Received: 8 October 2020 | Accepted: 22 April 2021

DOI: 10.1002/tea.21697

RESEARCH ARTICLE

JRST | WILEY

To know about science is to love it? Unraveling cause–effect relationships between knowledge and attitudes toward science in citizen science on urban wildlife ecology

Till Bruckermann[1,2] | **Hannah Greving**[3] | **Anke Schumann**[4] | **Milena Stillfried**[5] | **Konstantin Börner**[5] | **Sophia E. Kimmig**[5] | **Robert Hagen**[5] | **Miriam Brandt**[4] | **Ute Harms**[1]

[1]Department of Biology Education, IPN—Leibniz Institute for Science and Mathematics Education, Kiel, Germany

[2]Institute of Education, Leibniz University Hannover, Hannover, Germany

[3]Knowledge Construction Lab, Leibniz-Institut für Wissensmedien (IWM), Tübingen, Germany

[4]Science management, Leibniz Institute for Zoo and Wildlife Research (IZW), Berlin, Germany

[5]Department of Ecological Dynamics, Leibniz Institute for Zoo and Wildlife Research (IZW), Berlin, Germany

Correspondence
Till Bruckermann, Leibniz University Hannover, Schloßwender Str. 1, 30159 Hannover, Germany.
Email: till.bruckermann@iew.uni-hannover.de

Funding information
Bundesministerium für Bildung und Forschung, Grant/Award Numbers: 01|O1725, 01|O1727, 01|O1728

Abstract

Nowadays, citizens collaborate increasingly with scientists in citizen science (CS) projects on environmental issues. CS projects often have educational goals and aim to increase citizens' knowledge with the ultimate goal of fostering positive attitudes toward science. To date, little is known about the extent to which CS projects strengthen the positive interrelationship between knowledge and attitudes. Based on previous research, it has been suggested that the knowledge–attitude relationship could be further examined by focusing on different aspects: (1) different attitudinal domains, (2) topic-specific knowledge, and (3) its direction. Our study contributes to the clarification of the interrelation between scientific knowledge and attitudes toward science within the specific domain of urban wildlife ecology using cross-lagged panel analyses. We collected survey data on five attitudinal domains, topic-specific knowledge, scientific reasoning abilities, and epistemological beliefs from $N = 303$ participants before and after they participated in a CS project on urban wildlife ecology. Participants collected and analyzed data on terrestrial mammals in a German metropolitan city. Our results provide evidence for the relationship between knowledge and attitudes due to the topic-specificity of knowledge in CS projects (e.g., wildlife ecology). Our method provided a rigorous assessment of the direction of the knowledge–attitude relationship and showed that topic-specific knowledge was a predictor of more positive attitudes toward science.

KEYWORDS

attitudes, cross-lagged panel analysis, informal science, science literacy

1 | INTRODUCTION

In recent years, the number of research projects in which citizens participate has increased (Follett & Strezov, 2015; Kullenberg & Kasperowski, 2016). In these citizen science (CS) projects, citizens collaborate with scientists (Heigl, Kieslinger, Paul, Uhlik, & Dörler, 2019), for example, to investigate environmental topics through biodiversity and wildlife monitoring (Frigerio et al., 2018; McKinley et al., 2017). Besides scientific goals, many CS projects also have educational purposes (Wals, Brody, Dillon, & Stevenson, 2014) such as increasing citizens' knowledge about the environment and science (e.g., Groulx, Brisbois, Lemieux, Winegardner, & Fishback, 2017). This is based on the assumption that enhancing participants' knowledge through CS projects should ultimately foster more positive attitudes toward science (Crall et al., 2013; Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). To date, the effects of CS projects on knowledge and attitudes have mostly been investigated separately, and only little is known about their interrelation (e.g., Price & Lee, 2013; see Crain, Cooper, & Dickinson, 2014, for an overview). Therefore, it is important to know more about how knowledge and attitudes toward science affect each other in CS projects.

2 | ATTITUDES TOWARD SCIENCE AND THEIR RELATIONSHIP WITH KNOWLEDGE

Promoting positive attitudes toward science among the public has been guided by the assumption that negative attitudes potentially have severe consequences: decreasing support for public funding of scientific research (Muñoz, Moreno, & Luján, 2012), falling numbers of students who choose to study science (Osborne, Simon, & Collins, 2003), and refusal to appreciate scientific advances (e.g., in the case of genetically modified organisms; Hanssen, Dijkstra, Sleenhoff, Frewer, & Gutteling, 2018, or climate change, Kahan et al., 2012). However, the way in which public attitudes toward science develop and how they can be promoted seems to be unclear. Although surveys have shown that the majority of people see science as beneficial and highly respect scientists (Castell et al., 2014; European Commission, 2014; National Science Board, National Science Foundation, 2020), there is doubt about whether public attitudes toward science rest on the public's scientific knowledge (Drummond & Fischhoff, 2017; Kahan et al., 2012). The association between scientific knowledge and attitudes toward science has been discussed since the 1980s (e.g., Ahteensuu, 2012; Sturgis, Cooper, & Fife-Schaw, 2005). According to the deficit model, negative attitudes toward science of the public are caused by a lack of knowledge (e.g., Doble, 1995) or a lack of scientific literacy (e.g., Miller, 1983, 1998). However, the model has been criticized for empirical and theoretical reasons (e.g., Evans & Durant, 1995; Scheufele, 2013). Research on the public understanding of science has since then been trying to disentangle the role that scientific knowledge plays in attitudes toward science (see Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008, for a meta-analysis).

Some studies found evidence for a positive—albeit not very strong—association between scientific knowledge or scientific literacy and attitudes toward science (e.g., Allum et al., 2008; Bauer, Durant, & Evans, 1994; Evans & Durant, 1995; McBeth & Oakes, 1996; Sturgis & Allum, 2004). However, other studies found opposing results and described the relationship between knowledge and attitudes toward science as being more complex (e.g., Miller, 2004). Moreover, the definition of attitudes toward science is unclear as they are often defined rather broadly (Osborne et al., 2003; Pardo & Calvo, 2002; Potvin & Hasni, 2014). Hence, an examination of the relationship between attitudes and knowledge might be more robust if three aspects are accounted for. First, instead of general attitudes, several specific domains of attitudes toward science, such as intentions to engage with science and behavioral beliefs in the benefits of science, could be examined (Fishbein & Ajzen, 2010; Summers & Abd-El-Khalick, 2018). Second, topic-specific knowledge rather than general scientific knowledge could be examined (e.g., about wildlife ecology; Allum et al., 2008; Daamen, van der Lans, & Midden, 2016; Pardo & Calvo, 2002; Scheufele, 2013). Third, because cross-sectional studies were not able to identify the direction of this relationship (Allum et al., 2008; Osborne et al., 2003; Potvin & Hasni, 2014), the direction might be clarified by using cross-lagged panel analyses to provide a causal explanation of whether knowledge or attitude is the influencing factor.

3 | THE FIVE DOMAINS OF ATTITUDES TOWARD SCIENCE

Attitudes toward science can be defined as comprising science-related beliefs, evaluative dispositions, and intentions that influence individuals' decisions to engage with science (Summers & Abd-El-Khalick, 2018). In contrast to measures of general attitudes toward science, which do not differentiate between such different components (Pardo & Calvo, 2002) or confound them with interest in scientific topics and motivation to pursue scientific activities (for an overview, see Osborne et al., 2003; Potvin & Hasni, 2014), the theory of planned behavior introduces a more differentiated view on attitudes (Ajzen, 1991; Fishbein & Ajzen, 2010). Specifically, the theory of planned behavior disentangles the attitude toward a specific object from the attitude toward a specific behavior in relation to this object (Osborne et al., 2003).Therefore, it establishes a closer link between individuals' attitudes toward science and their actual performance of science-related behavior such as further participating in scientific projects (Summers & Abd-El-Khalick, 2018). According to the theory of planned behavior, attitudes toward science can be perceived as consisting of several subconstructs (i.e., attitudinal domains) that all contribute to individuals' overall attitudes toward science (Osborne et al., 2003; Summers & Abd-El-Khalick, 2018).

Five attitudinal domains have been defined that are all relevant for the development of attitudes (Summers & Abd-El-Khalick, 2018): *Control beliefs* refer to the perception that one is capable of performing scientific activities. They represent individuals' perception of their ability to learn about science (e.g., "Science is easy for me"; Summers & Abd-El-Khalick, 2018, p. 196) and their efficacy when learning about science (e.g., "I am confident that I can understand science"; Summers & Abd-El-Khalick, 2018, p. 196). *Behavioral beliefs* refer to the perception of positive consequences associated with science and scientific engagement. They represent the perceived consequences of gaining scientific knowledge on the societal and individual level (e.g., "We live in a better world because of science"; Summers & Abd-El-Khalick, 2018, p. 196). *Normative beliefs* reflect an individual's perception of approval within different reference groups (e.g., family and peers). They are representative of how individuals experience science-related behavior in their social context and how this influences their perception of social pressure and social norms (e.g., "It is common for my peers to talk about science"; Summers & Abd-El-Khalick, 2018). *Attitudes* toward different facets of science reflect positive evaluations of science in different areas of an individual's life. Besides the positive evaluation of science in general (e.g., "I really like science"; Summers & Abd-El-Khalick, 2018, p. 196), this domain includes science as an educational endeavor and science as a leisure activity (e.g., "I really enjoy learning about science"; Summers & Abd-El-Khalick, 2018). Finally, *intentions* to engage with science refer to an individual's aim to further participate in science, which is an antecedent of actual engagement with science. Individuals' intentions concern their targeted behavior in science such as pursuing future learning in science (e.g., "I will continue studying science"; Summers & Abd-El-Khalick, 2018, p. 196) or engagement in science-related activities (e.g., "I will engage in science projects in the future"; Summers & Abd-El-Khalick, 2018).

