A learner's tactic: How secondary students' anthropomorphic language may support learning of abstract science concepts

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Abstract

For much of the past century, the predominant view within science education has been that students' anthropomorphic explanations hinder their learning of science concepts. This view has been supported in part by evidence of the tendency for young students to use anthropomorphisms, and a perception that this tendency declines with age. This article draws upon recent research with adults and young students to suggest that it is not age but the degree of one's knowledge that indicates the tendency to use teleological anthropomorphisms, and that these analogies may be a first response of the learning mind when confronted by a lack of understanding, or inability to recall previous knowledge about a problem. This article then reports on evidence from a multiple case investigation into anthropomorphic utterances made by 11-15 year old students in chemistry, which took place in eight classes in seven schools in the UK. The data comes from a wider study of an innovative pedagogy to teach particle theory. Anthropomorphic utterances were explored via ethnographic analysis of seventy-two interviews taken at pre, post, and delayed stages. Findings suggested that interviewees used anthropomorphisms across a range of tactics, including self-reflexive, metacognitive approaches by which some students would 'talk around' unknown concept features. The study supported a hypothesis of Taber and Watts (1996) that anthropomorphisms reduce as understanding of a science topic improves, and suggested a potential for the assessment and teaching of anthropomorphic analogies in secondary science.

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Anthropomorphisms: a changing debate

Anthropomorphic analogies relate human attributes to non-human phenomena (Taber & Watts, 1996). The utility of anthropomorphic analogies within science education has been a subject of caution and debate for decades. Framing this debate is evidence that children (Looft & Bartz, 1969; Laurendeau & Pinard, 1962) and adolescents (Jungwirth, 1975; Gilbert, Watts & Osborne, 1982; Taber and Watts, 1996) intuitively choose anthropomorphic, teleological explanations, in which 'cause' is assigned to desires and perceptions (e.g., atoms *want* to form bonds), as part of their scientific reasoning. For the past century, this tendency has been perceived as an obstacle to learning, to the extent that Jungwirth, for example, in concluding a study of 300 Israeli secondary school biology students, argued that their reliance on anthropomorphism had reached the point of 'alarming' levels, which indicated an 'emergency' (1975).

Since Piaget first described animistic ideas in young children (1929) there has been a perception that intuitive anthropomorphic reasoning is an aspect of *childhood*

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development. This has been supported by longitudinal, quantitative studies that suggest that anthropomorphic reasoning declines as students mature (Laurendeau & Pinard, 1962; Friedler, Zohar, & Tamir, 1993; Looft & Bartz, 1969). This appears to have influenced the perception of anthropomorphism as a syndrome of youth, in that it has been related to the physical maturation of the human mind (Horne, 1958; Laurendeau & Pinard, 1962). Although Oakes pointed out that anthropomorphisms were common amongst ancient adult Greeks in their descriptions of scientific phenomena (1956), and others argued that anthropomorphic models may be a valuable means to teach science to primary aged learners (Horne, 1958; Sharefkin & Ruchlis, 1974) there has been little research over the past forty years to investigate the potential affordances of secondary students' anthropomorphisms. The lack of research into anthropomorphic reasoning has led Watts and Bentley to claim that there had been an 'exorcism' of anthropomorphism from science (1991) and led to Zohar and Ginossar's description of its *taboo* status in biology (1998, p. 682).

The traditional view amongst educators has been to caution against teaching approaches which may promote anthropomorphisms (Jungwirth, 1975; Friedler et al., 1993; Taber & Watts, 1996; Treagust & Harrison, 2000; Kallery & Psillos, 2004). In the past two decades, however, research has shifted from investigating frequencies of anthropomorphism towards a focus on the potential affordances of anthropomorphic analogies in science. For example, based on an interview analysis of A-level (17-18 year-old) chemistry students, Taber and Watts (1996) argued that the affective and social effects of *some* anthropomorphic analogies may help promote conceptual development with secondary students (p. 566). Zohar and Ginossar (1998) revealed positive results from two quantitative studies on the influence of anthropomorphic analogies taught to high school biology students. Watts and Bentley (1991; 1994, p. 86) argued that these analogies could help to engage girls in Science, by *humanising* an otherwise traditionally mechanistic approach to scientific reasoning. Taber and Watts, (1996), held that some 'descriptive' analogies were less prone to elicit tenacious misconceptions than other 'teleological' analogies. Hellden's (2005) longitudinal study of biology students from age nine to fifteen, led him to observe that students' anthropomorphic reasoning played an important role in conceptual development, and to reiterate a claim of Zohar and Ginossar (1998) that students' anthropomorphic ideas do not inevitably hinder learning.

