Teleology in biology, chemistry and physics education: what primary teachers should know

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ABSTRACT

Recent research in cognitive psychology suggests that children develop intuitions that may clash with what is accepted by scientists, thus making certain scientific concepts difficult to understand. Children possess intuitions about design and purpose that make them provide teleological explanations to many different sorts of tasks. One possible explanation for the origin of the bias to view objects as made for something derives from an early sensitivity to intentional agents and to their behavior as intentional object users and object makers. What is important is that teleological explanations may not be exclusively restricted in biological phenomena, as commonly assumed. Consequently, primary school teachers should take that into account when teaching biology, chemistry or physics concepts and try to refrain from enforcing students' teleological intuitions.

KEY WORD

Teleology, biology, chemistry, physics

RÉSUMÉ

La recherche récente en psychologie cognitive suggère que les enfants développent des intuitions qui peut être en conflit avec ce qui est acceptable par les scientifiques, faisant en effet certains concepts scientifiques difficiles à comprendre. Les enfants possèdent des intuitions pour dessin et but qui les font donner des explications téléologiques à des problèmes différentes. Une explication possible pour l'origine du biais de considérer les objets comme désignés pour faire quelque chose dérive d'une sensitivité antérieure aux agents intentionnels et de leur compor-

tement comme usagers de but intentionnel et fabricateurs d'objets. Ce qui est important est que les explications téléologiques peut ne pas être exclusivement limitées aux phénomènes biologiques, comme on croit souvent, En conséquence, les professeurs de l'école maternelle devraient considérer cela quand ils enseignent des concepts biologiques, chimiques ou physiques et essayer de se retenir de renforcer les intuitions téléologiques des étudiantes.

Mots-clés

Téléologie, biologie, physique, chimie

Introduction

The main problem with teaching science to children does not have to do with what they do not know, but with the preconceptions they possess, which can be major obstacles in understanding the scientific concepts they are taught (Carey, 2000). Studies in conceptual development research suggest that children develop intuitions that may clash with what is accepted by scientists. Consequently, it can be very difficult for children to understand and accommodate scientific concepts that seem counter-intuitive. Moreover, resistance to scientific ideas may derive from intuitions which originate in childhood and which may persist into adulthood. In general, both adults and children have been found to resist acquiring scientific information that clashes with their intuitions and the main source of resistance depends on what children know before they are taught about science (Bloom & Weisberg, 2007).

For example, children's belief that unsupported objects fall downward makes it difficult for them to see the world as a sphere; if it were a sphere, objects on the other side should fall off. It is not until about 8 or 9 years of age that children demonstrate a coherent understanding of a spherical Earth, and younger children often may deny that people can live all over Earth's surface (Siegal, Butterworth & Newcombe, 2004). Just as children's intuitions about the physical world make it difficult for them to accept that Earth is a sphere, their psychological intuitions about purpose and design make them see the world in teleological terms. Pre-school children may insist that every entity, living or non-living, exists for a purpose. It is possible that the bias to view objects as made for something derives from an early sensitivity to intentional agents and their behavior as intentional object users and makers. The subsequent development of a teleological bias might occur because young children draw on their early knowledge of human intentional behavior. As a result, in the absence of other explanations, they treat objects of all kinds as artifacts that have been intentionally designed (Kelemen, 1999a).

The aim of this paper is to suggest that primary school teachers should be careful when teaching biology, chemistry, or physics concepts and try to avoid enhancing students' preconceptions and teleological intuitions.