Other conceptualizations of attitudes toward science relate to science identities as another factor that explains individuals' behavior in science (see Summers & Abd-El-Khalick, 2018, for a discussion). A science identity includes not only individuals' evaluative dispositions of their attitudes and performance in science (i.e., a psychological construct) but also the recognition of science in a local and social context by others (i.e., social and cultural construct; Vedder-Weiss, 2018). Summers and Abd-El-Khalick (2018) conclude that it might be difficult to empirically estimate the influence of identity on an individual's intentions because of its overlap with an individual's control and normative beliefs as well as attitudes. Therefore, we acknowledge the influence of an individual's science identity and account for the perceived self-efficacy and normative influences (i.e., control and normative beliefs) as two domains that contribute to an individual's attitudes toward science. We consider an individual's control beliefs, behavioral beliefs, normative beliefs, attitudes toward facets of science, and intentions as estimates that contribute to the latent trait of an individual's attitudes toward science.

The relationship between knowledge and attitudes toward science may be more robust if attitudes toward science embrace the five different domains outlined in the theory of planned behavior (Summers & Abd-El-Khalick, 2018). These domains have only been investigated separately until now (e.g., intentions to engage with science and behavioral beliefs in the benefits of science; Summers & Abd-El-Khalick, 2018). Previous studies, which focused only on single attitudinal domains and confounded them with interest in a specific science-related object or motivation toward a specific science-related behavior, provided limited support for the empirical relationship because a theory-based conceptualization of attitudes toward science was missing (Pardo & Calvo, 2002). Thus, an investigation of all of these five domains together is lacking so far and may help clarify the knowledge–attitude relationship.

4 | KNOWLEDGE OF SCIENTIFIC CONTENT AND METHODS, AND EPISTEMOLOGICAL BELIEFS

The relationship between attitudes toward science and knowledge seems to depend strongly on the type of knowledge. Knowledge types can be divided into knowledge of scientific content, knowledge of scientific methods (i.e., scientific knowledge and scientific reasoning; Allum et al., 2008; Potvin & Hasni, 2014), and epistemological beliefs (Fulmer, 2014; Kapucu & Bahçivan, 2015). Empirical support for the relationship between scientific knowledge and attitudes appears to depend on the scientific domain (Allum et al., 2008; Scheufele, 2013). For example, biology and genetics knowledge were stronger predictors of attitudes toward science than general scientific knowledge (see Allum et al., 2008, for a meta-analysis). Furthermore, "'local' types of knowledge" (i.e., topic-specific knowledge directly related to everyday issues) can be regarded as more robust predictors of attitudes than other types of knowledge (Allum et al., 2008, p. 51). They also appear to strengthen the positive association with attitudes toward science by embedding knowledge in local contexts (Potvin & Hasni, 2014; Stocklmayer & Bryant, 2012) such as in CS projects (Haywood, 2015).

Besides knowledge of scientific content, knowledge of scientific methods—that is, scientific reasoning—may also contribute to the development of more positive attitudes toward science. Scientific reasoning refers to solving problems in a scientific way (Bao et al., 2009) and entails the cognitive strategy of testing alternative hypotheses (Lawson et al., 2000; for other strategies, see Kind & Osborne, 2017). This ability to reflect upon scientific processes might positively affect attitudes toward science (Potvin & Hasni, 2014), but research on this relationship is sparse (e.g., Evans & Durant, 1995). As measures of scientific reasoning and scientific knowledge correlate, Allum et al. (2008) did not expect to find any differences in their relationships to attitudes toward science and, thus, excluded scientific reasoning from their meta-analysis. Similarly, previous studies assessed knowledge of scientific content and scientific methods in a single scale (Evans & Durant, 1995) and, thus, were not able to specify the unique effects of each of the two concepts separately (Pardo & Calvo, 2002).

Epistemological beliefs represent individuals' perceptions of the development and structure of knowledge within science (Hofer & Pintrich, 1997) or within specific topics of science (Stahl & Bromme, 2007). Although epistemological beliefs are part of scientific literacy (She, Lin, & Huang, 2019), there is little or even contradictory evidence for their relationship to attitudes toward science (Fulmer, 2014; Kapucu & Bahçivan, 2015). In summary, it is, therefore, relevant to separately investigate the relationships of scientific knowledge, scientific reasoning, and epistemological beliefs with attitudes toward science.

5 | DIRECTION OF THE RELATIONSHIP BETWEEN KNOWLEDGE AND ATTITUDES TOWARD SCIENCE

The theoretical assumption underlying the deficit model has been criticized for the absence of evidence that a lack of knowledge causes negative attitudes toward science (e.g., Ahteensuu, 2012). So far, cross-sectional studies have not been able to investigate the causal relationship between knowledge and attitudes, that is, which of the two factors is the influencing factor (for a review, see Ahteensuu, 2012; Osborne et al., 2003) or the mechanisms underlying their relationship (Allum et al., 2008; Potvin & Hasni, 2014). In order to examine the causal relationship, the use of cross-lagged panel designs (Reinders, 2006; Vötter & Schnell, 2019) in longitudinal studies can be one methodological approach. According to the theory of planned behavior (Ajzen, 1991), knowledge can be assumed to be a necessary precondition for attitude development (Kaiser & Fuhrer, 2003). Nonetheless, causal explanations for the development of attitudes toward science still need to be empirically tested (Summers & Abd-El-Khalick, 2018).

6 | DEVELOPMENT OF KNOWLEDGE AND ATTITUDES IN CITIZEN SCIENCE

The field of CS offers an opportunity to test the relationships between knowledge and attitudes more robustly. CS projects are often concerned with specific topics that address knowledge in local contexts (Haywood, 2015). In CS projects, scientists and citizens collaborate to develop knowledge, enabling both citizens and scientists to learn in participatory approaches (Bela et al., 2016; Bonney et al., 2009; Haywood & Besley, 2014). In this way, CS projects address the criticism that the deficit model assumes a unidirectional communication and transfer of scientific knowledge to the public (Bonney, Phillips, Ballard, & Enck, 2016). In the discussions around the deficit model, paradigms of science communication changed in the 1990s from a unidirectional communication *from experts to the lay public* toward public engagement and the *3Ds—dialogue, discussion, and debate* (Ahteensuu, 2012; Nisbet & Scheufele, 2009; Scheufele, 2013). Since then, CS has established a model of collaborative knowledge exchange between scientists and members of the public to foster positive attitudes toward science (Bela et al., 2016; Jordan et al., 2011), transcending the idea of the unidirectional communication of knowledge postulated in the deficit model (Bonney et al., 2016). In this context, CS has been argued to be a suitable tool to increase scientific knowledge and literacy (e.g., Bonney et al., 2009; Bonney et al., 2016) and knowledge of scientific methods (e.g., Trumbull, Bonney, Bascom, & Cabral, 2000)—with the ultimate goal of promoting more positive attitudes toward science (e.g., Crall et al., 2013; Jordan et al., 2011). Although an increasing number of reviews and synthesis papers on CS projects document that some learning outcomes were achieved, they also highlight that most projects have yet to provide scientifically robust evaluations of learning outcomes such as knowledge of scientific content and methods or behavioral intentions (Bela et al., 2016; Crain et al., 2014; Jordan, Ballard, & Phillips, 2012; Peter, Diekötter, & Kremer, 2019; Phillips, Porticella, Constas, & Bonney, 2018; Stylinski, Peterman, Phillips, Linhart, & Becker-Klein, 2020).

Studies examining the effects of CS projects on attitudes toward science are even more sparse—because attitudes receive less attention than knowledge (Groulx et al., 2017)—and they present mixed results (for an overview, see Aristeidou & Herodotou, 2020; Peter et al., 2019) that correspond to previous research on the public understanding of science (Allum et al., 2008). Although one study found that more positive attitudes toward science were connected to participants' access to scientific knowledge (Price & Lee, 2013), other studies found only modest changes in attitudes despite an increase in participants' scientific knowledge (Crall et al., 2013). One study even found small negative changes in participants' attitudes (Druschke & Seltzer, 2012). Most research on CS projects, however, has investigated effects on knowledge and attitudes separately. Little is known so far about their interrelation (Crain et al., 2014).

Yet, if CS projects aim to promote more positive attitudes toward science (e.g., Jordan et al., 2012), it is important to know more about the prerequisites with which citizens enter a CS project (Golumbic, Orr, Baram-Tsabari, & Fishbain, 2017), such as their knowledge and abilities within science, which might contribute to attitude development. Although citizens entering a CS project might already have more positive attitudes toward science than non-participating citizens (Price & Lee, 2013), positive attitudes toward science are only one of the factors that affect citizens' decisions to participate in CS projects (Land-Zandstra, Devilee, Snik, Buurmeijer, & van den Broek, 2016). Other factors, such as enjoyment of the activities or awareness of contributing to the project with their own knowledge of the topic, affect citizens' participation in CS projects as well (Jones, Childers, Andre, Corin, & Hite, 2018; Phillips, Ballard, Lewenstein, & Bonney, 2019; West & Pateman, 2016). Many participants also bring previous knowledge into CS projects (Phillips et al., 2019). Therefore, it is important to know more about other prerequisites such as topic-specific knowledge, which might enhance positive attitudes toward science or might conversely be influenced by those attitudes. CS projects allow us to conduct longitudinal studies of the knowledge–attitude relationship because citizens often engage in CS projects over a more extended period and not just temporarily (e.g., Aristeidou, Scanlon, & Sharples, 2017; Ponciano & Brasileiro, 2014; cf. Ballard et al., 2017, for BioBlitzes). Our study, therefore, contributes to the clarification of the interrelation between knowledge and attitudes toward science in a CS project on urban wildlife ecology.

