Stop avoiding the inevitable: The effects of anthropomorphism in science writing for non-experts

Rockwell Tomson Lyon McGellin[1], Ann Grand[2,3] and Miriam Sullivan[4]

1 Freelance Writer & Masters Graduate in Science Communication, University of Western Australia
2 Lecturer in Astrobiology Education, The Open University, UK
3 Adjunct Lecturer in Science Communication, University of Western Australia
4 Lecturer, Faculty of Business and Law, Curtin University, Australia

Abstract

While anthropomorphism – the attribution of human characteristics to non-human things or events – is a fundamental part of human psychology and language, some scientists regard it as a source of misconceptions. This creates tension for those writing about science. Taking an experimental approach to diagnosing misconceptions, we compared the effects of anthropomorphic and non-anthropomorphic writing on 174 adult readers' knowledge, understanding, confidence in and connection with the material. Reading any text at all improves readers' knowledge and ability to answer questions. There was no difference in understanding, enjoyment or frequency of anthropomorphic thinking between anthropomorphic and non-anthropomorphic texts. Those who read anthropomorphic text tended to use more vivid examples and fewer generalisations. This suggests that anthropomorphism acts as an evocative, albeit potentially distracting, technique but does not cause significant misconceptions. Writers should feel free to use anthropomorphic techniques if they are appropriate for their topic and their audience.

Keywords
Journalistic practice, anthropomorphism, popular writing, science communication, objectivity

Background

Anthropomorphism is the 'attribution of human characteristics to non-human things or events' (Guthrie, 1997, p.51). Although the tendency to anthropomorphise varies among individuals and cultures (Waytz, et al., 2010), some degree of anthropomorphism appears to be an inevitable and universal part of human psychology (Guthrie, 1997): we assume something is human if it looks (Harrison and Hall, 2010) or acts like a human (Epley et al., 2008) . If we have a better way of understanding how that thing really works (Epley et al., 2007), we correct our assumption. If we lack that understanding, we fall back on our anthropomorphic ideas. We are more motivated to anthropomorphise, and to anthropomorphise more intensely, if we feel lonely (Epley et al., 2008), or lack confidence and a sense of control (Waytz, et al., 2010).

In writing, anthropomorphism is inevitable (Master, 1991). It is built into spoken and written language, from storytelling (Sealey and Oakley, 2013) to grammar, especially when using the active voice (Master, 1991) or analogies (Glynn and Takahashi, 1998). These more 'approachable' styles are especially important when writing for audiences who are not experts in the topic (including scientists reading work from outside their field (Lévy-Leblond, 1992)), or in texts that aim to educate, engage or entertain (Brown and Scholl, 2014) rather than rigorously describe processes or results for other experts.

Writers, especially those working as both scientists and writers, are thus left in the unenviable position of trying to avoid the inevitable. They will seek to compromise, and the decisions on how to do so should be based on evidence (Kahan, 2013).

What do we know?

The psychological basis of anthropomorphism, and the scientific community's position on it, has been relatively consistent. Scientists are often advised to avoid anthropomorphic explanations wherever possible (see Kennedy, 1992). Scientists are concerned that anthropomorphism is unscientific (Wynne, 2004). Anthropomorphic explanations have problems with causality (Hanke, 2004), falsifiability (Wynne, 2007) and complexity (Guthrie, 1997). However, the bulk of research into the use of anthropomorphism was carried out in the 1990s/2000s, so the time is clearly ripe for a re-examination.

Recent research, particularly in the field of science communication, has focused on case studies of the strategic deployment of anthropomorphism to manipulate audiences to change their behaviour, for example, in conservation contexts, (Cooremans & Geuens, 2019), product marketing (Huang, Wong, and Wan 2020), or even following health recommendations against disease (Wang, Toure-Tillery and McGill 2019). Despite these studies, questions of the "scientificness" of anthropomorphism are still raised and discussed in academic circles (e.g. Williams, Brosnan and Clay, 2020; Yanai and Lercher, 2020) and science communication (e.g. Wood, 2019).

Scientists offer three broad concerns about anthropomorphism. First, anthropomorphic explanations are often teleological (Hanke, 2004). They explain phenomena in terms of objects 'needing' or 'wanting' to achieve an end state, rather than in terms of cause and effect. In assuming that things are human, we give them human plans and goals, and attribute their actions to those plans. Scientific explanations, however, generally demand some exploration of causes (Lipton, 2004).

Second, anthropomorphism requires us to infer the subject's internal state (Wynne, 2004). While some non-human entities, such as animals, may have a subjective experience of the world, our knowledge of how those states work is speculative and incomplete (Millikan, 1997). Those subjective experiences cannot be observed, and thus cannot be tested (Wynne, 2007). Hypotheses based on anthropomorphic thinking are generally considered unscientific (Kennedy, 1992) as science requires all elements to be falsifiable (Popper, 2002),

Finally, anthropomorphism can lead us to include unevidenced and unnecessary external forces in our explanations. Rather than basing explanations on evidence alone, we invent an outside entity responsible for phenomena (Guthrie, 1997). Traditionally this has been a supernatural entity or deity (Guthrie, 1997), but more recently has come to include ideas about 'nature selecting' (Hanke, 2004) and 'the universe knowing' (Leane, 2007). Previous research shows that using anthropomorphism in scientific texts or discussions indeed promotes both teleological reasoning (Taber and Watts, 1996) and invoking of external forces (Legare, et al., 2013) in explanations.

The concerns of scientists therefore rest on the ideals of objectivity and accuracy. Although writers also value these ideals, there is conflict between the two groups with regards to how objectivity is seen to be maintained (Post, 2014). However, journalists place a higher value on relevance and engagement with the audience than do scientists (Hartley, 2015; Reed, 2001), and these goals are well suited to anthropomorphic writing.

Anthropomorphism allows writers to construct narratives in contexts where they would not otherwise be possible (Sealey and Oakley, 2013). This gives writers a powerful tool for making science more personally relevant to non-expert audiences (Dahlstrom and Ho, 2012), from understanding the purpose of complex technology (Mignone et al, 2016) to using empathy to further conservation goals (Tam, et al. 2013) and making abstract ideas, or those beyond the human scale, more accessible (Dahlstrom, 2014).

What do we not know?

Most investigation into how anthropomorphising science affects non-expert audiences comes from other fields.

