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Intentional water and tired wood: exploring causes for primary teachers' reference to intuitive construals in science education

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ABSTRACT
Research reveals that teachers regularly refer to intuitive construals (IC) in formal science education. Only a few studies, however, have investigated why teachers refer to them. Alarmingly, these studies suggest didactic consideration is not the main reason for this. Instead, teachers introduce IC unintentionally or due to a lack of expertise. A possible explanation for an unconsidered reference to IC – a part of lack of expertise – is that teachers spontaneously align their language with the students' perspective as a form of implicit didactisation. We asked fifty prospective primary teachers to explain a basic scientific phenomenon of inanimate nature to fictitious recipients of varying expertise (a science expert and a student). We reasoned that if lack of knowledge was the reason for using IC, explanations should be equally intuitive for all addressees. If spontaneous language didactisation is the reason, only the explanations for students should contain intuitive elements. Results show that the majority of participants use IC exclusively when addressing students and not when addressing experts. In a substantial minority, however, lack of knowledge is a more likely cause. We conclude that there might be a tendency towards language didactisation even outside didactic professional knowledge. Implications for teacher training are discussed.

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Introduction

When people attempt to explain phenomena in their environment, they tend to rely on intuitive conceptualisations (also termed conceptual biases or intuitive construals, IC) of the world (e.g. Coley & Tanner, 2015; Kelemen, 2012). Building on intuitive concepts allows people to make sense of natural phenomena without ever having attended school (Shtulman, 2017). Intuitive explanations work as a thumb rule and have great explanatory power in everyday life while also saving cognitive capacity (Allen & Lauder, 1998; Sharefkin & Ruchlis, 1974). For instance, teleological reasoning, as discussed by Kelemen (2012),

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often simplifies causal relationships. It creates distinct, purpose-driven explanations for natural phenomena, which are more cognitively accessible than multifaceted scientific explanations. A pertinent example is the intuitive understanding of ecosystem dynamics. Children and adults might naturally resort to teleological reasoning by assuming that certain species exist to fulfil specific roles, such as bees existing 'for' pollination. This reasoning pattern simplifies the complex interdependencies within ecosystems by assigning clear, purpose-driven roles to each organism, thereby facilitating comprehension and reducing the cognitive load. While these intuitive explanations offer practical cognitive shortcuts, they often diametrically contradict scientific conceptualisations (Atran & Medin, 2008; Carey, 1985; Lakoff & Johnson, 1980; Reiner et al., 2000). Indeed, the turning points in the history of science often resulted from the abandonment of specific intuitive explanations, such as the misconceptions that the earth is a disc or that different biological species emerged as a result of purposeful design (Carey, 2000). Consequently, many authors argue that IC hinder the adoption of scientific perspectives and are responsible for persistent misconceptions (e.g. Shtulman & Lombrozo, 2016). Accordingly, they see it as a major task of science education to help students overcome their IC to clear the way for adopting scientific knowledge (e.g. Carey, 2000, pp. 13–14; Kelemen et al., 2013).

ICs are used in everyday life to explain phenomena. Accordingly, not only are ad-hoc explanations in the classroom influenced by IC, but IC are often an integral part of the pre-existing conceptual frameworks that students introduce into the instructional setting (Stern, Kampourakis, Huneault, Silveira, & Müller, 2018). Compounding the issue is the fact that such resulting misconceptions often appear to be seemingly true in everyday life, thereby reinforcing themselves. For instance, the misconception that solar radiation itself is warm (Reinfried & Tempelmann, 2014). However, while some strictly reject the reference to IC, others advocate reflecting and deconstructing them. However, research of recent decades shows that IC are so firmly anchored in human cognition that they are never fully overwritten by science education (Lombrozo et al., 2007; Shtulman & Valcarcel, 2012; Zaitchik & Solomon, 2008). Instead, they *co-exist* alongside scientifically accurate explanations (Shtulman & Legare, 2020), even among experts (Kelemen et al., 2013; Shtulman & Harrington, 2016). For instance, Goldberg and Thompson-Schill (2009) demonstrated that even biology professors, when classifying objects as living or non-living, are influenced by the intuitive concept that movement signifies 'aliveness'. Some psychologists and didacticians have therefore chosen the path of allowing IC in the classroom as long as they do not impede the learning process (e.g. to meet affective and motivational needs; Evans et al., 2012; Kattmann, 2005; Legare et al., 2013; Slaughter & Lyons, 2003;Zohar & Ginossar, 1998). For instance, Legare et al. (2013) suggest that in teaching evolution, narratives centred on animals' fundamental survival needs (i.e. teleological explanations) could act as an effective intermediary step to facilitate children's understanding of evolutionary concepts. There is agreement, however, that IC should be referred to very thoughtfully in the classroom (e.g. Evans & Rosengren, 2018; González Galli et al., 2020; Halls et al., 2021).

Although the reference to IC in the classroom is controversial among science educators, research revealed that in-service teachers integrate them regularly in their teaching. For example, they integrate them when explaining the behaviour of molecules to physics students (Treagust & Harrison, 2000; see also Feynman et al., 2011), the principle of evolution to secondary school students (Gresch, 2020), or life in the tree stump to preschoolers (Thulin & Pramling, 2009). While many promote this for didactic reasons (such as Nobel Prize winner

Feynman), the limited research to date reveals substantial malpractices. Apparently, secondary school teachers refer to them unconsciously and in a scientifically ambiguous way (Gresch, 2020; Gresch & Martens, 2019), kindergarten teachers due to a lack of subject knowledge (Kallery & Psillos, 2001, 2004), while data for primary school teachers is completely lacking. Further research is urgently needed to better understand these potentially alarming results.