The perception that anthropomorphic reasoning is mainly a childhood trait has likewise been challenged by recent evidence that it has also been found in the reasoning of young adults, such as Taber's findings in extended interviews of 17-18 year old chemistry students that 'students believed that reactions occurred because of the 'needs' of the atoms involved' (2007). Also, Friedler et al, (1993) employed a Causal Anthropomorphic-Teleological Reasoning (CATR) oral personal interview tool with 168 students, of which sixty-eight were university students, and found that a subgroup of fifteen education majors exhibited a high level of TEL/ANT [teleological/anthropomorphic] reasoning. From this they concluded:

> Taking into consideration that those students have a higher level of education in comparison with an average adult in the general population, it

> may be concluded that TEL/ANT reasoning is fairly common in the general [adult] public. (p. 443)

Not age-related, but situation-related anthropomorphic tendencies?

The authors concluded that education mitigated the tendency to anthropomorphise. Based on their biology student sample, they noted that, 'a linear relationship exists between the study of biology and the possession of causal, non-teleological reasoning' (p. 443). This comment was of particular interest in respect to a recent psychology study with university biology students (Kelemen & Rosset, 2009), that suggested that despite their education, the students nonetheless employed TEL/ANT reasoning in *specific* situations: Their study indicated that college students, with a higher degree of science knowledge than the general population, tended to rely upon these explanations when response time in testing was reduced (i.e., questions were shown on a monitor for 3200ms rather than 5000ms). When response time was extended (to 5000ms), students provided more scientific explanations. In this study, a 3200ms reaction time reduced the subjects' access to their knowledge. Such findings suggested that it may not be age or experience that indicates the level of anthropomorphic reasoning in a learner, but rather the availability, or accessibility of knowledge.

A first heuristic

The idea of anthropomorphisms as an initial reasoning tactic has been mooted previously within science education, albeit in respect to a different situation of inaccessible knowledge. Commenting upon a 1999 study on students' initial explanations of an investigation into a chaotic pendulum, Wilbers and Duit (2006) first appeared to corroborate previous research into frequencies in their observation that 'a remarkable number of students use animistic dictions' (p. 46). They then made the interesting observation that, 'However, [the animistic analogies] do not appear to hamper understanding but merely serve as first heuristics'. As with Kelemen and Rosset's students, it appeared that an initial impulse in both secondary students and adults trained in science was to employ human analogies within their explanations.

The investigation: physical simulations

Aside from these studies, there has been little research into how students' perceive, and how they employ anthropomorphic analogies in science. Given that these analogies may support conceptual learning (Zohar & Ginossar, 1998; Hellden, 2005) then what might be the affordances? This article reports on an exploration of this question. It relates to one research question within a larger study: an exploration of conceptual development when role-play pedagogy is used to teach particle theory topics to students aged 11-14.

The study followed upon recent research that explored how drama-based activities were being used as a 'classroom resource' (Neelands, 1984) by five typical science teachers in physics, biology, and chemistry, across the ages of 11-16 (Author, 2009) in which a pedagogical model of teaching approaches was developed. Known variously as physical simulations (Author, 2009), drama models (Metcalfe, Abbot, Bray, Exley, & Wisnia, 1984), and role play simulations (Aubusson, Fogwill, Barr, & Perkovic, 1997) such activities use mime and imagination to create dynamic models of phenomena such as electric circuits (Tvieta, 1996), the decomposition of copper carbonate (Wilson & Spink, 2005), and neurons (McSharry and Jones, 2000). A small group of quantitative and qualitative studies in the past thirty years had suggested that physical simulations engender learning of abstract concepts (Metcalfe et al., 1984; Tveita, 1993; 1996; Aubusson, et al. 1997). However, the field was as yet undertheorised (Odegaard, 2003; Aubusson & Fogwill, 2006). Furthermore, studies had tended to consist of small samples, single case designs; or employed complex intervention designs which were not sufficiently clear to be replicable: issues within cross-curricular drama that have made comparison difficult in previous meta-analyses (Conard, 1998; Harvard-Project-Zero, 2001). These issues warranted an exploratory approach into the relationship between the characteristics of lessons in which these strategies were employed, and of students' resultant conceptions. The study design replicated teaching protocol in intervention lessons across eight cases, with qualitative analysis at case and cross-case levels. The key research questions were:

How can physical simulations promote conceptual development of particle theory topics in secondary science?

- What are the features of student interaction that may support conceptual development?
- What are the characteristics of students' resultant conceptions?
- Does the pedagogy develop conceptions which promote or enable further development?

Some researchers have noted that physical simulations employ anthropomorphic analogies, both implicitly in the resource (students) and explicitly in the content (Metcalfe et al. 1984; Aubusson & Fogwill, 2006; Author, 2009). Given the debate over whether anthropomorphisms hinder or help conceptual development in science, it was felt that this issue warranted a subsidiary question into the degree that concepts may be mediated through anthropomorphic imagery:

What are the features of students' anthropomorphic analogies that may support conceptual development in chemistry?

Sampling

Eight classes were chosen on an opportunity sampling basis, with the intention to explore the pedagogy across a variety of learning environments and a diversity of abilities, genders and schools (Table 1). Classes were drawn from UK state and independent schools across three counties. Students' ages within the study were from 11-15, which allowed for a range in the maturity and sophistication in student responses.