Education researchers have explored anthropomorphism in science with school-age children. Using anthropomorphism in texts or discussions promoted use of both teleological reasoning (Taber & Watts, 1996) and external forces (Legare, Lane, & Evans, 2013) in explanations. Most educators agree that anthropomorphism is not an acceptable explanation (Kallery & Psillos, 2004), and focus on correcting it (Zohar & Ginossar, 1998) or using it as a stepping stone to build more accurate understanding (Taber, Trafford, & Quail, 2006). However, some research also suggests there may be constructive uses of anthropomorphism. Educators have used anthropomorphism to increase engagement (Watts & Bentley, 1994) and confidence (Taber et al., 2006) with unfamiliar concepts, constructively using the emotive effects (Waytz, Morewedge, et al., 2010) of anthropomorphism while building towards a more correct explanation (Davis, Horn, & Sherin, 2013).

Conservation researchers have had success using these emotional effects to build empathy and connectedness (Epley et al., 2008) with specific species (Jacobs & Harms, 2014) or with the idea of nature in general (Tam, Lee, & Chao, 2013) to further conservation goals. Technology researchers have also had some success with anthropomorphism, turning teleological reasoning to their advantage. In some contexts

where humans are designing technology or conducting research, it is not necessarily inaccurate for inanimate subjects to have goals. In fields such as robotics (Duffy, 2003) and space exploration (Mignone et al., 2016), anthropomorphism has allowed non-expert audiences to identify with the goals of the human researchers behind the technology.

Existing research into anthropomorphism in science communication has focused on text analysis (Leane, 2007; Pramling & Säljö, 2007; Sealey & Oakley, 2013), rather than its effects on audiences. Experimental studies are mostly small scale interviews with school students or teachers (e.g. Taber & Watts, 1996; Legare et al., 2013). They tend to be verbal (Taber et al., 2006) or visual (Tam et al., 2013) rather than written. Larger-scale experimental studies have been limited to students, and have focused on who is affected by anthropomorphism (Friedler, Zohar, & Tamir, 1993; Waytz, Cacioppo, et al., 2010; Stern et al., 2018), with only limited research into how they are affected (Tam et al., 2013).

As a result, theory on the effects of anthropomorphism in science is well-developed but has not always been tested experimentally, especially in popular science writing for adults. We know that anthropomorphism changes the way people think and feel about science, but it is not clear how strong or widespread those effects are. If science writers are to make an informed decision about how and when to use anthropomorphism in their writing, they will want concrete evidence about what the consequences will be.

To address this gap, and test the concerns and opportunities raised by previous research, we posed two questions:

1. How does anthropomorphic science writing affect non-expert audiences' knowledge and understanding of the subject matter?
2. How does anthropomorphic science writing affect non-expert audiences' confidence in and connection with the subject matter?

The methods were designed to compare outcomes between the anthropomorphic and control groups, as a complement to earlier research that looked at the influence of anthropomorphism on individual understanding (e.g. Legare, et al. 2013), and an extension of previous work comparing narrative and non-narrative writing (e.g. Glynn & Takahashi, 1998; Negrete & Lartigue, 2010).

Methodology

Adult participants were recruited through social media, including Reddit communities, personal and promoted Tweets on Twitter, and Facebook groups and pages, allowing recruitment from a broad audience (Duggan and Brenner, 2013).

Recruitment materials mentioned testing for writing styles, misconceptions, and attitudes, but did not include references to anthropomorphism, as awareness of anthropomorphism might cause participants to correct the idea (Epley et al., 2007) before it could be measured.

Participants were randomly assigned to an anthropomorphised text, an edited un-anthropomorphised text, or a no-text control. The text and the following questionnaire were presented online. Participants were asked to complete the questionnaire immediately after reading the text.

Participants were also offered the opportunity to explain the reasoning behind their answers in a free-text comment. As with any textual data, researchers must trust that participants answer honestly and within the experimental parameters. However, evidence suggests that there is less distortion in responses to computer-administered questionnaires (Rowe, et al., 2006) and that when respondents are in their own space, they feel more comfortable and, with no human to please (Couper et al., 2002), are probably more honest in their answers.

A control group was used, rather than a pre- and post-test, to simulate a normal reading experience and avoid any potential pre-test effects (Willson and Putnam, 1982). All groups completed questionnaires measuring knowledge and understanding and the two groups who read a text completed a questionnaire measuring their connectedness to the text. Limited demographic data were collected.

Anthropomorphic text

'Diary of a Space Zucchini' ('Diary') is a first-person account by a zucchini plant describing its subjective experience of being in space, written by the NASA astronaut Don Pettit (Supplemental Material, File 1).

This text was chosen because it is an excellent example of popular, rather than educational or academic science writing. Published in April 2012, the post attracted 46 comments (Pettit, 2012a) and 52 retweets (Pettit, 2012b) on Twitter. It received significant coverage on science and technology websites (Moskowitz, 2012) and was adapted into an equally popular audio drama (Davis, 2013). As a NASA document, it is in the public domain, and thus freely legally available for reuse and modification (NASA, 2015).

Anthropomorphism is 'Diary's' primary stylistic feature, making it an excellent example to analyse. While plants are undeniably alive, they are seldom considered conscious (Thorn et al., 2016). Thus, 'Diary's' first person viewpoint, relating subjective experiences, perceptions and future plans, makes it a clear and unambiguous case of deliberate anthropomorphism.

'Diary's' subject matter is an excellent combination of common and unfamiliar ideas. Misconceptions about plants are well-characterised (Thorn et al., 2016), providing a strong basis for formulating questions and coding responses. However, while plant biology is a core part of most educational curricula (Haslam and Treagust, 1987), audiences are less exposed to the effects of microgravity on plants. This provides an element of unfamiliarity that may make elicited anthropomorphic reasoning more likely

(Epley et al., 2007). Additionally, examination of the comment threads below the blog posts (Pettit, 2012a) reveals several anthropomorphic formulations.

Non-anthropomorphic text

The re-writing of the non-anthropomorphic version of the text (Supplemental Material, File 2) kept the phrasing as similar as possible, without removing scientific content. It used third-person rather than first-person pronouns, and all references to internal states, subjective needs and desires and susceptibility to social influence were removed; for example, the subjective 'happy' became the more externally observable 'healthy'. While we acknowledge that some implicit anthropomorphism is always present in English grammar (Master, 1991), this reformulation allowed us to test the effects of explicit stylistic anthropomorphism while leaving the reading experience otherwise intact.

Some passages in which objective re-wording would not have made sense were removed entirely; for example an instance of in-story anthropomorphism in which the astronauts themselves anthropomorphised and named the plant. Removing these passages enabled the reduction, as far as possible, of details that readers might have used to infer an emotional connection with the plant on the part of the astronaut.

The modified text was slightly shorter than the original (1402 and 1686 words respectively). It had a similar Flesch Reading Ease (74.4) to the original (77.9), putting both texts at roughly an 8th grade reading level (Flesch, 1979). At an average reading speed, reading time would have been approximately ten minutes. Six independent communication researchers confirmed that the factual content of the two texts was equivalent.

