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Students' reasons for preferring teleological explanations

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ABSTRACT

The teleological bias, a major learning obstacle, involves explaining biological phenomena in terms of purposes and goals. To probe the teleological bias, researchers have used acceptance judgement tasks and preference judgement tasks. In the present study, such tasks were used with German high school students (N = 353) for 10 phenomena from human biology, that were explained both teleologically and causally. A sub-sample (n = 26) was interviewed about the reasons for their preferences. The results showed that the students favoured teleological explanations over causal explanations. Although the students explained their preference judgements etiologically (i.e. teleologically and causally), they also referred to a wide range of non-etiological criteria (i.e. familiarity, complexity, relevance and five more criteria). When elaborating on their preference for causal explanations, the students often focused not on the causality of the phenomenon, but on mechanisms whose complexity they found attractive. When explaining their preference for teleological explanations, they often focused not teleologically on purposes and goals, but rather on functions, which they found familiar and relevant. Generally, students' preference judgements rarely allowed for making inferences about causal reasoning and teleological reasoning, an issue that is controversial in the literature. Given that students were largely unaware of causality and teleology, their attention must be directed towards distinguishing between etiological and non-etiological reasoning. Implications for educational practice as well as for future research are discussed.

ARTICLE HISTORY

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KEYWORDS

Teleology; causality; explanation; reasoning; student conceptions

Introduction

Students tend to prefer teleological explanations to causal explanations¹ (Keil, 1992; Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990; Talanquer, 2013). Whereas causal explanations provide valid causes for biological phenomena, teleological explanations refer to biological functions as the causes of biological phenomena (Bartov, 1978; Galli, & Meinardi, 2011; Kampourakis, Palaiokrassa, Papadopoulou, Pavlidi, & Argyropoulou, 2012). Evidence for students' tendency to give teleological rather than causal explanations comes from studies focusing on biological fields as diverse as plant physiology, human physiology and evolution (Abrams & Southerland, 2001; Michael, 1998; Tamir & Zohar, 1991). When asked to explain evolutionary or

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physiological mechanisms, students often consider biological functions the driving force for biological phenomena rather than referring to biological mechanisms. For example, students argue that organisms develop new traits because they need them to survive (Bishop & Anderson, 1990; Nehm & Ridgway, 2011). Additionally, in prediction tasks related to biological phenomena, students focus on functions and tend to assume purposeful actions. For example, when asked to predict whether deciduous trees will continue to shed their leaves when kept under constantly warm conditions, students argue that plants will stop shedding their leaves because it is purposeless (Tamir & Zohar, 1991). Students' preference for teleological explanations is particularly evident in so-called explanation judgement tasks, in which they are given two explanations for the same phenomenon - one teleological and one causal – and asked to choose the one they prefer. In explanation judgement tasks, students favour teleological explanations over causal explanations (Keil, 1992; Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990; Talanquer, 2013). Little is known about how students justify their preference for teleological explanations. Although potential reasons have been discussed (Kampourakis, Pavlidi, Papadopoulou, & Palaiokrassa, 2012; Kelemen & Di Yanni, 2005; Talanquer, 2013), a systematic study is lacking. Therefore, in this study, we investigated students' preference in explanation judgement tasks and, as a main emphasis, how they justify their preference.

Theoretical framework

Explanation in science education

The term 'explanation' addresses multiple constructs. On the one hand, it refers to an instructional activity (= 'explain a thing to someone'), and on the other hand, it refers to a research activity (= 'explain a thing') (Horwood, 1988; Tang, 2016; Treagust & Harrison, 2000). In instructional communication, explanations denote pedagogical actions that attempt to answer implicit or explicit questions that follow from instructional goals or from students' inquiries (Leinhardt, 2001). Instructional explanations are meant to promote understanding in the student, which is best achieved by establishing connections between the newly introduced information and the students' prior knowledge in the particular context (Wittwer & Renkl, 2008; Wittwer, Nückles, & Renkl, 2010). The criteria for judging the success of an instructional explanation differ greatly from the criteria for judging the validity of a scientific explanation in research (Horwood, 1988). Whereas instructional explanations aim to expand students' personal knowledge, scientific explanations aim to expand current scientific thinking (McCain, 2015). Furthermore, philosophers have argued that scientific explanations meet the criteria 'empirical adequacy', 'causality', 'explanatory power' (the explanation covers a range of phenomena) and 'predictive power'. These criteria serve as characteristic features rather than defining criteria of explanation because there is no unitary account of scientific explanation. Although philosophers generally agree that scientific explanations move beyond descriptions of observable phenomena, the way in which a specific explanation 'moves beyond' description depends on specific explanatory aims and on the context in which an explanation is given (Braaten & Windschitl, 2011; Brigandt, 2013; Tang, 2016). Whereas in mechanics, scientific explanations take the form of law-like statements, a biological phenomenon such as a higher incidence of cancer in a small town is explained probabilistically, for example,

by reference to carcinogens that exist in the area (Braaten & Windschitl, 2011). In physiological contexts, scientists explain phenomena by stating mechanisms that cause the phenomenon in question. Additionally, functional ascriptions such as 'The heart pumps blood in order to provide the body with oxygen' can be used as explanations in response to research questions such as 'What role does the heart play in the operations of the body?' (McLaughlin, 2001). Explanatory uses of functions can be problematic. If a function is given as the sole cause of a biological phenomenon, that is, if a teleological assumption is made, scientific facts are contradicted. However, teleological explanations can be used as shorthand formulations to express more complex causal relationships in a way that focuses on the causal role of functions. For example, the teleological explanation 'People have hearts because hearts pump blood' is scientifically warranted given the underlying assumption that the function has emerged due to its fitness advantage in the course of evolution and that the trait development was caused by evolutionary factors (Galli et al., 2011; Lennox & Kampourakis, 2013). The logical link between the explanandum (what is explained) and the explanans (what explains) is established through conjunctions such as 'because' to express causal relations or 'hence' to express consecutive relations (Tang, 2016; Unsworth, 2001).

Students' preference for teleological explanations

Students tend to explain biological phenomena teleologically rather than causally. In a study by Tamir and Zohar (1991), high school students were asked to predict what would occur if certain biological phenomena no longer fulfilled any function. For example, they were asked whether a male peacock would spread its tail when 'the expected benefit of the behaviour had been removed' (Tamir & Zohar, 1991, p. 62). Once the students had been informed that peacocks continue to show their courtship behaviour even if there are no direct benefits to the individual, the number of their teleological responses decreased but remained considerable. In another study, students were presented with pictures of various biological phenomena and asked to explain biological mechanisms, for example, how plants grow towards light (Abrams & Southerland, 2001). Some students did not address how the biological phenomenon occurs but elaborated on its function. For example, one student responded that a plant 'need[s] light to grow, so it grows that way' (Abrams & Southerland, 2001, p. 1275). In a study by Kampourakis, Pavlidi, et al. (2012), pre-school children and primary students also provided teleological explanations in response to a question about why duck feet and booby feet are shaped as they are. In another study, Kampourakis and Zogza (2008) documented that secondary school students gave teleological explanations for the existence of biological traits. For example, when students explained the morphological similarities between wolves, dogs, and foxes, they argued that all three animals needed to catch prey and, therefore, 'need some features such as sharp nails and teeth' (Kampourakis & Zogza, 2008, p. 35). As documented by Jensen and Finley (1996), college students assumed that organisms have their current features solely because of their functions for survival. The authors found this type of student thinking even after instruction in evolution.

