Teleology as a tacit dimension of teaching and learning evolution: A sociological approach to classroom interaction in science education

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Abstract
Teleology has been described as an intuitive cognitive bias and as a major type of student conception. There is controversy regarding whether teleological explanations are a central obstacle to, are legitimate in, or are even supportive of science learning. However, interaction in science classrooms has not yet been investigated with regard to teleology. Consequently, this study addresses the question of how teleological explanations emerge in science classroom interactions about evolution and how teachers and students address emerging teleology. In this article, we introduce a theoretical and methodological framework drawing from the sociology of knowledge and systems theory, suggesting that this framework may enrich the understanding of knowledge construction and of social practices in the science classroom because it enables distinguishing between explicit and tacit knowledge. We investigated seven secondary school units about evolution and present data from four grade-12 classes in Germany, a country with very few creationists, to contrast two ways in which teleology is addressed. In the first type, the teachers combine intentional and need-based teleological explanations with aspects of scientific theories in an ambiguous way. Contrastingly, in the second type, the teachers construct a duality between correct mechanistic and incorrect teleological explanations by discrediting preceding scientific theories. In the discussion, we argue that the presented sociological approach can also be valuable in other science education contexts, such as creationism, the nature of science and socio-scientific issues, because classroom interaction involves tacit communication, such as a tacit epistemology, which are essential grounds for the students’ knowledge construction.
1 | INTRODUCTION

The prevalence of teleological explanations, that is, goal-directed explanations, which involve a focus on functions, need-based views, intentionality, or design (Kelemen, 2012), has been widely described in the science education literature on evolution (Gregory, 2009), and their legitimacy in instruction has been discussed from a normative viewpoint (e.g., Evans, Rosengren, Lane, & Price, 2012; Kampaourakis & Zogza, 2008; Zohar & Ginossar, 1998). However, there is a lack of evidence concerning classroom interactions regarding teleology. To answer the research questions of how teleological explanations emerge in science classroom interactions on evolution and how teachers and students situationally address emerging teleology, we introduce the documentary method, a research approach to analyze classroom interaction (Asbrand & Martens, 2018) based on Mannheim's sociology of knowledge (Mannheim, 1952) and Luhmann's systems theory (Luhmann, 1995, 2002; cf. Bohnsack, 2010). With this approach, we consider classroom interactions as explicitly and implicitly structured by interactional and organizational norms, rules, and patterns of behavior (Luhmann, 2002). Moreover, we focus on teaching and learning as complementarily related but categorically distinct social processes, which are based on teachers' and students' explicit, or theoretical, in addition to implicit, or a-theoretical, knowledge (tacit in the terms of Polanyi, 1966; cf. Mannheim & Stewart, 1962; Mannheim, 1982). Applying this general approach to our research objectives, we describe teleology as a tacit dimension of teaching and learning evolution. We assume that in classrooms, teleology emerges and is processed on a rather implicit interactional level and therefore profoundly structures the students' understanding. From this perspective, the science classroom is not only a place to address students' conceptions and to develop a scientific understanding but also an experiential space (Mannheim, 1982), where – beyond pedagogical intentions and the rational choice of the agents – misconceptions also emerge and are reproduced. Consequently, we argue that the presented framework provides a novel perspective for science education research because it combines theoretical considerations of knowledge acquisition and conceptual understanding with perspectives on situated interactions. This sociological framework has been advanced and applied to different educational contexts (Asbrand & Martens, 2018), and in this article, we discuss in which way it may inform the analysis of science classroom interactions focusing on the tacit dimension of teleology. We contrast this framework with previous approaches used in research regarding classroom interactions, such as functional linguistics or social semiotics, and qualitative methods, such as the grounded theory approach (cf. Corbin & Strauss, 2015), to illustrate its additional value.

To begin, we unfold our theoretical and methodological framework describing classroom interaction from different perspectives: first, we describe the tacit dimension of classroom interaction drawing on Mannheim's sociology of knowledge (Mannheim, 1982) and Luhmann's systems theory (Luhmann, 2002). Second, we turn to science education research on classroom interaction (cf. Kelly,
2007, 2014; Lemke, 1990, 2012) to summarize recent findings on the tacit dimensions of interaction in science classrooms. Routines and patterns of participation as well as implicit domain-specific knowledge relevant in science classrooms are in the focus of this review. Third, we collect indications from developmental research (Coley & Tanner, 2012; Kelemen, 1999; Kelemen, 2012) and science education research on students' teleological conceptions (e.g., Gregory, 2009); this enables us to characterize teleology as a tacit dimension of students' knowledge. Regarding our research rationale, we argue that research regarding teleology has mostly focused on the students' perspective, neglecting that teachers themselves may hold a teleological bias that influences classroom interactions. Based on this rationale, we concretize our research questions and discuss the way in which the sociology of knowledge and systems theory can inform our research about classroom interaction. We take up the challenges and potentials from this relation of perspectives and discuss the additional value relative to previous approaches. In the results section, we present four selected contrasting classroom sequences showing two types of approaches with which teachers and students address teleological explanations concerning evolution in different ways. Referring to our interpretations, we finally discuss the way in which the theoretical and methodological framework may provide further insights into classroom interaction. The implications for both fields – research on teaching and learning evolution as well as research on classroom interaction in science education – are discussed.