Knowledge and understanding

As misconceptions are the focus of scientists' criticism of anthropomorphism (Hanke, 2004), questions were developed based on Treagust's (1988) process for diagnosing misconceptions.

We first developed a set of 'propositional knowledge statements' that describe the claims the text makes about the world (Supplemental Material, File 3) These were based on existing literature on misconceptions about plant biology (Haslam and Treagust, 1987; Hershey, 2004; Thorn et al., 2016) and validated by a group of six biologists and communication researchers

We then developed eight pairs of questions based on these statements. Each pair consisted of a closed yes-no question about that topic, followed by an open-ended question asking participants to explain their answer. Responses to the closed-ended question indicate participants' background knowledge and comprehension of the text, while the open-ended question probed for misconceptions by eliciting deeper explanations (Treagust, 1988).

Confidence and connection

We measured participants' experience of reading each text using the Intrinsic Motivation Inventory (IMI), a widely-used (Van Dijk, et al., 2012) and validated (McAuley, et al., 1989; Tsigilis and Theodosiou, 2003) instrument for measuring self-reported subjective experiences in experimental tasks.

The IMI comprises several subscales, each assessing a different aspect of subjective experience. Two measures each tested the primary constructs of social relatedness (Epley et al., 2008), perceived competence (Waytz, Morewedge, et al., 2010), and value/usefulness (Falk, et al., 2007), and three measures tested the communication objective of enjoyment/interest (Brown and Scholl, 2014). Each question was posed as a statement, and participants indicated their level of agreement on a seven-point Likert scale.

Demographic questions

Participation was limited to adults (18+). Age, education (Legare et al., 2013), field (Friedler et al., 1993) and language (Master, 1991) are the demographic factors with the strongest links to both attitudes and misconceptions around anthropomorphism. In particular, we expected educators (Zohar and Ginossar, 1998) and native English speakers (Master, 1991) to be better able to correct anthropomorphism, and scientists to have a noticeably worse attitude to it (Wynne, 2004).

The full survey is available in the Supplemental Material (File 4).

Ethical approval for this research was granted by the UWA Human Research Office on 23 May 2017, RA/4/1/9154.

Coding and validation

Coding is the process of identifying common themes and features in textual data (Patton, 2002). We coded responses for each of the three major misunderstandings associated with anthropomorphism (teleology, subjective states, and external forces (Supplemental Material File 3)). During analysis, we added a 'non-explanation' code to quantify responses which either explicitly claimed to not know, or where no meaningful reasoning was provided. These tended to be either generalisations ('yes, because all plants need this') or overly specific ('no, because the story said so').

Responses to the final question ('Do humans need plants in space? /Why?') were coded separately, as referring to either physical needs (food or oxygen) or emotional needs (happiness or aesthetic value), leaving seven questions assessing knowledge and understanding. Unusual or exemplary responses were flagged and annotated for later qualitative analysis, including evidence of emotional responses (such as putting words in inverted commas e.g. ‘instincts’, or other forms of textual emphasis), to complement the subjective experience data from the IMI scales.

A second researcher cross-coded a subset of the data (32 participants) with an inter-coder reliability of 83%, determined by the number of responses coded identically (Creswell, 2016).

Statistical analysis

For each feature in the codebook, participants were given a score out of seven, representing the number of responses containing that feature. The data were not normally distributed and did not have equal variances, and thus did not meet the assumptions for parametric tests (Pallant, 2011). The non-parametric Kruskall-Wallis test was used to determine if there were any significant ($p<0.05$) differences between the three groups, followed by the Mann-Whitney U Test to compare groups. Effect sizes are given as $r\leq0.1$ representing a small effect, $r=0.3$ representing a medium effect, and $r\geq0.5$ representing a large effect (Pallant, 2011).

The data on human needs were analysed using a series of chi-square tests for independence to isolate any difference between groups (Pallant, 2011). For these data, effect sizes were calculated using phi-values where $r\leq0.07$ represents a small effect, $r=0.21$ represents a medium effect, and $r\geq0.35$ represents a large effect (Pallant, 2011).

Results

There were 174 completed responses (of 375 started). Incomplete responses were excluded from further analysis.

Of the complete responses, 54 had been randomly allocated the anthropomorphic text (A) to read, 44 the non-anthropomorphic text (NA), and the remaining 75 read no text (control, C).

There was no significant difference between any groups in terms of education ($p=0.68$), background ($p=0.67$) or English language status ($p=0.63$). Median education level was an undergraduate degree and most (69%) participants had a background in science or education (Table 1). Only 18 of 174 participants reported that English was not their first language.

The range of knowledge and understanding about the topic was consistent across the three groups and across demographics. Participants generally had some ideas about what they were being asked, but weren't always certain:

> "I guess artificial light works as well but probably hasn't got the other benefits of sunlight."
> - *A, HS.*

Responses ranged from a single word ("*Photosynthesis*") to several sentences of in-depth exploration:

> "The sun provides all wavelengths of light that the plant needs to absorb to photosynthesise. Maybe lights can be used for this purpose, but you'd need to consider how long the lights were switched on/off for, and also what sort of light was being emitted."
> - *NA, PD, Bio.*

Knowledge and understanding

Closed-ended knowledge questions

Participants who received any text at all appeared on average to get one more closed-ended question correct than participants in the control group (Figure 1).

This difference was significant between anthropomorphic and control ($p<0.00$, $r=0.38$) and between non-anthropomorphic and control ($p<0.00$, $r=0.43$). There was no significant difference between the anthropomorphic and non-anthropomorphic text groups ($p=0.18$).

Anthropomorphic misconceptions

Explanation questions elicited anthropomorphic explanations across all three groups. Most (107) of the 174 participants showed evidence of at least one misconception, with an average of one misconception each across the seven questions (Table 2).

Across all groups, and all classes of misconception, statistical tests indicate that there is no significant difference in occurrence of misconceptions between groups.

Teleology

Teleological answers tried to explain the plant's state in terms of **needing or desiring** to achieve a particular **goal**. In this case, that goal was usually some variant on growth or continued survival:

> "All living things **need** water **to grow and thrive**."
> *NA, Coll, Sci*

More accurate non-teleological responses would explain the plant's state in terms of the processes at work in the plant, or what causes the plant's requirement for water, rather than just its outcome:

> "Plants **use** water to carry out **photosynthesis**, for **turgor pressure** and **cellular reactions**."
> - *C, PhD, Ed*

"**For transport** and **photosynthesis**"
- *A, HS*

Some responses expressed more specific goals, but were still ultimately teleological, relying on an end state to explain rather than a cause:

"As long as the plants are getting what they need, they will still **want** to be able to **reproduce.**"
- *C, Coll, Bio*

These responses were more commonly given on topics that are not generally well understood (Barman et al., 2006), such as the reasons why plants need water or light, which requires deeper understanding of photosynthesis and respiration.

