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Research paper

Public perception and knowledge on nanotechnology: A study based on a citizen science approach

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ABSTRACT

Even with the widespread use of nanomaterials (NMs) in everyday life, consumer knowledge about the functionality, benefits, and possible dangers of nanotechnology (NT) is still modest. As with any developing technology, its public perception has direct implications on future policies and has to be taken into account by academia and industry alike. As part of the "Nan-O-Style" interdisciplinary research project, an online survey was conducted using a Citizen Science-guided approach. The main goal was to evaluate the current levels of knowledge and the attitude towards NT among the general Austrian public and to determine how differing sociodemographic factors may affect these. Over the course of 17 months, a total of 1067 responses were collected and quantitatively analysed. We found that while Austrians display a generally optimistic view and a positive attitude towards NT, there are still remaining concerns about its safety and possible risks. Participants expressed great desire for more information about NT and its applications, as well as for clear labelling and transparency of products containing NMs. Notably, we found that age did not affect the general attitude towards NT nor the levels of NT awareness. While participants with a university degree were generally more knowledgeable on this specific topic, surprisingly, there were no significant differences in the attitude towards NT among people from different educational backgrounds. Similar to previous studies, we observed that male participants demonstrated a more positive attitude towards NT and scored slightly higher in our NT quiz compared to female participants. However, female participants voiced greater desire for more information and transparency regarding NMs. Interestingly, while participants with a negative attitude towards NT scored lowest on the NT quiz, they also expressed the least interest in receiving more NT-related information. This illustrates a difficulty in mitigating public aversion solely by providing more information.

1. Introduction

As one of the assumed key technologies of the twenty-first century, nanotechnology (NT) has been established worldwide as an innovative approach to enhance the durability and function of various classes of products. Over the course of the last decades, the number of consumer goods containing nanomaterials (NMs) has been rapidly increasing. When the Nanotechnology Consumer Product Inventory was created by the Project on Emerging Nanotechnologies (PEN) in 2005, 54 NM-containing products were listed (Vance et al., 2015). As of May 2019, PEN has identified over 1829 products from 714 companies in 33 countries that make use of NT. Thereby, silver, titanium, and carbon are the most common materials used (Project on Emerging Nanotechnologies, 2013). Skin care, electronics, textiles, and sports equipment are prominent consumer good areas in which NT has been successfully applied to improve modern lifestyle products. In recent years, NT has also gained traction in the medical field with promising outlooks on improved drug delivery and new therapeutic approaches (Pelaz et al., 2017).

As for any developing technology, its public perception has direct implications on future policies and has to be taken into account by academia and industry alike (Roco and Bainbridge, 2005; Hett, 2004). The importance of public opinion on implementation and regulation was demonstrated when the sale and, to a lesser degree, the production of genetically-modified organisms (GMOs) was prohibited in some countries in the face of public opposition (Vogel, 2012). Studies on the

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social perception of developing technologies are important not only to identify the reasons behind public concerns, but also to better understand how to mitigate these concerns and to enable informed public debate. Consequently, a comprehensive understanding of the interactions between society and technology is required. The value of gaining insight into the opinions voiced by the general public and their understanding of technologies is reflected by the growing number of agencies engaged in opinion research (Luján et al., 1993).

Even with the widespread use of NMs in everyday life, consumer awareness and knowledge about the functionality, benefits, and possible dangers of NMs is still modest (Gehrke, 2018), as demonstrated by surveys conducted in various countries. When investigations on the public perception on NT were first conducted in the early 2000s, Michael Cobb and Jane Macoubrie published a US telephone survey (n = 1536), which found that more than half of the respondents "had heard nothing" of NT, and around a third said they "had heard a little" (Macoubrie, 2004). Hart et al. and Kahan et al. reported similar findings in 2007 from surveys among 1014 and 1850 American adults, respectively. They found that more than two thirds of the respondents had heard little or nothing about NT (Hart, 2007; Kahan et al., 2007a). While reports on NT familiarity have shown comparable results in early surveys, investigations into the its public support did not deliver a uniform picture. Whereas Cobb/Macoubrie and Kahan et al. found that 40–53% of respondents expected more benefits than risks would come with the establishment of NT applications (Macoubrie and Cobb, 2004; Kahan et al., 2007a), Hart et al. reported that only 15% subscribed to that sentiment (Hart, 2007).

A 2005 paper comparing public perceptions among the US and Europe reported a more optimistic stance towards NT among Americans, with 50% believing that NT would improve their way of life compared to only 29% of Europeans (Gaskell et al., 2005). In contrast, a 2010 Eurobarometer survey on Life Sciences and Biotechnology by Gaskell et al. found that among representative samples from 32 European countries, an average of 45% of Europeans said they had heard of NT, and 60% expressed their support for NT applications (Gaskell et al., 2010). This support varied among EU countries and was reported to be highest in Poland, Cyprus, Czech Republic, Finland, and Iceland and lowest in Austria, Greece, and Turkey. The indicated rise in NT support is accompanied by an increase in NT awareness in countries such as Germany, which saw an elevated number of people who report to "know a lot" about NT, and a decreased number of people who "know nothing about NT" from 2007 to 2012 (Zimmer, 2008; Correia-Carreira et al., 2016). However, a 2009 international meta-analysis of 20 countries reported that big parts of the population had not formed an opinion on NT yet and could be easily swayed by the information available (Satterfield et al., 2009).

When Germans were asked about their willingness to purchase products containing NMs, a great discrepancy between different consumer good areas was observed (Correia-Carreira et al., 2016). In general, the use of NMs in the technology and medical sector was favoured over its use in food or cosmetics. This sentiment was furthermore observed in similar studies conducted between 2007 and 2015 (Cormick, 2009; Cacciatore et al., 2011; Pidgeon et al., 2009; Larsson and Boholm, 2018; Siegrist et al., 2007; Gupta et al., 2012; Gupta et al., 2015), and elucidates the public's concern with direct interaction with NMs, while demonstrating faith in the potential of NMs used in medicine and technology (Correia-Carreira et al., 2016). As part of a European Commission-funded initiative, NanOpinion has conducted a large-scale survey investigating the public's knowledge and attitude towards NT in 18 European countries. Their 2014-released final comparative data report (http://nanopinion.eu) showed that only 20% of the 6779 questioned respondents had never heard of NT. The survey furthermore recorded that older and employed respondents were more aware of NT than younger or retired ones. Even though they were aware of NT, most respondents did not display solid knowledge on the topic. Across all countries, less than half of the people surveyed could answer two out of five questions about NT correctly, with males knowing slightly more than females.