Interested in interrelationships among the range of teleological explanations that students give, Kelemen (2012) reviewed students' teleological explanations of evolutionary phenomena and distinguished three types: 'basic function based', 'basic need based' and

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'elaborated need-based' (Kelemen, 2012, p. 67). Kelemen argued that these three types of explanations reflect views of 'different levels of causal-mechanical elaboration and explanatory depth' (Kelemen, 2012, p. 67). Basic function-based teleological explanations refer to functions as the only cause for the existence of current traits, as, for example, in the following explanation: 'Giraffes have long necks so that they can reach high food' (Kelemen, 2012, p. 67). Basic need-based explanations state that a need to adapt is the driving force for change, as in the following example: 'Giraffes got long necks because they needed them to reach high food' (Kelemen, 2012, p. 68). Like basic need-based explanations, elaborated need-based explanations refer to needs as the driving force for change. Additionally, elaborated need-based explanations provide details about the mechanism of how the need-driven change occurs. One example of a mechanism that students consider a cause for change in traits is effort. For example, students explained that giraffes have long necks because they have tried repeatedly to reach the leaves high up in trees. Another example of a mechanism that students consider a cause for change might be nature. For example, students might explain that giraffes have long necks because Mother Nature adapted them that way (Kelemen, 2012).

Explanation judgement tasks for teleological and causal explanations

Another research strand on teleology has been focusing on how students (and other participants) judge pre-formulated teleological explanations and causal explanations in socalled explanation judgement tasks. In such tasks, teleological one-sentence explanations are presented in writing, for example, 'They had flat feet so that they could stand on wet ground without slipping' (Casler & Kelemen, 2008, p. 362). In some tasks, the teleological one-sentence explanations are juxtaposed with causal one-sentence explanations, for example, 'They had flat feet because their toe bones were shortened and all smoothed out' (Casler & Kelemen, 2008, p. 362) (Casler & Kelemen, 2008; Keil, 1992; Lemke, 1990; Lombrozo, Kelemen, & Zaitchik, 2007). Explanation judgement tasks come in two forms: acceptance judgement tasks and preference judgement tasks. In acceptance judgement tasks, participants are encouraged to indicate whether they agree or disagree with the teleological and causal explanations offered, either in the form of a yes-no judgement or a rating (Coley & Tanner, 2015; Evans, 2001; Friedler, Zohar, & Tamir, 1993; Jungwirth, 1975; Kelemen, 1999c; Kelemen & Rosset, 2009; Kelemen, Rottman, & Seston, 2013; Lombrozo et al., 2007; Rottman et al., 2017; Tamir & Zohar, 1991). In preference judgement tasks, participants are asked to make a forced-choice judgement and indicate whether they prefer the teleological explanation to the causal explanation of a particular biological phenomenon or vice versa (Casler & Kelemen, 2008; Keil, 1992; Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990; Lombrozo et al., 2007). For example, in a preference judgement task study, Lemke (1990) presented 10 phenomena from human biology to high school students and undergraduate students. For each phenomenon, the students were offered a causal explanation, for example, 'During physical activity, oxygen enters muscle tissue from the blood because oxygen content inside muscle tissue decreases as the oxygen is used' (Lemke, 1990, p. 9) and a teleological explanation, for example, 'During physical activity, oxygen enters muscle tissue from the blood because muscles require oxygen to produce energy' (Lemke, 1990, p. 9). In 6 of 10 phenomena, students preferred the teleological to the causal explanation. Studies by Kelemen and her research group also documented that participants with different backgrounds accepted teleological explanations and preferred them to causal explanations (Casler & Kelemen, 2008; Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005) Thus, the authors concluded that humans are biased to favour teleological explanations. Acceptance of and preference for teleological explanations were particularly strong among participants with limited knowledge of biological causation, that is, children, uneducated people and patients with the Alzheimer disease. The authors also found that the teleological bias can be observed in highly educated adults if they are asked to provide explanation judgements under time constraints (Kelemen et al., 2013).

Whereas acceptance of and preference for teleological explanations have been amply documented, two different interpretations exist. Some authors assume that individuals who accept teleological explanations, also reason teleologically (Casler & Kelemen, 2008; Kelemen, 1999c, 1999b, 2003; Kelemen et al., 2013; Kelemen & Rosset, 2009; Lemke, 1990; Lombrozo et al., 2007; Rottman et al., 2017), whereas other authors are more sceptical. The results of Tamir and Zohar (1991), Friedler et al. (1993) and Coley and Tanner (2015) suggest that acceptance of teleological explanations is not necessarily motivated by teleological reasoning. In particular, Tamir and Zohar (1991) and Friedler et al. (1993) investigated the link between acceptance judgements and the underlying reasoning. The authors conducted explanation judgement tasks with high school students, and, Friedler et al. (1993) also included university students. The participants were asked to 'indicate for each [teleological] statement whether or not it might be included in a science textbook' (Friedler et al., 1993, p. 440). If the participants did not accept the teleological explanation, they were asked to justify their decision. Both studies found that students did not refer to teleology when they justified their rejections of teleological explanations. Hence, Friedler et al. (1993, p. 442) stated that 'it may be concluded that acceptance of teleological formulations does not necessarily imply teleological reasoning patterns'. Additionally, they argued that '[...] there are indeed two different aspects involved concerning the use of teleology in biology: (a) teleological formulations [i.e. pre-formulated teleological explanations presented to the students in the explanation judgement task] and b) teleological reasoning patterns'.² Unfortunately, neither study specifies how, other than 'non-teleological', students justified their rejection of teleological explanations.

In a more recent study by Coley and Tanner (2015), further evidence emerged that supports the need to distinguish between teleological reasoning and other types of reasoning in explanation judgement tasks. University students were asked to rate their acceptance of teleological explanations (such as 'Genes turn on so that a cell can develop properly' (Coley & Tanner, 2015, p. 4)) and justify their choice. Students reasoned teleologically not only when they accepted teleological explanations but also when they rejected them. Furthermore, a considerable percentage of students who accepted a teleological explanation reasoned *non*-teleologically. Depending on the specific item, 45–77.5% of the students (n = 137) accepted the teleological explanation but used non-teleological justifications. Unfortunately, as the authors were primarily interested in teleological reasoning, they did not specify the kinds of non-teleological reasoning.

What may be behind students' preference for teleological explanations?

Given that some studies distinguish between explanation judgements about teleological explanations and teleological reasoning and others do not make this distinction, we investigated how high school students justify their choice in explanation judgement tasks. In the following paragraphs, we review the literature regarding the question of how students might justify their explanation judgements about teleological explanations and causal explanations.

Preference judgements in favour of teleological explanations might be ascribed to the human tendency to draw on everyday experience, in which teleological reasoning is common (Kelemen, 2012; Sehon, 2010). As an intuitive kind of reason, teleological reasoning is appealing to individuals for explaining functional qualities in the living world in analogy to human intentional actions, that is, in terms of purpose rather than biological mechanisms (Evans, 2001; Kampourakis, Palaiokrassa, et al., 2012). Teleological explanations seem to account for biological phenomena very well, as organisms became adapted to the environment in the course of evolution, a process that upon initial inspection appears goal oriented – and thus teleological (Galli et al., 2011; Kampourakis & Zogza, 2007; Zohar & Ginossar, 1998). Preference judgements in favour of causal explanations, in contrast, might be ascribed to more deliberative and informed judgements. The two alternative ways of judging, that is, intuition vs. deliberation, are accounted for by dual process models in psychology (Evans, 2008; Kelemen et al., 2013). Intuitive cognitive processes, such as teleological reasoning, are assumed to persist throughout life. Psychologists also use the term 'bias' in speaking about an intuitive cognitive process. The term 'teleological bias', in particular, refers to the human tendency to reason teleologically (Kelemen et al., 2013). Deliberative cognitive processing abilities, such as causal reasoning, develop in the course of (not necessarily formal) education; they can override but not replace intuitions. Hence, the implicit intuitive knowledge system, i.e. teleological reasoning, competes with explicit and deliberative knowledge, i.e. causal reasoning (Evans, 2008). In the absence of causal knowledge, intuitive teleological explanations serve as placeholders for causal explanations (Kampourakis & Zogza, 2009; Kelemen, 1999a, 1999c, 1999b). Even if causal knowledge is present, the teleological intuition might still be faster and more convincing than the causal explanation. According to dual-process models, causal reasoning can overwrite the teleological bias if the causal belief system is very strong and highly explicit and if cognitive processing is not taxed by time constraints or other factors (Kelemen et al., 2013; Kelemen & Rosset, 2009).