2 | THEORETICAL AND METHODOLOGICAL FRAMEWORK: TACIT DIMENSIONS OF CLASSROOM INTERACTION

2.1 | Tacit dimensions of classroom interaction from the perspective of systems theory and sociology of knowledge

It is commonplace to characterize teaching and learning in schools not only as explicit and intentional processes in terms of transmitting, receiving, and constructing knowledge. In addition, a tacit dimension has to be taken into account to understand teaching and learning more adequately (e.g., Brock, 2017; Forman & Ansell, 2002; Lave & Wenger, 2007; Neuweg, 2004; Rogoff, 1990; Schön, 1983). Furthermore, educational and sociological theories commonly refer to classroom interaction as a highly complex social phenomenon, in which students and teachers internalize norms, rules, and patterns of behavior: Large numbers of persons – adults, children, and adolescents – with different perspectives, social or organizational roles, and expected behaviors are involved in interactions. Teaching and learning, as well as a variety of peer-cultural activities, occur simultaneously in the classroom. Another aspect of complexity is that classroom interactions have a multimodal character (Givry & Roth, 2006; Kress, 2010), meaning that interaction is based on verbal and nonverbal aspects as well as on interactions with material artifacts. All three modes serve to transport meaning, are involved in and are a result of routines developed in the history of the interaction. Within this complex social interaction, implicit “rules of behavior that enable and constrain interaction in the classroom” emerge and solidify in a “grammar of schooling” (Vanderstraeten & Biesta, 2006, p. 169; with reference to Hamilton, 1989; Tyack & Cuban, 2000).

The strength of Luhmann's theoretical approach to educational processes is its ability to explain the complex character of classroom interaction within an enfolding theoretical framework of systems theory (Luhmann, 1995, 2002; cf. Asbrand & Martens, 2018). Luhmann (2002) categorically differentiates between the interaction system (e.g., the classroom interaction) and the psychological systems (e.g., the teacher and the students) that are located in the environment of the interaction system. Accordingly, in “education and other complex situations, two kinds of worlds play a role, namely the
'inner world' of the different participants and the 'social world' of the interaction itself’ (Vanderstraeten & Biesta, 2006, p. 169). Luhmann (2002) describes the classroom interaction as both a closed, self-referential system and as a complex social order that can be characterized as a unique reality (Vanderstraeten, 2001; Vanderstraeten & Biesta, 2006). Particularly in the case of classroom interaction, some additional sources of complexity arise from the organizational context of school: First, for teachers and students, participation in classroom interaction is characterized structurally as "involuntary togetherness" (Luhmann, 2002, p. 108; Mannheim & Stewart, 1962). According to Vanderstraeten, this has effects on participation in the classroom, as learning is never only an intrinsic, individual process but also an extrinsic, organizational requirement. Second, the teacher occupies a privileged position in the classroom and is therefore able to organize the course of interaction and the students' opportunities to present themselves (cf. Cazden, 1988; Mehan, 1979, 1980). From this perspective, classroom interaction is characterized as an asymmetric role structure. The opportunities and patterns of participation are to be considered categorically distinct but complementary (Luhmann, 2002; cf. Vanderstraeten, 2001; Helsper & Hummrich, 2009). Third, the students are expected to close the gap between what they know so far and what they are supposed to know based on curricular demands (Vanderstraeten & Biesta, 2006). From this perspective, the classroom interaction operates with the expectation that the students, as psychological systems, change or develop (Luhmann, 2002). This expectation has an uncertain status because education generally lacks technology (Luhmann & Schorr, 2000; cf. Lortie, 1975; Vanderstraeten, 2001; Vanderstraeten & Biesta, 2006). As psychological systems located in the environment of the interaction system, the individual students and teachers self-referentially interface with the classroom interaction based on different perspectives, interests, motives, and experiences. Therefore, instruction or teaching cannot determine the learning processes of students.

In classrooms, various forms of explicit and implicit knowledge are communicated or enacted by the teacher, the students and the classroom material: factual scientific knowledge of specific content, domain-specific acting schemes and routines, knowledge about teaching and learning processes, and knowledge about the positioning of the agents within school as a societal institution. Although teaching and learning processes may involve deliberate and reflexive decisions, much of the knowledge that serves to orient the actions remains implicit. In fact, participants in classroom interaction have more knowledge of their actions than they can explicitly state (Polanyi, 1966; focusing on teachers' implicit knowledge: Schön, 1983; Shulman, 1987; Loughran, Mulhall, & Berry, 2004). From the perspective of sociology of knowledge, Mannheim (1952, 1982) systematically distinguishes between explicit or theoretical knowledge on the one hand and experiential or a-theoretical knowledge on the other. The latter is also called implicit or tacit knowledge, with reference to Polanyi (1966), or practical or incorporated knowledge, with reference to Bourdieu (1996; cf. Bohnsack, 2010). This knowledge guides actions in everyday practice and is, hence, referred to as the agents' framework of orientation (Bohnsack, 2010).