While the NanOpinion survey has resulted in a high-throughput analysis of the European population at large, so far, no survey has been conducted which focuses specifically on the Austrian population. There is furthermore a worldwide lack of recent studies that investigate the social perception of NT. Austria may be representative for other Central European countries and its population has voiced considerable scepticism about new technologies (*i.e.* GMOs) in past debates. The EU progresses towards regulatory guidelines for nanomaterials *via* nanoREACH. Furthermore, there is increased support for the development of OECD standards and guidance on nanosafety. While Austria is not developing its own regulations, it has been responsible for running the NanoTrust project (https://www.oeaw.ac.at/ita/projekte/nanotrust/ueberblick) since 2007, which aims to inform the public about the topic of NT. It can be proposed that due to such active interventions, NT has not seen as extreme antagonism as other technologies have.

As part of the "Nan-O-Style" interdisciplinary research project, an online survey was conducted with the main goal to investigate the current attitude towards NT. Moreover, we assessed the levels of knowledge, awareness, and interest in NT among the Austrian public. The survey also aimed to identify potential differences between sociodemographic groups (*e.g.* in terms of age, sex, and educational background), and analyse possible correlations between attitude/knowledge and attitude/interest.

In recent years, increased effort has been exerted to involve citizens into the different phases of the scientific research process (Curtis, 2018). The term Citizen Science (CS) has first been coined in the 1990s (Irwin, 2002; Bonney, 1996), describing the active engagement of people outside of academia into research endeavours and is frequently classified into different levels (*e.g.* "crowdsourcing", "distributed intelligence", and "participatory research") (Haklay, 2013). In line with this trend, we used a Citizen Science-guided approach to collect datasets by including students into the circulation/distribution process of our survey.

2. Methodology and measures

2.1. Participants

An online survey was launched in February of 2018 using the SurveyMonkey software, and data was collected over the course of 17 months. Fig. S1 shows two waves of increased response activity, which were the result of several promotional initiatives conducted by the Nan-O-Style project team. To reach Austrians from all age groups and different educational backgrounds, various different routes were facilitated to promote for the survey. This included Citizen Science events (*i.e.* "Long Night of Research" www.langenachtderforschung.at, Salzburg; "Open NanoScience Congress", Salzburg), social media initiatives, dedicated *Citizen Science* online platforms and workshops (*e.g.* "Österreich forscht", www.citizen-science.at; https://youngscience.at), as well as newspaper announcements. During the initial survey distribution phase, we observed an increased number of academic- and school-aged respondents. To counteract this unwanted response bias, we asked students to act as scouts and help distribute the survey to a broader audience. So-called *Mobile Nano Labs* were organized in collaboration with Austrian schools with diverse educational foci, ranging from scientific to economic (*e.g.* secondary schools for fashion and product design) and multimedia arts. We aimed for non-probability sampling by facilitating a "snowball-approach" during the later phase of the survey, whereby every student forwarded the survey to several members of their social circle/environment. This way, the survey was in later phase intentionally guided to people with different ages and educational backgrounds. Data of 1067 questionnaires was collected and analysed. The age of the respondents ranged from 11 to 87 years, with an average age of 34.1 years (Fig. S2). 59.7% (n = 620) of the respondents were female. The educational backgrounds ranged from no secondary education (12.6%, n = 131), lower secondary education (28.9%, n = 300), higher-level technical/vocational school (6.8%, n = 71), high school (26.1%, n = 271) to university graduates (25.6%, n = 266) (Fig. S3).

2.2. Measures

We included 23 questions inquiring about the respondents' knowledge (self-estimated and factual), attitude, opinion on future impact and interest in NT. Moreover, we asked questions regarding the participants' sociodemographic background (*i.e.* age, educational background, sex). *Self-estimated knowledge/NT awareness* was measured by the question "To what extent do you feel informed about NT?" with scores ranging from 1 (*I don't know anything about NT*) to 4 (*I am well versed in NT*). To measure participants *factual knowledge*, we included eight "true or false" questions about NT (see Supplementary data, Table S1). Subsequently, *attitude* towards NT was measured by questioning "How would you describe your opinion on NT?" with "*I feel good about NT*", "*I am neutral towards NT*", "*I do not feel good about NT*" and "*I am unsure*" as possible answers. We furthermore inquired about the participants' *outlook* on what impact NT will exert within the next 20 years. Thereby, possible answers ranged from "*Mostly positive impact*", "*Mostly negative impact*" to "*No impact*" and "*I am unsure*". *Interest* in NT was determined by asking about the participants' desire for information on the functionality of NMs, possible side effects of NT and transparent labelling of NM-containing products. We also asked about the respondents' attitude towards the use of NT in different areas (*i.e.* diet, cosmetics, technology, and medicine), with scores ranging from 1 (*I fully approve*) to 4 (*I fully disapprove*).

To evaluate whether age affects the public perception of NT, we divided our sample into groups commonly used by social scientists and the US Pew Research Center, namely: "Baby Boomers/Maturists" (born 1932–1960), "Generation X" (born 1961–1980), "Generation Y" (born 1981–1995) and "Generation Z" (born 1996–2008). Since we received a large number of responses from young participants, we furthermore divided "Generation Z" into school aged (born 2000–2008) and student aged (born 1996–2000).

2.3. Statistics

Data analysis is presented descriptively with a focus on examining possible relationships between variables. One-way statistical differences due to sex, age, and education were determined using either an unpaired Student's *t*-tests or Ordinary one-way ANOVA followed by Tukey's multiple comparisons test with a single pooled variance in GraphPad Prism 6 Software. Nonparametric inference methods Brunner, et al., (2019) implemented in the R package rankFD (Brunner et al., 2017) were used for the analysis of two-way effects of education, sex, age, and attitude on knowledge, with particular attention to interaction effects between the explanatory variables. The statistical test chosen for each of the following situations was the nonparametric ANOVA-type statistic (ATS). *p*-Value range as indicated: $*p < 0.05$, $**p < 0.01$, and $***p < 0.001$.

3. Results

3.1. General public perception and knowledge

In our sample, 26.1% (n = 278) were not aware of NT and reported to have no related knowledge (Fig. 1A). 60.7% (n = 648) reported to know a little about NT, while 13.2% (n = 141) felt well or very well informed. When asked about their general attitude towards NT, 29.9% (n = 319) reported to feel good about NT, 42.4% (n = 452) felt neutral, while 25.4% (n = 271) were still unsure (Fig. 1B). Only 2.3% (n = 25) of the sample reported to have a negative attitude towards NT. 55% (n = 571) of participants believed that NT will have a mostly positive impact on our lives within the next 20 years. 7.5% (n = 78) believed it will have no impact, and 7.9% (n = 81) thought NT will have a mostly negative impact (Fig. 1C). When the participants were asked to take our NT fact quiz, a mean of 4.8 out of 8 questions was answered correctly across the sample.