Another explanation comes from the biology education literature. According to Abrams and Southerland (2001), the preference for teleological to causal explanations might result from biology instruction that emphasises functions of biological processes over causes so that students focus on functions and accept teleological rather than causal explanations. Additionally, students might have acquired teleological formulations from educators, textbooks, popular nature programmes and even scientists, who do not assume teleological etiology, but use teleological formulations to facilitate communication (Abrams & Southerland, 2001).

A further possibility might be that students base their explanatory preferences not on causality and teleology but on other criteria. For example, Talanquer (2013) argued that students might prefer teleological explanations because they seem more familiar, less

complex and 'actually productive in making predictions about the outcome of [chemical] interactions and processes' (Talanquer, 2013, p. 1423). Thus, Talanquer (2013) recommended conducting qualitative studies to explore students' reasons for preferring teleological to causal explanations. Similarily, Kampourakis, Pavlidi, et al. (2012) considered the possibility that when students make their explanation judgements, they focus not only on teleology and causality but also on other criteria. These authors criticise explanation judgement tasks that present pre-formulated explanations to the participants because they consider this a major limitation of these studies; 'not only because students were not free to express their own views, but also because the answers among which they had to choose may have influenced them in various ways, i.e. to select the answers that seemed to be more 'correct' and not the ones that were really closer to their own views (if there were any)' (Kampourakis, Pavlidi, et al., 2012, p. 655, 656). Thus, students might be hypothesised to base their explanation judgements on etiological criteria, that is, causality and teleology, but also on *non-etiological criteria*, such as familiarity and complexity. Etiology is a technical term used in philosophy to refer to the ascription of causes (Buller, 1998; Mossio, Saborido, & Moreno, 2009). We use the terms etiological and nonetiological in this study to distinguish between two fundamentally different types of reasoning.

According to Wouters (2013), persons who accept teleological explanations might assume valid causal relationships. Wouters views organisms as systems whose survival 'depends not only on the system's material composition, but also on the arrangement of its components and on the order and timing of their activity' (Wouters, 2013, p. 485). Hence, the statement 'The heart pumps blood around the body because in this way, nutrients and oxygen get to all organs' could be understood as a reference to one of the many causes for an organism's survival. According to Wouters, this understanding is 'in line with the practice of reasoning in contemporary biology' (Wouters, 2013, p. 457); therefore 'explanations of both kinds [mechanistic and functional explanations] are needed to understand systems whose existence depends on an organized ability' (Wouters, 2013, p. 462). Given the possibility that not only scientists but also students might read teleological explanations as functional analyses, students must be given the opportunity to elaborate on their choice in explanation judgement tasks so that researchers have sufficient information to interpret them.

Aims of the study and research questions

This study investigates high school students' choices in explanation judgement tasks as well as the justifications they provide for those choices. First, the study examines the degree to which high school students accept teleological and causal explanations. Second, it examines the degree to which high school students prefer teleological to causal explanations when they are confronted with 10 phenomena that are explained both teleologically and causally. The third research question investigates what reasons students provide for their preference. Since students gave reasons that were highly specific to individual item topics, another research question was added in the course of the study. The fourth research question examined the extent to which students can infer the commonality across the explanation judgement task items, that is, the juxtaposition of causal and teleological explanations. In sum, this study investigates the following research questions:

- (1) To what degree do secondary students accept teleological and causal explanations?
- (2) Which type of explanation causal or teleological do secondary students prefer?
- (3) How do secondary students explain their preference judgements?
- (4) To what extent can students infer the commonality across explanation judgement task items, in which causal explanations are juxtaposed with teleological explanations?

Methods

Participants and setting

Three hundred fifty-three secondary students (age 10–18) from five high schools located in five small-to medium-sized cities (9000–40,000 inhabitants) in Germany participated in the study. The distribution of the participating students – in the questionnaire survey and the interviews – by grade level is presented in Table 1.

Data collection procedure

The questionnaire survey was distributed at the beginning of regular biology lessons. The first author of this paper administered the questionnaire survey. The students were told that the survey was not an examination but would be used to determine how students thought about physiological phenomena. Filling in the questionnaire took approximately 15 minutes on average. Immediately after completion of the questionnaire, 26 participating students were randomly selected for semi-structured individual interviews, which were conducted by the first author (see Table 1 for participating students by grade level). The participants represented both sexes and a range of abilities. The interviews lasted approximately 15–30 minutes.

Assessment instruments

This study draws on three data sources: an acceptance judgement task questionnaire, a preference judgement task questionnaire, and guideline-based individual interviews (for the questionnaires and interview guidelines, see the appendix).

Acceptance judgement tasks and preference judgement tasks

To be able to report on students' responses to teleological explanations and causal explanations as comprehensively as possible, we proceeded as in Lombrozo et al. (2007) and

internetts by grade level.					
Grade level	Questionnaire survey	Interviews			
5 (aged 10–11)	54	2			
6 (aged 11–12)	22	2			
7 (aged 12–13)	24	3			
8 (aged 13-14)	87	6			
9 (aged 14–15)	32	3			
11 (aged 16–17)	96	10			
Total	315	26			

Table 1. Participating students in the questionnaire survey and the interviews by grade level.

asked students for both acceptance and preference judgements. The items for the preference questionnaire and the acceptance questionnaire were developed based on items used by Lemke (1990), which focus on human biology, a prominent topic in high school biology. According to the teachers of the participating students, the students were familiar with the 10 phenomena presented in the questionnaire, but the younger students were more familiar with the functions than with the mechanisms, which is in accordance with the curricula that introduce human biology by the end of year 6 but focus more on functions than on mechanisms (Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen [Ministry of Education and Training of the State of North Rhine-Westphalia] (2008); Sächsisches Staatsministerium für Kultus und Sport [Saxon State Ministry of Education and Sports], 2011). Because Richardson (1990) published only 3 of 10 items, we developed additional items, adopting the principle of item development that each item presents a phenomenon from the field of human biology followed by the causal conjunction 'because' (e.g. 'The heart pumps blood around the body because ...'; see the appendix for all items) and two one-sentence explanations, one teleological (e.g. '... in this way nutrients and oxygen get to all organs') and one causal (e.g. '... the heart muscle contracts and relaxes periodically').

Individual interviews

The purpose of the interviews was to investigate whether students base their judgements of teleological and causal explanations on the etiological difference between the two explanation types or on non-etiological criteria. The interviewees had the questionnaire, which they had filled in, in front of them. For each of the 10 preference judgements, the students were encouraged to justify their judgements in the individual interviews. Following the analysis of the first two interviews, which revealed that the students based their judgements on surface features, such as familiarity and complexity, as well as on the etiological difference between the two explanation types, we added RQ 4. Consequently, the remaining 24 students were asked an additional question at the end of the interview. They were told that each item consisted of two alternative explanations focusing on the same biological phenomenon and were then asked to elaborate on the question 'What does each of the two explanation types characterise?'.