In the present study, we aimed to close this important research gap and learn more about primary teachers' inclination to use intuitive explanations. Specifically, we tried to find out whether prospective primary school teachers adopt IC in their instructions and, if so, why this occurs. Before introducing the present study in more detail, we will first discuss findings on humans' reliance on IC in everyday life with a special focus on the particularly well-studied teleological and anthropomorphic patterns of explanation, followed by an overview of research on the use of intuitive explanations in science education.

Intuitive theories about natural phenomena

People's intuitive explanations about natural phenomena often show the signature of typical intuitive construals (IC), which early in ontogeny characterise people's intuitive thinking (e.g. Kelemen, 2012). These IC result in typical regularities in the intuitive access to the world, visible in children's and adults' spontaneous explanatory patterns as 'a set of assumptions, a type of explanation, or […] a particular type of reasoning' (Coley & Tanner, 2015, p. 2). Accordingly, while those explanations are constructed individually, people still have similar (unscientific) explanations for natural phenomena. This construal-based thinking is deeply anchored in human cognition. Due to their fundamental nature, IC influence the manner in which individuals process and understand new information, frequently leading to misconceptions.

Many IC can be viewed as grounding in spatial 'figurative' schemata or body-based conceptual metaphors (e.g. Alibali & Nathan, 2012; Lakoff & Johnson, 1999). Examples of such construals are teleology (i.e. things are ascribed purposive or goal-directed movement), anthropomorphism (i.e. non-human structures are conceptualised to have human characteristics), entity bias (i.e. processes are modelled as material objects) and container schema (e.g. abstract ideas/processes are modelled as spatially defined structures) (e.g. Atran & Medin, 2008; Carey, 1985; Lakoff & Johnson, 1980; Reiner et al., 2000). Construals play a central role in intuitive explanatory patterns and greatly impact children's and adolescents' learning of science concepts.

Teleology and anthropomorphism are the most prominent and best-described construals in the literature. Both are (at least partially) related to *agentive causality* (e.g. the notion that events are caused by an acting agent; e.g. Gergely & Csibra, 2003; Scholl & Tremoulet, 2000). They are also frequently used in science education by educators from kindergarten to university level (e.g. Adler, Fiedler, & Harms, 2022; Betz et al., 2019; Crawford et al., 2005; Gresch & Martens, 2019; Kallery & Psillos, 2001, 2004; Talanquer, 2007; Thulin & Pramling, 2009; Treagust & Harrison, 2000), making them an interesting point of departure for the present research.

Teleology and anthropomorphism

The concept of anthropomorphism is defined as applying human characteristics and traits (e.g. desires, will, reflective thinking) to non-human or even non-living entities and phenomena (e.g. Scholl & Tremoulet, 2000). It was first described by Piaget (1974), who observed it in children's explanations of natural phenomena (e.g. describing clouds or rivers as living and moving in a self-initiated fashion). According to Piaget, the underlying cause of anthropomorphism is the phenomenalistic-egocentric blending of subject and object, i.e. children transfer their perspective to the entities of the external world (see Bödeker, 2006; Brown et al., 2020). Although Piaget's explanatory approach is now considered outdated in developmental psychology, there is consensus that anthropomorphic explanations are characterised by tracing phenomena or states of entities to an 'agentive cause' (e.g. Gergely & Csibra, 2003; Scholl & Tremoulet, 2000).

Teleology (from Greek telos [goal] and logos [explanation]) refers to the tendency to explain phenomena in terms of purposes. Teleological explanations 'account for objects and events by reference to a functional consequence or purpose' (Kelemen et al., 2013, p. 1074). In contrast to anthropomorphism, teleological explanations are often correct. For example, the form of a purposefully produced artefact can be explained by its function (e.g. 'A screwdriver has a specific shape so that screws can be tightened'). However, as with anthropomorphism, intuitive teleological causality is also often rooted in agentive causality, leading to incorrect explanations (e.g. 'The clouds want to make rain so that the animals can drink').

Due to the substantive conceptual overlap, some authors consider teleology to be a special case of anthropomorphism (Tamir & Zohar, 1991) and distinguish between teleological anthropomorphism (i.e. attributing non-existent desires and feelings as an explanation of why an entity seeks a particular target state) and metaphorical anthropomorphism (i.e. drawing analogies with an agentive human-being; Kallery & Psillos, 2004; see Figure 1).

However, contrary to anthropomorphism, teleological statements must not necessarily root in agentive causality and thus are not a perfect subset of anthropomorphic statements (see Figure 1). For example, the explanations 'there is water so that we can drink' or 'the bird has a beak so that it can peck grains' are teleological by referring to a specific purpose or function and not by referring to an acting agent (cf. Scott, 2022), thus representing non-agentive teleology, the use of which may be legitimate under certain circumstances even in the case of living entities (see Kampourakis (2020) for or a broad discussion of the topic).

The use of intuitive theories by teachers

Science educators agree that intuitive concepts and explanations are a great challenge for science teaching. There is less agreement, however, on how to deal with intuitive notions. The most obvious option as a teacher is to ignore them. In-service teachers actually often speak against the integration of intuitive explanations in the classroom, insisting that only scientifically correct concepts should be addressed (e.g. kindergarten teachers: Kallery & Psillos, 2001, 2004; secondary teachers: Gresch, 2020; Gresch & Martens, 2019).