Table 1 shows that the majority of the participants felt that NT had mainly positive effects on human health, while 25.7% (n = 274) rather disagreed with that statement and 4.5% (n = 48) wholeheartedly disagreed. Approximately 70% (n = 758) thought that NT was being used prematurely and that possible repercussions were not sufficiently researched yet. In contrast, around 37% (n = 395) of the participants found that NT-related impacts were well researched. Additionally, the majority (79.5%) of our sample (n = 484) did not think that NM-containing products were clearly or transparently labelled.

71.7% (n = 765) reported that they had heard about NT from reading about it in journals, newspapers, books, or online media. 43.8% (n = 467) had come into contact with the topic via TV, advertisements, and product placement (Fig. S4). 37.4% (n = 399) had been involved in conversations about NT with friends/family or experts, and 14.1% (n = 150) had seen exhibitions or talks/lectures about it. Approximately 43% (n = 459) of respondents recalled having been taught about NT in school or university, mostly as part of science classes (*i.e.* biology, chemistry and physics) (Fig. S5). Around 60% stated that they would have liked to hear more about NT during the course of their education (Fig. S6).

When asked about the characteristics they associated with NT, the most common answers given were "*small*" (57.3%), "*useful*" (58.9%), "*modern*" (56%), "*futuristic*" (43.1%), and "*practical*" (40.6%) (Fig. S7). Only small parts of the sample associated NT with terms like "*dangerous*" (12.5%), "*health-threatening*" (8.4%) or "*bad for the environment*" (11.2%).

When scoring the respondents' approval of NT applications in different areas ranging from 1 (*I fully approve*) to 4 (*I fully disapprove*), the medical sector received the greatest approval (average score = 1.41), followed by NT used for technological advances (average score = 1.83) (Fig. 2). Our sample responded with caution when they were asked about their opinion on NMs being used in cosmetics (average score = 2.20) and dietary products (average score = 2.67). However, only 9.6% (n = 102) reported that they ever consciously decided against the purchase of a product containing NMs (Table S2). Among those, 66% had decided not to buy a cosmetic product and 35% have not bought a dietary product (Table S2). Textiles and medical products containing NMs were avoided by 18% or 15%, respectively. 31.2% (n = 324) of respondents reported that given an equal price, they would rather purchase a product which has been improved by NT, while 25.1% (n = 261) would prefer the NT-free product (Table S2).

3.2. Relationship between variables

3.2.1. Age

As can be conjectured from Fig. 3A, the attitude towards NT did not vary significantly between generations. NT awareness, however, differed between generations. It was higher among "Generation Y" ($p = 0.0016$), "Generation X" ($p = 0.0230$) and "Baby Boomers/Maturists" and lower in "Generation Z, school aged" (Fig. 3B). In our survey, "Generation Y" was significantly more knowledgeable on the topic of NT than "Generation X" ($p = 0.0447$) and "Generation Z, student aged" ($p = 0.0370$) (Fig. 3C). We found the lowest levels of knowledge among "Baby Boomers/Maturists". When asked about their opinion on the impact NT will have on our lives within the next 20 years, younger generations generally seemed to have a more positive outlook with 56.7–61% of participants expecting a mostly positive impact, as opposed to 48–48.6% among "Baby Boomers/Maturists" and "Generation X" (Fig. 3D). "Generation X" expressed the most interest in

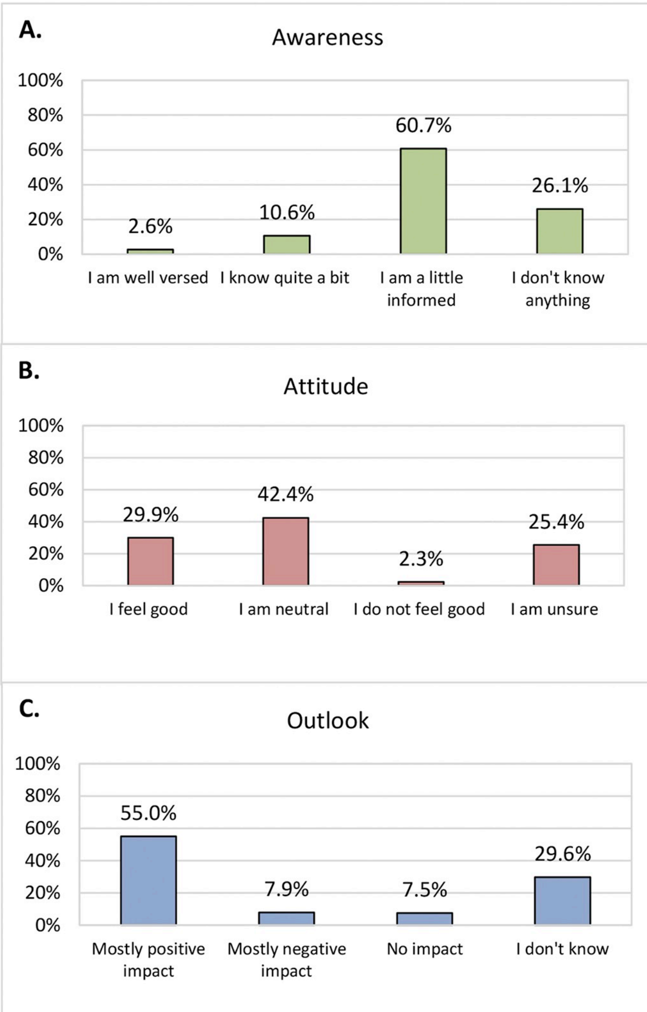

Fig. 1. Responses to the questions concerning A) NT awareness: "To what extent do you feel informed about NT?" (n = 1067) B) Attitude towards NT: "How would you describe your opinion about NT?" (n = 1067) and C) Outlook: "What impact do you think NT will have within the next 20 years?" (n = 1039).

NT-related information and transparency, followed by "Baby Boomers/ Maturists". Younger generations responded with the lowest interest in NT-related information in our sample (Table 2).

3.2.2. Educational background

In our sample, the educational background did not significantly affect the attitude towards NT (Fig. 4A). We found that NT awareness was significantly higher in respondents with a university degree compared to respondents with a high school diploma, apprenticeship diploma, compulsory education, or no secondary education ($p \leq 0.0001$–0.0002) (Fig. 4B). University-educated participants furthermore showed significantly higher levels of NT-related knowledge compared to respondents with a high school degree, an apprenticeship diploma, compulsory education, and respondents with no secondary education (Fig. 4C). Although not significant, a higher percentage of high school- (57.8%) and university-educated (58.7%) participants believed that NT will have a positive impact on their lives within the next 20 years (Fig. 4D). We found that university- and high school-educated participants expressed the most interest in NT-related information with a mean of 92.3% and 91.1%, respectively (Table 3). We observed the lowest desire for NT information among respondents with an apprenticeship diploma (83.3%), a higher-level technical/vocational college degree (83.1%) and no secondary education (82.3%).