7 | THE CURRENT RESEARCH

In the current research, we investigated the relationship between attitudes toward science and topic-specific knowledge in a CS project on urban wildlife ecology. The present study extends previous research on the effects of CS projects on scientific knowledge and attitudes toward science (e.g., Crall et al., 2013; Price & Lee, 2013) by taking a longitudinal approach that made it possible to discern causal relationships through cross-lagged panel analyses. In line with previous research on the relationship between attitudes and knowledge (e.g., Allum et al., 2008), we expected that topic-specific knowledge would positively influence attitudes toward science. More precisely, we hypothesized a time-lagged positive influence of topic-specific knowledge on attitudes toward science as operationalized by five attitudinal domains, that is, normative beliefs, control beliefs, behavioral beliefs, attitudes toward different facets of science, and intentions. We did not expect to find a reverse effect, that is, of attitudes toward science on topic-specific knowledge.

We also examined intentions to engage with science and behavioral beliefs in the benefits of science more closely as intentions usually precede actual behavior and behavioral beliefs represent the perceived positive consequences of that behavior (Summers & Abd-El-Khalick, 2018). Thus, we exploratorily tested whether topic-specific knowledge and scientific reasoning abilities positively influence behavioral beliefs and intentions to engage with science. Furthermore, we exploratorily tested the relationship between epistemological beliefs and behavioral beliefs as well as intentions to engage with science.

8 | METHOD

Citizens of a metropolitan city in Germany participated in an urban wildlife ecology CS project on terrestrial mammals (Wildlife Researchers). For 2 months, they engaged with an online platform to contribute to urban wildlife ecology research and build a community of citizen scientists and academic scientists. Within the project, participants installed a wildlife camera in their garden, shared the resulting photos of wildlife in an online database, identified animal species in the pictures with the help of a tutorial, and analyzed the collected data on species' occurrence in relation to landscape variables. We used a two-wave cross-lagged panel design to analyze causal relationships. Participants answered two questionnaires (T1 and T2) with a 2-month interval, one at the start and one at the end of their participation in the project. We report on data from three field studies of this CS project, conducted in 2018 (October/November) and 2019 (April/May and October/November). All three field studies included attitudes toward science and topic-specific knowledge as measures, which means that we included the data of $N = 303$ participants in our main analysis. We assessed scientific reasoning and epistemological beliefs as exploratory measures. In our exploratory analysis, we included the data of $n = 110$ participants because we assessed scientific reasoning only in one of the three field studies in order to reduce the effort required to complete the questionnaires for participants. Participants gave their informed consent to participate in the field studies, and a local ethics committee approved the questionnaires.

8.1 | Participants

Participants were recruited through public relations campaigns directed at the general public. Across all three field studies, 538 participants completed the questionnaire at T1 and 303 participants completed the questionnaire at T2. Thus, 235 participants dropped out after T1, which is a dropout rate of 43.7% between T1 and T2. Besides the dropouts, there were no further missing cases. Those participants who dropped out did not differ from those participants who completed both questionnaires regarding their gender, $\chi^2(2) = 3.82$, $p = 0.148$, age, and education (by ISCED classification as described below), all ts $< |1.1|$, all ps > 0.20. They also did not differ concerning their topic-specific knowledge and attitudes toward science (i.e., their behavioral beliefs, control beliefs, normative beliefs, attitudes toward different facets of science, and intentions), all ts $< |1.4|$, all ps > 0.19.

We, thus, included 303 participants in our main analyses. This number of participants represents a typical sample size for structural equation modeling (Kline, 2011). From these 303 participants, 177 were female, 125 were male, and one indicated a diverse gender. The mean age was $M = 52.93$ ($SD = 11.93$, range: 22–80). Our sample was well educated: In terms of their highest education, 3.3% had a general certificate of secondary education (International Standard Classification of Education [ISCED] 2; OECD, European Union, UNESCO Institute for Statistics, 2015), 6.3% had a general qualification for university entrance (ISCED 3), 1.0% had a qualification for advanced technical college entrance (ISCED 4), 8.9% had a training qualification (ISCED 4; German: "Lehre"), 10.2% had a vocational school degree (ISCED 4), 53.5% had a college of higher education or university degree (ISCED 6 or 7), 13.2% had a doctoral degree or postdoctoral lecture qualification (ISCED 8), and 3.6% had a different degree.

8.2 | Procedure

Participants completed the questionnaire on the online platform before beginning the project (T1) and 2 months later at the end of the project (T2). At T1, participants provided demographic data and answered questions on attitudes toward science, topic-specific knowledge, scientific reasoning, and epistemological beliefs in addition to a range of other measures (i.e., on motivation and emotions). At T2, participants completed the same questionnaire again.

8.3 | Measures

Attitudes toward science were assessed with a measure that distinguished between five different attitudinal domains (i.e., behavioral beliefs, control beliefs, normative beliefs, attitudes toward facets of science, and intentions to engage with science; Summers & Abd-El-Khalick, 2018). This instrument is preferable to other instruments (see Osborne et al., 2003, for an overview) as it is theory-based and applicable to a wide range of age groups (Summers & Abd-El-Khalick, 2018), such as those of individuals who participate in CS. The original items were translated into German and adapted to the context of CS. The measure consisted of 16 items comprising five subscales. With three items each, we measured behavioral beliefs, control beliefs, normative beliefs, and intentions to engage with science (see Table 1 for item examples and the scale reliability of the measures). With four items, we assessed attitudes toward different facets of science (see Table 1). All items were assessed on 5-point Likert scales ranging from 1 *(does not apply at all)* to 5 *(fully applies)*. The scores of the items were averaged across each subscale.

In order to assess *topic-specific knowledge*, we identified relevant topics from the citizens' and the scientists' perspective beforehand (Bruckermann, Stillfried, Straka, & Harms, 2020) based on a Delphi approach (e.g., Blanco-López, España-Ramos, González-García, & Franco-Mariscal, 2015). To assess these topics, 25 single- and multiple-choice questions were used (see Table 1). Participants' correct answers were divided by the total number of questions. Thus, topic-specific knowledge was assessed as the percentage of correct answers.

8.4 | Exploratory measures

Scientific reasoning was assessed with a questionnaire that was adapted to different subjects (Krell, 2018). It consisted of 18 single-choice questions (see Table 1). Participants' correct answers were divided by the total number of questions. Thus, scientific reasoning was assessed as the percentage of correct answers.

To assess *epistemological beliefs*, we used the Connotative Aspects of Epistemological Beliefs scale (CAEB; Stahl & Bromme, 2007). This measure consisted of 17 semantic differentials (e.g., dynamic—static, objective—subjective), which assessed how participants evaluated scientific knowledge (see Table 1). All items were assessed on bipolar 5-point scales. The scores per item were averaged for each participant, with higher scores indicating beliefs in scientific knowledge as being "soft" (i.e., more dynamic and subjective; Stahl & Bromme, 2007).

8.5 | Data analysis

We used a cross-lagged panel design over two waves (T1 and T2) with an interval of 2 months between T1 and T2 (for a detailed account of cross-lagged panel designs, see Kulgemeyer et al., 2020). In each wave, we assessed the same variables (see Measures and Exploratory

TABLE 1 Measures and descriptive statistics for five attitudinal domains (1–5), topic-specific knowledge (6), scientific reasoning (7), and epistemological beliefs (8)

Measure	*N* items	*N* Particip.	M_{T1} (SD_{T1})	$Range_{T1}$	α_{T1}	M_{T2} (SD_{T2})	$Range_{T2}$	α_{T2}	Example	Ref.
1. Behavioral beliefs (BB)	3 (RS)	303	4.27 (0.62)	2–5	0.67	4.19 (0.60)	2–5	0.62	"Science will help me understand the world around me."	a
2. Control beliefs (CB)	3 (RS)	303	3.31 (0.90)	1–5	0.88	3.31 (0.91)	1–5	0.88	"Science is easy for me."	a
3. Normative beliefs (NB)	3 (RS)	303	3.63 (1.06)	1–5	0.76	3.62 (1.09)	1–5	0.81	"It is common for my peers to talk about science."	a
4. Attitudes toward different facets of science (AS)	4 (RS)	303	4.48 (0.58)	2.25–5	0.84	4.40 (0.65)	2.25–5	0.87	"I really like science."	a
5. Intentions (IE)	3 (RS)	303	3.93 (0.81)	1–5	0.78	3.80 (0.88)	1–5	0.81	"I will engage in science projects in the future."	a
6. Topic-specific knowledge	25 (SC/MC)	303	0.59 (0.11)	0.35–0.96	0.40	0.58 (0.10)	0.32–0.96	0.36	see Appendix S1	b
7. Scientific reasoning	18 (SC)	110[c]	0.67 (0.17)	0.17–0.94	0.72	0.66 (0.20)	0.22–1	0.79	Formuling hypotheses; testing hypotheses; analyzing data; see Appendix S1	d
8. Epistemological beliefs	17 (RS)	110[c]	2.80 (0.46)	1.94–4.24	0.83	2.78 (0.44)	1.76–3.94	0.82	"Knowledge about wildlife in biology is … ", e.g., stable/ unstable; see Appendix S2	e

Abbreviations: RS, rating scale; SC, single-choice; MC, multiple-choice.
[a]Summers and Abd-El-Khalick (2018).
[b]ad hoc.
[c]As an exploratory measure, we assessed scientific reasoning and epistemological beliefs in only one of three field studies, so the sample size is smaller.
[d]Krell (2018).
[e]Stahl & Bromme (2007).

Measures). This longitudinal design allowed us to test for causal relationships between our variables while controlling for their stability (Cole & Maxwell, 2003). The stability of variables indicates how strongly the pretest values of a specific variable influence the posttest values of the respective variable. In our main analysis ($N = 303$), we tested the stability of each variable between T1 and T2 in autoregressive analyses and, thereby, estimated how much variance of a variable in the posttest was explained by the same variable's variance in the pretest. We also tested the cross-lagged paths (normal and reversed causation) to estimate the reciprocal influence of the two variables. In the cross-lagged paths (i.e., cross-lagged effects), we estimated the influence of one variable on another variable while controlling for the other variable's stability. The coefficients indicating the cross-lagged effects were standardized regression coefficients (i.e., β). We tested the cross-lagged paths between topic-specific knowledge and attitudes toward science in one model. Testing both cross-lagged paths between the two variables and controlling for the variables' stabilities in one model allowed us to compare the variables' reciprocal influences as indicated by the standardized regression coefficients (Reinders, 2006). With the cross-lagged panel design, we were able to test our hypothesis of whether topic-specific knowledge has an influence on attitudes toward science while controlling for the pretest values of attitudes toward science.