Teleological Explanations in the History and Philosophy of Science

Teleological explanations characterize the philosophies of Plato and Aristotle (Lennox, 1992; Ariew, 2002). In *Timaeus*, Plato attempted to explain the creation of the universe as the artifact of a Divine Craftsman or Demiurge. For Plato, the final cause of the creation of the universe was the transfusion of the soul of the Demiurge in His artifact, something that could be achieved by the imposition of order over disorder. Order in the perceived universe was equal to the existence and domination of the mind. The universe should have a body, but a mind and a soul as well in order to be a perfect artifact. Hence, the major aim of the Demiurge was to form the universe and create its soul. This process had to take into account the actions of Need that seemed to impose constraints to the work of the Demiurge. Need was a second force, after the Demiurge, and referred to the properties that had to do with the atomic structure of matter. Thus, Plato recognized two types of causes: the divine (final) and the necessary (mechanistic), and thought that they were interdependent and not in conflict. Consequently, the universe was an artifact that resulted from the purposeful and rational action of the Demiurge that finally dominated over the irrational Need (Kalfas, 1995; Lennox, 2001).

On the other hand, Aristotle thought that there were four causes acting within nature and that knowledge could be gained through their understanding. These causes were the efficient cause, the material cause or matter, the formal cause and the final cause. Aristotle considered all four causes necessary for explanations. Final causes referred to goals that in order to be achieved required to be preceded by a particular event. But, contrary to Plato who thought that final causes were external, set by the Demiurge, Aristotle thought that final causes were internal and served the maintenance of the organism. In particular, the final cause for the existence of an organ would be its usefulness to the organism that possessed it when it would use it. In other words, Plato accepted teleological explanations as long as whatever was being explained was the outcome of rational design whereas Aristotle thought that organisms acquired some features because they were functionally useful to their life, without any requirement of a preceding purpose or design (Kalfas, 1999; Lennox, 2001).

Teleological explanations, either in the Platonic or in the Aristotelian sense, can be found in several cases in the history of science. For example, Johannes Kepler was a Platonist, like most of his 17th century contemporaries, and thought that the universe operated according to harmonic principles. While he accepted Copernicus's idea that there were six planets, he was puzzled over why this had to be the case, and eventually came up with the idea that the number of planets might be related to the number of solid figures that could be constructed using Euclidean geometry (octahedron, icosahedron, dodecahedron, tetrahedron, and cube). This idea was based on a mystical belief that the heavens must be governed by geometry. However, he later rejected this idea as he came to realize that the shape of the orbits of the planets were actually elliptical (Gribbin, 2003, p. 54-56). Joseph Priestley believed that there was an aerial economy in nature, meaning that different airs played particular roles in the natural order. He regarded this as a proof of divine benevolence, a natural mechanism through which God kept the world in a state of equilibrium. Priestley in general thought that everything in nature had a role to play in order to maintain its economy (Bowler & Morus, 2005, p. 64).

These cases, from the history of physics and chemistry respectively, are examples of Platonic teleology. An example of Aristotelian teleology can be found in the history of biology. Georges Cuvier reconstructed the fossilized remains of extinct animals and postulated geological catastrophes that had wiped out populations from entire continents. However, Cuvier's teleological view of life prevented him from realize that extinct species were supportive for evolution which he considered impossible. He thought that entire species could go extinct due to catastrophes but could not change into something else. If the structure of the organisms was arranged in teleological terms, the transition from one form to another would be precluded as transitional forms would have modified parts that would fail to serve the purpose of the organisms overall well-being (Bowler & Morus, 2005, p. 136-138).

In many cases teleological explanations had heuristic value because they supported the discovery of how natural phenomena occurred. This is more clearly illustrated in the case of Aristotelian teleology. The teleological approach actually made Aristotle notice functions that could not have been noticed in a solely descriptive approach. In *Timaeus*, Plato had described the possible role of invisible structures in the organisms' functions, thus failing to identify the exact structures that were involved in particular functions. On the contrary, Aristotle having studied systematically the anatomy of organisms succeeded in explaining in detail which structures were related to particular functions (Cosans, 1998). However, this does not mean that he had a full understanding of these functions. It is one thing to discover what a structure does and another thing to explain why and how it does it.