Mannheim relates these forms of knowledge “to the experience, institutions, traditions, practices, and positions of social groups and the individuals within those groups” (Goldman, 1994, p. 266). With reference to Mannheim (1982), Bohnsack (2010, p. 105) calls this the “conjunctive space of experience”. Thus, a-theoretical knowledge is generated in social interactions within a certain community or milieu. In social interaction, members of a community may understand each other immediately without interpreting each other's utterances. Consequently, there is no need to explicate this knowledge because the understanding can be taken for granted. The origin of this understanding is a common history of socialization and common experiences (Bohnsack, 2010). As classroom interaction is characterized by routines and habits of thought (Mannheim & Stewart, 1962, with reference to
Dewey, 1916), we can consider the interaction as a conjunctive space of experience. At the same time, according to Luhmann's understanding of classroom interaction as an asymmetric and complementary relation between teacher and students, it cannot be considered the same conjunctive space of experience for the teacher and the students. Although the teacher and students co-construct the classroom interaction, they do it on the basis of different types of implicit knowledge or frameworks of orientation, and they consequently acquire different implicit (and explicit) knowledge from the interaction (Asbrand & Martens, 2018). According to this theoretical perspective, simple communication models that assume transmission and reception of information are inadequate (cf. Vanderstraeten & Biesta, 2006). Rather than assuming explicit and intentional processes of knowledge transfer between teachers and students, we conceptualize interactions between social milieus in the classroom as a process of recontextualization (Fend, 2008). This means that within an asymmetric but complementary relation, students integrate impulses or requirements from the teacher or the classroom material with their own frameworks of orientation (with Luhmann, 2002 to their self-reference). Similarly, the teacher also interfaces and processes the students' impulses and the classroom material in terms of recontextualization (Asbrand & Martens, 2018).

2.2 Tacit dimensions of interaction in science classrooms

A mutual assumption of research projects about learning in science classrooms is that teaching and learning are genuinely social processes that are “constructed through discourse and interaction” (Kelly, 2007, p. 443). Consequently, many studies in the field of science education are based on theoretical frameworks such as social semiotics, sociolinguistics, critical discourse analysis or ethnomethodology (e.g., Carlsen, 1991; Lemke, 1990, 2012; Moje, 1997; Roth, 2015; cf. Cameron, 2001; cf. Kelly, 2007, 2014).

Science education research on the internalized norms, rules, and patterns of participation in classroom interaction describes tense perspectives on science classrooms. On the one hand, classroom interaction is described as a mutual practice and discourse between (emerging) members of a science community; on the other hand, classroom interaction is seen as an arena of rather incommensurable discourses between teachers and students. From a socio-cultural perspective, Lemke (1990, 2001), for example, argues that communication always creates a community of people who share the same language. Moreover, meanings are constructed in a way that is characteristic of that community, that is, words, gestures or objects do not have meanings per se. Therefore, communication between members of different communities may be impeded because the same words may have different functions and meanings. Lemke claims that “teachers belong to a community of people who already speak the language of science” (Lemke, 1990), while students mostly do not belong to such a community. The underlying normative assumption is that students should become members of this community by doing science and that they should come to identify with the scientific discipline through enculturation (Kelly, 2014; Lemke, 1990). Focusing on categorical differences between teachers' and students' discourses in science classrooms, Aikenhead and Jegede (1999, p. 271) even describe this transition between the students' life world and the science classroom as a “cross-cultural experience.” In their work on discourse in project-based science, Moje, Collazo, Carrillo, and Marx (2001) extend this notion of intersecting discourses in the classroom. In addition to scientific disciplinary discourses and social or everyday discourses, Moje et al. (2001) consider instructional and interactional discourses in their framework. From this perspective, classroom discourse is a challenge for students with regard to not only scientific practices but also the norms of classroom practice, such as the role of the teacher as an authority (cf. Luhmann, 2002). As a result, these distinct discourses may hinder communication and conceptual learning (Moje et al., 2001; cf. Lemke, 1990). Regarding the norms of classroom
interaction, the characteristic IRE patterns of classroom communication – consisting of initiation, reply and evaluation (Lemke, 1990; Mehan, 1979) – have since been replicated in many (science) education studies. The IRE pattern puts the teacher in an authoritative position and produces an asymmetric relation between teacher and students (cf. Oliveira, Akerson, Colak, Pongsanon, & Genel, 2012). These underlying structures, norms, rules, and cultural differences, in addition to an asymmetric relation between teachers and students, are seen as influential tacit dimensions of science education classrooms.

Science education research also refers to domain-specific implicit knowledge and routines. Concerning the nature of science (NOS) and epistemology as domain-specific knowledge funds, Oliveira et al. (2012) investigated – through different types of teacher evaluations of students’ answers – the implicit messages that are transmitted by the teacher. They argue that teachers’ endorsements of students' answers implicitly transport a positivist notion of true knowledge rather than tentativeness. Regarding epistemology, this enforces a dualistic understanding of right and wrong answers. Moreover, this goes along with an authoritative role of the teacher as knowledgeable, and it reinforces the unequal position of the students. Oliveira et al. (2012) emphasize that classroom interactions can be investigated on two different levels. While the science content is explicitly communicated, the NOS, the epistemology of science and the social structure are co-constructed through implicit communication (cf. Clough, 2006).