Data coding and data analysis

Acceptance judgements and preference judgements

Students' acceptance judgement scores ranged from 1 to 4, with higher scores indicating higher acceptance of a type of explanation. Students' preference judgements, which were in favour of either the teleological or the causal explanation, were binary coded. For each participant, mean acceptance scores for both teleological and causal explanations as well as mean preference scores across all 10 items and standard deviations were calculated using the statistics software SPSS. For each grade, average acceptance scores as well as the average preference score were calculated. To assess the relationship between grade level and the acceptance scores as well as between grade level and the preference scores. Spearman's rank correlation coefficients were computed. To examine differences between preference of teleological and causal explanations as well as differences between preference for teleological and causal explanations, Wilcoxon signed-ranks tests were used.

To assess scale reliability, Cronbach's alpha coefficients were calculated for the acceptance judgement and preference judgement scales.

Students' justifications for their preference judgements

To code students' justifications for their preference judgements, scoring rubrics were developed using a deductive-inductive process (Mayring, 2010). In several cycles of analysis, categories were added and refined. Based on studies with comparable questionnaire designs that interpreted the preference judgements in favour of causal or teleological explanations as an indication of causal or teleological understanding of biological causation (Kelemen et al., 2013; Lemke, 1990), the categories 'causal justifications' and 'teleological justifications' were included in the scoring rubric. In analogy to the three types of teleological reasoning described by Kelemen (2012), we formed three sub-categories of teleological justifications: basic function based, basic need based and elaborated need based.

Inductive data analysis revealed that many students did not only apply causal and teleological reasoning, i.e. etiological reasoning, when justifying their preference decisions. In addition, the students based their preference decisions on a variety of non-etiological criteria, that is familiarity, student conceptions, interestingness, complexity, relevance, holism, addressing function and no preference (for detailed descriptions of the categories consult the supplemental online material). Interrater reliability for the three main categories 'causal justifications', teleological justifications' and 'non-etiological justifications' was analysed by comparing two persons' coding of the student responses (Cohen's k = 0.87).

Students' identifications of the two explanation types

To code students' identifications of the two explanation types offered in the preference judgement tasks, scoring rubrics were developed. Based on prior explanation judgement task studies, that are based on the assumption that participants reason either causally or teleologically about the two explanation types, we expected students to distinguish the two explanation types in terms of 'cause vs. effect'. In line with that expectation, the analyses revealed that students did distinguish between the two explanation types in terms of 'cause vs. effect'. Following the analysis of the first two students' justifications of their preference judgements, which often were non-etiological, we expected that some students might distinguish between the causal and the teleological explanation not in terms of etiology but in terms of other distinctive features. Indeed, the analysis revealed that students distinguished between the two explanation types in terms of 'more complex vs. less complex explanation', and 'process vs. meaning'. Student responses were coded independently by two persons and interrater reliability was found to be high (Cohen's k = 0.88).

Results

High school students' performance in acceptance tasks and preference tasks (RQ 1 and RQ 2)

In the explanation judgement task questionnaire, the students' acceptance of teleological explanations (M = 3.28, SD = 0.42; Cronbach's $\alpha = 0.71$) was higher than their acceptance

of causal explanations (M = 2.93, SD = 0.47, Cronbach's $\alpha = 0.74$) (see Figure 1a). The difference is statistically highly significant (Wilcoxon: z = -10.672, p < .001). Note, however, that the theoretical mean for both scales is 2.5 so that both means are clearly above the theoretical mean of the scales. In the preference judgment task questionnaire, similarly, students preferred teleological explanations (M = 6.44 of 10 items, SD = 1.86) to causal explanations (M = 3.56 of 10 items, SD = 1.86) (Cronbach's $\alpha = 0.46$). The difference is statistically highly significant (Wilcoxon: z = -11,405, p < .001) (Figure 1b). Acceptance judgments for teleological explanations (Spearman: r = 0.107, p = .045) and causal explanations (Spearman: r = 0.274, p = .000) were found to correlate significantly with students' grade level, whereas preference judgements were found not to correlate significantly with students' grade level (Spearman: r = -0.069, p = .195).

We observed variation between items in both the preference and the acceptance questionnaires (see Table 2). In eight of 10 items, students' preference and acceptance judgements were in favour of teleological explanations. In the remaining two items, students' preference and acceptance judgements were in favour of causal explanations.

Students' justifications for their preference judgements (RQ 3)

General overview

In the interviews, the students readily justified their preference judgements. In most of their justifications, they used a variety of non-etiological reasons such as familiarity and complexity. Furthermore, the students argued teleologically and less often also causally. Figure 2 displays the frequencies of the different types of justifications given. In the following paragraphs, we provide an overview of students' non-etiological and etiological justifications (for more detailed descriptions of all types of justifications and exemplary student justifications, see the supplemental online material).



Figure 1. Students' (a) acceptance judgements and (b) preference judgements. The bar charts display the mean scores over all classes (year 5–9, 11; N = 353).

Item topic	Causal explanation accepted (%)	Teleological explanation accepted (%)	Teleological explanation preferred (%)
1. Ear wax production	71	79	62
2. Skin colour adaptation	78	66	42
3. Sweating	49	87	83
4. Blood clotting	63	89	70
5. Blood pumping by the heart	74	95	73
6. Development of sex characteristics in puberty	61	90	73
7. Fever	62	78	68
8. Tear production	65	89	78
9. Smelling	91	66	29
10. Oxygen diffusion in muscle tissue	70	86	66
Total score	68	82	64

Table 2. Students' acceptance and preference judgements for all items (percentage of students; based on dichotomised data). Boldface distinguishes between items, where students preferred causal over teleological explanations (boldface) and vice versa (no boldface).

Non-etiological justifications

In most of their justifications, the students used a variety of non-etiological justifications. For example, they preferred 'the more familiar' explanation, which was often the teleological one. Additionally, they preferred the teleological explanations because they felt that the biological function given in them was more 'relevant' and 'holistic' than the mechanism given in the causal explanations. Some students simply stated that they preferred the teleological explanation because of the function described ('addressing function') without giving reasons for preferring the function (such as 'relevance' or 'holism'). The students who argued in favour of causal explanations most frequently mentioned the 'higher complexity' of the causal explanations compared to the teleological explanations. Additionally,



Figure 2. Justification types (frequencies) given by students in preference judgements (absolute numbers, N = 283 justifications). Criteria arranged from highest frequencies of preference for causal explanations (top) to lowest frequencies of preference for causal explanations (bottom).

the students referred to the 'interestingness' of the causal or teleological explanations to justify their preference. However, other preference judgements were based on 'student conceptions', which led students to reject one of the two explanations and prefer the alternative that was more in line with their conceptions about the topic. Moreover, some students had no preference but rather argued that 'both [explanation types] are important to know' ('no preference').

Several students referred to particular school contexts in which they prefer one or the other explanation, i.e. they conceived the explanations as primarily 'instructional explanations' rather than 'causal explanations' and 'teleological explanations'. For example, the students explicitly referred to school contexts by using phrases such as 'in lessons', 'general knowledge and grammar school knowledge', or 'what teachers should give as an explanation'. The students used the criteria 'familiarity', 'interestingness', 'relevance' and 'complexity' when they decided which of the two explanations they would prefer to learn about in a particular school context. They argued that these criteria would vary from context to context and that their explanatory preference would therefore vary as well. For example, a student argued that in the particular context of 'blood pumping by the heart' in item five, one of the two explanations was familiar and that therefore the student preferred that the hitherto unfamiliar explanation be dealt with 'in the lesson': 'I prefer the second one [C], because I have heard about the simpler explanation [T] before and in that case, I like it that way [that is, to learn about the more complex explanation] in the lesson.' Another student argued that 'in lessons, I prefer to learn about the simpler explanation first [referring to T] and later, if I am interested in the topic, I would like to learn more about the second explanation [referring to C]'.