Topic-specific knowledge was a manifest variable; attitudes were modeled as a latent variable consisting of the five attitudinal domains in our main analysis ($N = 303$). In our exploratory analysis, due to the smaller sample size ($n = 110$), we specified different models for normal and reversed causation as well as for the stabilities (e.g., Vötter & Schnell, 2019). All variables in the exploratory path models were manifest variables (for further details, see Deng, Yang, & Marcoulides, 2018; Jackson, 2003). Path analyses of the cross-lagged panel design were performed in AMOS (v22).

9 | RESULTS

9.1 | Main analysis

We expected that topic-specific knowledge would positively influence attitudes toward science. To test our hypothesis, we specified attitudes toward science as a latent variable comprising the five domains of attitudes (i.e., behavioral beliefs [BB], normative beliefs [NB], control beliefs [CB], attitudes toward different facets of science [AS], and intentions to engage with science [IE]) at T1 as well as T2. We added topic-specific knowledge at both T1 and T2 as manifest variables to the path model. The manifest variables of the five attitudinal domains at T1 were allowed to covary with their corresponding subcategory at T2. Attitudes toward science and topic-specific knowledge were not allowed to covary at T1 and T2. Following the cross-lagged panel design, we then tested the cross-lagged paths between attitudes toward science and topic-specific knowledge while controlling for stabilities between T1 and T2. Thus, we tested two autoregressive paths and two cross-lagged paths in our main analysis ($N = 303$, see Model 1, Figure 1).

Model 1 fitted well to the data, $\chi^2/df = 1.83$, $p < 0.001$, RMSEA $= 0.05$, 90% CI_{RMSEA} [0.03, 0.07], CFI $= 0.98$ (see Table 2). The autoregressive analysis indicated the temporal stability of attitudes toward science and topic-specific knowledge between T1 and T2 ($ps \leq 0.001$). Results for the test of cross-lagged paths indicated a positive relationship between topic-specific knowledge at T1 and attitudes toward science at T2 ($\beta = 0.08$, $B = 0.42$, $SE = 0.21$, 95% CI_{B} [0.01, 0.83], $p = 0.048$). There was no relationship between attitudes toward science at T1 and topic-specific knowledge at T2 ($\beta = -0.009$, $B = -0.002$, $SE = 0.01$, 95% CI_B [−0.02, 0.02], $p = 0.856$). Hence, topic-specific knowledge positively influenced attitudes toward science, but not vice versa.

9.2 | Exploratory analysis

We exploratorily tested the relationship between different domains of attitudes toward science and scientific reasoning abilities, topic-specific knowledge, and epistemological beliefs. We assumed that participants' topic-specific knowledge and scientific reasoning abilities at T1 would influence their behavioral beliefs and intentions to engage with science at T2. Furthermore, we also tested whether participants' epistemological beliefs at T1 influenced their behavioral beliefs and intentions to engage with science at T2. Hence, we tested a normal causation model (Model 2a) and a reversed causation model (Model 2b) in our exploratory analysis ($n = 110$). The autoregressive model (Model 2c) tested the autocorrelations of all variables

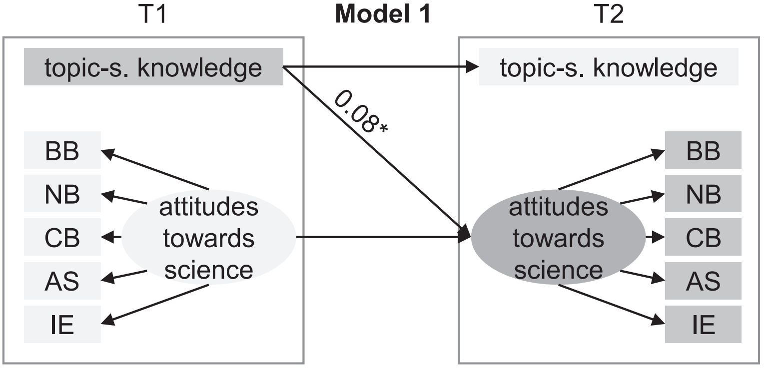

FIGURE 1 Two-wave cross-lagged model for time-lagged effects between topic-specific knowledge and attitudes toward science. *Note*. BB, Behavioral beliefs; NB, Normative beliefs; CB, Control beliefs; AS, Attitudes toward different facets of science; IE, Intentions to engage with science; Topic-s. knowledge, Topic-specific knowledge. Only significant ($p \leq 0.05$) cross-lagged paths are reported with standardized regression coefficients (β), with all predictors for latent variables and autoregressions, ps ≤ 0.001. *$p \leq 0.05$

TABLE 2 Fit indices and model comparisons for models 1 and 2a–2c with the variables scientific reasoning, topic-specific knowledge, epistemological beliefs, attitudes toward science, and its domains

Model	χ^2	df	p	RMSEA	TLI	CFI	AIC	Comparison	$\Delta\chi^2$	Δdf
1	86.16	47	<0.001	0.05	0.97	0.98	172.16	–	–	–
2a	8.00	10	0.63	0.00	1.02	1.00	58.00	M2c − M2a	49.557*	26
2b	16.81	16	0.40	0.02	0.99	1.00	72.81	M2c − M2b	40.746*	20
2c	57.56	36	0.01	0.07	0.92	0.93	155.56	–	–	–

Abbreviations: RMSEA, root mean square error of approximation; TLI, Tucker–Lewis fit index; CFI, comparative fit index; AIC, akaike information criterion.
*$p \leq 0.05$.

across time (see Figure 2). We tested the model-fit of Model 2a and Model 2b compared to Model 2c with χ^2 difference tests. Model 2a showed a statistically significant better fit to the data than Model 2c, $\Delta\chi^2 = 49.557$, $\Delta df = 26$, $p \leq 0.05$. Model 2b also had a better fit than Model 2c, $\Delta\chi^2 = 40.746$, $\Delta df = 20$, $p \leq 0.05$. Model 2a explained the data best based on the Akaike Information Criterion, AIC = 58.00 (see Table 2).

Model 2a fitted the data excellently, $\chi^2/df = 0.80$, $p = 0.629$, RMSEA ≤ 0.001, 90% CI_{RMSEA} [0.00, 0.09], CFI = 1 (see Table 2). The autoregressive analysis indicated the temporal stability of intentions and behavioral beliefs between T1 and T2 (*ps* ≤ 0.001). Results for the test of cross-lagged paths indicated a positive relationship between scientific reasoning at T1 and behavioral beliefs at T2 ($\beta = 0.16$, $B = 0.57$, $SE = 0.28$, 95% CI_B [0.02, 1.13], $p = 0.043$) as well as a marginal relationship between topic-specific knowledge at T1 and behavioral beliefs at T2 ($\beta = 0.15$, $B = 0.86$, $SE = 0.44$, 95% CI_B [−0.01, 1.72], $p = 0.051$). Furthermore, there was a

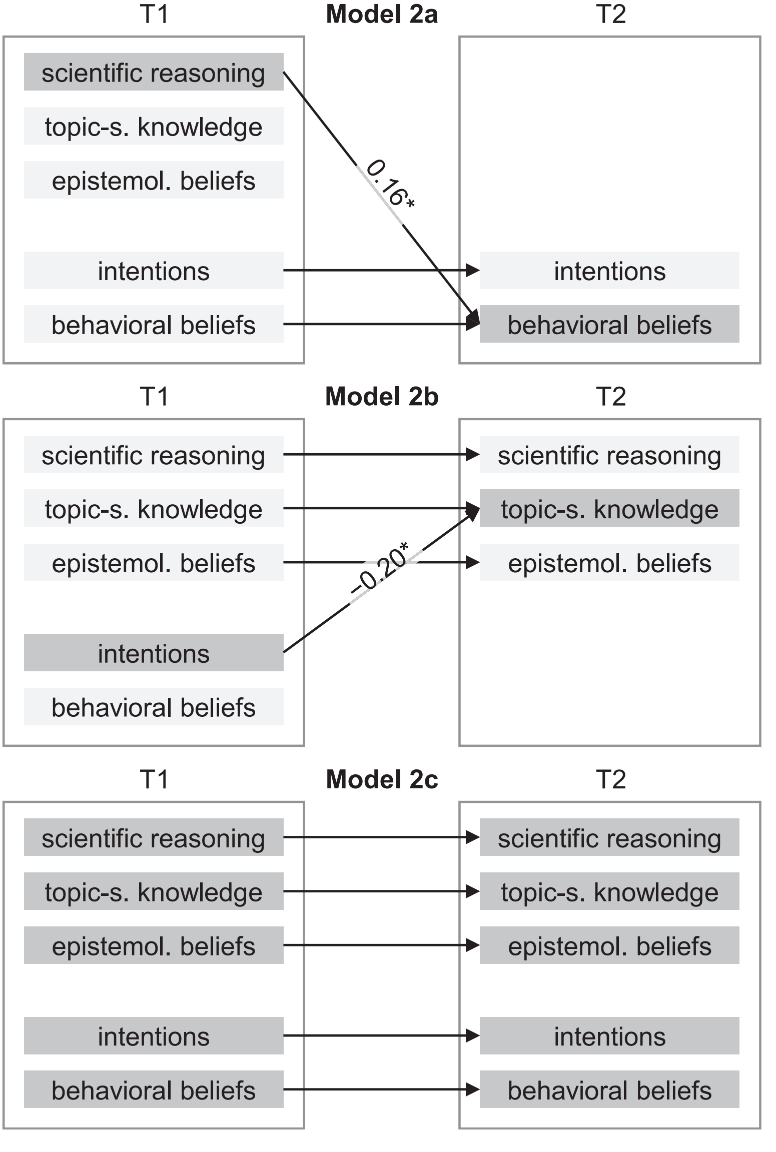

FIGURE 2 Two-wave cross-lagged models for time-lagged effects between scientific reasoning, topic-specific knowledge, epistemological beliefs, intentions to engage with science, and behavioral beliefs. *Note*. Topic-s. knowledge, Topic-specific knowledge; epistemol. beliefs, Epistemological beliefs; intentions, Intentions to engage with science; Model 2a (top) represents the normal causation model, Model 2b (center) represents the reversed causation model, Model 2c (bottom) represents the autoregressive model. Only significant ($p \leq 0.05$) cross-lagged paths are reported with standardized regression coefficients (β), with all autoregressions, *ps* ≤ 0.001. *$p \leq 0.05$

marginal and negative relationship between epistemological beliefs at T1 and behavioral beliefs at T2 ($\beta = -0.14$, $B = -0.18$, $SE = 0.10$, 95% CI_B [−0.35, 0.01], $p = 0.065$). Thus, the relationships for topic-specific knowledge and epistemological beliefs were only significant at the level of $p \leq 0.10$. There were no significant relationships between scientific reasoning, topic-specific knowledge, and epistemological beliefs at T1, and intentions to engage with science at T2 ($\beta = -0.048$–0.11, all Bs < |0.85|, all SEs < 0.57, all ps > 0.10).