Teleological explanations were the most common misconception, with 76 participants using at least one. However, a Kruskall-Wallace test revealed there was no significant difference between any groups' tendency to use this kind of explanation ($p=0.23$).

Internal states

Forty-five participants made at least one unfalsifiable reference to the internal, subjective states or experiences of the plant. These varied in terms of degree and kind, but generally fell into one of two categories.

Most commonly, participants conflated emotional happiness with physical health when discussing the plant's requirements. Healthy plants were characterised as 'happy', and unhealthy ones as 'sad':

"Different light schedules **makes the plant sad**"
- *A, Ug, Bio*

“The plant seemed **happier** with 'real' sunlight in a cycle with the artificial light"
- *A, Ug, Ed*

Participants who read the anthropomorphic text expressed more strongly anthropomorphic ideas about human emotions, while those in the control group showed weaker (but still unfalsifiable) ideas about 'balance' or 'preferences':

"It is possible to grow plants under direct light, but lacking a day-night cycle **seemed to leave it out of balance**"
- *NA, HS*

We noticed a qualitative difference in the descriptive terms used in responses (although there was no significant difference in frequency). Questions about physical requirements, particularly about the difference between sunlight and artificial light, tended to provoke

response that used strongly anthropomorphic terms, such as the plant ‘thinking’ rather than ‘feeling’.

The other frequently-referenced subjective internal state was the idea that the plant had some degree of conscious knowledge of the world around it, and was using that knowledge to make decisions. Rather than 'feeling', as above, the plant was 'thinking', planning and deciding.

> "Tests show that germination can be a bit weird in space **(which way do my roots grow?!)**, but already mature(ish) plants should be mostly fine.”
> - *C, PD, Sci*

These responses almost always related to tropisms, either gravitropism (gravity-seeking growth) or phototropism (light-seeking growth). Since these aspects of plant biology externally resemble a decision-making process this comparison makes sense, but is still ultimately unfalsifiable.

Both kinds of unfalsifiable internal states were coded together. A Kruskall-Wallis test showed no significant difference between the three groups ($p=0.20$) in how many of these claims were made.

External forces

Across all questions, only 15 participants invoked forces external to the plant to explain their answers, making this the least common type of misconception. However, they did invoke a wide variety of forces. Scientists and engineers appeared several times:

> "I don't think **scientists** have yet found a way to grow anything without water."
> - *A, Bio*

As did generic references to human intervention:

> "If they have the nutrients they need, they can produce flowers but they won't be pollinated **unless humans help**"
> - *NA, PD, Ed*

There were no references to supernatural entities or to 'nature' or 'evolution' actively 'selecting' (Hanke, 2004, p. 148), although two responses came close:

> "They still exhibit phototropism and stuff even if most of the stimuli they exhibit on Earth aren't present. **It still has the same genes and therefore the same 'instincts'** to react a certain way to certain things."
> - *A, HS*

There were no significant differences (p=0.30) between the groups in the use of external agents as an explanation.

Non-explanations

Some participants gave a reason for their answer, but not an explanation of their ideas. For whatever reason, they engaged with the question on a superficial level rather than with the ideas behind it.

Represented among these are arguments from generalisation:

> "**All plants** need light"
> - *A, Coll*

Arguments from authority, with the supplied text as the authority:

> "The story **said so**"
> - *NA, Ug, Sci*

Or statements that they didn't know why, despite having (correctly) answered the first part of the question with a yes or no rather than 'I don't know'.

The difference between total non-explanations was significant across groups (p=0.02, $\chi 2$ (2, n=174)=8.35). The difference between anthropomorphic and control groups was significant (p<0.00, r=0.25), but the non-anthropomorphic group was not significantly different from either the anthropomorphic (p=0.37) or control (p=0.10) groups.

Human needs

All groups successfully identified the physical needs plants might fulfil for astronauts. There was minimal difference in the details provided between groups. Participants usually identified either oxygen or nutrients, or both, as reasons to take plants to space.

> "Plants can help remove carbon dioxide and **produce the oxygen we need to survive**. They also provide a ready **source of nutrients** for humans"
> - *C, Ug, Ed Bio Sci*

Some identified these needs as roles plants fulfil on earth, but stated they could be fulfilled by other means while in space, or that plants would only be needed for long-duration space missions.

> "However, on an **extended flight** they would definitely need them **both for eating and air purifying** stuff"
> - *C, PD, Ed*

The psychological benefits of plants to astronauts during long-duration spaceflight were discussed in both texts, and both text groups were able to identify these psychological or emotional needs alongside, or instead of, purely physical ones.

> "To provide a **psychological/ emotional connection** through care of the plant and from its smell"
> - *A, PD, Sci*

However, participants in the control group were generally unable to identify psychological benefits.

There was no significant difference between anthropomorphic and non-anthropomorphic groups in identification of either physical ($p=0.43$) or psychological needs ($p=0.30$). However, both text groups identified significantly more psychological needs (Figure 2, $p<0.00$) with a large effect size ($phi=0.41$) and significantly fewer physical needs (Figure 2, $p=0.03$) with a medium effect size ($phi=0.20$) than the control group.

Subjective reading experience

Responses to both texts were positive. Participants generally agreed that both texts were interesting and enjoyable, and had some value or utility. They felt they understood the content well, and could relate to the subject matter (Figure 3).

Perceived competence was slightly higher for the non-anthropomorphic text, with a median subscale score of 5.5 / 7 (against 5.0 for anthropomorphic text; $p=0.023$, $r=0.23$). Interest/Enjoyment had a slightly higher median subscale score for the anthropomorphic text, of 6.0 / 7 (compared with 5.67 for non-anthropomorphic text) but the difference was not significant ($p=0.077$).

Discussion

In these data, we see no evidence of the supposed 'perils of anthropomorphism' (Wynne, 2004, p.606), but neither do we see any evidence of potential communicative benefits.

Both text groups performed significantly better than the control group on several measures. They answered more closed-ended questions correctly, and tended to provide more substantive explanations.

The effects of anthropomorphic text on knowledge and understanding were minimal. Qualitative evidence suggested participants had more strongly anthropomorphic ideas about plants' subjective 'experiences', but there was no quantitative evidence of any difference in knowledge and understanding between the two text groups.

The effects of anthropomorphism on confidence and connection with the text were likewise minimal. Both text groups had consistently positive experiences, while the non-anthropomorphic text showed a small but significant increase in perceived competence.