3.2.3. Sex

In our survey, male participants demonstrated a significantly more positive attitude towards NT ($p \geq 0.0001$) with 38.7% of males reporting to "*feel good about NT*" compared to only 23.6% of females (Fig. 5A). Male participants estimated their knowledge to be higher than female participants ($p \geq 0.0001$) with 17.4% reporting to "*know quite a bit*" or "*being well versed in NT*" compared to approximately 10% of females (Fig. 5B). Males participants furthermore scored slightly higher in our NT quiz compared to female participants ($p = 0.0035$) (Fig. 5C) and demonstrated a more optimistic outlook on the impact of NT (Fig. 5D). However, we observed a greater desire for more NT information and transparency regarding the use of NMs among female participants. Thereby, especially clear labelling of NT products was of interest (Table 4).

A two-way analysis of the *education* and *sex*-dependent effects confirmed the significance of each factor, and gave no indication of a two-fold interaction effect ($p = 0.39$). A two-way analysis of the variables *age* and *sex* confirmed the above results from the one-way analysis, without showing an interaction effect ($p = 0.91$). In a two-way analysis of the variables *attitude* and *sex*, the main effect of *sex* disappeared ($p = 0.85$), and the interaction was not significant ($p = 0.19$). Hence, the effect of *attitude* was clearly dominating in this combination of explanatory factors ($p = 0.0003$). For a two-way analysis of the variables *education* and *attitude*, the category "*I do not feel good*" had to be merged with "*I feel neutral*" in order to allow for inference. The respective analysis confirmed the above-mentioned main effects of both factors, and there was no interaction between them ($p = 0.42$). The same was shown for the variables *age* and *attitude* (no interaction, $p = 0.43$).

3.2.4. Other variables

Our survey found that participants with a negative attitude towards NT scored lowest on the NT quiz, while a positive attitude correlated with increased levels of knowledge (Fig. 6A). The effect of attitude on NT-related knowledge was significant ($p = 0.0003$). We furthermore observed that a negative attitude towards NT correlated with a decreased interest in NT-related information in our sample (Fig. 6B).

Table 1
Frequencies and percentages of participants' responses to four different statements about NT (n = 1067).

	Wholeheartedly agree (1)	Rather agree (2)	Rather disagree (3)	Wholeheartedly disagree (4)
NT has a lot of positive effects on human health	14.9%	54.9%	25.7%	4.5%
NT is already used, even though the repercussions on health and environment are not sufficiently researched yet	18.7%	51.4%	25.2%	4.7%
Impacts of NT are well researched	2.5%	34.5%	48.1%	14.9%
Products containing NMs are clearly and transparently labelled	3.7%	16.9%	45.1%	34.4%

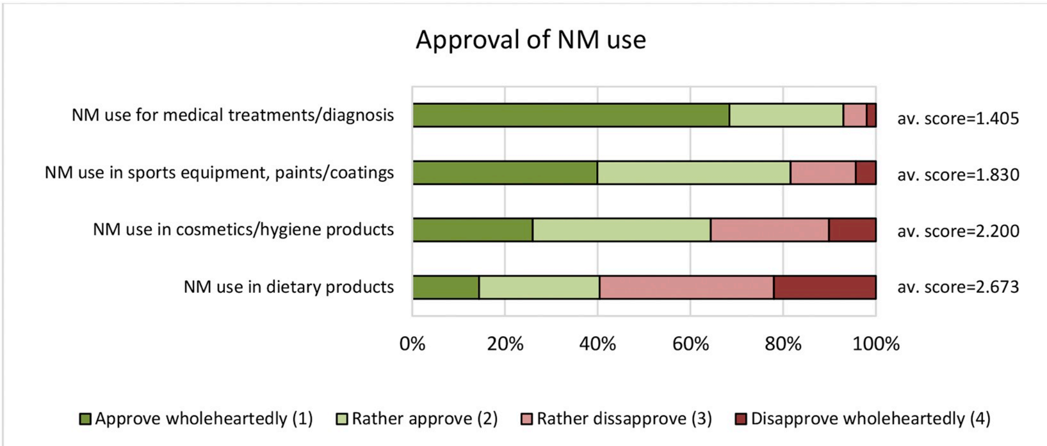

Fig. 2. Responses of 1067 individuals to the question "Do you approve or disapprove of NT application in these areas?" ranging from 1 (*I fully approve*) to 4 (*I fully disapprove*). Areas: 1) medicine (*e.g.* improved medical treatments and medical diagnosis), 2) technology (*e.g.* stain-repellent textiles, scratch-resistant paints/coating, improved/light-weight sports equipment) 3) cosmetics/hygiene (*e.g.* improved efficacy of sunscreens, use in soaps/creams, blocking odour development of textiles) 4) dietary products (*e.g.* as preservatives or packaging material).

4. Discussion

While NT is no longer in its infancy and various applications have been well established in different markets (*e.g.* sports equipment, textiles, and cosmetics), studies on whether the public awareness and knowledge has increased alongside its implementation are showing mixed results.

To investigate the current state of NT-related knowledge and public opinion, the Nan-O-Style project team launched an online survey. The survey was promoted through a multi-channel approach, including media outlets, scientific events and a congress open to the general public. The present analysis reports new insights into the social perception on NT, while for the first time using a Citizen Science-guided approach involving school students. Therefore, so-called "*Mobile Nano Labs*" (www.sciencetainment.com) were organized in collaboration with Austrian teachers. Attending school students were encouraged to participate in the survey and were furthermore tasked to recruit adult participants within their social circle/environment. The engagement of school students was crucial for the distribution of the survey. This way, we were able to collect over a thousand completed surveys from participants with various socioeconomic backgrounds and from all across Austria. However, it has to be noted that our sample shows a differing demographical distribution compared to what we would expect to see in a well-randomized sample. When compared to the general Austrian public, our sample exhibits higher levels of education. According to a recent statistic on 25- to 64 year olds, 12.5% of Austrians have a compulsory education, 54.8% completed an apprenticeship or a lower secondary education, 16% attended high school and 16.7% graduated university (Statistik Austria, 2019). Among our sample population, 12.6% do not (yet) have a secondary education, 20% have a compulsory education, 15.7% completed an apprenticeship or a lower secondary education, 26.1% attended high school and 25.6% graduated from university. However, our sample has a broader age distribution with participants ranging from 11 to 87 years of age. As of 2019, the Austrian population consists of roughly 50.8% females. Our survey was completed by 59.7% female participants. In 2015, the median age of the Austrian population was 42.3 years. Our respondent had an average age of 34.1 years, which is due to the high numbers of students participating in our survey. Naturally, these deviations in our sample have to be taken into account when interpreting the results.