Table 1
Sample sizes for cases and total number of students

Case	**Year**	**School type; (size)**	**Age**	**Ability; special features**	**Number of students**
1	9	State	13-14	high ability; early GCSE group	26
2	7	Independent	11-12	mixed ability	18
3	10	State	14-15	mixed ability	18
4	7	State	11-12	low ability	20
5	9	State	13-14	mixed ability	23
6	9	State	13-14	mixed ability; multicultural	27
7	9	State	13-14	mixed ability	24
8	10	independent	14-15	high ability	18
				Total	**174**

Interventions

Each intervention was delivered over a double-lesson period consisting of 70 to 100 minutes, depending on the standard length of the schools' individual lessons. Each followed a research model developed in Author's (2009) study of science teacher's drama-based approaches. The research model provided an opportunity for an iterative, model-making format, in which the modeling resources were the students themselves. It began with what Mortimer and Scott have identified as interactive/authoritative teaching (2003) and progressed towards the construction of interactive/dialogic learning environments in which students were asked to engage in group thought experiments, the results of which they performed to the class, and then evaluated within a forum session (see Author, 2009, p. 18).

Data collection

In light of criticisms by Conard (1998), above, this research supported comparison across investigations with similar methodologies, by treating each intervention as constituting a case. Informed by Stake's ethnographic approach (2006), these were treated as idiographic, in order to retain an understanding of the situated nature of the lesson. The study later included a multiple case study analysis in order to generalize across cases (see Analysis). Following Stake, data collection foregrounded the inclusion of multiple perspectives, focusing on triangulation across a wide and varied range of sources (2006). Data for this study consisted first of seventy-two student interviews, eight videotaped interventions, eight teacher interviews (to elicit their 'expert' observations of the interventions), and school documentation. Video data was employed in order to provide a detailed script of verbal and non verbal events (Franks and Jewitt, 2001, p. 206).

Table 2
Interview Durations

Stage	Teacher (minutes)	Each student (minutes)	Total per Case (minutes)	Total for the study (minutes)
Pre test		30	90	**720**
Post test	40	40	160	**1280**
Delayed post test		30	90	**720**
Total time	40 (and informal conversations)	100	340 (7hrs) **10 interviews per case**	**2720 (45.3 hrs)** 80 interviews in total

Interviews

The primary data upon which this article reports is the students' interview data. In a purposive sample, three students from each class were given pre, post, and delayed (at four months) interviews (Table 3). The students were interviewed separately. Each student interview lasted approximately thirty to forty-five minutes. Each interview was semi-structured, consisting of a set of open questions, allowing the opportunity to probe for more detail. Flexible, semi-structured interviews have been argued to provide a systematic framework which makes pattern-matching in analysis easier than with a more unstructured interview design (Cohen, Manion & Morrison, 2000). Students were asked to generate concept maps and drawings in order to stimulate discussion and focus the interviews.

The pre-interviews elicited data for an interpretation of baseline understanding of the topic concepts. The data also informed the design of the lessons, providing an indication of the students' cognitive levels, their previous experience of the topic, their personalities, their perceptions of classroom management and their normal group work configurations. These were done within a day of each intervention.

The post interviews aimed to elicit participant perspectives which would support analysis of student behavior during the intervention. In respect to this article, they also aimed to provide evidence of the interviewees' resultant conceptions. Responses were compared to baseline, pre-interviews, and with the delayed interviews in order to explore differences in understanding of the topic concepts. In this stage, data collection began within a few days of each intervention. The initial three students in each class were again interviewed individually, with a semi-structured approach similar to the pre-interview protocol. This post interview included a focused interview approach, which elicited 'subjective responses to a known situation' (Cohen et al., 2000, p. 273), i.e., to the interventions.

The delayed data collection aimed to provide evidence of longer-term conceptual development. The protocol was similar to the post interview, with the three student interviewees asked to recall the topic concepts and apply their understanding to thought experiment-type questions. This final set of interviews was conducted between three to four months, using a similar semi-structured design as with the post intervention interviews, but with no simulated recall. This provided further longitudinal data for an interpretation of the utility and durability of students’ emergent conceptions over the medium term.

Table 3
Case Data Collection

	Pre interview	**Intervention**	**Post interview**	**Delayed post interview (at 3-4 months)**
Intervention		(approx)1hr 15min lesson; Either KS3 or KS4 particle theory - curriculum topic		
Data Collection Method	Semi-structured interviews for students and teacher (30min each)	Participant observation (researcher); two video recordings of the lesson observation of lesson by the class teacher	Semi-structured interviews for teacher and students (40min each)	Semi-structured interviews for students (30min)
Rationale for data collection methods	Provided a baseline context for student understanding	Data collection provided multiple perspectives through which to explore descriptions of interaction.	Highlighted key behaviour and student expressions during the intervention; compared students post concepts with baseline data	Explored features of students’ delayed conceptions; enabled comparison of base and post interviews
Specific resources	Concept maps; drawings	Three video recorders per class	Concept maps; drawings; stimulated recall	Concept maps; drawings

Analysis

Analysis occurred at case and cross-case levels. Eight individual case analyses were done before the multiple case analysis. Each case was treated as an ideographic, bounded study, as advised by Stake (2006). The analysis began with a series of initial themes identified within the literature review. These themes provided a focus which helped to draw out data that resonated with the themes. New patterns in the data generated new themes: Stake noted that during this analysis process, the researcher becomes attuned to themes which are either subtle or submerged in the data (2006). Through triangulation, the strongest patterns or differences then became the case findings. In relation to anthropomorphism, these included initial and emergent themes:

Initial themes:

- The scope and breadth of anthropomorphic utterances
- The extent to which anthropomorphisms were either *strong* or *weak*, using Taber and Watt's (1996) theory which categorizes these into descriptive and teleological analogies (described in detail below).