Better examples

However, participants in the anthropomorphic group were significantly better at explaining their answers, especially at using fewer generalisations, than participants in the control group. The non-anthropomorphic group also performed somewhat better than the control, but not significantly. One possible explanation is that anthropomorphism provided readers with a more memorable narrative.

Narrative tends to have more impact (Dahlstrom, 2014) than facts or data, and anthropomorphism allows writers to construct narratives more easily (Sealey and Oakley, 2013). The more extreme and vividly described the example, the more memorable and impactful (Zillmann, 1999). With a clearer sense of personality, an obvious protagonist, and more subjective descriptions, the anthropomorphic text may have served as a more compelling and evocative narrative setting for the text's examples of plant biology. The non-anthropomorphic text, while still informative, was less evocative and memorable.

Exemplification may also explain why both text groups were better able to identify the emotional needs of humans in space. Most discussion of the role of plants in space (Ferl et al., 2002) and on Earth (Barman et al., 2006) focuses on how they affect the physical environment. After reading the single concrete example of the emotional value of plants given in both texts, participants in both text groups were significantly more likely to identify how plants fulfil humans' emotional needs and significantly less likely to identify physical needs. This is consistent with previous findings, in which readers weighted a single compelling example more highly than ideas without examples (Dahlstrom, 2014).

More strongly anthropomorphic formulations

While there were no significant differences in how often participants relied on internal states as an explanation, we noticed a qualitative difference in how strong those ideas were. Participants in the anthropomorphic group used more specific and more emotive ideas when using subjective internal states to explain their responses.

Psychological theories of anthropomorphism allow for differences in intensity (Epley et al., 2007) as well as frequency (Waytz, et al., 2010), as measured here. While anthropomorphic text does not appear to change how often people make these explanations, it may affect how strongly they hold those anthropomorphic ideas.

All groups made just as many unfalsifiable assumptions about plants' internal processes. In the anthropomorphic group, however, these assumptions were stronger and more explicitly anthropomorphic. Taber and Watts (1996) suggest that stronger, more explicit anthropomorphic metaphors are more easily recognised and the underlying knowledge structures more easily corrected (Epley et al., 2007). This suggests that calling attention

to anthropomorphism (Zohar and Ginossar, 1998) with a strong, explicit metaphor may be better for countering misconceptions than allowing audiences to make their own anthropomorphic assumptions.

Lower perceived competence

Both text groups were asked to rate how well they felt they understood their text. The non-anthropomorphic text group rated their perceived competence higher than the anthropomorphic text group by a small but significant margin. However, their actual performance was not significantly different.

Readers are not always accurate judges of their ability (Kruger and Dunning, 1999), and especially of their comprehension (Glenberg, et al., 1982). In particular, people frequently mistake being familiar with a piece's style (Fenesi et al., 2014) or being able to recall details easily (Benjamin, et al., 1998) with having a good understanding. In this case, the non-anthropomorphic text was presented in a more straightforward, less stylised way, and thus may have felt more familiar or easy to remember for participants.

Anthropomorphism may also have acted as a seductive detail, "novel, active, concrete, and personally involving" (Garner et al., 1992, p. 239); aspects of a text which, while interesting and memorable, are not related to the text's key message. The vivid anthropomorphic examples may have distracted readers from the topics and structure required to answer the questions (Harp and Mayer, 1998), making the anthropomorphic text a subjectively more difficult experience.

Positive effects of reading

Readers had a consistently positive experience with both texts, with only minimal significant differences between groups. The greatest differences between groups came from reading anything at all, perhaps because recently acquired knowledge is more readily available for making judgements (Tversky and Kahneman, 1974). After reading, participants are more likely to have relevant knowledge in their working memory (Daneman and Carpenter, 1980), either new knowledge learned from the text or existing knowledge activated from their long-term memory (Cantor and Engle, 1993). While this study cannot measure whether any new knowledge learned would persist in readers' long-term memories, the greater emotional connection suggested by responses to the anthropomorphic text may help with recall (Kensinger, 2009).

Limitations

Although the sample is representative of the post's original audience (Ranger and Bultitude, 2016), it is not representative of the overall population, being skewed towards scientifically-minded, university-educated, English speakers. The length of the texts may have affected completion rates; the reading time would have been approximately ten minutes, suggesting that those who didn't enjoy the text probably dropped out before

reaching any questions (Groves, et al., 2004). A shorter text or multiple-choice quiz may have increased the completed response rate (Deutskens et al., 2004). However, selecting for an interested audience is not necessarily a problem. Interested participants provide higher-quality data (Gosling et al., 2004), and are more representative of the free-choice learners associated with popular science writing (Falk et al., 2007), especially online science writing (Jarreau and Porter, 2017).

These data also consist entirely of self-reported measures. Anthropomorphic formulations do not necessarily imply anthropomorphic reasoning (Tamir and Zohar, 1991), and may be used as a mental heuristic or communication shortcut (Zohar and Ginossar, 1998), such as jokes or metaphors. Education researchers characterise anthropomorphism in these cases as a 'way of thinking about or talking about' rather than a 'way of explaining' (Taber et al., 2006). The anthropomorphic formulations coded in this data may not represent participants' actual thought processes. In-depth unstructured interviews (Taber and Watts, 1996) may be better at determining this, but they lack the ability to scale up to larger sample sizes.

It should also be noted that the texts were in English and even though only a small minority (10%) of respondents stated that English was not their first language, we must nonetheless be wary of extrapolating these results to other languages and cultures. For example, anthropomorphism is used more extensively in science education in Japan, which is likely to influence acceptance, interpretation and understanding of the technique (Wood, 2019).

Future research on anthropomorphism should also consider measures of intensity, rather than frequency, of anthropomorphic ideas in explanations, as suggested by the qualitative data. A more quantitative approach to assessing strength of anthropomorphism would help determine if this was part of a wider trend.

Finally, without follow-up research it is difficult to say how long any of the effects will persist (Guzzetti, et al., 1992), or whether there were any further effects after data were collected. Further tests may have addressed this issue, but as participants were anonymous and the project had a limited timeframe, this was not viable.

Conclusion

In this large, experimental study diagnosing misconceptions, anthropomorphism had only subtle effects on the way readers think and feel. While the reported subjective experience of reading the text remained the same, these results suggest that anthropomorphism makes examples more vivid and lets writers build memorable characters and narratives.

This has the potential to be distracting and reduce confidence with the subject, but not at the cost of accurate knowledge or understanding. It appears that educated adults can generally tell the difference between an illustrative metaphor and a substantive explanation.