2.3 Teleology as a tacit dimension of students' knowledge

Regarding the factual scientific knowledge in evolution classes, the complex processes of natural selection as the cause of evolutionary change need to be understood. The most relevant components of a scientific explanation are described as “key concepts of natural selection” by Nehm and Schonfeld (2008, p. 134): “(1) the causes of phenotypic variation (e.g., mutation, recombination, sexual reproduction); (2) the heritability of phenotypic variation; (3) the reproductive potential of individuals; (4) limited resources and/or carrying capacity; (5) competition or limited survival potential; (6) selective survival based on heritable traits; (7) a change in the distribution of individuals with certain heritable traits.” In contrast to scientific explanations of evolutionary change, students often use teleological explanations, that is, explanations in which a “property, process, or entity is explained by appealing to a particular result or consequence that it may bring about.” (Lennox & Kampourakis, 2013, p. 421) Moreover, teleological explanations may involve goal directedness, reference to the needs of the organisms, or a notion of intentionality or design (Kelemen, 2012). Various studies describe teleology as a dominant type of student conception in the context of evolution (Gregory, 2009) and as an intuitive cognitive bias from a developmental psychology perspective (Coley & Tanner, 2012; Kelemen, 1999, 2012). Empirical research has repeatedly shown that students construct teleological explanations or prefer teleological over causal explanations (Abrams & Southerland, 2001; Bartov, 1981; Bishop & Anderson, 1990; Kelemen, 1999; Richardson, 1990; Tamir & Zohar, 1991). Furthermore, students have little reflexive knowledge about the differentiation between causal and teleological explanations on a meta-level and are mostly unable to distinguish the two types explicitly (Trommler, Gresch, & Hammann, 2018). Kelemen (1999) observed the tendency to explain the existence not only of man-made artifacts but also of natural living and nonliving objects in a goal-directed way. Consequently, she coined the term “promiscuous teleology” (Kelemen, 1999, p. 1440) and states that “in sum, students' teleological beliefs about adaptation are prevalent, [and] are potentially embedded in a framework of implicit underlying intentional assumptions about nature” (Kelemen, 2012, p. 71). Therefore, we argue that teleology can be considered a tacit dimension of students' thinking because it emerges as experiential knowledge from everyday interaction,
where intentionality, goal directedness and the fulfillment of needs are intuitive and therefore proper categories to explain one’s own actions and the actions of others (cf. Gregory, 2009; Kelemen, 2012). In contrast, factual knowledge, such as knowledge about natural selection, is not rooted in social everyday interactions or routines and thus represents explicit knowledge in terms of the sociology of knowledge.

Casler and Kelemen (2008) argue that it is formal education rather than developmental processes that leads to a reduction in teleological explanations because a comparison of schooled and non-schooled adults revealed a significant difference in the use of such explanations. Therefore, the role of teleological explanations in the science classroom has been discussed in the context of various scientific disciplines (Kampourakis, 2007; Kelemen, 2012; Talanquer, 2007; Treagust & Harrison, 2000). There is much controversy over whether teleological explanations should be considered impedimental, legitimate or even supportive for science learning, and the role of educators and classroom materials such as textbooks has been discussed (Abrams & Southerland, 2001; Nehm & Schonfeld, 2007; Talanquer, 2007; Treagust & Harrison, 2000; Zohar & Ginossar, 1998). Particularly in the field of evolution, many science educators consider a teleological bias to be a central obstacle in understanding and explaining evolutionary processes, especially natural selection and adaptation (Evans et al., 2012; Kampourakis & Zogza, 2008; Kelemen, 2012; Sinatra, Brem & Evans, 2008). Instead of offering ultimate causal reasons, students consider the function of a specific trait and the organism's need to adapt to be the causes of the evolution of the trait (Bishop & Anderson, 1990; Kelemen, 2012; Nehm & Ridgway, 2011). If these teleological explanations imply goal directedness, purpose or a notion of design, they are considered illegitimate as scientific explanations (Abrams & Southerland, 2001; Lennox & Kampourakis, 2013). Mead and Scott (2010a, 2010b) describe purpose and design as “problem concepts” in the field of evolution, which interfere with the concepts of chance and cause. This suggests that these concepts need to be analyzed in combination because randomness as a scientific explanation seems less plausible, as well as more counterintuitive and difficult to grasp (Garvin-Doxas & Klymkowsky, 2008; Ross et al., 2010; Tibell & Harms, 2017), whereas teleological explanations seem intuitive (Gregory, 2009; Kelemen, 2012). Regarding the illegitimacy of teleological explanations, it has been argued that teleological thinking is linked with an intentionality constraint, a predisposition to assume an intentional agent, and moreover, creationist beliefs (Evans, 2001; Sinatra et al., 2008).

Although teleological explanations are, to some extent, considered illegitimate, functional explanations may be regarded as legitimate because the function of a trait plays an important role in explaining the fitness of an individual and thus in evolutionary selection. Scientists frequently shorten evolutionary explanations by merely stating the function or using intentional formulations “as if [the organisms] were designed” (Boerwinkel, Waarlo, & Boersma, 2009, p. 14), as the underlying processes such as variation or differential survival in the process of selection do not need be mentioned (Abrams & Southerland, 2001). Therefore, formulations may seem teleological despite a thorough knowledge of the underlying causal processes. Consequently, explicit teleological formulations and teleological understanding in terms of a tacit cognitive bias should be differentiated (cf. Trommler et al., 2018; Zohar & Ginossar, 1998).

Instead of being an obstacle, teleological (and anthropomorphic) formulations may also serve pedagogical aims, for example, to increase empathy, to abbreviate explanations and to relate topics to the students’ world (Zohar & Ginossar, 1998). Moreover, teachers may use teleological and anthropomorphic metaphors deliberately to increase motivation and to reduce the complexity and the number of technical terms (Treagust & Harrison, 2000). However, this is only considered legitimate if the
teacher and the students are conscious of “breaking the rules,” which are implied in scientific norms (Lemke, 1990, p. 134, Taber & Watts, 1996).