Model 2b fitted the data well, $\chi^2/df = 1.05$, $p = 0.40$, RMSEA = 0.02, 90% CI_{RMSEA} [0.00, 0.09], CFI = 0.99 (see Table 2). The autoregressive analysis revealed temporal stability for scientific reasoning, topic-specific knowledge, and epistemological beliefs between T1 and T2 (ps ≤ 0.001). Testing the reverse relationship between behavioral beliefs in science at T1 and scientific reasoning, topic-specific knowledge, and epistemological beliefs at T2 did not reveal a significant relationship ($\beta = -0.063$ to -0.014, all Bs < |0.03|, all SEs < 0.06, all ps > 0.10). Hence, scientific reasoning, topic-specific knowledge, and epistemological beliefs at T1 at least marginally influenced behavioral beliefs in science at T2. In Model 2b, we found that intentions to engage with science at T1 were negatively related to topic-specific knowledge at T2 ($\beta = -0.20$, $B = -0.03$, $SE = 0.01$, 95% CI_B [−0.05, −0.001], $p = 0.037$). Furthermore, there was a marginal positive relationship between intentions to engage with science at T1 and scientific reasoning at T2, which was only significant at the level of $p \leq 0.10$ ($\beta = 0.16$, $B = 0.04$, $SE = 0.02$, 95% CI_B [−0.01, 0.08], $p = 0.094$). Both relationships were not present in Model 2a (i.e., there was no relationship between scientific reasoning at T1 or topic-specific knowledge at T1 and intentions to engage with science at T2). Therefore, intentions to engage with science at T1 influenced topic-specific knowledge and, at least marginally, scientific reasoning at T2.

10 | DISCUSSION

The current research aimed to unravel the relationship between attitudes toward science and topic-specific knowledge in a CS project (e.g., Brossard, Lewenstein, & Bonney, 2005; Jordan et al., 2011; Price & Lee, 2013). We predicted that topic-specific knowledge would contribute to the development of positive attitudes toward science. Our prediction was in line with previous research on the knowledge-attitude nexus that indicated that this relationship might be more robust for topic-specific knowledge and specific domains of attitudes toward science (e.g., Allum et al., 2008; Summers & Abd-El-Khalick, 2018). As the nature of this study was longitudinal and relied on cross-lagged panel analyses, its results extend the mixed findings on attitude development from previous research on CS (see Crain et al., 2014, for an overview). Previous research indicated either no (or slightly negative) changes in attitudes toward science (Brossard et al., 2005; Druschke & Seltzer, 2012; Jordan et al., 2011) or more positive attitudes (Haywood, 2015; Price & Lee, 2013; Sickler, Cherry, Allee, Smyth, & Losey, 2014) but did not test for a causal relationship between attitudes toward science and topic-specific knowledge. Our results reveal that topic-specific knowledge elicited more positive attitudes toward science across the 2 months of a CS project on urban wildlife ecology. We did not find evidence for the reversed causal direction.

First, the results indicate that higher topic-specific knowledge from the respective field of research (i.e., urban wildlife ecology) led to more positive attitudes toward science. Both knowledge and attitudes are central project outcomes in CS (Crain et al., 2014; Groulx et al., 2017). Our findings suggest that, in line with our first assumption, attitude development profits from knowledge on specific topics in CS projects. Compared to previous research, which mostly investigated the relationship with general knowledge, our research found that the relationship between attitudes toward science and knowledge was stronger when we accounted for topic-specific knowledge (Allum et al., 2008; Stocklmayer & Bryant, 2012). In contrast to Fox-Parrish and Jurin (2008), for example, who did not find a relationship between knowledge and attitudes, our study tested participants' "local" knowledge (i.e., topic-specific knowledge directly related to everyday issues). CS projects may provide favorable settings for the positive attitude development of participants with prior topic-specific knowledge because those participants can use that particular knowledge in the inquiry process. We cannot provide any alternative (behavioral) data for the application of knowledge in our CS project to support or reject this explanation (e.g., log file data from the platform; Aristeidou et al., 2017). Nevertheless, our finding is in line with previous studies that also indicated that acquiring knowledge in the inquiry process of a CS project may lead to more positive attitudes toward science (Price & Lee, 2013).

Conversely, we did not find that more positive attitudes toward science promoted topic-specific knowledge. One might assume that positive attitudes toward science foster active participation in CS projects and, hence, elicit more topic-specific knowledge. Besides positive attitudes toward science, individuals need the skills and knowledge of scientific methods to actively participate in scientific activities during CS projects, as previous research suggested (Stylinski et al., 2020). When individuals struggle during the learning process due to their limited knowledge of scientific methods, they might not achieve the learning outcomes of a CS project such as acquisition of topic-specific knowledge (Edwards, McDonnell, Simpson, & Wilson, 2017). Positive attitudes toward science, therefore, are probably not a sufficient precondition for developing topic-specific knowledge in CS projects. Furthermore, knowledge is a precondition for attitude formation according to the theory of planned behavior (Fishbein & Ajzen, 2010). Therefore, it is reasonable to conclude that applying topic-specific knowledge within CS projects might foster more positive attitudes toward science but not that positive attitudes toward science will result in more topic-specific knowledge after participating in a CS project.

Second, our results found an effect of topic-specific knowledge on attitudes across the different domains of attitudes toward science that we accounted for in the latent variable of attitudes toward science (Summers & Abd-El-Khalick, 2018). In line with our assumption, the different domains helped account for the complexity of attitudes toward science that has been previously observed (Brossard et al., 2005). Thus, distinguishing between several domains of attitudes toward science may be a promising way to investigate the knowledge–attitude relationship in future studies.

Third, we also explored the knowledge–attitude relationship in more detail by investigating two specific attitudinal domains and the role of scientific reasoning as well as of epistemological beliefs. Our findings indicate that not only topic-specific knowledge but also participants' scientific reasoning abilities promoted slightly stronger behavioral beliefs in the usefulness of science (see Model 2a, Figure 2). This finding suggests that participants' understanding of the scientific research process helps them value scientific thinking as a guide for everyday decisions and, therefore, to have more positive behavioral beliefs in the usefulness of science (Price & Lee, 2013). This result corresponds to other findings showing that abilities to reflect upon scientific processes positively affect attitudes (Potvin & Hasni, 2014). Therefore, scientific reasoning abilities, alongside topic-specific knowledge, may also contribute to the development of more positive attitudes toward science. However, previous research rarely considered knowledge of scientific methods as a predictor of attitudes toward science (Allum et al., 2008) as it did not differentiate between the different components of scientific literacy, that is, knowledge of scientific content, knowledge of scientific methods, and epistemological beliefs in science (She et al., 2019). Hence, our finding on the positive effect of scientific reasoning abilities is worth further investigation as it helps disentangle the effects of knowledge of scientific content and of scientific processes. Regarding implications for practice, our finding suggests that promoting individuals' scientific reasoning abilities (i.e., strategies of "*first-hand evaluation* [...] about the question 'What is true?'"; Bromme & Goldman, 2014, p. 65) helps individuals perceive science as useful for everyday decisions.

Interestingly, we also found a marginal effect of epistemological beliefs on behavioral beliefs. This result extends previous research on the relationship between epistemological beliefs and attitudes toward science (Fulmer, 2014; Kapucu & Bahçivan, 2015). Our findings provide evidence that epistemological beliefs are a predictor of behavioral beliefs, which is one dimension of attitudes toward science (Summers & Abd-El-Khalick, 2018). For CS, this finding is noteworthy because a previous study showed that attitudinal changes in CS projects were derived from the reinforcement of previous epistemological beliefs (Price & Lee, 2013). The effect of epistemological beliefs on behavioral beliefs found in our study was negative: Stronger epistemological beliefs—that scientific knowledge is "soft" (i.e., that its texture is ambiguous and its variability is high)—enhanced the perception of science as less useful for one's behavior. This finding extends previous research that found negative as well as positive relationships between epistemological beliefs and attitudes toward science (Chin-Chung Tsai et al., 2011; Fulmer, 2014). While the perceived certainty of scientific knowledge was negatively related to attitudes toward science for university students (Fulmer, 2014), our finding for citizen scientists points in the opposite direction. Citizen scientists who regard scientific knowledge as ambiguous and unstable might feel discomfort when they rely on this knowledge for their everyday decisions. They may need more certainty in scientific knowledge in order to base their decisions on that knowledge (Kruglanski, Dechesne, Orehek, & Pierro, 2009). Possibly, citizen scientists preferably rest their everyday decisions on information that they perceive as hard facts instead of tentative evidence. Further research needs to test whether CS projects increase the perception of epistemological beliefs as being "soft", which, in turn, influences attitude development.