Emergent themes:

- The degree to which anthropomorphic utterances occurred within self-reflexive contexts
- The ubiquity of anthropomorphic analogies across the secondary ages and across gender

(These themes form the sub-headings in the following Findings section)

Analysis of strong and weak analogies

Within this analysis, and pertinent to this article, anthropomorphic utterances were identified and categorized according to a classification theorised by Taber and Watts (1996). They presented a dichotomy of *strong* and *weak* anthropomorphisms. In this classification, *strong* anthropomorphisms were those which provided teleological explanations for processes, and tended to promote tenacious alternative conceptions. *Weak* versions tended to be descriptive, and promoted more labile conceptions. **The results of the analysis are presented at the start of the findings section,** and include a table of anthropomorphic utterances across the interview stages (Table 4).

Findings

Scope and Breadth of anthropomorphic utterances

The discussion below is not an attempt at quantitative analysis, but rather aims to juxtapose the data in order to illustrate patterns and differences discussed in subsequent sections.

Anthropomorphic utterances were recorded in twenty of the twenty-four student interviews, across all interview stages, in all cases, and from both younger and older boys (e.g., C4:S3 (11 year old); (e.g., C8:S1 (14 year old)), and girls (e.g., C4:S2 (11 year old); C1:S3 (13 year old)). Of the seventy anthropomorphic utterances from twenty-four interviewees, thirty utterances occurred in the pre-intervention interviews while nineteen occurred in the post intervention interviews, and twenty-one in the delayed interviews. Of these, twenty-seven utterances were made by four students across three cases.

Table 4
Anthropomorphic utterances in interviews

Pre Intervention	*Post intervention*	*Delayed Interviews*
Particles		
Liquid particles are like dancing. C4:S3 They are living; with heat they will die – disappear. C4:S3 Microorganisms*. C2: S3 Particles want to move around*. C2:S3 *Particles are squashed together.* C3:S2 Tiny little things that live in different things. C3:S2 They are trying to push away from each other because there are so many they are all like crashing. C8:S3 They have got more energy to move around so they like need more space. C8:S3	*Solid particles are strong in a line.* C4:S1 Alive because they are moving*. C2:S3 Alive because they are moving*. C4:S2 Gas is where the particles are allowed to move randomly. C1:S2 They are not allowed [to move], and it is just like nature. C1:S2	*Pretend that particles are like little men… they like grab the [heat].* C3:S3 *A solid goes crazy with heat.* C4:S1 [Particles] and microbes are both living things. C4:S2 *Well the [halogen] is like gas jumping around all the time, and in a liquid they are more like more relaxed.* C6:S1 *One particle is more hyperactive.* C5:S3 [Solid particles] want to get away but they can`t. C1:S1 A particle, the hotter it gets, the more excited it gets, and so it moves. C1:S1
Dissolving		
Sugar will come to little pieces because they will struggle at the force of water which is trying to get rid of tiny bits of sugar. C4:S3 *[Water particles] kind of intercept [sugar particles] and make them spread apart.* C1:S2 *…it has mixed and diffused within the, diffuse isn't the right word but you know, spread itself out with him the water and water has managed to hold it in it.* C8:S1 *However, some of [the gas particles] still manages to go right to the top. C8:S1* Because the hotter it gets, like the	The gas is like, it needs more energy than them, if you know what I mean. C8:S3 The water is warm the gas can’t get out of the way. If you see what I mean. C8:S3	*And it would try to break the bonds... No but trying, it isn`t a human thing.*C8:S1