Etiological justifications

Students also justified their preference decisions etiologically, that is, causally and teleologically. As an example of a causal justification, one student preferred the causal explanation that hormones cause the development of sex characteristics 'because that includes these messenger substances, which *trigger* the development'. As an example of a teleological justification, another student argued that 'the body heats up *in order to* kill germs'. As in other teleological justifications given by students, this one is ambiguous. If read literally, it suggests that the purpose of killing germs is the cause of the rise in body temperature. If read non-literally, the statement does not imply the etiological assumption that the increase in temperature is a goal-oriented process directed towards 'killing germs'. Instead, the increase in temperature could be read from a functional perspective; after all, the temperature increase is functional for the human body, even though non-intentional.

The students' causal and teleological justifications were either explicit or implicit. In the explicit etiological justifications, they used terms such as 'cause' and 'reason', indicating that they consciously based their preference decision on the etiology of the explanation type. For example, a student preferred the causal explanation because he considered the teleological explanation 'rather the effect [and] not really the *cause*' thus demonstrating awareness of the etiology of the two explanation types. In implicit etiological justifications, it was less clear whether students based their preference decision consciously on the etiology of the two explanation types or whether they simply rephrased the explanations from the questionnaire in their own (but similar) words. For example, the wording in the justification 'because that includes these messenger substances, which trigger the

development' is close to the wording of the explanation in the questionnaire ('because then more messenger substances are formed which trigger this development').

Relationships between the etiology of the preferred explanation and the etiology of the justification

Figure 3 shows how frequently students justified their preference judgements (as surveyed in RQ 1) either etiologically or non-etiologically (as surveyed in RQ 3). The students justified their preference judgements mostly non-etiologically: Of the total 283 justifications that they gave in the interviews, 187 (66.1%) were non-etiological and 96 (34.0%) were etiological. Of all the teleological explanations, 81.4% occurred in connection with preference for teleological explanations. There were also cases of etiological mismatches: 18.6% of all the *teleological* explanations occurred in conjunction with preference for causal explanations occurred in conjunction with preference for teleological explanations. The following quotation illustrates an etiological mismatche:

Well, not the second one $[T]^3$ because we already have something else in the ear to prevent dirt from getting inside the ear. I just can't remember its name. (year 5, item 1, preference: C)

The student prefers the *causal* explanation but reasons *teleologically* (to prevent dirt from getting inside).

References to the conjunction 'because' in students' etiological justifications

The conjunction 'because' is a crucial element in determining the etiology of the two explanation types in this study. 'Because' acts as a logical connective that initiates causal sentences. Thus, grammatically, the mechanism and the function given in the two explanation types are marked as 'causes'. In their justifications, the majority of the



Figure 3. Frequency of non-etiological justifications and etiological justifications for students' preference judgements (absolute numbers, N = 283 justifications).

interviewees (n = 23) did not refer to the conjunction 'because'. Two students called attention to the conjunction 'because' when they justified their preference of the *causal* explanation, whereas one called attention to it when justifying his/her preference of the *teleological* explanation. In the following quotation, the student considered the teleological explanation to be the explanation that stated the cause:

The actual cause is not the fact that [...] the glands in the ear canal produce it, because that would ultimately be why it is like that, but this isn't the cause what this 'because' means. That's why I've ticked that it prevents dirt from getting inside the ear. (year 11, item 1, preference: T)

In the following quotation, the student considered the causal explanation to be the explanation that stated the cause: '[...] Again, more the cause [C] than the effect [T]. That's because the "because" rather demands the cause' (year 11, item 6, preference: C).

Occurrence of the different types of justifications across students

We investigated, whether the high frequency of non-etiological justifications was characteristic of the whole sample or typical only of particular students. By examining the distribution of etiological and non-etiological justifications across students (n = 26; see Figure 4). The analyses revealed that non-etiological justifications were not due to particular students but occurred across 25 students, with teleological justifications given by 23 and causal justifications given by 10. Notably, the non-etiological justification 'familiarity' is particularly widely distributed: It was given by 24 students. Most students did not justify their preference judgements systematically on the basis of a single justifications. Only one student (8_5) argued systematically causally. Eight students argued teleologically and causally. Although most students did not base their preference judgements systematically on a single criterion, some applied a particular preference criterion more frequently than others. For example, student 11_5 repeatedly used 'relevance', and student 11_4 repeatedly used '(higher) complexity'.

Occurrence of the different types of justifications across items

These analyses are parallel to the analyses in the preceding paragraph, but focus on items rather than students. The aim was to investigate, whether the high frequency of non-etio-logical justifications was characteristic of the whole sample or only of particular items. Thus, we examined the distribution of etiological and non-etiological justifications across items (n = 26; see Figure 5). The main finding of these analyses was that non-etio-logical justifications were not only due to particular items but occurred across all 10 items, paralleling the findings described in the preceding paragraph, which focused on justifications across students. Both teleological and causal justifications were given for all 10 items. Note that the non-etiological justification 'familiarity' was particularly widely distributed across all 10 items. The type of justification 'higher complexity' also occurred quite frequently; it occurred across nine items and only in conjunction with preference for the causal explanation for items 1, 2 and 10. The justification 'addressing function' occurred especially frequently in conjunction with item 7.



Figure 4. Occurrence of justifications across 26 students. Black circles indicate justifications, which occurred in connection with preference judgements in favour of teleological explanations, grey circles justifications, which occurred in connection with preference judgements in favour of causal explanations. The bigger the circle diameter, the more frequently occurred a justification in connection with a particular student. Each student justified 10 preference judgements. For each of the 10 preference judgements students gave at least one justification. It was possible to give more than one justification.

Students' identifications of the two explanation types (RQ 4)

When asked to describe 'What do the two explanation types characterise?', students made distinctions in three different ways: 'more complex vs. less complex explanation', 'cause vs. effect' and 'process vs. meaning'. In the following sections sample statements are provided.

Non-etiological reasoning ('more complex vs. less complex explanation')

Eleven of 24 students distinguished the two explanation types as 'more complex vs. less complex'. For example, one student characterised the causal explanation as the explanation that 'contains more factual words [...] and is more difficult' and the teleological explanation as the explanation that 'contains normal words so that you know straight-away: "Ah, that's it".



Figure 5. Occurrence of justifications across 10 items. Black circles indicate justifications, which occurred in connection with preference judgements in favour of teleological explanations; grey circles indicate justifications, which occurred in connection with preference judgements in favour of causal explanations. The bigger the circle diameter, the more frequently occurred a justification in connection with a particular item. Each student justified 10 preference judgements. For each of the 10 preference judgements students gave at least one justification. It was possible to give more than one justification. The circle diameter displays how frequently justifications occurred in connection with a particular item.

Causal reasoning ('cause vs. effect')

Eight of 24 students distinguished the two explanation types as 'cause vs. effect'. This distinction was accompanied by different preference decisions. Six students, although they distinguished between cause and effect, did not base their preference on the etiology of the two explanation types. For example, one student argued that whether s/he preferred the causal or the teleological explanation depended on the specific item topic:

If there are such things as the heart, where it is actually quite self-explanatory how the function is caused [C],⁴ I find it more important to learn about the function [T].⁵ But where you don't hear it very often, as for example with the sweat glands, I find it important how the function is caused [C]. (year 11)

Two students, however, based their preference systematically on the etiology of the explanation types and preferred the causal explanation because, as one of the students argued, 'the "because" demands the cause, and then to say that's what it means, that's nonsense somehow'.