Scientists' concerns about anthropomorphism, while well placed in a scientific context, may not be justified when writing for non-experts. Anthropomorphism may be better avoided for some audiences, such as younger children, who struggle to distinguish metaphors from explanation (Friedler et al., 1993), and some content, such as discussion of evolution (Legare et al., 2013).

However, the effects of anthropomorphic or non-anthropomorphic writing are minimal compared with the difference between participants who read something and participants who didn't. These results suggest that it isn't *what* we read, but *whether* we read, that matters most.

Writing about science for a non-expert audience is challenging, and writers should use every tool at their disposal to make that writing as clear, as focused, as interesting, and as coherent as possible. For competent adult readers, with the right subject matter, we see no reason why those tools should not include anthropomorphism.

Acknowledgments

Thanks to Associate Professor Farida Fozdar, Grace Ritter, Jessica Smith, James Westgarth-Taylor, Morgan Lewis and Amanda Mwenda for their input and feedback.

Additional thanks to Andrew Hannah, for asking the question that sparked this research.

Finally, thanks to everyone who shared and reposted recruitment materials around the web, as well as the 174 anonymous participants who responded to those materials. Thank you for your contribution to science (writing)!

References

Alexander PA and Kulikowich JM (1994) Learning from physics text: A synthesis of recent research. *Journal of Research in Science Teaching* 31(9): 895–911. https://doi.org/10.1002/tea.3660310906

Barman CR, Stein M, McNair S and Barman N S (2006) Students' Ideas About Plants & Plant Growth. *The American Biology Teacher* 68(2): 73–79. https://doi.org/10.1662/0002-7685(2006)068[0073:SIAPPG]2.0.CO;2

Benjamin AS, Bjork RA and Schwartz BL (1998) The mismeasure of memory: when retrieval fluency is misleading as a metamnemonic index. *Journal of Experimental Psychology. General* 127(1): 55–68.

Brown P and Scholl R (2014) Expert interviews with science communicators: How perceptions of audience values influence science communication values and practices. *F1000Research* 3: 128 *https://*10.12688/f1000research.4415.1.

Cantor J and Engle RW (1993) Working-memory capacity as long-term memory activation: An individual-differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19(5): 1101. https://doi.org/http://dx.doi.org/10.1037/0278-7393.19.5.1101

Chartrand TL, Fitzsimons GM and Fitzsimons GJ (2008) Automatic Effects of Anthropomorphized Objects on Behavior. *Social Cognition* 26(2): 198–209. https://doi.org/10.1521/soco.2008.26.2.198

Cooremans, K., & Geuens, M. (2019). Same but Different: Using Anthropomorphism in the Battle Against Food Waste. *Journal of Public Policy & Marketing*, 38(2), 232–245. https://doi.org/10.1177/0743915619827941

Couper, M., Traugott, M., and Lamias, M. (2002) Web survey design and administration. *Public Opin. Q*. 65, 230–253.

Creswell, J.W. (2016). 30 Essential skills for the qualitative researcher. SAGE Publications: USA.

Dahlstrom MF (2014) Using narratives and storytelling to communicate science with non-expert audiences. *Proceedings of the National Academy of Sciences* 111(Supplement 4): 13614– 13620. https://doi.org/10.1073/pnas.1320645111

Dahlstrom MF and Ho SS (2012) Ethical Considerations of Using Narrative to Communicate Science. *Science Communication* 34(5): 592–617. https://doi.org/10.1177/1075547012454597

Daneman M and Carpenter PA (1980) Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior* 19(4): 450–466. https://doi.org/10.1016/S0022-5371(80)90312-6

Davis L (2013, September 21) Listen to the radio diary of a zucchini plant aboard the ISS.Available at: https://io9.gizmodo.com/listen-to-the-radio-diary-of-a-zucchini-plant-aboard-th-1363179032 (Accessed 21 September 2017).

Davis PR, Horn MS and Sherin BL (2013) The Right Kind of Wrong: A "Knowledge in Pieces" Approach to Science Learning in Museums. *Curator: The Museum Journal* 56(1): 31–46. https://doi.org/10.1111/cura.12005

Deutskens E, De Ruyter K, Wetzels M and Oosterveld, P (2004) Response Rate and Response Quality of Internet-Based Surveys: An Experimental Study. *Marketing Letters* 15(1): 21–36. https://doi.org/10.1023/B:MARK.0000021968.86465.00

Duggan M and Brenner J (2013) *The demographics of social media users, 2012* (Vol. 14). Pew Research Center's Internet & American Life Project Washington, DC.

Epley N, Waytz A, Akalis S and Cacioppo JT (2008) When We Need A Human: Motivational Determinants of Anthropomorphism. *Social Cognition* 26(2): 143–155. https://doi.org/10.1521/soco.2008.26.2.143

Epley N, Waytz A and Cacioppo JT (2007) On seeing human: A three-factor theory of anthropomorphism. *Psychological Review* 114(4): 864–886. https://doi.org/10.1037/0033-295X.114.4.864

Falk JH, Storksdieck M and Dierking LD (2007) Investigating public science interest and understanding: evidence for the importance of free-choice learning. *Public Understanding of Science* 16(4): 455–469. https://doi.org/10.1177/0963662506064240

Fenesi B, Heisz JJ, Savage PI, Shore DI and Kim JA (2014) Combining Best-Practice and Experimental Approaches: Redundancy, Images, and Misperceptions in Multimedia Learning. *The Journal of Experimental Education* 82(2): 253–263. https://doi.org/10.1080/00220973.2012.745472

Ferl R, Wheeler R, Levine HG and Paul A-L (2002) Plants in space. *Current Opinion in Plant Biology* 5(3): 258–263. https://doi.org/10.1016/S1369-5266(02)00254-6

Flesch RF (1979) *How to write plain English: a book for lawyers and consumers*. Harper & Row.

Friedler Y, Zohar A and Tamir P (1993) The effect of age and of learning on the ability to distinguish between anthropomorphic and teleological explanations. *International Journal of Science Education* 15(4): 439–443. https://doi.org/10.1080/0950069930150407

Garner R (1993): "Seductive Details" and Adults' Learning from Text. In: *Reading Across the Life Span*. Springer, New York, NY, pp. 215–222. https://doi.org/10.1007/978-1-4612-4376-2_10

Garner R, Brown R, Sanders S and Menke DJ (1992) "Seductive details" and learning from text. In: Renninger KA, Hidi S, Krapp A (eds) *The Role of Interest in Learning and Development* Psychology Press, pp.239–254.