However, because science education cannot simply overwrite intuitive notions (dual process theory, e.g. Kahneman, 2012), it certainly makes sense to develop didactic solutions for dealing with intuitive conceptions other than ignoring them. Therefore, many scholars opt for deliberately integrating intuitive notions in science education by reflecting on them as starting points of the learning process (e.g. Carey, 2000) or using them in science instructions and textbooks (e.g. Feynman et al., 2011; Kattmann, 2005;

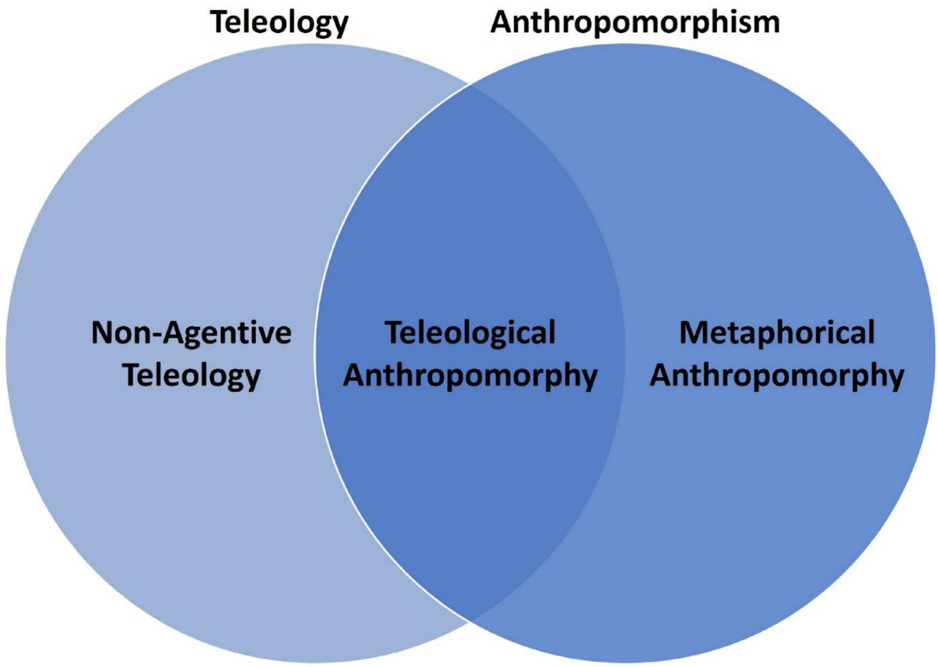

Figure 1. Union of teleological and anthropomorphic statements.

Treagust & Harrison, 2000). Proponents of relying on intuitive explanations as a pedagogical strategy argue that this may facilitate learning because these construals meet learners' spontaneous cognitive and affective needs (e.g. Carey, 2000; Kattmann, 2005 see also: Feynman et al., 2011) and allow educators to align with the way of thinking of scientific novices (Carey, 2000; Evans, 2001; Harrison, & Treagust, 2006; Sinatra et al., 2003; see also Talanquer, 2013). This didactic approach may therefore function as a bridge between formal scientific and intuitive reasoning (e.g. Evans & Rosengren, 2018; González Galli et al., 2020; Pramling & Säljö, 2007; Thulin & Pramling, 2009). Overall, these approaches aim to enable students to distinguish IC from scientific explanations. The goal is to develop an explicit conceptual *bilingualism* (Gebhard et al., 2017). As scientific theories often exist in competition with intuitive theories, which are built on IC, the ability to deal reflexively and critically with IC (Henderson et al., 2015) can be understood as an essential aspect of scientific literacy (Halls et al., 2021). Consequently, educators must recognise the necessity of identifying, uncovering, and contextualising ICs in their teaching, essentially turning them into a topic of learning.

However, the reality in the classroom is quite different from what one would assume based on the debates in the didactic literature. Numerous research studies show that integrating intuitive explanations for scientific phenomena in formal science education is not an exception but the rule. This has been documented in teaching kindergarten children (Kallery & Psillos, 2001, 2004; Thulin & Pramling, 2009), secondary school students (Crawford et al., 2005; Gresch, 2020; Gresch & Martens, 2019), and university education (Betz et al., 2019; Talanquer, 2007; Treagust & Harrison, 2000). While the reference to intuitive concepts has been confirmed in numerous studies, only a few small-scale studies have investigated *why* teachers refer to them. These studies suggest that a main reason is a lack of expertise (e.g. kindergarten teachers, Kallery & Psillos, 2001, 2004) or unconscious use (e.g. secondary school teachers, Gresch, 2020; Gresch & Martens, 2019). For example, educators don't know the scientifically correct explanation, do not recognise intuitive elements as scientifically incorrect, or integrate IC unintentionally without noticing it. As outlined in the Continuum Model of Teachers' Professional Competencies by Blömeke et al. (2015), fundamental knowledge in the sense of a professional disposition is essential for the development of adequate, situation-specific skills of teachers. In turn, teachers' reflection-in-action leads to the further development of professional dispositions. Conversely, insufficient comprehension of ICs not only detrimentally impacts teaching behaviour but also hinders the initiation of learning processes that would typically emerge from classroom experiences. Therefore, these findings are concerning. The set goal of promoting conceptual 'bilingualism' (Gebhard et al., 2017) in students could not be achieved if even teachers fail to master it. Nevertheless, one should not overestimate these results. The few existing studies included only very small samples of teachers, not allowing for a conclusive judgement. Accordingly, more research is urgently needed, especially in the context of primary school, where no data is available so far.

A first important question is whether primary teachers also spontaneously rely on intuitive explanations without having an explicit didactic intention to do so. If primary teachers use IC unreflectively in their lessons, as exemplified by Nadelson (2009), they risk impeding students' development of adequate scientific knowledge. Furthermore, as Yates and Marek (2014) have substantiated, misconceptions held by biology students can be partially attributed to the inadvertent perpetuation of erroneous concepts by their educators. A clearer picture of the situation in primary school is important to ensure the quality of primary education and bears important implications for teacher training.