more lively the atoms get and try and break out. C8:S2 The coke with go lively, like they will try and get away as well. C8:S2		
Diffusion		
Gas wants to escape a bottle*. C4:S2 Particles kind of, like, want to breathe. C4:S2 And they try to move and all they do is vibrate. C6:S3 [Particles] get more excited and they move around, and then they just kind of break free. C1:S3 They would try and equal, and balance themselves out. C1:S2	Particles are trying to get out [of a bottle]. C4:S2 They will die with too much heat. C4:S3 *Maybe to the particles, it might be, like, fast.* C4:S3 Yes, so they kind of run and kind of bump into each other and release the smell. C1:S3	*Gas particles splurt out… they are all waiting, smashing against the lid.* C2:S3 In a couple of hours they will start to die. C2:S3 Gas particles try to go as fast as they can.* C1:S1 Gas particles always want to make things balanced.* C1:S1
Pre Intervention	***Post intervention***	***Delayed Interviews***
Atoms		
Nucleus is the heart and brain of the atom. C5:S1 There's a brain inside the nucleus. C5:S3 Nucleus has organisms inside which make it work, or just do its job properly. C5:S3	Nucleus is the brain. C5:S1 Nucleus is kind of like the brain. C5:S3 *The tiny time things, that like, sit on the end of a, sit on the end of a pin.* C7:S3 Atoms, atoms of gas, I guess. Just, like, dancing about. C7:S1	*That they travel around in pairs, the atoms are in pairs.* C6:S3 *Nucleus is sort of the brain of the atom… it is not a living thing but it decides…* C5:S1
Ions		
Starting to fill the fourth shell, and then deciding that it could actually have another ten. C6:S3 And the Chlorine has kind of like given [the electron] up in the chemical reaction. C5:S3 *[Two types of] elements grabbed each other to make a bond.* C5:S1 An atom wants to gain an electron, to become stable, like the noble gases, which is when it has a full outer shell. C6:S1 *Gaining an electron is negative because if you gained weight you wouldn't be too happy about it.* C5:S2	*Before I pictured dots on paper and now I picture people.* C5:S3 *It takes the electrons, to make the full shell.* C5:S2 They sort of try to have a full shell. C5:S2 One electron is sent off to complete the shell, which makes them stay in a fixed place. C5:S1	It needs to attract one more, needs to obtain one more electron. C6:S1 Because this one needs to lose electrons to gain a full outer Shell, that's what they are all trying to achieve. C6:S3 …so they need one more electron to become, to obtain a full outer shell. C6:S1 It wants to make it neutral so it causes a loss of an electron. C5:S2 One atom loses its electron to give it to another so they can complete their outer shell.

		C5:S3 It would prefer to be; yes; like a person, because like then it could have a full shell of electrons. C8:S3
Displacement Reactions		
War between two halogens for an alkali ion. C5:S1 Like planets that feel weaker. C5:S1 *They kind of like the battle with the other elements, and will displace that element out and make a compound.* C6:S1		*I think it should be nearer to the fluorine, so that it can steal the electron away.* C6:S1
Utterances: 30	**19**	**21**

Note: *Italics*: weak anthropomorphism
Regular Calibri font: strong anthropomorphism
Case number and student number are included: i.e., C5:S2
N.B. Ambiguous examples such as 'floating' and 'bouncing' which could be construed as machine analogies were omitted from the table. At times, utterances were shortened for ease of representation, and are marked with an asterisk.

Strong and Weak anthropomorphisms and their association with particular features in the topic concepts

Anthropomorphisms spanned a breadth of topics and focussed on concept features related to movement (C4:S3), shape (C5:S3), inter molecular (C1:S1) and intra molecular forces (C6:S1). Of the total, twenty-two appeared to reflect 'weak' anthropomorphisms in which the students aimed to describe, rather than explain a phenomenon. Examples included particles 'dancing' (C4:S3); 'jumping' (C6:S1); 'go[ing] crazy' (C4:S1); 'battl[ing]' (C6:S1); 'grab[bing]' (C3:S3); and 'pulling' (C4:S3). These descriptions tended to be used once, and did not recur across interview stages.

'Strong' anthropomorphisms were interpreted in thirty-eight utterances. There were two predominant situations in which these occurred: in explanations of particle movement in states of matter, and in explanations relating to mechanisms for interaction between ions. The states of matter examples emphasised 'intentions' as an aspect of why particles move (or do not move) as illustrated in a description of gas particles, in a container, when the top is opened:

> Particles kind of, like, *want* to breathe [and therefore escape].
> (C4:S2 pre intervention)

Some utterances also suggested *competing* intentions, with the opposition between the particle objectives and the objectives of the substance (or 'nature') signified by 'allowed',

> [The solid particles] are not allowed to move, and it is just like nature.
> (C1:S2 post interview)

Further 'strong' anthropomorphisms appeared in some student responses in relation to ionisation and displacement reactions (see ions and displacement reactions in Table 4; for example, C2:S3; C6:S1). Again, the language tended to focus on intention, such as to 'want' as in,

> An atom wants to gain an electron, to become stable, like the noble gases, which is when it has a full outer shell.
> (C6:S1 pre-interview)

Or such as to 'prefer' as in this justification of a halogen's attraction of an alkali metal electron,

> It would prefer to be; yes; like a person, because like then it could have a full shell of electrons.
> (C8:S3 delayed interview)

In both examples the anthropomorphic conceptions focussed upon a mechanism for attraction between particles. These examples were interpreted to indicate an octet heuristic approach in which atoms are imbued with a need to develop a noble gas electronic configuration (Taber 1995; 1998).