Regarding implications for practice, our finding suggests that individuals with more naïve epistemological beliefs might profit from strategies that promote "*second-hand evaluation* [...] by asking, Who to believe?" (Bromme & Goldman, 2014, p. 65); that is, individuals with naïve epistemological beliefs about the certainty of scientific knowledge are more likely to base their decisions on trust in the sources of knowledge (see Sinatra, Kienhues, & Hofer, 2014, for an overview). Strategies of second-hand evaluations such as promoting individuals' abilities to evaluate the reliability of sources would, therefore, add to strategies of first-hand evaluations for those individuals who struggle epistemologically. When individuals do not have the same methodological knowledge as experts, which is necessary to judge knowledge claims, they need to know how to use sources of scientific expertise to make science-based decisions (i.e., being "competent outsiders" with regard to science; Feinstein, 2011, p. 180).

In addition to the effects of topic-specific knowledge, scientific reasoning abilities, and epistemological beliefs on behavioral beliefs, we found that intentions to engage with science increased scientific reasoning abilities but not topic-specific knowledge. In line with the theory of planned behavior (Ajzen, 1991; Fishbein & Ajzen, 2010; Summers & Abd-El-Khalick, 2018), participants with higher intentions to engage with science may have favored doing science (Hodson, 2014) when participating in the CS project and, hence, increased their scientific reasoning abilities. However, this explanation is not yet supported by data on participants' actual participation in scientific activities during the CS project (Bruckermann et al., 2020). Future research should investigate whether participants' engagement with scientific activities in a CS project further explains the positive effect of intentions to engage with science on scientific reasoning abilities.

10.1 | Strengths, limitations, and future research

To the best of our knowledge, this study is the first to examine relationships between topic-specific knowledge and attitudes toward science in a CS project. More precisely, we were able to unravel the relationship of topic-specific knowledge and scientific reasoning abilities with attitudes toward science and the behavioral belief domain as well as intentions to engage with science. Previous literature reviews systematized the ambiguity of research findings on how participants in CS projects develop more positive attitudes toward science at the end of the project (Aristeidou & Herodotou, 2020; Crain et al., 2014; Groulx et al., 2017; Peter et al., 2019). In particular, analyses of the complexity of attitudes toward science and their relationships with other variables have gone underexplored in previous research on the effects of CS projects (Crain et al., 2014). The current study also draws its strength from the longitudinal design that facilitated structural equation modeling in a cross-lagged panel design. Hence, we were able to explain participants' positive attitudes toward science at the end of a CS project by predictors such as topic-specific knowledge and, partly, scientific reasoning abilities.

Alongside the strengths of our study, we also need to discuss some limitations. All citizens in the sample voluntarily participated in our CS project. Participants in this sample were highly educated, as is the case in many CS projects (e.g., Trumbull et al., 2000). Therefore, our findings might not be generalizable to more inclusive samples of participants with more diverse educational backgrounds (Pandya, 2012). Further research should specifically investigate whether topic-specific knowledge and scientific reasoning still predict more positive attitudes toward science within a sample of participants with lower prior knowledge of scientific content and methods. More positive attitudes toward science and more topic-specific knowledge, however, were not related to participant dropout. Thus, participants who dropped out did not differ from participants included in our analyses, which means that our analyses were not biased toward participants who stayed with the project. It seems that participant dropout did not indicate a shift in attitudes, that is, we did not lose participants with less positive attitudes toward science. Future research, however, should explore other factors that are more important for participants' long-term participation (e.g., social and collective reasons such as trust and acknowledgment), as individual dispositions are more important for initial participation (e.g., positive attitudes toward science; Rotman et al., 2014).

One strength of this study lies in the cross-lagged panel design that made it possible to test for cause–effect relationships. However, our study does not explain whether participants' positive attitudes are related to the actual application of scientific reasoning and their actual behavior in the CS project. Hence, further data on actual participation might provide valuable information on whether the effects of topic-specific knowledge and scientific reasoning abilities on attitudes toward science are mediated by participants' application of their knowledge and scientific abilities in project activities. Conversely, participants' engagement with scientific activities in the CS project might help explain why their intentions to engage with science positively predicted their scientific reasoning abilities, but not their topic-specific knowledge, at the end of the project. Thus, future research should take into account the participation patterns of individual citizen scientists in CS projects (Aristeidou et al., 2017; Sauermann & Franzoni, 2015).

The theory of planned behavior (Ajzen, 1991; Fishbein & Ajzen, 2010) allowed us to account for the complexity of attitudes toward science (e.g., Brossard et al., 2005; Summers & Abd-El-Khalick, 2018). In our exploratory analysis, topic-specific knowledge and scientific reasoning were related mainly to the domains of behavioral beliefs and intentions to engage with science. Some of the relationships, however, were only significant at the level of $p \leq 0.10$. As the goal of our exploratory analysis was not to test hypotheses but to highlight relationships that require further investigation, we suggest a reexamination of those relationships with latent variables. Because the sample of our exploratory study was at the boundaries for an acceptable sample size for structural equation modeling (Kline, 2011), we were not able to test all domains in one latent variable. Latent modeling of variables reduces the measurement error (Reinders, 2006) and, therefore, might have contributed to more robust estimations of marginal relationships in our exploratory models. We suggest that further research should specifically reinvestigate the effects of scientific reasoning with a larger sample and latent modeling.

10.2 | Implications

Our findings have some implications for practitioners considering attitude development as an essential individual learning outcome of their CS project. In the course of a CS project, the development of attitudes toward science may differ between individual participants because individuals with higher prior knowledge on the topic may develop more positive attitudes. Therefore, CS project leaders might want to think about how to account for prior knowledge before citizens participate in the project in order to provide an equal starting point for all participants. Relating the project to prior knowledge helps enhance participants' self-efficacy within the project right from the beginning and, therefore, promotes more positive attitudes toward science throughout the project (Price & Lee, 2013).

For researchers, our findings have implications concerning the measurement and modeling of participants' outcomes. In previous research, difficulties in evaluating the effect of CS projects on attitudes stemmed from the complexity of the attitude construct (e.g., Brossard et al., 2005) and from underexplored relationships to other variables (Crain et al., 2014). We suggest that future research should consider theory-based questionnaires (e.g., the BRAINS framework; Summers & Abd-El-Khalick, 2018) to investigate the different domains of attitudes toward science as well as to unravel their relationship to cognitive variables of scientific literacy such as scientific knowledge and scientific reasoning (e.g., Allum et al., 2008). Regarding topic-specific knowledge, we suggest that future research should account for participants' prior knowledge when evaluating the impact of CS projects on attitudes toward science (see Crain et al., 2014, for an overview). Regarding scientific reasoning abilities, we identified an effect on the attitudinal domain of behavioral beliefs. However, future research should test the effect of scientific reasoning abilities on all domains of attitudes toward science in a latent variable.

11 | CONCLUSION

We conducted a longitudinal study in a CS project on urban wildlife ecology with the aim of unraveling the knowledge–attitude relationship. Our findings add to previous research on attitude development in CS (e.g., Brossard et al., 2005; Jordan et al., 2011; Price & Lee, 2013) by testing cause–effect relationships between participants' attitudes toward science and their topic-specific knowledge as well as their scientific reasoning abilities. We present evidence that citizens' topic-specific knowledge before participating in a CS project positively influenced their attitudes toward science in general. Moreover, citizens' topic-specific knowledge and scientific reasoning abilities elicited more positive behavioral beliefs in the usefulness of science at the end of the CS project. Thus, CS projects' goals to improve their participants' positive attitudes toward science depend on citizens' topic-specific knowledge and scientific reasoning abilities.

ACKNOWLEDGMENTS

This study was supported by the German Federal Ministry of Education and Research (BMBF) (grant numbers 01|O1725, 01|O1727, 01|O1728). The funding source was involved neither in conducting the research nor in preparing the article. We want to thank Gráinne Newcombe for language review. Open Access funding enabled and organized by Projekt DEAL.

ORCID

Till Bruckermann https://orcid.org/0000-0002-8789-8276
Hannah Greving https://orcid.org/0000-0001-5487-9506
Sophia E. Kimmig https://orcid.org/0000-0002-4140-6002
Robert Hagen https://orcid.org/0000-0002-4342-9216
Ute Harms https://orcid.org/0000-0001-6284-9219

REFERENCES

Ahteensuu, M. (2012). Assumptions of the deficit model type of thinking: Ignorance, attitudes, and science communication in the debate on genetic engineering in agriculture. *Journal of Agricultural and Environmental Ethics*, *25*(3), 295–313. https://doi.org/10.1007/s10806-011-9311-9

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Allum, N., Sturgis, P., Tabourazi, D., & Brunton-Smith, I. (2008). Science knowledge and attitudes across cultures: A meta-analysis. *Public Understanding of Science*, *17*(1), 35–54. https://doi.org/10.1177/0963662506070159

Aristeidou, M., & Herodotou, C. (2020). Online citizen science: A systematic review of effects on learning and scientific literacy. *Citizen Science: Theory and Practice*, *5*(1), 11. https://doi.org/10.5334/cstp.224

Aristeidou, M., Scanlon, E., & Sharples, M. (2017). Profiles of engagement in online communities of citizen science participation. *Computers in Human Behavior*, *74*, 246–256. https://doi.org/10.1016/j.chb.2017.04.044

Ballard, H. L., Robinson, L. D., Young, A. N., Pauly, G. B., Higgins, L. M., Johnson, R. F., & Tweddle, J. C. (2017). Contributions to conservation outcomes by natural history museum-led citizen science: Examining evidence and next steps. *Biological Conservation*, *208*, 87–97. https://doi.org/10.1016/j.biocon.2016.08.040

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., Liu, Q., Ding, L., Cui, L., Luo, Y., Wang, Y., Li, L., & Wu, N. (2009). Learning and scientific reasoning. *Science*, *323*(5914), 586–587. https://doi.org/10.1126/science.1167740