Based on the previous research, we focus on two potential reasons for an unconsidered use of construals. First, also in primary education, a lack of expertise might promote the unreflective use of IC. In addition to guiding young learners towards age-appropriate scientific thinking, primary and kindergarten teachers play a pivotal role in fostering a broad range of developmental skills. While it is observed that teacher education programmes, particularly for kindergarten and primary school teachers, may sometimes lack scientific rigour (e.g. Möller, 2004), these programmes are often designed with a holistic educational philosophy. While the generalist nature of these programmes facilitates a comprehensive grasp of child development and interdisciplinary mentoring, which are vital in the early stages of education, these training programmes may be insufficient in equipping educators for the specialised requirements of science education (s. Breitenmoser et al., 2022, for a discussion on this topic regarding Swiss primary teacher education). However, Kallery and Psillos (2001, 2004) identify the rudimentary subject-specific training of Greek kindergarten teachers as a main cause for why teachers have too little expertise to identify intuitive construals. In general, lower education has been shown to be associated with a higher endorsement of intuitive explanations (e.g. teleological statements: Casler & Kelemen, 2008; Kelemen et al., 2013; Rottman et al., 2017). In fact, kindergarten as well as primary school teachers often receive much less science training than secondary school teachers. The Swiss primary teacher training focuses mostly on pedagogical content knowledge, assuming that the essential scientific education is acquired in secondary schools. The consequence is that very little subject-specific science is taught in teacher training. It is therefore possible that the low level of science training also leads to unreflective use of construals by primary school teachers.

As a second important source of unconsidered reference to IC, we identify what was termed *natural pedagogy* (cf. Csibra & Gergely, 2009, 2011; Strauss et al., 2014), the human tendency to spontaneously didacticise language in cultural learning contexts (Tempelmann & Cacchione, 2021). Face-to-face interactions might tempt teachers to use intuitive explanations spontaneously to structure and simplify content (Strauss et al., 2014; Thulin & Pramling, 2009), aligning their language with the student perspective. This may explain why the secondary teachers examined by Gresch (2020) and Gresch and Martens (2019) unknowingly referred to construals in spontaneous interactions with students, although having sufficient scientific knowledge. Indeed, research has demonstrated that experts have the tendency to spontaneously didacticise their language output when interacting with novices (Saito & van Poeteren, 2012; Strauss et al., 2014) Moreover, there is a tendency to adapt the speech to the age and level of knowledge of the addressee, which is partly unconscious (Kalashnikova et al., 2017; Strauss et al., 2014). We suggest that this tendency could prompt teachers to use IC spontaneously in class regardless of their explicit professional didactic beliefs. It would then be reasonable to assume that this tendency is more likely to occur in face-to-face interaction (rather than in lesson planning) and probably also more pronounced among teachers with extensive interaction experiences than in prospective teachers.

Aim of the study

This study aims at two main goals. The first is to assess whether prospective teachers unthinkingly integrate intuitive elements when explaining scientific content to students (e.g. refer to inappropriate teleological and anthropomorphic notions). Secondly, we aimed to investigate which of two potential reasons accounts for a potentially observed unconsidered reference to IC (i.e. lack of knowledge or implicit tendency to didacticise educational language). A sample of prospective primary teachers (i.e. students of a university for teacher education) who completed their training in the natural sciences and were just starting their didactic training participated in the experimental study.

Accordingly, our sample reflects a specific stage in teacher education which provides a unique opportunity to investigate the didactic actions that are intuitively implemented in the absence of explicit formal pedagogical training. This allows us to determine the starting point of pedagogical training with respect to the use of IC.

The participants were asked to give explanations of one of two basic scientific phenomena of inanimate nature (collision or combustion). Specifically, they were asked to address their explanation to two different fictitious recipients of varying expertise: A science expert and a student (first or sixth grade, respectively). We reasoned that if lack of knowledge was the reason for using the construals, explanations should be equally intuitive for all addressees. If spontaneous language didactisation was the reason, only the explanations for students should contain intuitive elements. We further reasoned that in this case, the fictitious student's age/expertise (1st or 6th grade) might influence the amount of intuitive language (i.e. participants should rely more on intuitive concepts when teaching younger than older students; cf. Tempelmann & Cacchione, 2021). We assumed that the tendency to spontaneously didacticise language is more likely to occur in face-to-face interaction rather than in lesson planning (i.e. it could be triggered by the students' use of construals). In the context of the present discussion, it is crucial to emphasise that language didactisation does not inherently lead to the employment of ICs; this phenomenon should be regarded as merely one possible manifestation within a broader spectrum of instructional approaches. To maximise the probability of scientifically correct answers, we asked the participants to give written explanations (so that explanations could not be influenced by spontaneous interactions with students). In our view, this was the most conservative approach to testing lack of expertise in primary school teachers. It is possible that the suspected tendency to spontaneously didacticise cannot be demonstrated outside of face-to-face interactions; however, if it were to be found in written instructions, this would strongly support our hypothesis. The written explanations were then checked for intuitive elements, namely for teleological and anthropomorphic expressions. Focusing on teleological and anthropomorphic statements is justified as they are the most prominent and best-described intuitive explanations in science education literature.

From the results, we expected important insights regarding the propensity to refer to intuitive notions and the quality of scientific knowledge in prospective primary school teachers. Further, we expected to understand better the underlying reasons for a potentially observed unconsidered use of IC. The findings of this study will support us in designing primary teacher training in ways that promotes competent handling of IC.