3 | RESEARCH RATIONALE

The above literature review regarding teleology indicates that research has mostly focused on the students' perspective. Moreover, the controversy regarding the legitimacy of teleological explanations – in particular, the use of metaphors and conscious rule breaking – is based on the assumption that the teacher makes deliberate pedagogical decisions to use teleology and does not have a teleological bias himself. However, there is some evidence that biology teachers themselves hold problematic conceptions about evolution, natural selection, or the NOS (Nehm & Schonfeld, 2007). In particular, Lamarckian understanding involving use and disuse, as well as teleological need-based explanations, were found in more than 25% of the teachers' open responses. Learning materials may include teleological instructions (Talanquer, 2007). Consequently, how teleological explanations, whether deployed as intentional didactical and pedagogical tools or emerging as a teacher's bias in thinking, influence the students' understanding remains a rather open question. Moreover, how potential teachers' and students' teleological biases interact needs to be examined. Based on our argument that a teleological bias can be considered a tacit aspect of domain-specific knowledge, we investigate interactions focusing on the tacit dimension of teleology. Therefore, our research questions are the following:

How do teleological explanations emerge in science classroom interactions regarding evolution, and how do teachers and students situationally address emerging teleology?

We argue that the framework of systems theory and sociology of knowledge is appropriate to examine this research question regarding the tacit dimension of teleology because it enables us to address several challenges in the process of reconstructing knowledge structures and interactional structures, in particular, whether discourse practices are incommensurable or complementary and whether the agents share a common framework of orientation regarding the (re-)production of teleology. Furthermore, it extends former approaches by systematically differentiating between an explicit and a tacit dimension in the process of meaning making. Unlike many other studies identified in our literature review, which assume a form of tacit knowledge, the sociology of knowledge provides a substantial sociological foundation and explains the formation of implicit and explicit knowledge. Consequently, the framework links the social acquisition of knowledge and conceptual development as knowledge construction with sociological approaches, which have often been investigated separately in other studies that focus on either the cognitive dimension of conceptual understanding or the social interactions in the classroom. Moreover, the sociology of knowledge has a different perspective than functional linguistics or social semiotics, which focuses on communication processes rather than inherent knowledge funds, particularly implicit knowledge. Consequently, we argue that the presented framework has additional value relative to previous approaches and is particularly useful to investigate the tacit dimension of teleology in the classroom.

4 | ANALYSIS OF CLASSROOM VIDEOS: METHODICAL PROCEDURE

4.1 | Method and data analysis

The documentary method was elaborated by Bohnsack (2010) as a tool of qualitative social research; it was originally used for the analysis of group discussions but has since been enhanced as a tool for
video analysis in the classroom (Asbrand & Martens, 2018). Methodologically, the documentary method is based on Mannheim’s (1952) sociology of knowledge and aims to methodically differentiate and systematically relate the immanent (explicit, literal) meaning of what is said and done as well as the documentary (implicit, tacit) meaning, or how something is said and done. This distinction is represented in the data analysis through two subsequent steps, the formulating and the reflecting interpretation (see Table 1).

At the beginning, the enormous amounts of data produced in video studies require a careful selection of sequences for further analysis. The sequences are selected according to interactive density because dense interactions are more likely to reveal the underlying frameworks of the orientation of the agents and thus their implicit knowledge (Bohnsack, 2010). Furthermore, thematic criteria are used to determine sequences relevant to the research question, that is, sequences where teleological explanations are addressed. This means looking for sequences with goal-directed explanations, reference to the needs of the organisms, or a notion of intentionality or design according to the characteristics of teleological explanations stated by Kelemen (2012). The formulating interpretation, that is, the first-order interpretation, is conducted from the perspective of the subjects under study and reformulates what social reality is from their perspective (Bohnsack, 2010). Revealing the underlying implicit meaning requires going beyond the literal meaning and thus changing one’s analytical stance. In contrast to the formulating interpretation, the reflecting interpretation focuses on “how this reality is produced or accomplished” (Bohnsack, 2010, p. 102). The framework of orientation, or the habitus (sensu Bourdieu, 1996), of the agents is reconstructed to analyze how the agents address the topic. Implicit knowledge self-evident to the agents is explicated through the researcher. The reflecting interpretation includes a formal interpretation of the interactional order, that is, analyses of the formal function of utterances, gestures, and actions. With this methodical step, it is possible to determine whether the students’ and teacher’s frameworks of orientation are collectively shared, incommensurable or related in a complementary way (Asbrand & Martens, 2018). In the results section, the formulating and reflecting interpretations are then merged and condensed for purposes of a clear presentation. Rather than describing each individual case, the documentary method generalizes types in terms of generalized rules and frameworks of orientation from all cases. Throughout the entire process of data interpretation, comparative analyses are necessary. Only through comparison can the