Bauer, M., Durant, J., & Evans, G. (1994). European public perceptions of science. *International Journal of Public Opinion Research*, *6*(2), 163–186. https://doi.org/10.1093/ijpor/6.2.163

Bela, G., Peltola, T., Young, J. C., Balázs, B., Arpin, I., Pataki, G., Hauck, J., Kelemen, E., Kopperoinen, L., van Herzele, A., Keune, H., Hecker, S., Suškevičs, M., Roy, H. E., Itkonen, P., Külvik, M., László, M., Basnou, C., Pino, J., & Bonn, A. (2016). Learning and the transformative potential of citizen science. *Conservation Biology*, *30*(5), 990–999. https://doi.org/10.1111/cobi.12762

Blanco-López, Á., España-Ramos, E., González-García, F. J., & Franco-Mariscal, A. J. (2015). Key aspects of scientific competence for citizenship: A Delphi study of the expert community in Spain. *Journal of Research in Science Teaching*, *52*(2), 164–198. https://doi.org/10.1002/tea.21188

Bonney, R. E., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *Bioscience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R. E., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406

Bromme, R., & Goldman, S. R. (2014). The public's bounded understanding of science. *Educational Psychologist*, *49*(2), 59–69. https://doi.org/10.1080/00461520.2014.921572

Brossard, D., Lewenstein, B. V., & Bonney, R. E. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483

Bruckermann, T., Stillfried, M., Straka, T., & Harms, U. (2020). Citizen Science projects require agreement: A Delphi study to identify common questions from scientists' and citizens' perspectives on urban ecology. Manuscript submitted.

Bruckermann, T., Greving, H., Stillfried, M., Schumann, A., Brandt, M., & Harms, U. (2020). I'm fine with collecting data: Engagement profiles differ depending on scientific activities in online communities of Citizen Science projects.

Castell, S., Charlton, A., Clemence, M., Pettigrew, N., Pope, S., Quigley, A., Navin, J. N., & Silman, T. (2014). *Public attitudes to science 2014*. Ipsos MORI Social Research Institute. https://www.ipsos.com/sites/default/files/migrations/en-uk/files/Assets/Docs/Polls/pas-2014-main-report.pdf

Cole, D. A., & Maxwell, S. E. (2003). Testing mediational models with longitudinal data: Questions and tips in the use of structural equation modeling. *Journal of Abnormal Psychology*, *112*(4), 558–577. https://doi.org/10.1037/0021-843X.112.4.558

Crain, R., Cooper, C., & Dickinson, J. L. (2014). Citizen science: A tool for integrating studies of human and natural systems. *Annual Review of Environment and Resources*, *39*(1), 641–665. https://doi.org/10.1146/annurev-environ-030713-154609

Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., & Waller, D. M. (2013). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science*, *22*(6), 745–764. https://doi.org/10.1177/0963662511434894

Daamen, D. D. L., van der Lans, I. A., & Midden, C. J. H. (2016). Cognitive structures in the perception of modern technologies. *Science, Technology, & Human Values*, *15*(2), 202–225. https://doi.org/10.1177/016224399001500203

Deng, L., Yang, M., & Marcoulides, K. M. (2018). Structural equation modeling with many variables: A systematic review of issues and developments. *Frontiers in Psychology*, *9*, Article 580. https://doi.org/10.3389/fpsyg.2018.00580

Doble, J. (1995). Public opinion about issues characterized by technological complexity and scientific uncertainty. *Public Understanding of Science*, *4*(2), 95–118. https://doi.org/10.1088/0963-6625/4/2/001

Drummond, C., & Fischhoff, B. (2017). Individuals with greater science literacy and education have more polarized beliefs on controversial science topics. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(36), 9587–9592. https://doi.org/10.1073/pnas.1704882114

Druschke, C. G., & Seltzer, C. E. (2012). Failures of engagement: Lessons learned from a citizen science pilot study. *Applied Environmental Education & Communication*, *11*(3–4), 178–188. https://doi.org/10.1080/1533015X.2012.777224

Edwards, R., McDonnell, D., Simpson, I., & Wilson, A. (2017). Educational backgrounds, project design, and inquiry learning in citizen science. In C. Herodotou, M. Sharples, & E. Scanlon (Eds.), *Citizen inquiry: Synthesising science and inquiry learning* (pp. 195–209). Routledge.

European Commission (2014). *Special Eurobarometer 419: Public perceptions of science, research and innovation.* Luxembourg: European Union. Retrieved from: https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_419_en.pdf

Evans, G., & Durant, J. (1995). The relationship between knowledge and attitudes in the public understanding of science in Britain. *Public Understanding of Science*, *4*(1), 57–74. https://doi.org/10.1088/0963-6625/4/1/004

Feinstein, N. W. (2011). Salvaging science literacy. *Science Education*, *95*(1), 168–185. https://doi.org/10.1002/sce.20414

Fishbein, M., & Ajzen, I. (2010). *Predicting and changing behavior: The reasoned action approach*. Psychology Press.

Follett, R., & Strezov, V. (2015). An analysis of citizen science based research: Usage and publication patterns. *PLoS One*, *10*(11), e0143687. https://doi.org/10.1371/journal.pone.0143687

Fox-Parrish, L., & Jurin, R. R. (2008). Students' perceptions of a highly controversial yet keystone species, the black-tailed prairie dog: A case study. *The Journal of Environmental Education*, *39*(4), 3–14. https://doi.org/10.3200/JOEE.39.4.3-14

Frigerio, D., Pipek, P., Kimmig, S., Winter, S., Melzheimer, J., Diblíková, L., Wachter, B., Richter, A., & Bshary, R. (2018). Citizen science and wildlife biology: Synergies and challenges. *Ethology*, *124*(6), 365–377. https://doi.org/10.1111/eth.12746

Fulmer, G. W. (2014). Undergraduates' attitudes toward science and their epistemological beliefs: Positive effects of certainty and authority beliefs. *Journal of Science Education and Technology*, *23*(1), 198–206. https://doi.org/10.1007/s10956-013-9463-7

Golumbic, Y. N., Orr, D., Baram-Tsabari, A., & Fishbain, B. (2017). Between vision and reality: A case study of scientists' views on citizen science. *Citizen Science: Theory and Practice*, *2*(1), Article 6. https://doi.org/10.5334/cstp.53

Groulx, M., Brisbois, M. C., Lemieux, C. J., Winegardner, A., & Fishback, L. (2017). A role for nature-based citizen science in promoting individual and collective climate change action? A systematic review of learning outcomes. *Science Communication*, *39*(1), 45–76. https://doi.org/10.1177/1075547016688324

Hanssen, L., Dijkstra, A., Sleenhoff, S., Frewer, L., & Gutteling, J. M. (2018). Revisiting public debate on genetic modification and genetically modified organisms: Explanations for contemporary Dutch public attitudes. *Journal of Science Communication*, *17*(4), Article A01. https://doi.org/10.22323/2.17040201

Haywood, B. K. (2015). Beyond data points and research contributions: The personal meaning and value associated with public participation in scientific research. *International Journal of Science Education, Part B*, *6*(3), 239–262. https://doi.org/10.1080/21548455.2015.1043659

Haywood, B. K., & Besley, J. C. (2014). Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. *Public Understanding of Science*, *23*(1), 92–106. https://doi.org/10.1177/0963662513494560

Heigl, F., Kieslinger, B., Paul, K. T., Uhlik, J., & Dörler, D. (2019). Opinion: Toward an international definition of citizen science. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(17), 8089–8092. https://doi.org/10.1073/pnas.1903393116

Hodson, D. (2014). Learning science, learning about science, doing science: Different goals demand different learning methods. *International Journal of Science Education*, *36*(15), 2534–2553. https://doi.org/10.1080/09500693.2014.899722

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88–140. https://doi.org/10.3102/00346543067001088

Jackson, D. L. (2003). Revisiting sample size and number of parameter estimates: Some support for the N:Q hypothesis. *Structural Equation Modeling: A Multidisciplinary Journal*, *10*(1), 128–141. https://doi.org/10.1207/S15328007SEM1001_6

Jones, M. G., Childers, G., Andre, T., Corin, E. N., & Hite, R. (2018). Citizen scientists and non-citizen scientist hobbyists: Motivation, benefits, and influences. *International Journal of Science Education, Part B*, *8*(4), 287–306. https://doi.org/10.1080/21548455.2018.1475780

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs. *Conservation Biology*, *25*(6), 1148–1154. https://doi.org/10.1111/j.1523-1739.2011.01745.x

Jordan, R. C., Ballard, H. L., & Phillips, T. B. (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment*, *10*(6), 307–309. https://doi.org/10.1890/110280

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., & Mandel, G. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, *2*(10), 732–735. https://doi.org/10.1038/nclimate1547

Kaiser, F. G., & Fuhrer, U. (2003). Ecological behavior's dependency on different forms of knowledge. *Applied Psychology*, *52*(4), 598–613. https://doi.org/10.1111/1464-0597.00153

Kapucu, S., & Bahçivan, E. (2015). High school students' scientific epistemological beliefs, self-efficacy in learning physics and attitudes toward physics: A structural equation model. *Research in Science & Technological Education*, *33*(2), 252–267. https://doi.org/10.1080/02635143.2015.1039976

Kind, P., & Osborne, J. (2017). Styles of scientific reasoning: A cultural rationale for science education? *Science Education*, *101*(1), 8–31. https://doi.org/10.1002/sce.21251

Kline, R. B. (2011). Principles and practice of structural equation modeling. In *Methodology in the social sciences* (3rd ed.). Guilford Press.