Methods

Participants

The study included 50 prospective primary school teachers across four classes (m = 12, f = 38, mean age = 23.36). All participants have acquired their university entrance qualifications, thereby qualifying for enrolment in the bachelor's degree programme. Additionally, within the subject of NMG,[1] encompassing the disciplines of biology, physics, and chemistry, they have successfully completed their subject-specific academic courses. The gender distribution is representative of the occupational field.

Materials

We prepared two scientific texts, each describing a natural phenomenon, one with a physical topic (collision of a rubber ball and a ball of plasticine with a hard surface) and one with a chemical topic (combustion reaction). The texts were written in the style of a science textbook and covered central scientific concepts of the respective topics (collision: energy conversion, kinetic energy, potential energy, friction and heat energy, elastic and inelastic collision; combustion: chemical reaction, conservation and conversion of matter, activation energy, particle model of matter). The topics correspond to the Swiss curriculum for primary education (Lehrplan21). The participants read the texts as a basis to develop their explanations. We deliberately chose two thematic areas of inanimate nature to increase the generalizability of results and to broaden knowledge about how intuitive explanations are used across domains (Thulin & Pramling, 2009, p. 144). With this, we are also following the need to investigate teleological and anthropomorphic statements outside the biological domain (cf. Talanquer, 2007; Thulin & Pramling, 2009).

Design and procedure

Data collection took place within introductory didactic training courses for NMG teaching at the University of Teacher Education of Northwestern Switzerland (PH FHNW). Before the experiment, participants were informed and given a brief overview of the procedure. The participants were randomly assigned to (i) one topic and (ii) to conditions with either the 1st-grade or the 6th-grade student (see Table 1).

The submission of the written work was voluntary for the students, which led to a dropout rate of 12% and resulted in the distribution of participants as shown in Table 1. All participated in the expert condition, serving as a within-subject control condition. The participants were then given the explanatory text corresponding with their topic (combustion or collision). They were then asked to read the text carefully and prepare in their own words a written explanation tailored to two different recipients and two different contexts: a) a student (1st or 6th grade in a classroom setting) and b) an expert (in an exam setting). The explanations should cover answers to the following questions:

- Collision topic:

(1) What happens when a rubber ball collides with the ground, and why does a rubber ball bounce back?
(2) What happens when a clay ball collides with the ground?

- Combustion topic:

(1) What happens when you hold a lighter to a dry piece of wood?
(2) What happens when you hold a lighter to a wet piece of wood?

The participants were explicitly instructed to consider the relevant scientific concepts when designing the explanations and to use appropriate language for the respective addressees. They had approximately 30 minutes to work on the assigned tasks.

Coding strategy and quantification of codes

The written explanations were coded using MAXQDA by two independent specialised coders (first and second author) using qualitative content analysis (cf. Mayring, 2015;

Table 1. Assignment to experimental conditions.

Condition	N Collision	N Combustion	N Overall
1st grade	13	9	22
6^{th} grade	14	14	28
Overall	27	23	50

Saldaña, 2013). We analysed all written explanations for the three basic types of anthropomorphic and teleological (A&T) statements described in the introduction (see Figure 1 above). A description and anchor examples are given in Table 2 below.

The coding strategy followed multiple cycles. First, both coders coded the same proportion of the data individually for each participant using the initial coding system. This was followed by comparing the single codings and verbal agreement on a joint coding result. For this, the agreement of both coders was necessary to accept a single coding. The quantification was made possible by strict coding rules, amongst others, that repetitions of whole text passages within an explanation (e.g. student explanation) were not coded again. For each individual, we calculated an overall score of IC (= total frequency of A&T-statements), as well as a score for the frequency of each of the three types of intuitive construal (Non-agentive Teleology, Metaphorical and Teleological Anthropomorphism, see Table 2).

Data analysis

The statistical analyses of the quantified codes were carried out using SPSS and R Studio. The prerequisites were checked for all procedures used. Analyses were conducted for the full sample and individually for each topic.

To investigate whether there is a higher mean frequency of IC (= mean total use of A&T-statements) in written explanations addressed at a) students vs. experts and b) 1st-graders vs. 6th-graders, we calculated robust mixed 2×2 ANOVAs[2] based on trimmed means with trim level 0.2 (cf., Field & Wilcox, 2017; Mair & Wilcox, 2020; Wilcox, 2022) with the between-factor grade of the recipient (1st or 6th-grade student) and the within-factor expertise of the recipient (student vs expert explanation). The dependent variable was the mean frequency of IC observed or the mean frequency of each of the three IC subcodes, respectively.

To learn more about the reason for the use of IC in explanations (e.g. lack of expertise or implicit language didactisation), we assigned every participant to one of four possible

Table 2. Code description and example codings.

Agency	Code	Description	Example Combustion	Example Collision
No	Non-agentive teleology	Processes/structures are incorrectly assigned to a purpose/function (but not to an agent pursuing a goal)	'Oxygen is present in the air because it is also very important for humans to breathe.'	'As speed has to be converted into something else, [… , therefore] the kneading ball gives off heat on impact.'
Yes	Metaphorical anthro.	Inanimate objects are described as 'living' and performing actions (thereby indirectly explaining processes/ structures)	'If you light up wet wood, it must first become dry. After that, the ignition material is already tired.'	'The ball is so strong that it immediately makes itself round again.'
Yes	Teleological anthro.	Processes/structures are described as the object and result of intentions/ intentional actions of inanimate objects	'The water in the piece of wood wants to get out and evaporate.'	'Because the ball is so strong, it wants to return to its round shape. It pushes the dent out again and pushes itself off the ground.'