Teleological reasoning ('process vs. meaning')

Two of 24 students distinguished the two explanation types as 'process vs. meaning' and, on principle, preferred the teleological explanation. A closer analysis of the following

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description of the two explanation types reveals that the student who is quoted below demonstrated awareness of the causal relations between mechanism and function, although s/he used a teleological formulation:

One describes what happens, for example, that dirt gets inside the ear, and the other one describes how that happens. I think if I had only ticked the first one, it would not be enough because that wouldn't be the reason why; I mean, if I knew that specialized glands in the ear canal produce the ear wax, I'd know what happens biologically, but I wouldn't know what it meant. Generally, I think that both are correct, but at school, I'd prefer the second option as an explanation because if I knew for what my body has this thing, it's of more use to me than if I knew that the glands produce the wax. (year 11)

The student looked at the teleological explanation in descriptive terms rather than etiological terms ('One describes what happens [...] and the other one describes how that happens.'). Then, the student continued to reason teleologically that the function has 'meaning' for the human body ('for what my body has this thing'). Here, the student spoke of a purpose within the system of the organism, a functional argument that is biologically adequate. The student, however, did not refer to the function as a driving force for the mechanism, which would be causally inadequate. Assuming that both explanations were 'correct', the student preferred the teleological explanation on the basis of its personal relevance ('it's of more use to me').

General discussion

The general discussion is organised along the four research questions. Additionally, based on exploratory findings from this study, the last two paragraphs develop research perspectives on the aspects 'interpreting teleological formulations' and 'students' understanding of scientific explanations'.

The first two research questions are rooted in the research tradition of investigating acceptance (RQ 1) and preference (RQ 2) judgements about teleological and causal explanations. The findings described in this paper provide evidence that students prefer teleological to causal explanations in both explanation judgement task formats. These results confirm those of previous studies that documented that participants from a variety of backgrounds prefer teleological to causal explanations (Casler & Kelemen, 2008; Keil, 1992; Kelemen, 1999b, 2003; Lemke, 1990; Talanquer, 2013). For example, Lemke (1990), on whose items this study is modelled, found that high school students and college students prefer teleological explanations to causal explanations. Interestingly, the degree to which students prefer teleological explanations is similar in both studies (Lemke, 1990: M 6.1; this study: M 6.4). By complementing preference judgement tasks with acceptance judgement tasks, this study also provides an answer to the question of to what degree students accept the non-preferred alternative that is – in approximately six of 10 phenomena – the causal explanation. As a main finding from the acceptance judgement tasks, the present study documented that acceptance of both explanation types was strong (i.e. well above the theoretical mean of the scale), although students' acceptance of teleological explanations was stronger than their acceptance of causal explanations, and the difference was statistically highly significant.

To explore what one can infer from the results of the explanation judgement tasks, we conducted interviews in which students justified their preference judgements (RQ 3) and

described the two explanation types in their own words (RQ 4). As suggested by Talanquer (2013), the findings from the interviews provided empirical evidence for the claim that students prefer causal explanations due mainly to their complexity and teleological explanations because they find them more familiar and because they consider functions more relevant to their everyday life than mechanisms. Younger students favoured teleological explanations especially frequently because of their higher familiarity in contrast to the mechanistic explanations (see Figure 4). This finding suggests that the explanation judgements depended strongly on the students' prior knowledge. Prior knowledge of functions might be attributed to students' everyday experiences as well as the curricular focus on functions rather than mechanisms in biology lessons, especially in the younger school years (Abrams & Southerland, 2001; Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen [Ministry of Education and Training of the State of North Rhine-Westphalia] (2008); Sächsisches Staatsministerium für Kultus und Sport [Saxon State Ministry of Education and Sports], 2011). In the interviews, some students argued that they preferred biology instruction to focus initially on the functions of phenomena, and - if they are interested - they subsequently like to learn about the underlying mechanisms. The instructional challenge thus lies in sparking students' interest in the mechanisms that underlie the functions. The interview data also allowed us to investigate the common assumption that preference for teleological explanations coincides with teleological reasoning. In several studies, in fact, preference judgement tasks about teleological and causal explanations have been used to investigate the participants' tendency to explain biological processes teleologically (Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990). However, in other studies researchers argued that participants might base their preference judgements on criteria other than etiology, but this aspect remained largely unexplored (Friedler et al., 1993; Talanquer, 2013). Consequently, in the present study, we systematically examined for what reasons the participants preferred teleological explanations to causal explanations and vice versa (RQ 3). The empirical evidence described in this paper shows that the students justified some of their preference decisions etiologically (i.e. teleologically and causally), but across all items, the students argued non-etiologically even more frequently. This finding alone calls into question the claim that preference for one type of explanation corresponds to etiological reasoning. Some students also indicated that their preference decision was random, as they did not prefer one explanation to the other (see the supplemental online material for detailed description of the type of justification 'no preference'). Analyses of the interviews furthermore revealed mismatches insofar as some students justified a preference for teleological explanations causally (see Figure 3). Thus, data from this study provide multiple supports for the argument that one should carefully distinguish between preference for teleological explanations and teleological reasoning (Friedler et al., 1993). The same argument, of course, can be made for preference for causal explanations.

RQ 4 served to examine whether students' non-etiological reasoning can be explained by their inability to recognise the etiologies of the teleological and the causal explanation or by their deliberate choice to base their preference on other explanatory features than etiology. Thus, in the final interview question we asked students to focus on the structure of the entire questionnaire and asked them to describe what the two explanation types characterise. Interestingly, whereas researchers (Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990) distinguished the two explanation types in terms of etiology 20 🔄 F. TROMMLER ET AL.

as 'teleological vs. causal explanation', most students distinguished the two explanation types as 'more complex vs. less complex explanation'. Thus, the difference in complexity seems to be more salient for students than the etiological difference. However, one-third of the interviewees reasoned causally as they distinguished 'cause' (referring to the causal explanation) and 'effect' (referring to the teleological explanation). Teleological reasoning was rare. Surprisingly, even a student who used a teleological formulation by distinguishing 'process' (referring to the causal explanation) and 'meaning' (referring to the teleological explanation) reasoned causally that the mechanism causes the function. Contrary to our expectations from prior explanation judgement task studies (Kelemen, 1999b, 2003; Kelemen & Di Yanni, 2005; Lemke, 1990), the findings from RQ 4 primarily revealed a difference between students who were aware of etiology and those who were not rather than a difference between students who reasoned causally and those who reasoned teleologically. Additionally, students who demonstrated awareness of the etiological difference between the two explanation types still accepted teleological explanations as they read them as functional analyses. This finding is interesting, as it provides empirical evidence for the fact that reading teleological explanations as functional analyses is not only theoretically possible (Toepfer, 2004; Wouters, 2013) but in fact an approach that students use.

How do we interpret instances of teleological formulations documented in the interviews, for example, the lengthy student quotation provided in the description of the research findings for RQ 4? At first sight, students' teleological formulations seem to substantiate findings from prior studies, according to which teleological reasoning is common and indicative of nonscientific causal assumptions that future functions influence past events, in particular inappropriate goal-directed reasoning (Kampourakis, Pavlidi, et al., 2012; Kelemen, 2012). Teleological reasoning, to quote an influential interpretation, may go back to a cognitive bias that directs humans towards reasoning in terms of goals and purposes (Coley & Tanner, 2012; Kelemen et al., 2013). Additionally, students might have acquired teleological formulations from educators, textbooks and popular nature programmes (Abrams & Southerland, 2001; Aldridge & Dingwall, 2003; Zohar & Ginossar, 1998). Given that teleological formulations are often ambiguous, however, it is problematic to infer teleological reasoning from students' teleological formulations: Do students wrongly assume goal-directed development of biological structures (Kelemen, 2012), or do they legitimately refer to the causal role of functions for the whole organism (Wouters, 2013) when they comment on their preference for teleological explanations? Within the methodological framework of the current study, we found no evidence for scientifically incorrect causal assumptions about functions, but did find students who explicitly referred to the latter interpretation of teleological formulations. Items in this study, however, were not designed to probe students' understanding of teleological explanations of phenomena from human biology. Rather, students were encouraged to comment on their preference for one type of explanation over the other and – when they commented on their preference for teleological explanations - did not volunteer the explanation that biological functions exist because there are purposes and goals. Thus, future research should allow for distinguishing between students' use of teleological formulations and scientifically incorrect causal assumptions that future functions influence past events.