Glenberg AM, Wilkinson AC and Epstein W (1982) The illusion of knowing: Failure in the self-assessment of comprehension. *Memory & Cognition* 10(6): 597–602. https://doi.org/10.3758/BF03202442

Glynn, SM and Takahashi T (1998) Learning from analogy-enhanced science text. *Journal of Research in Science Teaching* 35(10): 1129–1149. https://doi.org/10.1002/(SICI)1098-2736(199812)35:10<1129::AID-TEA5>3.0.CO;2-2

Gosling SD, Vazire S, Srivastava S and John OP (2004) Should We Trust Web-Based Studies? A Comparative Analysis of Six Preconceptions About Internet Questionnaires. *American Psychologist* 59(2): 93–104. https://doi.org/10.1037/0003-066X.59.2.93

Groves RM, Presser S and Dipko S (2004) The Role of Topic Interest in Survey Participation Decisions. *Public Opinion Quarterly* 68(1): 2–31. https://doi.org/10.1093/poq/nfh002

Guthrie SE (1997) Anthropomorphism: A Definition and a Theory. In: Mitchell R, Thompson NS, and Miles HL (eds.), *Anthropomorphism, Anecdotes, and Animals.* Suny Press, pp.50-58.

Guzzetti BJ, Snyder TE and Glass GV (1992). Promoting Conceptual Change in Science: Can Texts be Used Effectively? *Journal of Reading* 35(8): 642–649.

Hanke D (2004) Teleology: The Explanation That Bedevils Biology. In: Cornwell J (ed.) *Explanations: Styles of Explanation in Science.* Oxford University Press, pp.143–155.

Harp SF and Mayer RE (1998) How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology* 90(3): 414–434. https://doi.org/10.1037/0022-0663.90.3.414

Harrison MA and Hall AE (2010) Anthropomorphism, empathy, and perceived communicative ability vary with phylogenetic relatedness to humans. *Journal of Social, Evolutionary, and Cultural Psychology* 4(1): 34–48. https://doi.org/10.1037/h0099303

Hartley JM (2015) When Homo Academicus meets Homo Journalisticus: An inter-field study of collaboration and conflict in the communication of scientific research. *Journalism* 18(2): 211-225. https://doi.org/10.1177/1464884915608817

Haslam F and Treagust DF (1987) Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education* 21(3): 203–211. https://doi.org/10.1080/00219266.1987.9654897

Hershey DR (2004) Avoid misconceptions when teaching about plants. Available at: http://www.actionbioscience.org/education/hershey.html (accessed 19 April 2017).

Feifei H, Wong VC and Wan EW (2020) The Influence of Product Anthropomorphism on Comparative Judgment, *Journal of Consumer Research*, 46(5): 936–955. https://doi.org/10.1093/jcr/ucz028

Jaeger AJ and Wiley J (2015) Reading an Analogy Can Cause the Illusion of Comprehension. *Discourse Processes* 52(5–6): 376–405. https://doi.org/10.1080/0163853X.2015.1026679

Jamieson S (2004) Likert scales: how to (ab)use them. *Medical Education* 38(12): 1217–1218. https://doi.org/10.1111/j.1365-2929.2004.02012.x

Jarreau, P. B., & Porter, L. (2017). Science in the social media age: Profiles of science blog readers. *Journalism & Mass Communication Quarterly*. 95(1):142-168. doi:10.1177/1077699016685558

Kahan DM (2013) Making Climate-Science Communication Evidence-Based — All the Way Down. In: Crow DA and Boykoff MT (eds) *Culture, Politics and Climate Change: How Information Shapes Our Common Future. Routledge, pp.203-220.*

Kendeou P and Van den Broek P. (2007) The effects of prior knowledge and text structure on comprehension processes during reading of scientific texts. *Memory & Cognition* 35(7): 1567–1577. https://doi.org/10.3758/BF03193491

Kennedy JS (1992) *The New Anthropomorphism*. Cambridge University Press.

Kensinger EA (2009) Remembering the Details: Effects of Emotion. *Emotion Review* 1(2): 99–113. https://doi.org/10.1177/1754073908100432

Kruger J and Dunning D (1999) Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology* 77(6): 1121.

Leane E (2007) *Reading Popular Physics: Disciplinary Skirmishes and Textual Strategies*. Ashgate Publishing, Ltd.

Legare CH, Lane JD and Evans EM (2013) Anthropomorphizing Science: How Does It Affect the Development of Evolutionary Concepts? *Merrill-Palmer Quarterly* 59(2): 168–197. https://doi.org/10.1353/mpq.2013.0009

Lévy-Leblond J-M (1992) About misunderstandings about misunderstandings. *Public Understanding of Science* 1(1): 17–21.

Lipton P (2004) What good is an explanation? In *Explanations: Styles of Explanation in Science* Oxford University Press, pp.1-21.

Master P (1991) Active verbs with inanimate subjects in scientific prose. *English for Specific Purposes* 10(1): 15–33. https://doi.org/10.1016/0889-4906(91)90013-M

McAuley E, Duncan T and Tammen VV (1989) Psychometric Properties of the Intrinsic Motivation Inventory in a Competitive Sport Setting: A Confirmatory Factor Analysis. *Research Quarterly for Exercise and Sport* 60(1): 48–58. https://doi.org/10.1080/02701367.1989.10607413

Mignone C, Baldwin E, O'Flaherty KS, Homfeld AM, Bauer M, McCaughrean M., … Palazzari C (2016) How a Cartoon Series Helped the Public Care about Rosetta and Philae. *Communicating Astronomy with the Public Journal* 19: 12.

Millikan RG (1997) Varieties of Purposive Behavior. In: Mitchell, R Thompson NS, and Miles HL (eds.) *Anthropomorphism, Anecdotes, and Animals* Suny Press, pp.189–197.

Moskowitz C (2012, April 16) Space Zucchini's Orbital Life and Times Blogged by Astronaut. Available at: https://www.space.com/15280-space-zucchini-orbit-astronaut-pettit.html (accessed 21 September 2017).

NASA (2015, March 11) Media Usage Guidelines [Text]. Available at: http://www.nasa.gov/multimedia/guidelines/index.html (accessed 22 September 2017)

Negrete, A., & Lartigue, C. (2010). The science of telling stories: Evaluating science communication via narratives (RIRC method). *Journal Media and Communication Studies* 2(4), 98-110.

Pallant J (2011) *SPSS survival manual: a step by step guide to data analysis using the SPSS program*, (4 ed). Crows Nest, N.S.W., Australia: Allen & Unwin.

Patton MQ (2002) *Qualitative research and evaluation methods* (3 ed). Thousand Oaks, California: Sage Publications.

Pettit D (2012a, April 3) Diary of a Space Zucchini. Available at: https://blogs.nasa.gov/letters/ (accessed 20 April 2017).