Note: Anthro. = anthropomorphism

IC usage types (Table 3). If IC are implemented only in explanations addressed at students but not at experts (Type 1), we assume intuitive didactisation is the cause (e.g. Tempelmann & Cacchione, 2021). If IC are used for both experts and students or only for experts (Types 2 and 3), lack of expertise is the likely cause (Geelan, 2012).

Results

The robust mixed ANOVA, with the between-factor grade (1st vs 6th), the within-factor expertise (expert vs. student condition) and the dependent variable mean frequency of IC showed that prospective teachers use IC significantly more often towards students (overall: $M = 1.86$, $SD = 1.75$; Collision: $M = 2.22$, $SD = 1.95$; Combustion: $M = 1.43$, $SD = 1.41$) than towards experts (Overall: $M = 0.24$, $SD = 0.52$; Collision: $M = 0.33$, $SD = 0.62$; Combustion: $M = 0.13$, $SD = 0.34$). This is true regardless of the teaching topic (overall: $F(1, 31.7) = 34.2$, $p < .001$; Collision: $F(1, 15.3) = 19.9$, $p < .001$; Combustion: $F(1, 7.6) = 11.6$, $p = .01$).

However, we found no effects for the factor *grade* (overall: $F(1, 31.8) = 2.3$, $p = 0.14$; Collision: $F(1, 13.8) = 0.2$, $p = .66$; Combustion $F(1, 7.9) = 4.7$, $p = .06$). There is no significant interaction effect. We did therefore not further report this factor in the graphs.

Investigating the mean frequency of use for the three IC subcodes separately reveals that the significant recipient main effects arise mainly due to the subcode metaphorical anthropomorphism (see Figure 2), which is the only IC subcode used significantly more often in the student ($M = 1.3$, $SD = 1.36$) than in the expert condition ($M = 0.2$, $SD = 0.49$), regardless of the topic (Collision S: $M = 1.41$, $SD = 1.53$/ E: $M = 0.3$, $SD = 0.61$; Combustion S: $M = 1.17$, $SD = 1.15$/ E: $M = 0.09$, $SD = 0.29$).[3] For teleological anthropomorphism, we only find significant differences between the expert and student condition in the collision sample (S: $M = 0.67$/ E: $M = 0.00$; $F(1, 11.6) = 5.75$, $p = .03$) but not in the combustion sample (S: $M = 0.67$/ E: $M = 0.00$; $F(1, 6) = 2.52$, $p = .16$). In turn, this explains why the tendency for higher mean use of teleological anthropomorphisms in the student condition yields no significant results in the overall sample ($F(1, 25.53) = 4.13$, $p = .053$). However, it is noteworthy that across topics, teleological anthropomorphism was not coded once in the expert condition. Lastly, non-agentive teleological expressions were rarely made, regardless of context. A detailed list of the results is offered in the appendix (Table A1).

Seventy-eight percent of the participants referred at least once to IC in their explanations. Table 3 shows the distribution of participants across the four IC usage types. The distribution does not reliably differ between topics (Fisher-Freeman-Halton exact test: 5.9, $p = .091$), which is why we combine the results of both topics in the following.

Table 3. IC usage types in science explanations.

Type	IC-use in student explanation	IC-use in expert explanation	Supports		N
			Implicit Did.	LoE	
(1)	Yes	No	x		29
(2)	Yes	Yes		x	8
(3)	No	Yes		x	2
(4)	No	No			11

Note. Implicit Did. = implicit didactisation; LoE = lack of expertise.

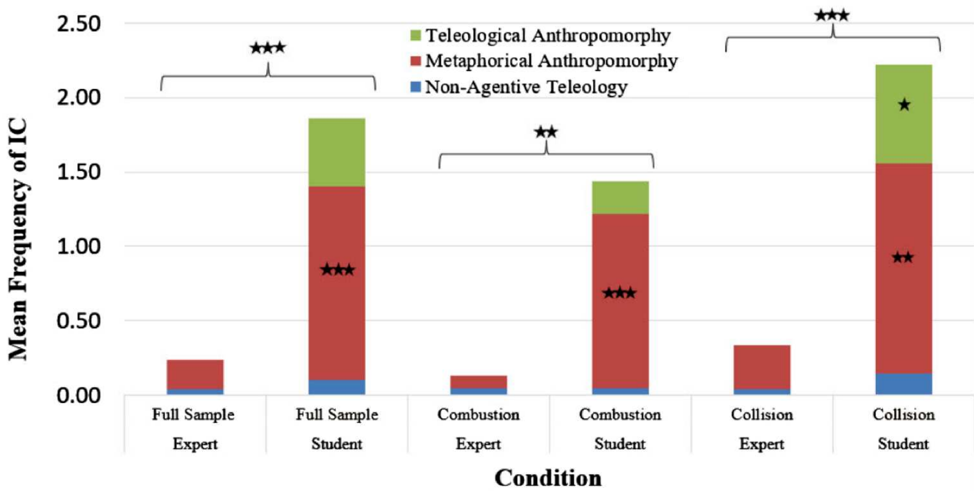

Figure 2. A&T usage in science explanation per condition.

Note: The asterisks refer to the results of the robust-mixed Anova analyses (trim-level 0.2) and show significant differences between the mean use of A&T statements in the expert and student conditions. Grade differences (1st grade vs 6th grade) are not reported, as we find no significant differences. Similarly, we find no significant interaction effects. Statistical significance: *p<0.05, **p<0.01, ***p<0.001.