In contrast to earlier studies conducted by Cobb and Macoubrie (Macoubrie and Cobb, 2004), Lee et al. (2005), Waldron et al. (2006), and Kahan et al. (2009), our analysis shows that the majority of Austrians are aware of NT and only approximately a quarter of the population has not heard about it yet. Our findings are in line with a 2014 report by NanOpinion (http://nanopinion.eu), showing that the Austrian NT awareness is comparable with the study-wide average among 18 European countries with a score of 6.4 (scale from 0 to 10; with 0 indicating they "*have heard nothing at all*" and 10 meaning they "*have heard a lot*"). In our survey, Austrians furthermore displayed a generally positive attitude towards NT. Only a small fraction of the respondents reported to have an aversion towards NT. A surprisingly big part of the sample, however, has not formed an opinion about NT yet and reported a neutral (non-attitude) stance. The majority of our sample believed that NT will have a positive impact on the future and positive effects on human health. A similar notion was observed by Gaskell et al. in 2010, who found that around 50% of Austrians expressed their support for NT (Gaskell et al., 2010). In contrast to those findings, a big part of our sample feels that NT is used prematurely and that possible repercussions on health and environment are not sufficiently researched yet. Furthermore, the majority of the population found that products containing NMs are not clearly or transparently labelled. Our findings mirror those of Gaskell et al., showing that Europeans rate NT to be generally beneficial, but potentially unsafe (Gaskell et al., 2010).

Approximately 10% of participants reported that they had at least once consciously decided against the purchase of a product containing NMs. Thereof, cosmetic and dietary products where the most commonly named. This sentiment was further confirmed when the public's approval of NT application in different consumer good areas was investigated. We saw the biggest approval of NM use in medical and technological applications (*e.g.* paint, sports equipment, and textiles). In contrast, we observed very low rates of approval for the use of NT in dietary products and cosmetics. This emphasizes that the acceptance of NMs is heavily dependent on their area of application. The concern about direct interactions with NMs (*i.e.* through ingestion or their application on the skin) has already been shown by various studies conducted in the US, the UK, Germany, Sweden, and North West Europe (Correia-Carreira et al., 2016; Cormick, 2009; Cacciatore et al., 2011; Pidgeon et al., 2009; Larsson and Boholm, 2018; Siegrist et al., 2007; Gupta et al., 2012; Gupta et al., 2015). Additionally, it has been shown that European citizens commonly view any alterations to dietary products, including genetic modifications, as lessening its "naturalness" (Sjöberg, 2000). To accurately assess the current levels of NT-related knowledge, we included a NT quiz in our survey. An average of 4.8 out of 8 questions was answered correctly by our sample, revealing

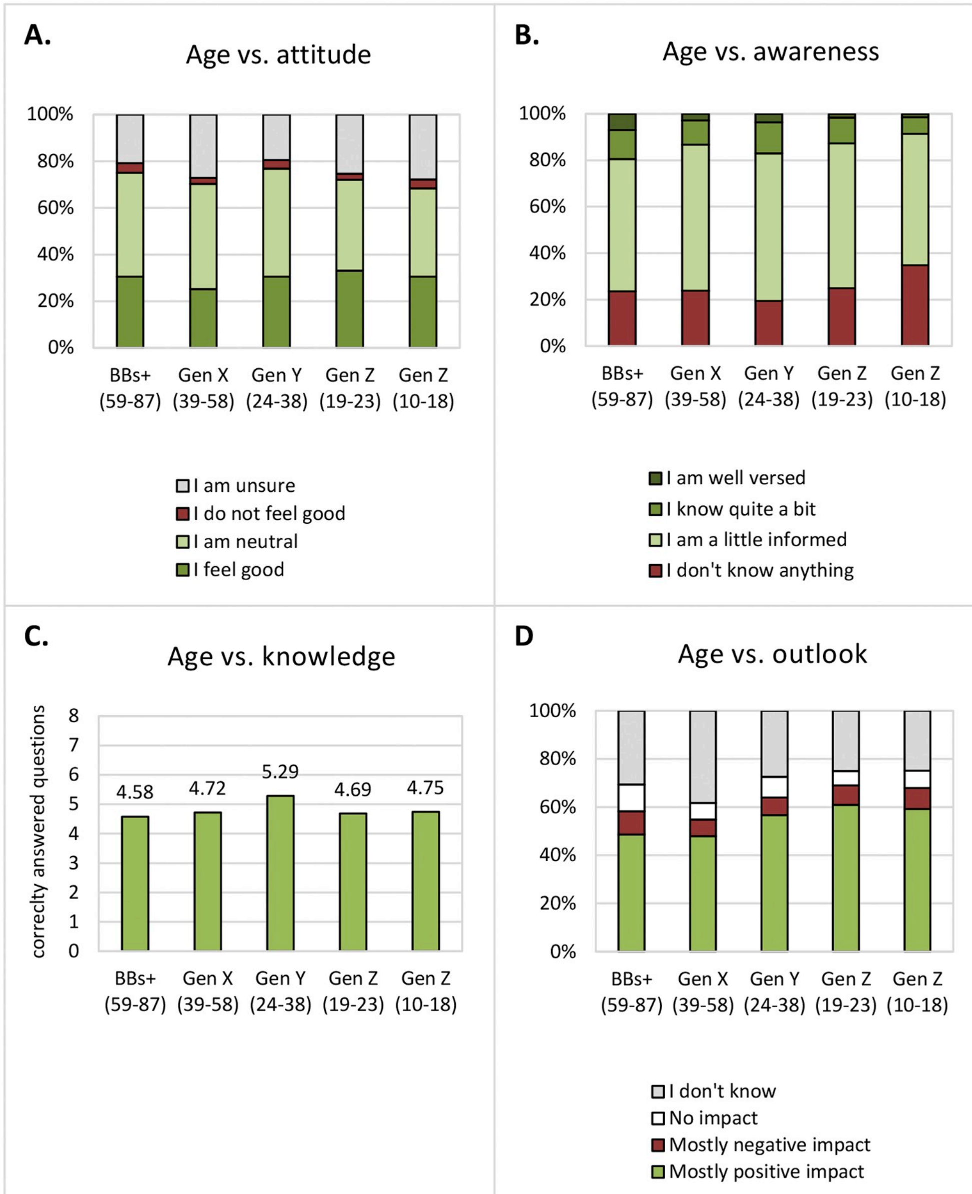

Fig. 3. Differences in NT attitude (A), awareness (B), -related knowledge (C) and outlook (D) among different age groups. Baby Boomers/Maturists, 59–87 years (n = 68); Generation X, 39–58 years (n = 295); Generation Y, 24–38 years (n = 145); Generation Z, student age, 19–23 years (n = 231); Generation Z, school aged, 10–18 years (n = 252).