Students' Intuitive Teleological Explanations

Teleological explanations seem to prevail in student's reasoning about natural phenomena, especially biological ones. Two proposals have attempted to explain the origin of students' intuitive teleological explanations. According to one proposal (selective teleology) children have selective ways of interpreting the world in teleological terms. They exhibit an innate tendency to view entities as 'designed for a purpose' from early in development, and view artifacts such as chairs, and biological properties such as ears, as existing to perform functions. Children are also aware that while artifacts exist to serve external agents, biological traits exist for the benefit of the organisms that possess them. This understanding is considered indicative of children's sensitivity to biological causality. As a result, when considering the natural world, they restrict their teleological reasoning to the properties of living things, thus differentiating them from non-living natural objects, such as mountains, which they view in entirely non-functional terms.

In a study, pre-school and second-grade children were shown either an emerald or a plant and were asked to choose between two explanations for the object's green appearance: a teleological explanation (e.g. they are green because it helps more of them to survive) and a physical explanation (e.g. they are green because tiny parts mix together to give them a green color). Both pre-school and second-grade children preferred teleological explanations for plants and physical explanations for emeralds (Keil, 1992). However, while the findings of this study are suggestive, the interpretation of these results has been questioned. Specifically, the wording of the teleological explanations always involved verb phrases such as 'it is better for A to have B', expressions that people tend to associate with organisms, given that such entities are more likely to receive some aid than inanimate objects such as stones. As a result, children might have applied these phrases mostly to biological entities because they associated them with living things and not because they were responding to teleological content (Kelemen, 1999a).

A more recent proposal (promiscuous teleology) argues that people find purpose-based explanations compelling because teleological reasoning derives from intentional reasoning, a mode of thought they are familiar with. In other words, human tendency to attribute purpose to objects might derive from the ability to attribute purposes to the minds of agents. Hence, early in childhood, infants demonstrate an increasing understanding that agents act on the basis of goals and they also show sensitivity to the fact that agents use objects to achieve their goals. This early awareness of intentional use of objects might influence children's explanations, particularly as, during infancy, most of the objects that children encounter are artifacts, whose presence in their environment is explained by the way agents use them as means to achieving their own ends. Such experiences might subsequently contribute to the tendency to over-generate purpose-based teleological explanations in the absence of other alternative explanations.

In one study, preschool children and adults were asked what they thought organisms, artifacts, non-living natural objects and their physical parts were 'for'. Although, they were explicitly given the option of saying they were not 'for' anything, four- and five year- old children responded by attributing a function to almost every type of object, in contrast to adults who selectively attributed functions to organisms, artifacts and their parts. As a result, in addition to noses, clocks and pockets, children also stated functions for nonliving natural objects, such as mountains ('for climbing') and clouds ('for raining'), and whole living things, such as babies ('for loving') and animals ('for walking around'). A second study checked whether children really viewed these activities as functions or simply things that the objects could do or be used to do. Preschool children and adults listened to two characters discussing whether different artifacts, organisms and other non-living natural objects were made for something or not. For example, in one case, the characters debated whether a tiger was 'made for something', such as 'walking and being in a zoo', or whether tigers 'aren't made for anything' and 'these are just things it does'. Participants then indicated which character they agreed with. As in the previous case, the study found that while adults were discriminating, pre-school students broadly asserted that entities of all types were made for something (Kelemen, 1999b). That teleology is not selectively applied to biological properties has been documented by other researchers as well (Opfer & Gelman, 2001).

Teleology in Biology Education

While scientific explanations are based on causal mechanisms, biology also involves teleological explanations in which body structures are explained in terms of how they benefit their possessors (e.g., "plants kept indoors bend toward the window so that they will obtain more light, thereby increasing their rate of photosynthesis"). Teleological explanations seem to prevail in biology because:

a) Organisms seem goal-oriented because their structure is often adapted to their survival

b) People tend to project from their own goals and intentions to natural phenomena

c) Teleological explanations have apparent explanatory value because they tend to make us feel that we really understand the phenomenon in question, as it is accounted for in terms of purposes, with which we are familiar from our own experience of purposive behavior

d) There is heuristic value to teleological approaches, as in the history of science biological research that was motivated by a teleological orientation often resulted in important scientific discoveries (Zohar & Ginossar, 1998).