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<th>Step of interpretation process</th>
<th>Function and link to theoretical framework</th>
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<td>Selection of sequences</td>
<td>Identification of passages containing teleological explanations according to Kelemen (2012) and sequences with high interactive density, which are considered to reveal the agents’ underlying (tacit) frameworks of orientation (Bohnsack, 2010)</td>
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<td>Formulating interpretation</td>
<td>Reformulation of immanent (explicit, literal) meaning of what is said and done (Bohnsack, 2010) according to the sociology of knowledge (Mannheim, 1952) Main topics/actions and subordinate topics/actions are assigned. The interpretation of multimodal interactions is done separately (verbal/nonverbal) according to Asbrand and Martens (2018)</td>
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<tr>
<td>Reflecting interpretation</td>
<td>Reconstruction of documentary (implicit, tacit) meaning of how something is said and done (Bohnsack, 2010) according to the sociology of knowledge (Mannheim, 1952) The formal interpretation of the interactional order is also informed by systems theory (Luhmann, 2002) to account for the asymmetry in institutional contexts. The interpretation of multimodal interactions is integrated according to Asbrand and Martens (2018)</td>
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structural differences and similarities between the frameworks of orientation be revealed (cf. Glaser & Strauss, 1967).

Regarding the validity of the empirical analyses, that is, whether the scientific and theoretical construction is adequate for the empirical phenomenon under investigation (Przyborski & Wohlrab-Sahr, 2014), we argue that the video and audio data show authentic practices in the classroom because the teachers were asked to continue with their lessons as usual without any demands or restrictions through the researcher. To question whether the reconstruction of these common-sense constructions of the teacher and the students is adequate, and to reflect upon the perspective and potential normative bias of the researcher, exemplary interpretations (all of those presented in this article) were discussed in one of two separate groups of researchers who are familiar with the methodological background. Reliability is sought through the identification of homologous structures within a teaching unit and between units. Only if similar patterns of interactions can be found across different thematic topics, the reconstruction of the habitual structures can be considered reliable (ibid.). Moreover, the intersubjective comprehensibility and a review by other researchers are ensured through the systematic interpretation procedure and the documentation of all steps of the process.

Despite some similarities with other qualitative approaches, we argue that the documentary method provides a more robust theoretical foundation for investigating the classroom interactions than other methodological procedures, such as the frequently used grounded theory approach (Corbin & Strauss, 2015), because the foundation of the documentary method in both systems theory and the sociology of knowledge takes relevant aspects of learning, knowledge construction and social interactions systematically into account.

4.2 | Sampling

A theoretical sampling strategy is necessary to take into account relevant cases and to develop an empirically grounded theory based on minimal and maximal contrasts (Glaser & Strauss, 1967; cf. Lemke, 2012). This study analyzes evolution classes that focus on adaptation processes because, from a theoretical viewpoint, teleological explanations are likely to occur in this context (Kelemen, 2012). To maximize the contrast of the sample, classes of grades 7, 9, and 12 (the latter at both basic and advanced levels) in grammar schools were chosen, and teachers with varying degrees of teaching experience participated. Schools in both small market towns and urban areas were included. So far, seven different classes were recorded for 4–10 periods of 90 min each (42 periods/63 hrs altogether). Two static cameras were installed in the classroom to observe as many of the interactions as possible. A full camera perspective was chosen and was not modified in the process of video recording. This allows reconstruction of the inner logic of the interactions and aims to reduce the influence of the researcher's perspective (Asbrand & Martens, 2018). In addition to the cameras, audio recorders were placed on the students' desks to analyze their interactions in pairs or small-group activities.

Out of the entire sample, we analyzed one to four periods within all seven units to find homologies and contrasting sequences. In this article, we will present interpretations of four sequences with different grade 12 classes and teachers. These sequences are contrasted with regard to the common aspect of comparison, the tertium comparationis, that is, the relation of intentionality and scientific principles, in particular randomness, are addressed in all four sequences but in different ways. Two sequences each represent one type of homologous interactions regarding the relation of teacher and student habitus. Even though the research project is still in progress, the comparison of the four sequences ensures a prospect of differentiating typology, including all analyzed sequences.
5 | EMPIRICAL ANALYSES

Sequence 1a: Evolution as lottery

(grade 12, advanced level course, teacher's experience: 10 years, 13 students [5 F, 8 M], Beethoven grammar school 2, small market town, period 1)

In the first sequence, the teacher introduces a lottery model and thereon he illustrates evolutionary mechanisms, particularly the role of the randomness of genetic mutations. Through the model, the traits of a fish are determined in a random way. Regarding the explicit level of what is said, the teacher asks the students to draw lots from a glass bowl. Each number on the lots determines the characteristics of one trait of a fish that should be drawn on the board later. The first number determines the color of the fish, the second its shape, and so forth. The characteristics are assigned according to a list, which had been prepared by the teacher and contains ranges of numbers that are attributed to each characteristic.

Looking at the implicit level, we first need to analyze the beginning of this sequence to understand the propositions made by the teacher and consequently his framework of orientation. Therefore, it is important to investigate how the teacher presents the lottery model.

The teacher introduces the lottery model as a creative task and as a game. He refers to gambling and addictiveness by citing a warning that is typically stated at the end of advertisements for lottery games, thus embedding it in an everyday context. Although the lottery is not an object of the students' world because they are not allowed to gamble, the experience of playing games is. The announcement to play a game results in laughter among the students, indicating their excitement. The way he presents the lottery model reveals an ambiguity. On the one hand, the drawing of the numbers involves randomness and defined deterministic rules, and the model illustrates the evolutionary principle of randomness in an abstract way. On the other hand, a fish that did not previously exist is designed in a creative and artistic process, which requires intentional actions and imagination of the student who draws the fish on the board. Consequently, initial aspects of the teacher's framework of orientation, that is, aspects of his implicit knowledge, can be reconstructed. The principle of randomness is highly relevant for the teacher, but at the same time, an ambiguous compatibility of randomness and creativity that involves designing an organism step-by-step in a sequence determined by human beings can be observed.