Table 2
Differences in the desire for NT-related information and transparency among different age groups. Baby Boomers/Maturists, 59–87 years (n = 68); Generation X, 39–58 years (n = 295); Generation Y, 24–38 years (n = 145); Generation Z, student age, 19–23 years (n = 231); Generation Z, school aged, 10–18 years (n = 252).

	BBs/maturists (59–87)	Gen X (39–58)	Gen Y (24–38)	Gen Z (19–23)	Gen Z (10–18)
I want to be informed if a product contains NMs	93.1%	93.1%	89.1%	85.2%	87.0%
I want to be informed if a product was developed with NT	88.9%	91.2%	77.0%	77.1%	80.6%
I want to know about the functionality of NMs	87.5%	92.2%	89.7%	89.8%	84.2%
I want to be informed about possible side effects	94.4%	94.8%	90.3%	94.9%	92.1%
Mean	91.0%	92.8%	86.5%	86.8%	86.0%

moderate levels of NT-related knowledge.

Surprisingly, age only had a limited impact on the general attitude towards NT in our survey. This is in contrast to observations made by the German Federal Institute for Risk Assessment, which found that younger generations tend to be more in favour of NT applications compared to older generations (Correia-Carreira et al., 2016). Concerning NT awareness, our findings matched those of the NanOpinion report (http://nanopinion.eu), which reported higher levels of NT awareness among older generations. Moreover, we found that older respondents had a greater desire for NT-related information, which is in

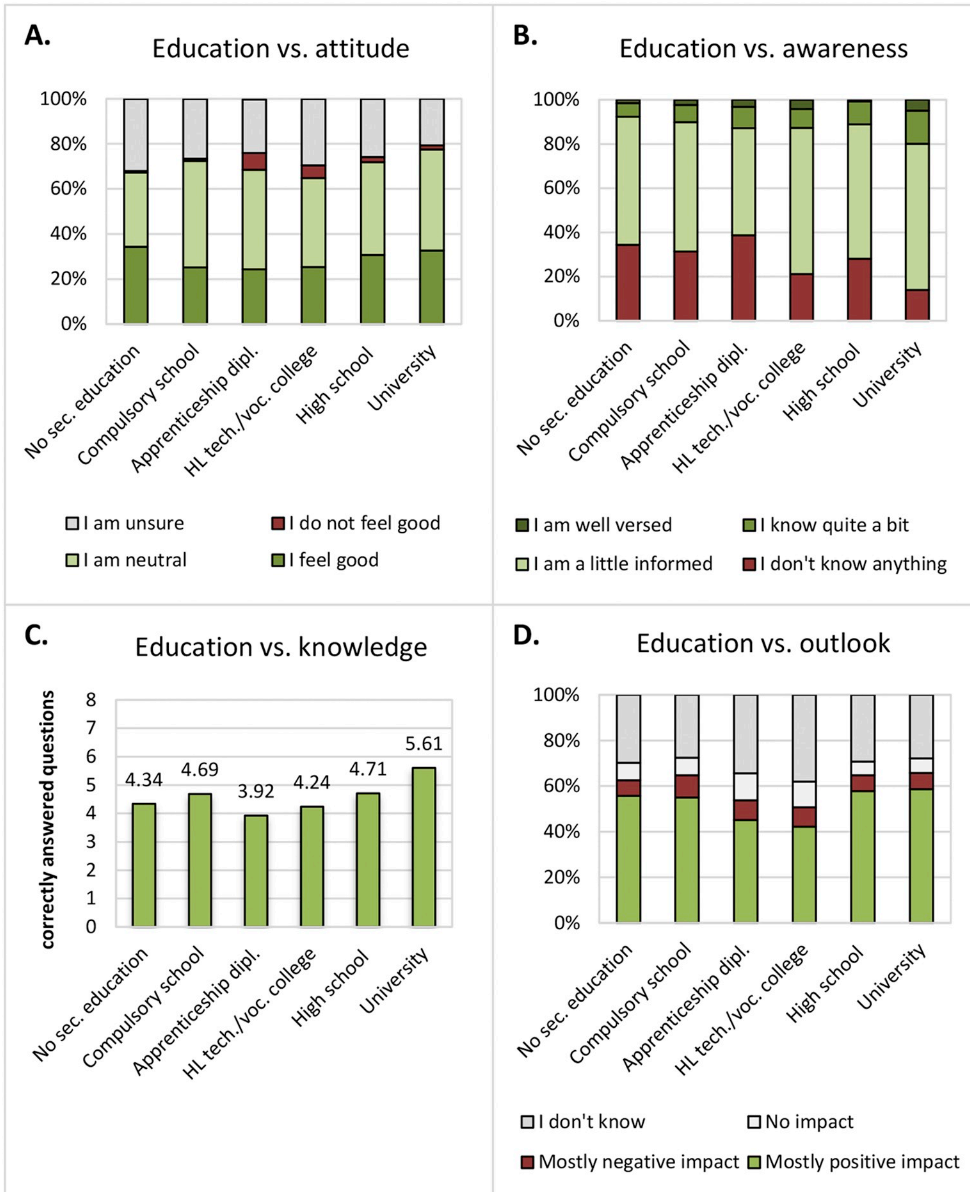

Fig. 4. Differences in NT attitude (A), awareness (B), -related knowledge (C) and outlook (D) among different educational backgrounds. No secondary education (yet) (n = 131); compulsory school (n = 207); apprenticeship diploma (n = 93); higher-level technical/vocational college (n = 71); high school (n = 271); university (n = 266).

line with the NanOpinion report. While we found no general correlation between age and NT-related knowledge, the cohort of 24- to 38-year-olds scored higher in our NT quiz than the population overall. This could partly be due to the confounding of age with the factor education, as university graduates, which scored highest in the NT quiz, were also more prominently represented in the group of 24- to 38-year-old participants (Fig. S8). We presume that the lower levels of NT-related knowledge among the younger and older generations could also be attributed to i) little to no active engagement with NT by the older population and ii) a lack of educational coverage of the topic in schools. However, not only the subject of possibly controversial technologies such as NT and biotechnology should be covered by education providers. Gardner et al. argues that students could benefit from “risk literacy” courses as part of science education to “construct well-formed attitudes and perceptions regarding complex topics” (Gardner et al., 2010).