An interesting study with students of various ages (2^{nd}, 5^{th}, 8^{th} and 12^{th} grades) aimed to explore the patterns that characterize students' explanations of biological phenomena, and through this exploration to examine the basis of students' biological knowledge structures. Many teleological explanations about biological phenomena were documented, and they were the most prevalent category in each of the four grade levels. For example, when a twelfth grade student was asked why birds migrated he answered: "[…] well they go down there to protect themselves. They can't stay here, because they can't stay warm. They won't be warm". Another twelfth grade student explained the growth of the plant as follows: "Ah, it's leaning toward the light because it absorbs light to grow. It needs light to help it grow. And so, wherever there's light, it'll grow. [. . .]". However, although teleological explanations were the most common pattern employed by students to explain the four types of biological phenomena presented in the interviews, the twelfth graders were less likely to employ teleological reasoning. Thus, there was some improvement in students' ability to reason scientifically within biological domains as grade levels increased (Southerland, Abrams, Cummins & Anselmo, 2001).

Teleological explanations seem to prevail especially in evolutionary biology. In a study of 14-15 year old students' intuitive explanations of evolution, it was found that in most cases teleological explanations predominated. In most teleological explanations the end or goal was the survival of the species. However, depending on the content of the task, students referred either to external or internal factors, or to both. External agents were often specified and in most cases were Nature, God or both whereas internal agents often were the conscious actions of the organisms which changed in order to adapt properly to the environment. In certain cases, students expressed a kind of vitalistic causality where an unknown (vital) power somehow succeeded to maintain organisms in existence, without being able to provide a detailed account of how this vital power might operate. Students' explanations of the origin of homologies provided evidence that the unconscious bias of anthropomorphically thinking may drive them to attribute the similarities of organisms and sometimes of cells to a kind of kinship among them. Examples of such explanations involved:

- "Many different animal species may look alike. This happens because all animals have approximately the same needs. All animals need food and thus they have to find some prey. But to achieve this, they need some features such as sharp nails and teeth … Although these three animals belong to different species they look alike for this reason."
- "I believe that all organisms have genetic material, ribosomes and cell membrane because these are necessary for their functions, and without those they could not exist…"

On the other hand, in students' explanations of the origin of adaptations it was found that teleological explanations predominated, although their amount depended on the information provided to students at each task. Examples of such explanations involved:

- "I believe that the neck of the giraffe was lengthened so that it could find food more easily…Giraffes were stretching their necks in order to reach the leaves of the trees. Thus, perhaps every new giraffe was born with a longer neck because this particular need was recorded in the DNA of its mother."
- "In order to overcome same dangers (e.g. being identified by other animals or man), they were 'obliged' to acquire some features, to imitate features of other organisms so that it could be hard for their 'enemies' to identify them."
- "Since birds could easily see the green beetles and eat them, something had to be done so that they [the green beetles] could survive. Thus, there was evolution and change in the DNA that produced the change in the color in order to survive the 'attacks' of the birds".

It was found that in general students had the tendency to look for purpose or plan when they did not have adequate information (Kampourakis & Zogza, 2008).

TELEOLOGY IN CHEMISTRY EDUCATION

Teleological explanations are not restricted to biology, and may be found in the physical sciences as well. In particular, they may play an important role in the explanations associated with topics in chemistry, particularly in cases in which a general rule, a principle, or a law are involved. Teleological explanations seem to have heuristic value in chemistry education: they help provide an explanatory reason for the occurrence of chemical processes. They also allow the transformation of complex formulations into simpler ones, and they help students organize their knowledge around central ideas with explanatory and predictive power. However, transposition frequently masks the actual implications, scope, and limitations of the ideas discussed as well as the true nature of the process by which the knowledge was gained. Teleological formulations may be useful educational tools, but they may also lead to the development of alternative conceptions and overgeneralizations, because they seem to imply that the behavior of the system is driven by intrinsic purposes, and their corresponding teleological explanations cannot be taken as purely metaphorical. Teachers should be encouraged to use multiple ways of modeling, representing, and explaining chemical systems and processes in order to avoid misinterpretations and to promote meaningful understandings (Talanquer, 2007).