Anthropomorphic utterances were a subset of a wider range of analogies employed by interviewees

As part of the wider study, anthropomorphic utterances formed only a subset of students' alternative responses. As an example of the scope of analogies, in just one case, in the pre-interviews, one student compared attraction between charged particles to plastic grey 'sticks' in molymods (chemical modeling sets) (S1pre) and another compared particle *attraction* to magnets (S3pre); two students described atom reactivity and structure in relation to radioactivity (S2pre; S3pre), and one said that an electron shell, 'helps keep [the atom] in balance so that it's not like a nuclear weapon or something... and it can become quite dangerous' (S3pre). The frequency of non-anthropomorphic analogies was not investigated in this study.

The degree to which anthropomorphic utterances occurred within self-reflexive contexts

The study found a range in the degree of self-reflexivity in which anthropomorphic responses were expressed. This was interpreted according to the degree by which the analogy as a figure of speech was made explicit by the learner. Three examples are presented in the following section that illustrate the interpretation in analysis of the scope for self-reflexive, metacognitive behaviour. For example, the following fifteen year old student, John, was asked to justify his statement that a solvent atom 'tries' to break solute bonds. The third line and final line suggest that John was unaware of the anthropomorphic nature of his reasoning. In this, and in subsequent passages, the interviewer's lines are italicized.

> And it would try to break the bonds.
> *Okay, it tries to break the bonds.*
> Oh, I am sorry, it would succeed actually
> *No but - 'trying'. Is it a human thing? Like is it actually going like, 'C,mon guys.'?*
> Alright, yes.
> *Is it doing that? Does it want to do this [break the bonds]?*
> I think it wants to.
>
> (C8:S1 delayed interview)

After an initially open-structured questioning, the interviewer subsequently aimed to challenge John's perception of 'tries' by exaggerating the concept of *intention*, '…does it want…'. Although the prompts can be seen to lead the student, the interest in John's response was not that he accepted the term 'wants', but that it suggested an interpretation of his confusion. John initially vacillated and became more tentative in his responses, as if trying to re-orient himself to the prompt. John's mimicking of the term 'want' in his final response, his acceptance of the term in light of his initial bewilderment suggested that his level of awareness of the figurative nature of his explanation appeared ambiguous at best.

By contrast, the passage below suggests the use of anthropomorphic language within a more explicitly metaphorical context. This thirteen year old, Maddy, corrected the interviewer for using her analogy as a literal statement. This occurred while defining the show card term, 'particle'. She said,

> I'm not quite sure what [particles] are but they are like quite tiny little things that live in other things.
> *Tiny little things that live in different things.*
> Yes.
> *So when we talk about particles in solids and in the air, they are, you say that they are tiny little things that live in other things. Do you mean-*
> They don't actually live.
> *Oh. Don't live.*
> No. They are just there.
>
> (C6:S1 pre-interview)

Maddy began her explanation tentatively. Her response was hedging, as espoused by her use of the vague words, 'quite', 'tiny little', and 'other things'. This contrasted with the authoritative tone of her final two sentences. Given her clarification of the metaphor 'live in', it is plausible that she expected the metaphor to be understood by the interviewer. To this extent, Maddy appeared to have a metacognitive awareness of 'live in' as an analogy for the concept of 'existing within.'

Whereas Maddy used one anthropomorphic analogy, another student employed several. In an episode relating to ionic bonding, a fourteen year old, Morley, appeared to describe the difference in attractive force between two nuclei by comparing it with the human trait of 'deciding' which atom gets an electron. In this dialogue, self-reflexivity was suggested in the use of similes rather than metaphors, and the shift between social (i.e., deciding) and science domain (gravity) metaphors:

> So what is giving [the ion] that strength? That's what I'm confused with -- The nucleus, the one that's [there] and that's why it is basically more strong because there are more exes [electrons] around it [the nucleus].
> *Okay,*
> And it is just deciding, oh you know --
> *Deciding.*
> Well not deciding, but like, thinking, I don't know. Maybe it is like a sort of war between the two [atoms] just pulling one another, and that one wins and [that one] loses.
> *A war, pulling*
> Yes sort of pulling...
> *What is pulling? Hands coming out of the atom, harpoons?*
> I think of it as like, gravity, and things get drawn in towards it a bit, and the stronger the gravity, more like… like a tug of war.
> (C5:S3 post interview)

The term 'deciding' was one of five possible descriptions that Morley entertained, including 'thinking', 'war' 'gravity' and 'tug of war'. He indicated that these were explicit analogies through the use of similes, 'like' and 'sort of'. He also shifted his focus from human analogy to the science analogy of 'gravity', which was also made explicit by the use of 'like'. Although Morley seemed to be unable to directly identify the cause of interaction, he closed-in on a more specific meaning by juxtaposing the synonyms of 'war', 'pulling', gravity, and 'tug of war'. The example suggested an attempt by Morley to employ an anthropomorphic analogy as one of several analogies in order to 'talk around' a vague conception.

Anthropomorphic terms as substitutes for science terms

Whereas in the previous examples, students were interpreted to employ anthropomorphic language as a tactic within discussions, the following case example suggests that tactics changed over time as new knowledge was learned. Here, a thirteen year old, Ani, explained the reactivity of fluorine in relation to the other halogens. She used an anthropomorphism within an explanation that contained several scientific terms. As with the passages above, the anthropomorphism seemed to provide a substitute for a specific term or phrase.