Fifty-eight percent of the participants addressed IC exclusively at students, whereas only 20% used IC with experts (types 2 and 3). Twenty-two percent completely refrained from using IC. Among those prospective teachers using IC, the usage type indicating implicit didactical use was observed reliably more often than those indicating a lack of expertise (together 25.64%; one-tailed exact binomial test $p < .001$, 95% confidence interval: [0, 0.396]).

Discussion

The present study aimed to assess whether prospective teachers spontaneously integrate intuitive elements when explaining scientific content to students. This was indeed the case. A very large proportion of participants (78%) used IC at least once when explaining scientific content to a (fictitious) recipient in an imagined communicative situation (i.e. a student in a classroom vs. an expert in an exam). In the majority of the cases, however, the use of IC was selective. 58% of the participants used IC only when addressing a primary school student but avoided IC in explanations designed for an expert recipient. This was the case irrespective of the scientific topic (i.e. collision and combustion). This rules out a lack of knowledge as the main cause for the reference to IC. Instead, the exclusive use of IC in a pedagogical setting speaks for a didactical cause, such as a spontaneous tendency to didacticise language to align with the student's perspective.

Our findings are in line with previous research arguing that the use of IC in science teaching is the norm, not the exception (e.g. Betz et al., 2019; Talanquer, 2007; Thulin & Pramling, 2009). They close the data gap for primary teachers and broaden the so far very thin empirical basis documenting the reasons for IC use in the classroom.

However, it is essential to consider that the teachers in our sample had completed their academic scientific training but not their training in subject-specific didactics. This aspect is critical in contextualising our exploration of the intuitive pedagogical strategies employed by these educators. In contrast to Kallery and Psillos (2001, 2004), however, lack of knowledge was not the main reason for adopting IC when explaining scientific phenomena. Still, it was not absent in our sample. About 20% of the prospective primary teachers used IC unsystematically, also when addressing experts, suggesting that they are far from reaching the goal of *conceptual bilingualism* (Gebhard et al., 2017; Halls et al., 2021) despite having completed the scientific training. This has implications for teacher education, which we will discuss below.

The majority of participants in our study thus behaved similarly to the secondary school teachers tested by Gresch (2020) and Gresch and Martens (2019), who adopted IC spontaneously despite having correct explicit scientific knowledge. Gresch and Martens (2019, p. 244) speak of an a-theoretical 'tacit dimension of teaching'. Unlike the in-service secondary teachers in the Gresch study, however, our prospective primary school teachers did not directly interact with students and could not draw on extensive teaching experience.

From this, we conclude two points. First, IC use was not inspired as a reaction to students (e.g. IC terms were not introduced by students into the conversation and picked up by teachers to align with them). This fits in with what was found by Thulin and Pramling (2009), who observed teachers introducing IC terms on their own accord when engaging with young children without being prompted by them. Second, it is not likely that our participants used IC as a consequence of their explicit professional knowledge. They had barely any explicit didactical knowledge at this point of their training, having completed their science training but just starting their didactic courses. Rather, their tendency to use IC for students arises from their spontaneous intuitive didactic repertoire. This tendency showed up clearly in our conservatively designed setting (written explanation for imaginary recipients), speaking for a strong tendency to spontaneously resort to IC in pedagogical settings. We argue that such a tendency might be an expression of an intuitive natural pedagogy which is suggested to be a universal communicative tendency apparent in the context of cultural knowledge transmission (Cacchione & Amici, 2020; Csibra & Gergely, 2009, 2011; Tempelmann & Cacchione, 2021). That is, the participants might have intuitively tailored their language didactically to the students' needs to reduce the complexity and to make it easier for the students to process the information. Various studies, especially from interaction and language research, show that adults unconsciously structure and simplify content for children to learn (Saito & van Poeteren, 2012; Strauss et al., 2014). Doing so, they adjust their speech to the recipient's age and level of knowledge in transmission contexts (Kalashnikova et al., 2017; Strauss et al., 2014). The intuitive tendency to didacticise one's own language in teaching-learning contexts arises spontaneously and often unnoticed by the speaker. It comes thus conceptually very close to what Gresch and Martens (2019) describe as a-theoretical tacit dimension of teaching. Indeed, the use of IC has been shown to support learning in some cases, e.g. by reducing the cognitive load (Evans et al., 2012). Teleological reasoning, for example, creates distinct relationships (Kelemen, 2012) and excludes «*chance*», which is difficult for children to comprehend (Tibell & Harms, 2017). It can be a useful starting point for learning by picking up students' perspectives (e.g. Evans & Rosengren, 2018). Also, in our study, participants adapted their language to the expertise of the recipients; however, we did not observe an adaptation to the age of the recipient (i.e. first vs. sixth grade, see further discussion below).

The present results have two important implications for primary teacher training. First, the tendency to language didacticism, universally assumed for adults (Csibra & Gergely, 2009; 2011), might not be discarded when entering the teaching profession. As a consequence, there might be an implicit tendency to introduce IC into language addressed at students. Even though intuitive didacticism often supports children's learning in everyday interactions (e.g. Golinkoff et al., 2015; Wakefield et al., 2018), an unreflected use can lead to serious problems in formal education (Kelemen et al., 2013; Yates & Marek, 2014). Unfortunately, the participants of the present study who use IC for didactic reasons rarely used such expressions reflectively, as only in three out of 93 (3.2%) instances was a meta-level implied. In particular, it prevents the achievement of *conceptual bilingualism*, which is considered the gold standard of science education. Thus, it seems recommended to address and reflect on the advantages and disadvantages of intuitive language didactisation in teacher training.

Secondly, 20% of the prospective primary teachers tested in our sample were not able to correctly explain a scientific topic. Although having completed the scientific part of teacher training, they lacked adequate scientific knowledge. Measured against the fact that they should design adequate science instructions as a part of their profession, this number is far too high. More research is urgently needed on the cause of this shortcoming and what measures can be taken to address it.

