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

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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 Kruskal-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 $r \leq 0.1$ representing a small effect, $r = 0.3$ representing a medium effect, and $r \geq 0.5$ 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 $r \leq 0.07$ represents a small effect, $r = 0.21$ represents a medium effect, and $r \geq 0.35$ 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 Kruskal-Wallis 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 Kruskal-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 (Ferland 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.

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