> [Halogens] have seven electrons in their outer layer.
> *Okay.*
> Outer shell, I mean.

> *Why is that important? If it is important at all? Is it important that there are seven electrons in the outer shell?*
> Yes, because, like, it makes it more reactive like that, it tends to, it tends to, *it wants to* react with other atoms to gain an electron and like that becomes stable, like the noble gases, which is when it has a full outer shell.
>
> (C2:S1 pre-interview)

Here, Ani vacillated over her terminology, first in 'outer layer'/'outer shell' but then after trying out the term, 'tends to' she instead favoured, 'it wants to'; in doing so, Ani seemed to have provided an octet heuristic response, with 'wants to react' within her description of ionic bonding between a halogen and an alkali metal. Within the context of the passage, the anthropomorphism appeared to describe the reason, or mechanism, for interaction.

Interestingly, four days later, Ani seemed to eschew her previous, anthropomorphic language in favour of more scientific language.

> Because it has an, okay it's, it's, I think it is because it has one, it is *one electron off having a full shell*. So it is easy for an electron [sic] to become stable. And also because it is from the halogens, so it is one that *has less electrons*, so this means that *it has less shells*. So, this means that *it is smaller*, and so there is a bigger *attraction to the outer shell* [for a free electron]. So, there will be a *bigger attraction to the other atom* to react.
>
> (C2:S1 post interview)

Ani presented a series of propositions which illustrated an increased use of consensus terminology, with *full shell*, *less [fewer] electrons*, *less [fewer] shells*, *smaller [shell]*, and *outer shell*, and 'there is a bigger attraction'. Ani was now focused on the reason for interaction: highlighting distance to the nucleus as an indicator of reactivity in halogens, as 'attraction' seems to now replace 'wants to'. This is more pithily stated later in the interview:

> *Fabulous, which is the most reactive halogen?*
> Fluorine… it is smaller [than the other halogens], and so there is a bigger attraction to the outer shell. So, there will be a bigger attraction then, to the other atom, to react.
>
> (C2:S1 post interview)

Ani was more concise than previously, expressing a more confident understanding of the underlying mechanism for interaction.

A benign anthropomorphic feature which coexisted within a wider developing conception of diffusion

The evidence above suggested the mutability of anthropomorphic expressions over time. The next case example suggested the non-linearity of this mutability, when a student held a seemingly tenacious and immutable alternative conception of 'living particles' over several months which did not appear to hinder his development of a wider conceptual framework related to the process of diffusion.

During a pre-interview task when this thirteen year old, Mark, was asked to pretend to look at the world through high magnification 'magic goggles' (after Novick and Nussbaum, 1982) he described water as continuous, and air as 'nothing' (C4:S3 pre-interview). Mark had heard of particles, he said, but in all three interviews he revealed a strong sense that he believed that 'particles' were animistic (see utterances for C4:S3). For example, in one explanation in the pre-interview, in which he described the effect of heat on the particle within a solid,

> They are living. With heat they will die – disappear.
>
> (C4:S3 pre-interview)

Despite the potential for a tenacious alternative conception, in the post intervention interview Mark described an incident outside the science classroom that indicated that his particle view of gas was now more consistent with the teaching model for diffusion. He first described the macro event:

> I tried this the other day because I, cause I was bored, and I was sitting in [Design and Technology class] and I had a bottle, and I finished my bottle of drink and I was squeezing it, and I went and I caused the smell of the drink and it took a second or thirty seconds or a minute, and the smell was coming from a bit away from me. It just kind of went round and then I smelt it.
>
> (C4: S2 post interview)

Next, he described the slow movement of the smell, and explained this at a submicro level:

> So I was like, oh. Because it don't come in [I did not smell it] straight away. They [The particles] go, like, really fast but in the end it [the gas] was quite slow, and it kind of takes time to [smell] it… Maybe to the particles it might be like, fast, because they are probably teeny teeny things. ... And I think to them, because they are so far away, because we can't see them moving quite fast, to us, because they are like, in a big bunch, then it would be really slow.
>
> (C4: S2 post interview)

Here, Mark provided key features in the concept of diffusion: the gas was slow because the 'big bunch' of gas particles, which were 'quite fast', were nonetheless so small that the relative distance to us was 'far away'; therefore the particles at the macro level slowly crossed the space between the drink and the boy. In this post interview explanation, Mark applied features of the submicro world to an empirical situation, whereas his pre-interview responses suggested that he was unable to relate phenomena across these levels of representation. However, despite this visualisation, he still professed a belief in ‘living’ particles in the post lesson interviews (C4:S2 post intervention). In this context, Mark appeared to hold both scientific and alternative conceptions simultaneously in mind.