Subsequently, the teacher explains the procedure of the drawing of the numbers and continues with the determination of the first four traits. In the following, the fifth trait is introduced:

T:  Have you noted this so far? (2) We will now get creative. [...] I would like to provide a warning in advance. Gambling can lead to addiction; it can be addictive.
Gambling can be addictive because I would like to play the lotto with you. 00:43:54
[Multiple laughs 0:43:55]

The teacher introduces the lottery model as a creative task and as a game. He refers to gambling and addictiveness by citing a warning that is typically stated at the end of advertisements for lottery games, thus embedding it in an everyday context. Although the lottery is not an object of the students' world because they are not allowed to gamble, the experience of playing games is. The announcement to play a game results in laughter among the students, indicating their excitement. The way he presents the lottery model reveals an ambiguity. On the one hand, the drawing of the numbers involves randomness and defined deterministic rules, and the model illustrates the evolutionary principle of randomness in an abstract way. On the other hand, a fish that did not previously exist is designed in a creative and artistic process, which requires intentional actions and imagination of the student who draws the fish on the board. Consequently, initial aspects of the teacher's framework of orientation, that is, aspects of his implicit knowledge, can be reconstructed. The principle of randomness is highly relevant for the teacher, but at the same time, an ambiguous compatibility of randomness and creativity that involves designing an organism step-by-step in a sequence determined by human beings can be observed.

Subsequently, the teacher explains the procedure of the drawing of the numbers and continues with the determination of the first four traits. In the following, the fifth trait is introduced:

T:  Fifth, photophore. 00:01:36
Jan:  Oh yes. 00:01:37
T:  One. (.) Photophore one is a weak photophore, and 49 is a strong photophore. 00:01:47
Lukas: Three. 00:01:47
[Multiple moans 00:01:47–00:01:51]
Lena: Doesn’t count. 00:01:52
T:  A weak photophore. 00:01:55
A photophore, a trait that only few fish, mostly in the deep sea, possess, was chosen by the teacher as the fifth trait. This reveals an orientation of the teacher toward exceptional phenomena and already means diverging from evolutionary processes, in particular, random occurrence of traits. Moreover, it locates the fish in a specific ecosystem, although the adaptation to specific environmental conditions is irrelevant for the model. The introduction of the photophore leads to excitement among some of the students and a positive comment on the teacher's decision to include this special trait. The interactions show high engagement of the students: they make a drum roll by knocking on their tables before a new number is about to be drawn, and they comment on the result in a casual way. Regarding the implicit orientations, the moaning of the students and Lena's comment that the small number does not count already suggest that the students do not fully accept the random drawing of the numbers. At the beginning of the sequence, the teacher proposed the compatibility of creativity and randomness in the use of the evolutionary model, but the reactions of the students to the model reveal that they do not hold the same but rather a complementary orientation. This means that based on their orientation, they interpret the utterances of the teacher in a different way and recontextualize it. In reaction to the ambiguous orientation of the teacher, which mixes aspects of the scientific world (model for explanations of evolutionary mechanism) and the everyday world (model as a creative game), the students reveal an orientation of playing a game rather than using an evolutionary model.

The orientations of both the teacher and the students are elaborated shortly afterward. After all numbers are drawn, Julia starts to draw the fish on the board. At the same time, Lukas takes another number out of the glass bowl, which is close to him:

Lukas: 47. 00:03:20
        [Squeak of the chalk on the blackboard]
Lukas: Can we make a big photophore? 00:03:27
?f: Please. 00:03:28
?f: Yes. 00:03:28
T: A spontaneous mutation occurred. The small photophore becomes a giant photophore. 00:03:37

On an explicit level, the students ask the teacher to change the size of the photophore, and he responds by introducing a spontaneous mutation. On an implicit level, according to their “game-like”-orientation, the students challenge the validity of the random drawing of numbers, as they do not accept its outcome, and they demand to change the rules of the game. The outcome of the game in terms of the characteristics of this specific fish and its exceptionality are more relevant than the general principle of randomness and adaptation to the environment. Consequently, the intentional decision of the students plays a major role in the construction of the fish. This, in turn, is recontextualized by the teacher because he interprets the utterances of the students, which reveal their orientation of playing a game, based on his framework of orientation by introducing the scientific concept of mutation in a teleological, intentional way. Consequently, all mechanisms of the model can be altered at will. The ambiguous compatibility of creativity, human agency and a game-like activity, on the one hand, and scientific principles, such as randomness represented in the concept of mutation, on the other, is proposed by the teacher and allows for this reaction of the students. In this passage, the difference between explicit and implicit meanings becomes apparent. On an explicit level, a mutation may be considered a causal mechanism. However, on an implicit level, how the random mutation is introduced is highly intentional and teleological.