Which understanding of 'explanation' did the students have? When justifying their explanatory preferences, most of the students analysed them in terms of how far the given explanations corresponded to their prior knowledge, met their personal interests and answered their personal questions. Thus, as Horwood (1988) argued, students are

used to thinking of the term 'explanation' not in its scientific sense but rather in terms of 'say something more about' (Horwood, 1988, p. 48). Additionally, within the 10 preference judgement task items, the students changed their preference criteria from one item context to another and argued that their explanatory preference depended on the school context. Thus, the students' justifications suggest that they understood 'explanation' mainly in terms of 'instructional explanation' (= 'explain a thing to someone'). Less frequently, the students analysed the given explanations using scientific criteria by referring either to the etiology and/or to the scientific correctness of the explanations (although students' comments on correctness reflected their conceptions), but only three students commented on the logical connective 'because' as the structural element that determines the etiology of the explanations. None of the students reflected upon the double meaning of the term 'explanation' as denoting either instructional (= 'explain a thing to someone') or scientific (= 'explain a thing') explanation. The students focused on their personal explanatory aims rather than on scientific explanatory aims. Thus, the findings of this study suggest that students should be sensitised to scientific explanatory aims. A better awareness of explanatory aims should help them judge the adequacy of scientific explanations in subjects as diverse as biology, physics and history (Brigandt, 2013). For example, in the case of the present questionnaire, the students should have argued that the mechanistic explanations (e.g. 'The heart pumps blood around the body because the heart muscle contracts and relaxes periodically') are adequate for explaining the physiological cause of the biological phenomena. The second explanation in the questionnaire (e.g. 'The heart pumps blood around the body because in this way, nutrients and oxygen get to all organs') might be judged an inadequate teleological explanation if it is analysed against the aim to explain the cause of the biological phenomenon. However, if the aim of the second explanation is to explain the role of the biological phenomenon in the survival of the human organism, the functional explanation is adequate (McLaughlin, 2001; Wouters, 2013). Surprisingly, even researchers who used explanation judgement tasks in their studies (Casler & Kelemen, 2008; Kelemen et al., 2013; Kelemen & Rosset, 2009; Lemke, 1990; Rottman et al., 2017) did not consider the importance of explanatory aims in judging explanations and hence discredited functional explanations as inadequately teleological without considering the explanatory potential of functional explanations against the aim of explaining the role of the biological phenomenon in the survival of the human organism (Wouters, 2013).

Practical implications

Students' attention must be directed towards causality and teleology

Given that about half of the students interviewed in this study did not recognise causal and teleological explanations as such but identified the two explanation types (RQ 4) in terms of 'less complex explanation versus more complex explanation', it is necessary to raise students' awareness of causality and teleology. Such an instructional approach must address three interrelated types of knowledge: knowledge of cause and effect, knowledge of the linguistic means that express cause and effect, and knowledge of the specific biological topic that is discussed. Based on findings from instructional psychology, acquiring and eventually transferring an abstract concept such as etiology is best achieved if students' attention is directed to the concept of etiology in connection with several concrete applications

(Renkl, 2014, 2015). Thus, teachers can demonstrate relevant causal relations in contrast to the shortcomings of teleological assumptions.

Students' teleological questions must be addressed

In their justifications, the students revealed that they would like to know the purpose of body structures ('Why the body has it, that's more important to know'; 'It [the function] is more relevant for real life, and as a student, you can relate to it'). Thus, students themselves ask teleological questions. From a constructivist viewpoint, teachers should respond to the students' interests and explain the purpose of body structures (Leinhardt, 2001; Treagust & Harrison, 2000). The pedagogical challenge in providing answers to these questions lies in considering both the interests of the students on the one hand and the ambiguity of teleological formulations for understanding biological concepts on the other. To meet both requirements, teachers should aim for a meta-level understanding, which involves the ability to distinguish between questions that can be answered by explanations containing teleological formulations (students' interest-motivated questions, such as 'For what purpose does my body have this structure?') and questions that cannot be answered by teleological explanations (scientific questions such as 'What caused the development of this structure?'). Furthermore, to avoid misunderstandings of teleological formulations, teachers should use multiple ways to explain, model and represent biological concepts (Talanquer, 2007).

Students must be able to decode teleological formulations

As outlined in this paper, teleological formulations are ambiguous. How should we address the ambiguity of teleological formulations in the classroom? We do not recommend adopting the view from explanation judgement task studies that teleological formulations are fundamentally inadequate (Lemke, 1990). As a consequence, we do not recommend banning teleological formulations from lessons. For pragmatic reasons, teleological formulations cannot be banned, as they are abundant in the media, for example, in popular nature programmes and books (Abrams & Southerland, 2001; Aldridge & Dingwall, 2003; Zohar & Ginossar, 1998). Additionally, scientists use teleological formulations because they have heuristic value for biological research insofar as they look at biological systems as if they were 'good designs' (Boerwinkel, Waarlo, & Boersma, 2009, p. 14) (Tamir, 1985). Given the abundance and the heuristic value of teleological formulations, banning them from science classes does not prepare students to understand the teleological formulations that they encounter (Talanquer, 2013; Zohar & Ginossar, 1998). Instead, science educators should initiate critical reflections that illustrate how biologists interpret teleological explanations in terms of as if formulations and how these explanations differ from inappropriate goal-directed reasoning so that students learn to decode teleological formulations (Lemke, 1990; Talanquer, 2010). Biology educators should make it clear that biologists provide causal explanations for biological mechanisms and that biological functions are instrumental categories that aid biologists in conceptualising living systems at higher levels of organisation (Toepfer, 2004, 2012; Wouters, 2013). These reflections about teleological formulations aim to counteract misconceptions that might be reinforced by teleological formulations (Galli et al., 2011; Kampourakis, 2007; Michael et al., 1999; Talanquer, 2007).

Limitations

Despite the relevance of the results obtained, the following limitations should be acknowledged. The first limitation is the small interview sample. The present study provides insights into students' reasoning in relation to preference judgements, but larger samples would be desirable for more representative results. The second limitation refers to the preference judgement task, which left room for a range of preference criteria other than 'etiology', because it encouraged the students to choose the alternative 'they preferred'. Essentially, thus, the students made a comparison between two explanations but were free to choose their own tertium comparationis, the criterion of the comparison. This fact might explain the low reliability of the test instrument. Thus, students legitimately used a wide range of mostly non-etiological criteria that were sometimes rather subjective. Although the use of this type of preference judgement task in this study succeeded in confuting the common claim that preference judgements can be used to make inferences about students' etiological views, data from the questionnaire do not contribute to our understanding of students' etiological reasoning. The latter, however, is of super-ordinate interest for biology educators because biology, as a science, attempts to explain the etiology of phenomena. Future studies should therefore go beyond the research interest in students' preference and probe students' understanding of the etiology of explanations.