Krell, M. (2018). Schwierigkeitserzeugende Aufgabenmerkmale bei multiple-choice-Aufgaben zur Experimentierkompetenz im Biologieunterricht: Eine Replikationsstudie [Difficulty-generating task characteristics in multiple-choice tasks for experimental competence in biology teaching: A replication study]. *Zeitschrift für Didaktik der Naturwissenschaften*, *24*(1), 1–15. https://doi.org/10.1007/s40573-017-0069-0

Kruglanski, A. W., Dechesne, M., Orehek, E., & Pierro, A. (2009). Three decades of lay epistemics: The why, how, and who of knowledge formation. *European Review of Social Psychology*, *20*(1), 146–191. https://doi.org/10.1080/10463280902860037

Kulgemeyer, C., Borowski, A., Buschhüter, D., Enkrott, P., Kempin, M., Reinhold, P., Riese, J., Schecker, H., Schröder, J., & Vogelsang, C. (2020). Professional knowledge affects action-related skills: The development of preservice physics teachers' explaining skills during a field experience. *Journal of Research in Science Teaching*, *57*(10), 1554–1582. https://doi.org/10.1002/tea.21632

Kullenberg, C., & Kasperowski, D. (2016). What is citizen science? A scientometric meta-analysis. *PloS One*, *11*(1), 1–16. https://doi.org/10.1371/journal.pone.0147152

Land-Zandstra, A. M., Devilee, J. L. A., Snik, F., Buurmeijer, F., & van den Broek, J. M. (2016). Citizen science on a smartphone: Participants' motivations and learning. *Public Understanding of Science*, *25*(1), 45–60. https://doi.org/10.1177/0963662515602406

Lawson, A. E., Clark, B., Cramer-Meldrum, E., Falconer, K. A., Sequist, J. M., & Kwon, Y.-J. (2000). Development of scientific reasoning in college biology: Do two levels of general hypothesis-testing skills exist? *Journal of Research in Science Teaching*, *37*(1), 81–101 10.1002/(SICI)1098-2736(200001)37:1<81::AID-TEA6>3.0.CO;2-I

McBeth, M. K., & Oakes, A. S. (1996). Citizen perceptions of risks associated with moving radiological waste. *Risk Analysis*, *16*(3), 421–427. https://doi.org/10.1111/j.1539-6924.1996.tb01476.x

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R. E., Brown, H., Cook-Patton, S. C., Evans, D. M., French, R. A., Parrish, J. K., Phillips, T. B., Ryan, S. F., Shanley, L. A., Shirk, J. L., Stepenuck, K. F., Weltzin, J. F., Wiggins, A., Boyle, O. D., Briggs, R. D., Chapin, S. F., … Soukup, M. A. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, 15–28. https://doi.org/10.1016/j.biocon.2016.05.015

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. *Daedalus*, *112*, 29–48.

Miller, J. D. (1998). The measurement of civic scientific literacy. *Public Understanding of Science*, *7*(3), 203–223. https://doi.org/10.1088/0963-6625/7/3/001

Miller, J. D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science*, *13*(3), 273–294. https://doi.org/10.1177/0963662504044908

Muñoz, A., Moreno, C., & Luján, J. L. (2012). Who is willing to pay for science? On the relationship between public perception of science and the attitude to public funding of science. *Public Understanding of Science*, *21*(2), 242–253. https://doi.org/10.1177/0963662510373813

National Science Board, National Science Foundation (2020). *Science and engineering indicators 2020: The state of U.S. Science and Engineering (NSB-2020-1)*. Alexandria, . Retrieved from: https://ncses.nsf.gov/pubs/nsb20201/

Nisbet, M. C., & Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany*, *96*(10), 1767–1778. https://doi.org/10.3732/ajb.0900041

OECD, European Union, UNESCO Institute for Statistics. (2015). *ISCED 2011 operational manual: Guidelines for classifying national education programmes and related qualifications*. France.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. https://doi.org/10.1080/0950069032000032199

Pandya, R. E. (2012). A framework for engaging diverse communities in citizen science in the US. *Frontiers in Ecology and the Environment*, *10*(6), 314–317. https://doi.org/10.1890/120007

Pardo, R., & Calvo, F. (2002). Attitudes toward science among the European public: A methodological analysis. *Public Understanding of Science*, *11*(2), 155–195. https://doi.org/10.1088/0963-6625/11/2/305

Peter, M., Diekötter, T., & Kremer, K. (2019). Participant outcomes of biodiversity citizen science projects: A systematic literature review. *Sustainability*, *11*(10), Article 2780. https://doi.org/10.3390/su11102780

Phillips, T., Porticella, N., Constas, M., & Bonney, R. E. (2018). A framework for articulating and measuring individual learning outcomes from participation in citizen science. *Citizen Science: Theory and Practice*, *3*(2), Article 3. https://doi.org/10.5334/cstp.126

Phillips, T. B., Ballard, H. L., Lewenstein, B. V., & Bonney, R. (2019). Engagement in science through citizen science: Moving beyond data collection. *Science Education*, *103*(3), 665–690. https://doi.org/10.1002/sce.21501

Ponciano, L., & Brasileiro, F. (2014). Finding volunteers' engagement profiles in human computation for citizen science projects. *Human Computation*, *1*(2), 247–266. https://doi.org/10.15346/hc.v1i2.12

Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: A systematic review of 12 years of educational research. *Studies in Science Education*, *50*(1), 85–129. https://doi.org/10.1080/03057267.2014.881626

Price, C. A., & Lee, H.-S. (2013). Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. *Journal of Research in Science Teaching*, *50*(7), 773–801. https://doi.org/10.1002/tea.21090

Reinders, H. (2006). Kausalanalysen in der Längsschnittforschung: Das cross-lagged-panel design [Causal analysis through longitudinal research: The cross-lagged-panel-design]. *Diskurs Kindheits-und Jugendforschung*, *1*(4), 569–587.

Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A., & He, Y. (2014). Motivations affecting initial and long-term participation in citizen science projects in three countries. In M. Kindling & E. Greifeneder (Eds.), *iConference 2014 proceedings*. iSchools. https://doi.org/10.9776/14054

Sauermann, H., & Franzoni, C. (2015). Crowd science user contribution patterns and their implications. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(3), 679–684. https://doi.org/10.1073/pnas.1408907112

Scheufele, D. A. (2013). Communicating science in social settings. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(Suppl 3), 14040–14047. https://doi.org/10.1073/pnas.1213275110

She, H.-C., Lin, H.-S., & Huang, L.-Y. (2019). Reflections on and implications of the Programme for international student assessment 2015 (PISA 2015) performance of students in Taiwan: The role of epistemic beliefs about science in scientific literacy. *Journal of Research in Science Teaching*, *56*(10), 1309–1340. https://doi.org/10.1002/tea.21553

Sickler, J., Cherry, T. M., Allee, L., Smyth, R. R., & Losey, J. (2014). Scientific value and educational goals: Balancing priorities and increasing adult engagement in a citizen science project. *Applied Environmental Education & Communication*, *13*(2), 109–119. https://doi.org/10.1080/1533015X.2014.947051

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist*, *49*(2), 123–138. https://doi.org/10.1080/00461520.2014.916216

Stahl, E., & Bromme, R. (2007). The CAEB: An instrument for measuring connotative aspects of epistemological beliefs. *Learning and Instruction*, *17*(6), 773–785. https://doi.org/10.1016/j.learninstruc.2007.09.016

Stocklmayer, S. M., & Bryant, C. (2012). Science and the public: What should people know? *International Journal of Science Education, Part B*, *2*(1), 81–101. https://doi.org/10.1080/09500693.2010.543186

Sturgis, P., & Allum, N. (2004). Science in society: Re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, *13*(1), 55–74. https://doi.org/10.1177/0963662504042690

Sturgis, P., Cooper, H., & Fife-Schaw, C. (2005). Attitudes to biotechnology: Estimating the opinions of a better-informed public. *New Genetics and Society*, *24*(1), 31–56. https://doi.org/10.1080/14636770500037693

Stylinski, C. D., Peterman, K., Phillips, T., Linhart, J., & Becker-Klein, R. (2020). Assessing science inquiry skills of citizen science volunteers: A snapshot of the field. *International Journal of Science Education, Part B*, *10*(1), 77–92. https://doi.org/10.1080/21548455.2020.1719288

Summers, R., & Abd-El-Khalick, F. (2018). Development and validation of an instrument to assess student attitudes toward science across grades 5 through 10. *Journal of Research in Science Teaching*, *55*(2), 172–205. https://doi.org/10.1002/tea.21416

Trumbull, D. J., Bonney, R. E., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education*, *84*(2), 265–275 10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.3.CO;2-X

Tsai, C.-C., Ho, H. N. J., Liang, J.-C., Lin, H.-M., Tsai, C.-C., Jessie Ho, H. N., Liang, J.-C., & Lin, H.-M. (2011). Scientific epistemic beliefs, conceptions of learning science and self-efficacy of learning science among high school students. *Learning and Instruction*, *21*(6), 757–769. https://doi.org/10.1016/j.learninstruc.2011.05.002

Vedder-Weiss, D. (2018). "Won't you give up your snack for the sake of science?" Emerging science identities in family everyday interaction. *Journal of Research in Science Teaching*, *55*(8), 1211–1235. https://doi.org/10.1002/tea.21449

Vötter, B., & Schnell, T. (2019). Cross-lagged analyses between life meaning, self-compassion, and subjective well-being among gifted adults. *Mindfulness*, *10*(7), 1294–1303. https://doi.org/10.1007/s12671-018-1078-x

Wals, A. E. J., Brody, M., Dillon, J., & Stevenson, R. B. (2014). Convergence between science and environmental education. *Science*, *344*(6184), 583–584. https://doi.org/10.1126/science.1250515

West, S., & Pateman, R. (2016). Recruiting and retaining participants in citizen science: What can be learned from the volunteering literature? *Citizen Science: Theory and Practice*, *1*(2), 197. https://doi.org/10.5334/cstp.8

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Bruckermann T, Greving H, Schumann A, et al. To know about science is to love it? Unraveling cause–effect relationships between knowledge and attitudes toward science in citizen science on urban wildlife ecology. *J Res Sci Teach*. 2021;58:1179–1202. https://doi.org/10.1002/tea.21697