Discussion

The degree to which anthropomorphisms may support conceptual development through enabling discussion and visualization of unknown conceptual features

Anthropomorphisms were found to be ubiquitous across all interview stages, and were applied across a range of contexts. For example, while *weak* analogies tended to focus upon movement and shape, students’ more recurrent *strong* anthropomorphisms tended to focus upon mechanisms for interaction within scientific processes. The cases supported the view that the interviewees employed a range of cognitive strategies, and levels of metacognitive awareness, illustrated in the examples of John’s lack of awareness of his word choice, Morley’s use of similes as he attempted to clarify his conceptions (C5:S3), and Maddy’s self-awareness in using a figure of speech (C6:S1). Such evidence suggests that these students’ anthropomorphic responses supported their development of particle theory conceptions.

Similar linguistic tactics have been echoed in problem solving in maths (Rowland, 2000), in which student responses revealed a *vagueness* and at times a hedging quality, such as in the use of ‘it’ in maths-talk between a student and a teacher, as a means of pointing to, and talking around, a concept which was otherwise indescribable by the student (Rowland, 2000). In one example case study, with a nine year old named Susie, the vague term ‘it’ was interpreted to allow her to stay immersed in a discussion about an abstract concept without knowing the appropriate terminology:

> … Susie’s use of the deictic ‘it’ enables us to share and discuss a concept which Susie possesses as a meaningful abstraction, yet is unable to name it.
>
> (p. 107)

Within this context, Rowland indicated the utility of such utterances as a placeholder expression for a conceptual gap within a wider conception. In relation to students’ anthropomorphic utterances, a key interpretation of this placeholding was that it allowed students to continue within their narratives of a process, and so piece together the conceptual features that they knew around those that they did not know.

Likewise, in both the short and longer term, the anthropomorphisms in this study seemed to provide the learners with time to ‘live with’ poorly understood conceptual features as they continued to construct wider conceptual frameworks in spite of gaps in their knowledge. This was suggested most clearly with Ani who in the post interview eschewed the anthropomorphic terms in favour of scientific terms in relation to ionisation. A different example of ‘living with’ came to light in Mark’s example, which reflected a situation that Bouwma-Gearhart, Stewart, and Brown have termed a dual-model approach (2009, p. 1167), in which a student holds two models that conflict, but does not realize that there is such a dichotomy in his understanding of the concept. In this example Mark developed an appropriate visualisation of particle movement in diffusion, without it conflicting with his conception of an animistic mechanism for particle movement.

An adaptation for when recollection of conceptual features is incomplete

As an exploratory study drawn from the interview data of a sample of twenty-four students, the claims made here do not aim to generalise beyond the multiple case study, but rather draw together and support recent research that suggests the plausibility of a greater scope for the utility of students' anthropomorphic analogies. In this context, it suggests scope for further research into viewing anthropomorphism as a *first heuristic* (Wilbers & Duit, 2006). This initial reasoning tactic has plausibility from an evolutionary perspective, given that the mind regularly omits sensory information due to limitations of attention (Proctor, Johnson, & Nieuwenstein, 2004, p. 192); information may not encode from short into long term memory, and other information may not be recalled when required (Cowan, 2005). As it conceptualizes and re-conceptualizes its models of the world, the mind has evolved heuristics which use its own experiences to bridge the missing, lost, or damaged conceptual features within a wider framework (Whittlesea & Leboe, 2000; Leboe & Whittlesea, 2002). This study draws attention to such heuristics in students' development of science concepts.

Further investigation into anthropomorphic responses might provide a lens for investigating processes of conceptual change over time. Ani's response, for example, suggested the potential in Taber and Watt's hypothesis,

> If *strong* anthropomorphism is just a stage in developing understanding, then one might expect anthropomorphic language to diminish as other levels of explanation become available (1996, p. 565).

In light of Ani's example (C2:S1), a study that aimed to investigate the degree to which students' ascribed anthropomorphisms to specific conceptual features may reveal that the edges or boundaries of students' conceptual understanding can be found, for example, in later interviews and in discussions where new scientific expressions and anthropomorphic expressions are juxtaposed. Corroboration of Taber and Watts' (1996) hypothesis might provide a tool for teacher assessments of student learning: Attention to patterns in students' use of anthropomorphic analogies, and the situations in which students rely upon them to create narratives of conceptual processes, may direct teachers to focus on the specific features in a concept that are hindering further development.

The study's findings support research within analogical reasoning in science education and psychology that suggest a shift away from a view of particular analogies as 'good' or 'bad' towards a situated view of analogies (Aubusson, Harrison, & Ritchie, 2006), wherein the central affordances are the familiarity of the base concept, and the students' metacognitive understanding of the key relations between base and target concepts (Gentner, Bowdle, Wolff, & Boronat, 2001; Goswami, 2001). By allowing students to draw upon personal experience in constructing their initial models of phenomena, then teachers may help to engender meaningful learning through discussion (Harrison & Treagust, 2006). Through the imaginative application of student-centric analogies, students may also derive the affective benefits of co-constructing scientific models with which they can gain ownership (Treagust,Chittleborough, & Mamiala, 2002). In this way, the teacher may be viewed as supporting a learner’s own tactics for conceptual development, highlighting anthropomorphism as a potential aid rather than a hindrance to learning.

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