results from a national survey. *J. Food Prot.* 78(7):1312–1319. https://doi.org/10.4315/0362-028X.JFP-14-574.

23. Kullenberg, C., and D. Kasperowski. 2016. What is citizen science? A scientometric meta-analysis. *PLoS ONE* 11:1-16. https://doi.org/10.1371/journal.pone.0147152. Accessed 27 August 2017.

24. Logue, C. M., J. S. Sherwood, L. M. Elijah, P. A. Olah, and M. R. Dockter. 2003. The incidence of *Campylobacter* spp. on processed turkey from processing plants in the midwestern United States. *J. Appl. Microbiol.* 95:234–241.

25. Mazengia, E., M. Samadpour, H. W. Hill, K. Greeson, K. Tenney, G. Liao, X. Huang, and J. S. Meschke. 2014. Prevalence, concentrations, and antibiotic sensitivities of *Salmonella* serovars in poultry from retail establishments in Seattle, Washington. *J. Food Prot.* 77:885–893.

26. Mūnoz, R., E. Ornelas Jr., L. Nickey, S. Balcorta, D. Sublasky, I. Rivas, J. T. McLauchlin, R. C. Krehoff, G. Garcia, G. Graves, J. Thompson, B. Lara, B. Jones, P. Allman, P. Gray, J. Miller, P. Gutierrez, J. White, L. Nims, and M. Eidson. 1986. Staphylococcal food poisoning from turkey at a country club buffet — New Mexico. *MMWR.* 35(46):715–716, 721–722.

27. National Turkey Federation. 2017. Turkey History & Trivia. Available at: http://eatturkey.com/why-turkey/history%0D. Accessed 27 August 2017.

28. Ratnieks, F. L. W., F. Schrell, R. C. Sheppard, E. Brown, O. E. Bristow, and M. Garbuzov. 2016. Data reliability in citizen science: learning curve and the effects of training method, volunteer background and experience on identification accuracy of insects visiting ivy flowers. *Methods Ecol. Evol.* 7:1226–1235.

29. Ravenholt, O., C. Schmutz, L. Empey, D. J. Maxson, P. Klouse, A. Bryant, and R. Todd. 1996. Salmonellosis associated with a Thanksgiving dinner — Nevada, 1995. *MMWR.* 45(46):1016–1017.

30. Redmond, E. C., and C. J. Griffith. 2003. Consumer food handling in the home: a review of food safety studies. *J. Food Prot.* 66:130–161.

31. Redmond, E. C., and C. J. Griffith. 2004. Consumer perceptions of food safety risk, control and responsibility. *Appetite* 43:309–313.

32. Ruiz-Mallén, I., L. Riboli-Sasco, C. Ribrault, M. Heras, D. Laguna, and L. Perié. 2016. Citizen Science: toward transformative learning setting the project. *Sci. Commun.* 38:523–534.

33. Ryan, S. F., N. L. Adamson, A. Aktipis, L. K. Andersen, R. Austin, L. Barnes, M. R. Beasley, K. D. Bedell, S. Briggs, B. Chapman, C. B. Cooper, J. O. Corn, N. G. Creamer, J. A. Delborne, P. Domenico, E. Driscoll, J. Goodwin, A. Hjarding, J. M. Hulbert, S. Isard, M. G. Just, K. Kar Gupta, M. M. López-Uribe, J. O'Sullivan, E. A. Landis, A. A. Madden, E. A. McKenney, L. M. Nichols. B. J. Reading, S. Russell, N. Sengupta. L. R. Shapiro, L. K. Shell, J. K. Sheard, D. Shoemaker, D. Sorger, C. Starling, S. Thakur, R. R.Vatsavai, M.Weinstein, P. Winfrey, and R. Dunn, 2018. The role of citizen science in addressing grand challenges in food and agriculture research. *P. Roy. Soc. B-Biol Sci.* 285.1–10.

34. Scallan, E., R. M. Hoekstra, F. J. Angulo, R. V. Tauxe, M.-A. Widdowson, S. L. Roy, J. L. Jones, and P. M. Griffin. 2011. Foodborne illness acquired in the United States — major pathogens. *Emerg. Infect. Dis.* 17:7–15.

35. Scharff, R. L. 2012. Economic burden from health losses due to foodborne illness in the United States. *J. Food Prot.* 75:123–131.

36. Silvertown, J. 2009. A new dawn for citizen science. *Trends Ecol. Evol.* 24:467–471.

37. Smith, A. M., S. Lynn, M. Sullivan, C. J. Lintott, P. E. Nugent, J. Botyanszki, M. Kasliwal, R. Quimby, S. P. Bamford, L. F. Fortson, K. Schawinski, I. Hook, S. Blake, P. Podsiadlowski, J. Jönsson, A. Gal-Yam, I. Arcavi, D. A. Howell, J. S. Bloom, J. Jacobsen, S. R. Kulkarni, N. M. Law, E. O. Ofek, and R. Walters. 2011. Galaxy Zoo Supernovae. *Mon. Not. R. Astron. Soc.* 412:1309–1319.

38. Snyder, O. P. 2004. Inaccuracy of food temperature measurement with the bimetallic coil (dial) thermometer. Available at: www.hi-tm.com/Documents2004/bitherm-cook.pdf%0A. Accessed 13 September 2017.

39. Source, J. P. C. 2008. Citizen Science: can volunteers do real research? *BioSci.* 58:192–197.

40. Stern, N. J., and J. E. Line. 1992. Comparison of three methods for recovery of *Campylobacter* spp. from broiler carcasses. *J. Food Prot.* 55:663–666.

41. U.S. Department of Agriculture Food Safety and Inspection Service. 2011. Food safety information: kitchen thermometers. Available at: https://www.fsis.usda.gov/wps/wcm/connect/d8151061-bb50-46db-b87e-%0Da3b9022c0c56/Kitchen_Thermometers.pdf? MOD=AJPERES.%0D. Accessed 8 August 2017.

42. U.S. Department of Agriculture Food Safety and Inspection Service. 2015. Basics for handling food safely. Available at: https://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/safe-food-handling/basics-for-handling-food-safely/ct_index. Accessed 7 August 2017.

43. U.S. Department of Agriculture Food Safety and Inspection Service. 2015. Let's talk turkey — a consumer guide to safely roasting a turkey. Available at: https://www.fsis.usda.gov/ wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/poultry-preparation/lets-talk-turkey/CT_Index%0D. Accessed 9 August 2017.

44. Wiggins, A., G. Newman, R. D. Stevenson, and K. Crowston. 2011. Mechanisms for data quality and validation in citizen science. *Proceedings 7th IEEE International Conference on E-Science Workshops, eScienceW 2011,* 14–19. https://doi.org/10.1109/eScienceW.2011.27 Accessed 21 July 2017.

45. Yang, B., M. Xi, X. Wang, S. Cui, T. Yue, H. Hao, H., Y. Wang, Y. Cui, W. Q. Alali, J. Meng, I. Walls, D. M. Wong, and M. P. Doyle. 2011. Prevalence of *Salmonella* on raw poultry at retail markets in China. *J. Food Prot.* 74:1724–1728.

46. Zerbe, W. J., and D. L. Paulhus. 1987. Socially desirable responding in organizational behavior: a reconception. *Acad Manage. Rev.* 12:250–264.

47. Zhao, C., B. Ge, J. De Villena, R. Sudler, E. Yeh, S. Zhao, D. G. White, D. Wagner, and J. Meng. 2001. *Escherichia coli* and *Salmonella* serovars in retail chicken, turkey, pork, and beef from the greater Washington, D.C. area. *Appl. Microbiol.* 67:5431–5436.