Teleological explanations in chemistry have been identified in studies of students' explanations of chemical phenomena. For example, students may think that ssubstances react to minimize their energy, that atoms share, give or take electrons to satisfy the octet rule or that molecules take a certain shape to minimize bond repulsions (Talanquer, 2006). In a study with students beyond the age of 16, familiar with atomic ideas and selected for their interest in chemistry, teleological explanations were documented among animistic and anthropomorphic ones. Students said that:

- "they [carbon and nitrogen atoms] want to fill up, like electrons on each one [orbital], to become like, stable, whereas neon has already got what it needs"
- "the first shell, it needs two electrons to become stable... it joins with another hydrogen, and it shares, the other hydrogen's electron, so it thinks that it's got two electrons"
- the atom "wants to get a lower energy level"
- "So, at that time, the side which all the electrons are on would be slightly negative, and the other side would be slightly positive. And because of this, and because the iodine molecules want to attract, want to be joined together in the lattice, the positive charge would induce a slightly negative charge"

In all these cases students referred that atoms needed or wanted to perform function which were implicitly related to hidden purposes (e.g. to become stable). Another usual teleological explanation in secondary level chemistry is that of the "full outer shell". The noble gases have relatively stable electronic configurations and when elements react to form compounds they 'achieve' or 'attain' a noble gas electronic structure (often described as having a full outer shell). Students may interpret the "full outer shell" as a sufficient explanation for chemical reactions: atoms react to form molecules or ions because they need to achieve a full outer shell. But if students consider that such teleological explanation can be a sufficient explanation of chemical change, then they will have no reason to seek other explanations (e.g. in terms of potential energy and electrical field.) In the case of chemical bonding this is certainly likely to be problematic because students will find that the "full outer shell" explanation is little help in discussing bond polarity, hydrogen bonding, van der Waals forces and many other phenomena. Hence, such teleological thinking could actually be an impediment to further learning (Taber & Watts, 1996).

Teleology in Physics Education

Teleological explanations seem to have a heuristic value in physics education as well. In an analysis of an exemplary set of physics explanations, by Richard Feynman, teleological explanations were included with metaphors as acceptable elements of effective pedagogical content. Feynman said that water particles are 'stuck together' instead of referring to cohesion, the respective scientific term. Had he used cohesion, he would have needed to differentiate cohesion from adhesion; besides, the metaphor he used was adequate in that particular context and had the advantage of keeping things simple. For example, teleology occurs in statements like 'they like certain partners' and 'why each one wants what it wants' used to describe oxygen atoms bonding to form molecular oxygen. Feynman used teleology to avoid having to stop and deal with difficult concepts that are peripheral to his immediate purpose. Thus, he was helping his audience develop a feel for the subject, while leaving the detailed theory and mathematics to later courses. This strategy facilitated understanding of concepts that are considered to be difficult for students, and motivated them to remain engaged in the teaching process (Treagust & Harrison, 2000). But this type of teleology is wrong because it presents physical entities as having minds and purposes when describing that something happens because it needs to.