Pettit D (2012b, April 10) Diary of a Space Zucchini. Read more at http://blogs.nasa.gov/cm/blog/letters/posts/post_1333471169633.html [Tweet]. Available at: https://twitter.com/astro_Pettit/status/187543744499826690 (accessed 21 October 2017).

Popper KR (2002) *The logic of scientific discovery*. London: Routledge.

Post S (2014) Scientific objectivity in journalism? How journalists and academics define objectivity, assess its attainability, and rates its desirability. *Journalism* 16(6): 730-749.

Pramling N and Säljö R (2007) Scientific Knowledge, Popularisation, and the Use of Metaphors: Modern genetics in popular science magazines. *Scandinavian Journal of Educational Research* 51(3): 275–295. https://doi.org/10.1080/00313830701356133

Ranger, M and Bultitude K (2016) 'The kind of mildly curious sort of science interested person like me': Science bloggers' practices relating to audience recruitment. *Public Understanding of Science* 25(3): 361–378. https://doi.org/10.1177/0963662514555054

Reed R (2001) (Un-)Professional discourse? Journalists' and scientists' stories about science in the media. *Journalism* 2(3) 279-298.

Rowe, G., Poortinga, W. & Pidgeon, N., (2006) A Comparison of Responses to Internet and Postal Surveys in a Public Engagement Context. *Science Communication*, 27(3), p. 352.

Sealey A and Oakley L (2013) Anthropomorphic grammar? Some linguistic patterns in the wildlife documentary series Life. *Text & Talk* 33(3): 399–420. https://doi.org/10.1515/text-2013-0017

Stern F, Kampourakis K, Huneault C, Silveira P, and Müller A. (2018). Undergraduate Biology Students' Teleological and Essentialist Misconceptions. *Education Sciences*, 8(3), 135. http://dx.doi.org/10.3390/educsci8030135

Taber KS and Watts M (1996) The secret life of the chemical bond: students' anthropomorphic and animistic references to bonding. *International Journal of Science Education* 18(5): 557– 568. https://doi.org/10.1080/0950069960180505

Taber KS, De Trafford T. and Quai, T (2006) Conceptual resources for constructing the concepts of electricity: the role of models, analogies and imagination. *Physics Education* 41(2): 155. https://doi.org/10.1088/0031-9120/41/2/006

Tam K-P, Lee S-L and Chao MM (2013) Saving Mr. Nature: Anthropomorphism enhances connectedness to and protectiveness toward nature. *Journal of Experimental Social Psychology* 49(3): 514–521. https://doi.org/10.1016/j.jesp.2013.02.001

Tamir P and Zohar A (1991) Anthropomorphism and teleology in reasoning about biological phenomena. *Science Education* 75(1): 57–67. https://doi.org/10.1002/sce.3730750106

Thorn CJ, Bissinger K, Thorn S and Bogner FX (2016) "Trees Live on Soil and Sunshine!"- Coexistence of Scientific and Alternative Conception of Tree Assimilation. *PLOS ONE* 11(1): e0147802. https://doi.org/10.1371/journal.pone.0147802

Treagust DF (1988) Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education* 10(2): 159–169. https://doi.org/10.1080/0950069880100204

Tsigilis N and Theodosiou A (2003) Temporal Stability of the Intrinsic Motivation Inventory. *Perceptual and Motor Skills* 97(1): 271–280. https://doi.org/10.2466/pms.2003.97.1.271

Tversky A and Kahneman D (1974) Judgment under Uncertainty: Heuristics and Biases. *Science*185(4157), 1124–1131. https://doi.org/10.1126/science.185.4157.1124

Van Dijk EMAG, Lingnau A and Kockelkorn H (2012) Measuring enjoyment of an interactive museum experience (pp. 249–256). In: *14th ACM International Conference on Multimodal Interaction, ICMI 2012*, New York, NY, USA: ACM. Available at: https://doi.org/10.1145/2388676.2388728

Wang L, Touré-Tillery R and McGill, AL (2019) ,When the Flu Speaks: the Effect of Disease Anthropomorphism on Protection Motivation. In: *Advances in Consumer Research*, Vol 47, eds. Rajesh Bagchi, Lauren Block, and Leonard Lee, Duluth, MN : Association for Consumer Research, Pages: 321-331

Waytz A, Cacioppo J and Epley N (2010) Who Sees Human?: The Stability and Importance of Individual Differences in Anthropomorphism. *Perspectives on Psychological Science* 5(3): 219–232. https://doi.org/10.1177/1745691610369336

Waytz A, Gray K, Epley N and Wegner DM (2010) Causes and consequences of mind perception. *Trends in Cognitive Sciences* 14(8): 383–388. https://doi.org/10.1016/j.tics.2010.05.006

Waytz A, Morewedge CK, Epley N, Monteleone G, Gao J-H and Cacioppo JT (2010) Making sense by making sentient: Effectance motivation increases anthropomorphism. *Journal of Personality and Social Psychology* 99(3): 410–435. https://doi.org/10.1037/a0020240

Williams LA, Brosnan SF and Clay Z (2020) Anthropomorphism in comparative affective science: Advocating a mindful approach. *Neuroscience & Biobehavioral Reviews* 115: 299-307. https://doi.org/10.1016/j.neubiorev.2020.05.014

Willson VL and Putnam RR (1982) A Meta-analysis of Pretest Sensitization Effects in Experimental Design. *American Educational Research Journal* 19(2): 249–258. https://doi.org/10.3102/00028312019002249

Wood, M. (2019) The Potential for Anthropomorphism in Communicating Science: Inspiration from Japan. *Cultures of Science* 2(1): 23-34. https://doi.org/10.1177/209660831900200103

Wynne CDL (2004) The perils of anthropomorphism. *Nature* 428(6983): 606–606. https://doi.org/10.1038/428606a

Wynne CDL (2007) What are animals? Why anthropomorphism is still not a scientific approach to behavior. *Comparative Cognition & Behavior Reviews* 2: 125–135.

Yanai, I., Lercher, M. (2020) The two languages of science. *Genome Biology* 21, 147. https://doi.org/10.1186/s13059-020-02057-5

Zillmann D (1999) Exemplification Theory: Judging the Whole by Some of Its Parts. *Media Psychology* 1(1): 69–94. https://doi.org/10.1207/s1532785xmep0101_5

Zohar A and Ginossar S (1998) Lifting the taboo regarding teleology and anthropomorphism in biology education? Heretical suggestions. *Science Education* 82(6): 679–697. https://doi.org/10.1002/(SICI)1098-237X(199811)82:6<679::AID-SCE3>3.0.CO;2-E

Author Biographies

Rockwell McGellin

Ann Grand

Miriam Sullivan is a lecturer at Curtin University. Her research focuses on how we can evaluate the effectiveness of science outreach methods.