Conclusions and perspectives for future research

This study contributes to the literature on students' reasoning about teleological explanations. Evidence from this study confirms that students justify their preference for causal and teleological explanations etiologically, that is, causally and teleologically. Furthermore, this study uncovers an aspect that was hitherto unknown: Students also justify their preference for causal and teleological explanations non-etiologically by referring to the criteria of 'familiarity', 'complexity', 'student conceptions', 'interestingness', 'addressing function', 'no preference', 'holism' and 'relevance'. The study succeeds in exploring factors that caused students to justify their preference judgements regarding causal and teleological explanations non-etiologically. First, it provides evidence that students are largely unaware of the concept of etiology, which inevitably results in their basing their preference judgement on non-etiological criteria. Second, the students' references to school contexts in their justifications suggest that they understood the task as a request to judge the explanations' instructional potential rather than their scientific validity, which influenced their choice of preference criteria. Third, the formulation of the teleological explanation in the preference judgement task questionnaire allows for nonetiological preference criteria as it can be read non-etiologically as functional analysis. If students see themselves confronted not with two explanations of different etiologies but rather with two different perspectives – the functional perspective and the mechanistic perspective on the biological phenomenon – they inevitably base their preference judgement on non-etiological criteria. Accordingly, future research that aims to probe students' teleological reasoning must disentangle teleological reasoning from teleological formulations on the one hand and teleological reasoning from a lack of awareness of the concept of etiology on the other. Exploring additional perspectives for research after analysing the findings of this study, the authors of this paper used an explanation judgement task format in which they asked students to choose the explanation that cites the *cause* rather than to choose the explanation they *prefer*. This variation of the explanation judgement task was intended to focus students clearly on the etiology of the explanation types. However, students scrutinised the two explanation types for the correctness of the suggested 'causes' but failed to analyse the logical causal relation among the explanandum and the explanans as expressed by the causal conjunction 'because'. Consequently, future research should develop scaffolding approaches that support students in structuring biological explanations and in applying necessary linguistic knowledge (see Tang, 2016, for a similar scaffolding approach for physics education). Additionally, such approaches should focus students on different explanatory aims and the corresponding explanation types. Furthermore, in reaction to the ambiguity of teleological formulations, we suggest to ask students for graphic representations of the causal relations between scientific phenomena and their functions and mechanisms.

Although this study focused mainly on biology education, in which teleological explanations of living beings are especially widespread, the students' non-scientific judgements of the causal and teleological explanations presented in this study imply explicit reflections about explanatory aims, not only in biology education but also in other subjects.

Notes

- In this study, we adopt the terminology commonly used in science education as we contrast 'teleological explanations' – which give purposes/functions as causes – with 'causal explanations' – which give mechanisms as causes. From a logical perspective, if teleological explanations give functions as causes, they are in fact a specific kind of *causal* explanation. However, in the science education context, the focus is not on this structural commonality but on the different kinds of causes given in the two explanation types.
- 2. In this paper, we adopt the terms 'teleological formulations' and 'teleological reasoning' from Friedler et al. (1993). 'Teleological formulations' contain teleological language. Whether the teleological formulation is meant metaphorically or literally can be deduced only from the context or by asking further questions. By 'teleological reasoning', we refer to literal teleological thought that considers functions causes of (biological) phenomena.
- 3. [T] The student refers to the teleological explanation.
- 4. [C] The student refers to the causal explanation.
- 5. [T] The student refers to the teleological explanation.

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Appendix

Preference judgement tasks

In this questionnaire, you will find statements about the human body. For each topic, two explanations are given.

For each topic, indicate the explanation that you prefer.

- 1. The ear contains wax because ...
 - \Box ... specialised glands in the ear canal produce it.
 - \Box ... it prevents dirt from getting inside the ear.
- 2. Exposure to the sun gradually tans the skin because ...
 - \Box ... darker skin protects the skin from sun damage.
 - \Box ... it causes the formation of a pigment in the skin cells.
- 3. Sweating occurs because ...
 - \Box ... in this way, the body can eliminate excess heat.
 - \Box ... the muscles that surround the sweat glands contract.
- 4. Once a blood vessel is damaged, the blood clots because ...
 - \Box ... the blood contains a substance that then solidifies.
 - \Box ... it protects the body from major blood loss.
- 5. The heart pumps blood around the body because ...
 - \Box ... the heart muscle contracts and relaxes periodically.
 - \Box ... in this way, nutrients and oxygen get to all organs.
- 6. During puberty, sex characteristics are developed because ...
 - \Box ... this development enables the reproduction of humans.
 - \Box ... then more messenger substances are formed, which trigger this development.
- 7. In some diseases, the body temperature increases (fever) because ...
 - \Box ... this supports the immune system in fighting the germs.
 - \Box ... substances of the germs cause the temperature to increase.
- 8. The eye waters if a foreign object enters it because ...
 - \Box ... the tear gland is stimulated to produce more tears.
 - \Box ... the foreign body is then flushed out of the eye.
- 9. People smell with the nose because ...
 - $\Box\ldots$ in this way, they can assess the state of food and perceive dangerous substances.
 - ... smelling cells react to odourant substances and send the information to the brain.
- 10. During physical activity, oxygen enters muscle tissue from the blood because ...
 - \Box ... the oxygen content inside the muscle tissue decreases as the oxygen is used.
 - \Box ... the muscles use oxygen to provide energy.

Acceptance judgement tasks

How reasonable do you find the following explanations? Please mark with a cross.

	I find this explanation reasonable			
1. The ear contains wax because	agree	rather	rather	disagree
		agree	disagree	
specialised glands in the ear canal produce it.				
it prevents dirt from getting inside the ear.				
2. Exposure to the sun gradually tans the skin because	agree	rather	rather	disagree
	_	agree	disagree	_
darker skin protects the skin from sun damage.	Ц	Ц	Ц	Ц
it causes the formation of a pigment in the skin cells.			\Box_{i}	Ļ
3. Sweating occurs because	agree	rather	rather	aisagree
in this way the heady say aligningto average heat	_	agree	aisagree	_
In this way, the body can eliminate excess heat.	H	H	H	
the muscles that surround the sweat glands contract.				dicaaraa
4. Once a blood vessel is damaged, the blood clots because	ugree	rutiler	dicaaroo	uisugree
the blood contains a substance that then solidifies		ugree		
it protects the body from major blood loss	H			
5. The heart numps blood around the body because	naree	∟ rather	L. rather	disaaree
s. The near pumps blood around the body because	ugice	οστέρ	disaaree	uisugree
the heart muscle contracts and relaxes periodically.				
in this way, nutrients and oxygen get to all organs.	H			
6. During puberty, sex characteristics are developed because	aaree	rather	rather	disaaree
······································		aaree	disaaree	
this development enables the reproduction of humans.				
then more messenger substances are formed, which trigger this	Ē	Π	Π	Π
development.	_	_	_	_
7. In some diseases, the body temperature increases (fever) because	agree	rather	rather	disagree
		agree	disagree	
this supports the immune system in fighting the germs.				
substances of the germs cause the temperature to increase.				
8. The eye waters if a foreign object enters it because	agree	rather	rather	disagree
		agree	disagree	
the tear gland is stimulated to produce more tears.				
the foreign body is then flushed out of the eye.				
9. People smell with the nose because	agree	rather	rather	disagree
	_	agree	aisagree	_
In this way, they can assess the state of food and perceive dangerous				
substances.	_	_	_	_
smelling cells react to odourant substances and send the information to				
the Dialit.	aaroo	rathor	rathor	dicaaroo
blood because	ugiee	οστρρ	disaaree	uisuyiee
the oxygen content inside the muscle tissue decreases as the oxygen is				
used.				
the muscles use oxygen to provide energy.				

Interview guidelines

- 1. *This question is asked for each of the* 10 *preference judgements*: 'Why do you prefer this explanation [pointing to the explanation the student preferred] to the other explanation?'
- 2. 'Imagine somebody asks you tonight what our interview was about. You would say that we spoke about this questionnaire and that in the questionnaire, 10 biological phenomena were given. You would go on to say that for each phenomenon, two alternative explanation types were given. How would you describe what the one explanation type always characterised and what the other explanation type always characterised?'