We could confirm the findings of various other studies (Hart, 2007; Gaskell et al., 2010; Correia-Carreira et al., 2016), reporting that men tend to be more in favour of NT and their applications compared to women. We furthermore found men to be slightly more knowledgeable than women on the topic of NT, along with a more positive outlook and increased awareness. Such sex-specific differences have also been observed with public- and risk perception studies on biotechnology and genetic engineering (Luján and Moreno, 1994; Kahan et al., 2007b; Simon, 2010; Jelsøe et al., 2002). Commonly, these differences are described to diverging values and/or worldviews instead of differing levels of scientific knowledge (Kahan et al., 2007b; Simon, 2010). A report by the German Federal Institute for Risk Assessment moreover found that women in general display less faith in the government (Correia-Carreira et al., 2016). This is echoed in our survey by the finding that women show a greater desire for more NT-related information and transparency in product labelling. While product labelling can be seen as a way of communicating NT to the public, it is not yet fully understood how labels and the information they contain

Table 3
Differences in the desire for NT-related information and transparency among different educational backgrounds. No secondary education (yet) (n = 131); compulsory school (n = 207); apprenticeship diploma (n = 93); higher-level technical/vocational college (n = 71); high school (n = 271); university (n = 266).

	No secondary education (yet)	Compulsory school	Apprenticeship diploma	HL technical/vocational college	High school	University
I want to be informed if a product contains NMs	80.9%	87.4%	86.0%	81.7%	91.9%	93.6%
I want to be informed if a product was developed with NT	73.3%	81.6%	80.7%	84.5%	85.2%	86.1%
I want to know about the functionality of NMs	84.7%	86.5%	82.8%	81.7%	92.3%	92.5%
I want to be informed about possible side effects	90.1%	94.2%	83.9%	84.5%	95.2%	97.0%
Mean	82.3%	87.4%	83.3%	83.1%	91.1%	92.3%

influence risk perception (Siegrist, 2010). Education and information are going to be needed along with clear product labelling for effective NT communication (Brown and Kuzma, 2013). Furthermore, the public has to be advised on how to interpret the information on labels and how to make informed decisions. Siegrist et al. moreover argue that mandatory labelling can lead to increases in the perceived risk of a product (Siegrist et al., 2007).

In preceding surveys, the impact of education on NT awareness and attitude has shown mixed results. While the German Federal Institute for Risk Assessment has not observed significant differences for this variable (Correia-Carreira et al., 2016), Vandermoere et al. reported a relationship between educational background and levels of information a respondent possessed on the topic of NT (Vandermoere et al., 2011). In our survey, we were able to confirm the assumption that higher levels of NT-related knowledge are more prevalent among higher-educated participants. To our surprise, education did not influence the attitude towards NT in our survey.

Whereas scientists often believe that familiarity with a specific scientific topic would bring about elevated rates of approval (Kohut et al., 2009), research has shown a rather limited impact of knowledge on the attitude towards emerging technologies (Satterfield et al., 2009; Lee et al., 2005; Sturgis and Allum, 2004; Bauer et al., 2007). However, various surveys conducted in Germany and France were able to show that this relationship does sometimes exist (Vandermoere et al., 2011; Vandermoere et al., 2010). Cobb and Macoubrie furthermore found a correlation between people's self-estimated knowledge and risk–benefit trade-offs (Macoubrie and Cobb, 2004). In agreement with those reports, we found a relationship between NT familiarity and the attitude towards NT in our survey. Moreover, we found that respondents who expressed a negative attitude towards NT also voiced the least desire for information about its functionality or its applications. Our finding suggests that mitigating public aversion for a technology by means of solely increasing information flux probably will not work. This comprises a major challenge for science communication and highlights a demand for new approaches in the future.

For the responsible development of any new technology, a comprehensive interplay between scientists, industry, policy makers and the public is essential. Concerning NT, there is still ongoing public concern about its use, which strongly emphasizes the need for increased communication about the possible risks and dangers deriving from it. Formal as well as informal channels and formats that foster discussion and dialogue lend themselves for much needed public dialogue. In our survey, we observed a lot of respondents reporting a neutral or non-attitude stance on the topic of NT, which indicates that there is still a necessity for more information and education of the public on the topic. However, Kim et al. (2014) argue that a communication strategy which aims to educate by solely providing information and does not take into account the inherent values and beliefs of the public is unlikely to create consensus on a risk issue. Such values are to a certain degree resilient to facts and new information, especially if such challenge the person's worldviews. There is furthermore no one-fits-all approach when it comes to NT- or science communication in general. The public is not homogeneous and different audiences process information differently (Priest, 2009). Targeting NT communication to specific audiences by considering their values and their levels of knowledge is a more effective approach. This is also in line with our findings, demonstrating that some parts of the population are especially hard to reach (*i.e.* people who already hold a negative attitude towards NT) and might not respond to generic approaches of science communication. It has been proposed that for effective public engagement, new media and peer-to-peer communication should be utilized (Bostrom and Löfstedt, 2010; Ho et al., 2010). In our experience, illustrating the functionality of NT-enabled products garners great enthusiasm from school students and visitors of scientific events. NT communication by demonstration and explanation has proven a helpful tool to reach crowds and to create a non-generic context-matching communication framework, suitable