The teleological stance is obvious in studies of pre-school children's preconceptions in astronomy. In one study on preschool age children representations about the shape of earth and the phenomenon of the day/night cycle, students were found to give teleological explanations such as "in order to be night, must pass the afternoon so that the day can go to other countries" (Kampeza, 2006). In another research, children of 4-5 years old said that things fell because they had to, that the sun and moon did not fall because they had to give light, and that the clouds did not fall because they had to give rain (Bar, Zinn, Goldmuntz & Sneider, 1994). But teleological explanations can be provided by older students as well. In a study on 11th graders conceptions of heat and temperature, a student selected to participate seemed to adopt teleological reasoning when he stated that objects react to thermal environmental changes based on their macroscopic properties. This means that the student believed he could predict which of the objects would be hotter than the others by thinking in teleological terms, on the basis of its use or function, and not based on its microscopic properties. In other words, he expected an object to be hotter than the others due to its function, which depends on what it is used for, and not due to its thermal conductivity, which in turn depends on several properties of a material such as its microscopic structure. The student said: "The nails would be the hottest, then the water, and least, the flour. Because the nails trapped heat, the water would be boiling by then, but the flour is just about 60°C."In everyday experiences with ovens, metal objects are very hot and will burn you, water boils or evaporates, and cereal foods such as flour are reasonably safe to handle. The student probably ascribed greater importance to the oven ("is hot") rather than the temperature ("is 60°C"). If the oven's properties and function dominated, then this supports the teleological notion and illustrates the degree to which prior knowledge and experiences interfere with science learning (Harrison, Grayson & Treagust, 1999).

Conclusions and Implications for Primary Education

Conceptual development research suggests that the tendency to view objects as designed for a purpose is a crucial feature of intuitive theory building. Moreover, intuitive teleology seems to be promiscuous rather than selective; hence it may not be restricted to biological concepts but may also exist in explanations in chemistry and physics, not only in childhood but in adolescence as well. Despite its heuristic value in biology, physics and chemistry education, teleology may prevent an accurate understanding of scientific phenomena. Taking these into account, it is important that primary teachers are careful in the expressions they use in order to avoid reinforcing students' teleological intuitions. If they manage to put emphasis on how natural phenomena take place and refrain from using teleological expressions, they will succeed in giving students an alternative way of explaining. What needs research is if this can be achieved in primary school. In particular it is important to study primary students' intuitive explanations about biological, chemical and physical phenomena, especially in ages of 8-10 years old when ideas of purpose and design and teleological explanations seem to predominate (Evans, 2001; Kelemen, 2003).

To achieve these goals it is required that primary teachers are explicitly taught not only which are the most usual primary students' preconceptions but also how to deal with them during instruction. In a study that aimed to explore how primary children's ideas in science affect science instruction, it was investigated if and how primary teachers recognize students' ideas, and if and how they take them into account when preparing instruction. Results showed that all teachers used a variety of ways to identify and elicit student ideas, but not always in an efficient manner. It was suggested that it is important to help teachers increase their content knowledge and expertise teaching primary students, to help pre-service teachers to develop a deeper understanding of characteristics of students' ideas and to have science educators recognize that primary teachers' goals for instruction focus on developing literate readers and writers (Akerson, Flick & Lederman, 2000). Since students' teleological intuitions may influence future learning, it is important that primary teachers develop instructional strategies which will help them identify these intuitions. Then activities can be designed to present a contradictory, scientifically acceptable view which will challenge their intuitions. These activities should allow students to test their own ideas as well as examine the scientifically accepted view. In this way, they may recognize the inaccuracy of their teleological intuitions and accommodate the new, scientifically acceptable, explanations.

The major aim of this paper is not to suggest that it is necessary that teleological explanations are avoided during instruction. If students possess an innate, promiscuous teleology from early in childhood, teleological explanations will probably be intuitively applied to several natural phenomena. So, teachers cannot actually avoid them since they exist in students' minds, no matter if they are not always expressed. What is necessary is that, whenever such explanations emerge from the topics being taught, teachers discuss about their meanings, and above all emphasize what they do not mean or why they are wrong. Then, teleological explanations can be contrasted with causal explanations of the same phenomena so that students are able to distinguish between the actual scientific explanations and the descriptions that are sometimes used in order to make the phenomena more comprehensible. If this is done during primary school, it will not make students entirely abandon their teleological intuitions. But having students discussing these intuitions will make them consider these more carefully and possibly enable their rejection in later years. On the contrary, students' misunderstandings may become deeper if primary teachers do not give the required attention and science instruction might be ineffective if teleological intuitions are left to be challenged during high school courses.

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