Finally, we would also like to discuss some caveats of our study. We are convinced that natural pedagogy might prove to be a relevant theoretical framework in understanding the use of IC in the classroom. Our findings point in this direction but are too limited to draw general conclusions. We take it as a strong pointer that prospective primary teachers used IC with students but not experts, even in a very conservatively designed test situation. Contrary to what might be expected from studies with younger children (e.g. Saint-Georges et al., 2013), however, they did not respond to the age of the students. It is possible that the ages we varied were not contrasting enough (first vs. sixth grade) to lead to measurable effects. Likewise, it is possible that our conservative setting proved counterproductive here, as prospective teachers may have been overwhelmed with imagining the difference between a first- and a sixth-grader. Another caveat is that we could not meaningfully address the explicit didactical beliefs of teachers in this study, as we tested prospective teachers prior to their didactic training. A study with in-service teachers would have allowed for investigating the important question of the interrelation of implicit and explicit didactic beliefs.

More research is urgently needed in this area. Future studies should address in more detail the poorly understood high prevalence of IC use across different school levels and investigate whether potentially identified differences relate to the type of teacher education (as suggested by Kallery & Psillos, 2001, 2004). Likewise, it would be important to investigate student-teacher interactions to learn more about how the use of IC is sparked in the dynamic of communication. Finally, there is a need for studies exploring explicit and implicit didactic beliefs in more detail. Research on IC use in the classroom is extremely important to achieve the goal of *conceptual bilingualism*, which could lay the foundation for the flexible, elaborate science education of tomorrow.

Notes

1. The swiss primary school subject NMG (Natur, Mensch & Gesellschaft) combines science (chemistry, physics & biology) and social studies.
2. We used the robust ANOVA as it is robust to violations of normality and homogeneity of variance. Overall, we resorted to robust statistical procedures in all analyses where the prerequisites for the standard procedures were not met.
3. Full Sample: $F(1, 32) = 28.7$, $p < .001$; Collision: $F(1, 13.9) = 14.0$, $p = .002$; Combustion: $F(1,10.6) = 20.8$, $p < .001$.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethics statement

Approval given by the Ethics Committee of the Faculty of Philosophical and Human Sciences of the University of Bern. Approval number: 2013-11-695125

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Appendices

Table A1. Descriptive statistics and robust mixed ANOVA results (20% Trim-level).

Topic	Variable	Expert *C*	Student *C* / C_{1st} / C_{6th}	Expert *M (SD)*	Student. *M (SD)* / M_{1st} *(SD)* / M_{6th} *(SD)*	Class main	Rec. main	Inter.
Pooled	Total	12	93	.24 (.52)	1.86 (1.75)	0.002	31.83***	0.13
N = 50			45	.04 (.20)	2.05 (2.06)			
N_{1st} = 22			48		1.71 (1.49)			
N_{6th} = 28	Non-Agentive Teleology	2	5	.04 (.20)	.10 (.30)	NA	NA	NA
			3		.14 (.35)			
			2		.07 (.26)			
	Metaphorical Anthro.	10	65	.20 (.49)	1.30 (1.36)	0.08	30.04***	0.08
			31		1.41 (1.62)			
			34		1.21 (1.13)			
	Teleological Anthro.	0	23	.00 (.00)	.46 (.76)	4.13	0.001	0.001
			11		.50 (.80)			
			12		.43 (.74)			
Collision	Total	9	60	.33 (.62)	2.22 (1.95)	1.71	27.44***	3.20
N = 27			38		2.92 (2.18)			
N_{1st} = 13			22		1.57 (1.50)			
N_{6th} = 14	Non-Agentive Teleology	1	4	.04 (.19)	.15 (.36)	0.39	0.39	0.39
			3		.23 (.44)			
			1		.07 (.27)			
	Metaphorical Anthro.	8	38	.30 (1.41)	1.41 (1.53)	0.67	14.01**	0.88
			24		1.85 (1.86)			
			14		1.00 (1.04)			
	Teleological Anthro.	0	18	.00 (.00)	.67 (.92)	2.01	5.75*	2.01
			11		.85 (.90)			
			7		.50 (.94)			
Combust.	Total	3	33	.13 (.34)	1.43 (1.41)	4.72	11.62**	2.87
N = 23			7		.78 (.97)			
N_{1st} = 9			26		1.86 (1.51)			

(*Continued*)

Table A1. Continued.

Topic	Variable	Expert C	Student C C_{1st} C_{6th}	Expert M (SD)	Student. M (SD) M_{1st} (SD) M_{6th} (SD)	Class main	Rec. main	Inter.
N_{6th} = 14	Non-Agentive Teleology	1	1	.04 (.21)	.04 (.21)	NA	NA	NA
			0		.00 (.00)			
			1		.07 (.27)			
	Metaphorical Anthro.	2	27	.09 (.29)	1.17 (1.15)	3.16	20.85***	3.16
			7		.78 (.97)			
			20		1.43 (1.41)			
	Teleological Anthro.	0	5	.00 (.00)	.22 (.42)	2.52	2.52	2.52
			0		.00 (.00)			
			5		.36 (.50)			

Note. Combust. = Combustion, Anthro = anthropomorphism, C = Count, Class main = main effect of class (1st/6th), Rec. Main = main effect of recipient (expert/student); Inter. = interaction, NA = F test not applicable. The results of the main and interaction effects refer to the *F* test score of the robust mixed ANOVA with 20% trim-level. * $p < .05$, ** $p < .01$, *** $p < .001$