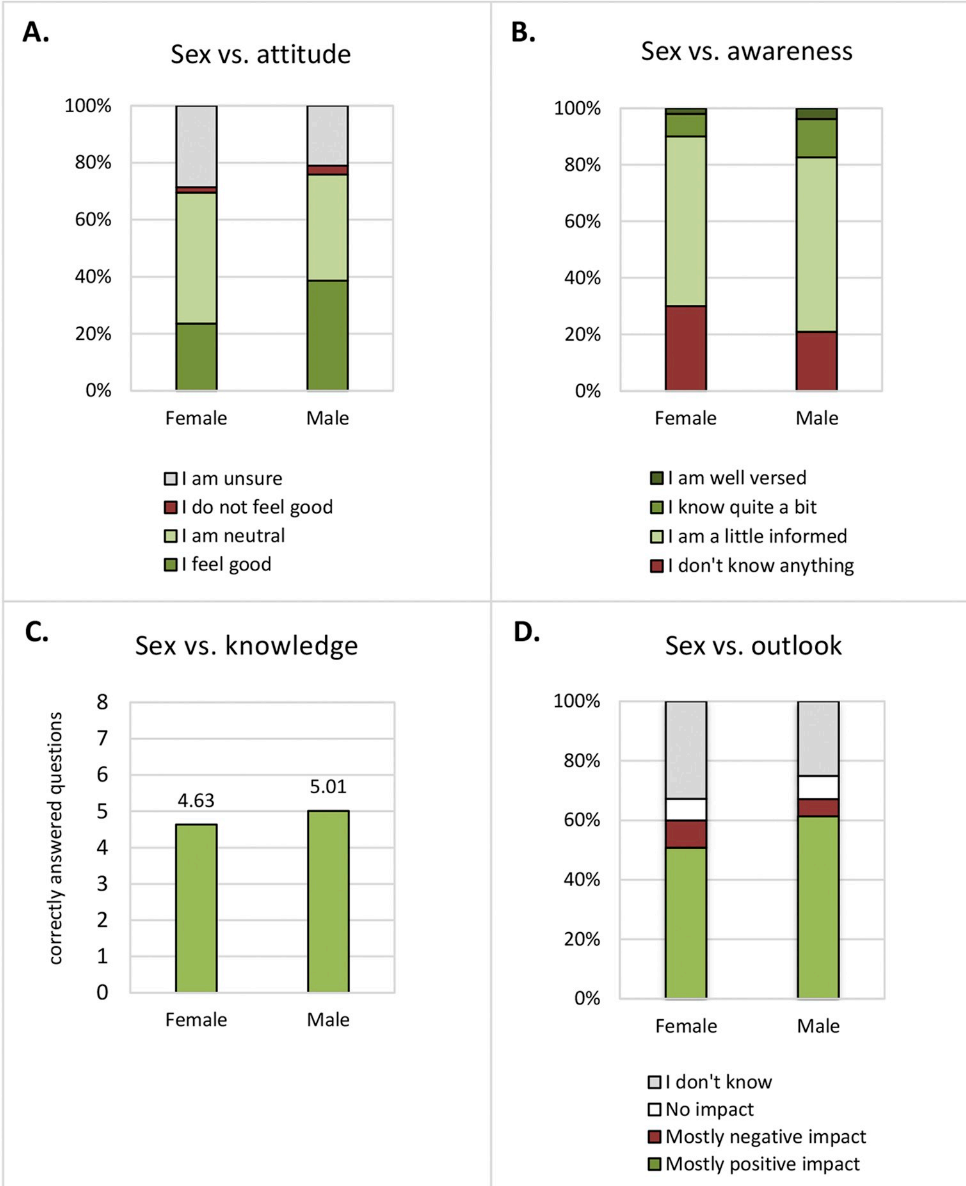

Fig. 5. Differences in NT attitude (A), awareness (B), -related knowledge (C) and outlook (D) between female (n = 620) and male (n = 419) respondents.

Table 4
Differences in the desire for NT-related information and transparency between female (n = 620) and male (n = 419) participants.

	Female	Male
I want to be informed if a product contains NMs	91.0%	85.7%
I want to be informed if a product was developed with NT	84.3%	80.4%
I want to know about the functionality of NMs	88.4%	89.0%
I want to be informed about possible side effects	93.4%	92.6%
Mean	89.3%	86.9%

for the needs of NT-related science and risk perception (Boholm and Larsson, 2019).

5. Conclusions

NT is an abstract and complex topic describing a world we cannot see and its various applications resulting from the manipulation of atoms and molecules. Enhancing the understanding of emerging technologies is crucial to enable social and political debates and to avoid public backlash.

While Austrians display a generally optimistic attitude towards NT, there are still remaining concerns about safety and possible risks, especially regarding NT use in dietary and cosmetic products. There is great desire for more information about NT and its applications, as well as petition for clear labelling and transparency. We furthermore observed a high number of respondents who reported a non-attitude towards NT, and we suggest an increase in information initiatives and media coverage. Sex, education, and age have varying but overall rather low effects on the perception of NT, most noticeably on knowledge and awareness. Surprisingly, the attitude was affected neither by age nor by education, indicating that educational institutions are not having the measurable influence we expected and/or hoped. Special consideration has to be given to our finding that participants with a negative attitude towards NT are less prone to engage themselves with information about the topic that might educate them or sway their perception. New avenues for more effective science communication,

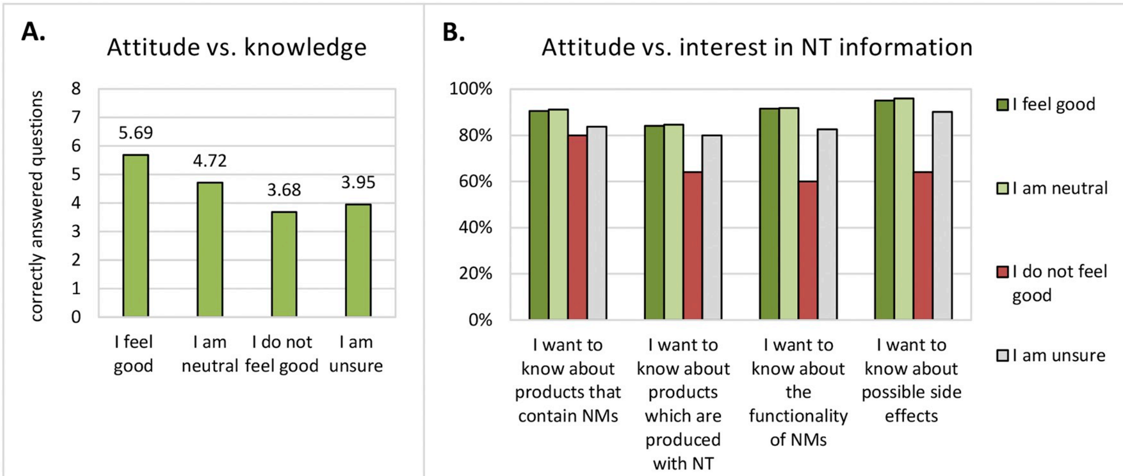

Fig. 6. Relationship between the general attitude towards NT and NT-related knowledge (A) and relationship between general attitude towards NT and the desire for more NT-related information (B).

science education and science engagement are in demand for this interdisciplinary technological field. Furthermore, it is crucial to facilitate a well-educated public debate, since active societal involvement deemed essential for NT risk governance in the future.

Naturally, all findings have to be interpreted carefully and in the constraints of the data that is available in this study. There are also possible limitations of the study, which include the absence of random sampling in any online survey, as well as potentially excluding non-technophile parts of the population.

Author contributions

IAJ was involved in formal analysis, data collection and curation, investigation, methodology incl. statistics, software, visualization, writing of original draft and revision.

MG was involved in conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology incl. statistics, visualization, review and editing.

SE was involved in conceptualization, investigation, data collection and curation.

RN was involved in conceptualization, funding acquisition, investigation, data collection and curation.

GG was involved in conceptualization, investigation, methodology, review and editing.

AD was involved in conceptualization, funding acquisition, resources, supervision, review and editing.

ACB was involved in methodology incl. statistics, visualization, conceptualization, formal analysis, investigation, review and editing.

MH was involved in conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, visualization, writing of original draft and revision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.impact.2019.100201.

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