After the fish has been drawn, Lukas comments on its characteristics:
Lukas: I don't think it would be able to survive because it doesn't have side fins and ( )

00:07:43

[Multiple laughs 00:07:46]

T: Would you like to supplement it? So it is capable of surviving? 00:07:52

Lukas: Mmh, I could do that. 00:07:51

Homologous to the previous interaction, the fish is modified according to its needs, in addition to the intentions, and rational decisions of the students. A fish that is not capable of surviving should be changed; Lukas enacts this idea, going to the board and modifying the drawing. This shows a teleological understanding on the part of the student and reveals how the teacher elaborates this understanding when he allows Lukas to modify the fish. Again, this need-based teleological interaction conflicts with the scientific principles and the deterministic rules of the model. Consequently, the model itself distorts scientific mechanisms by combining the design of previously nonexistent animal and random traits; in addition, the use of the model is teleological. As a result, the use of the model does not irritate or conflict with the teleological orientation of the students.

**Sequence 1b: Evolution of flightless birds**

(grade 12, basic-level course; teacher's experience: 30 years, 25 students [14 F, 11 M], Schubert grammar school, urban area, period 4)

In a sequence with a different teacher and a different course, we reconstructed a homologous ambiguity of the teacher regarding the compatibility of teleological, intentional explanations, and scientific principles. At the beginning of this sequence, the teacher presents five pictures of flightless birds living on different islands, among them a Kiwi and a Dodo.

T: What I want you to do now is (3) to think about why flightless birds could evolve specifically on remote islands. [...] So, what I want to know from you is how we can imagine that this came about. 0:24:28

In the way in which he introduces the task, he refers to the cause of the phenomenon as a fact that he wants to know and at the same time as something that needs to be imagined by the students, a first sign of ambiguity. After small group discussions without additional materials, the students present their explanations, revealing how they “imagine” the process. Similar to sequence 1a, many of them make teleological explanations of need-based adaptations, showing their framework of orientation:

Luisa: Yeah, maybe it's because they can find all the food and shelter they need on the island and basically don’t (need to) move away from there, (always) have land beneath their feet, and that's why they're flightless. 0:31:09

T: Okay. 0:31:10 [...] Carolin: [...] In the end, flying probably wouldn't do them much good anyway, in terms of fleeing or something like that, and that's why they're just adapted to their little living space, and if they could fly, they might be able to get across part of the ocean, but to really remote islands, to the next piece of land, where you could somehow settle, you wouldn't be able to reach that anyway, no matter how well you could fly. 0:32:02

T: Yeah, and we especially need to understand that it will only do you any good if you intellectually know that there's something out there. Preserving a skill just because at some point you say you'd like to take a trip to the ocean might be a bit (extensive). 0:32:12
Luisa and Carolin offer a need-based argumentation, as there is no need for the birds to fly because of ideal environmental conditions on the island. Carolin changes the perspective from “they” to “you,” making it seem more personal. The teacher validates the teleological answers as correct, but he differentiates the teleological utterance by introducing the notion of intellectual abilities of the birds. His formulation suggests an active, rational decision of the birds regarding whether to maintain the ability to fly. Because of the reference to human everyday life through the idea that birds may make a trip to the ocean, the use of the personal pronoun “you” when speaking about animals, and the reference to conscious decisions, the passage shows first signs of the teacher's anthropomorphic and teleological orientation, which is consistent throughout the sequence.

T: Let's have a look at this. It's actually more about why do they give something great like this up? Flying, in all honesty, wouldn't it be great if we could fly? Go outside, don't wait for the bus, spread your wings, and off you go. That's a pretty great thing, why do they give that up? 0:33:08

Abandoning the ability to fly is related to a rational decision. In an analogy, embedded in an everyday context, the teacher emphasizes the amenities for humans, making human experiences more relevant than scientific mechanisms to explain this natural phenomenon. This is the point at which the homology with sequence 1a becomes most apparent. Initially predominantly scientific material (a model illustrating evolutionary mechanisms or the evolutionary phenomenon of flightless birds) is transformed in the process of the interactions in a teleological way (intentional change of the trait “photophore” or intentional abandonment of the trait “ability to fly”). Moreover, it is the embedment of the material in an everyday context (game activity or an analogy between flying and bus travel) that sets the ground for intentional utterances. Subsequently, the teacher and the students continue with need-based teleological explanations of the inability to fly and why local migratory birds do not “give up” the ability to fly. Homologous to sequence 1a, an ambiguity can be constructed, that is, the compatibility of scientific and teleological explanations. In both sequences, it is the equivocality of the teacher's utterances and embedding the scientific phenomenon in an everyday context that set the ground for teleological explanations and lead to a distortion of the scientific principles. Consequently, the students' teleological orientation is not irritated.

Sequence 2a: Two hypotheses about antibiotic resistance

(grade 12, advanced-level course, teacher’s experience: 26 years; 22 students [13 F, 9 M]; Mozart grammar school 1, small market town, period 3)

In contrast to sequences 1a and 1b, the following two sequences demonstrate how the teachers construct a difference between teleological and scientific explanations by using a heuristic to distinguish between two poles: Lamarck’s evolutionary theory, intention and student's preconceptions as wrong opposed to Darwin's theory and mechanistic explanations involving randomness as right.

In sequence 2a, the students work on a textbook task about the development of antibiotic resistance in bacteria. The text describes an historical experiment, the fluctuation test, conducted by Luria and Delbrück. The results of the experiment show that mutations leading to antibiotic resistance or to resistance against bacteriophages (viruses that infect and kill bacteria) occur before the selective pressure of the environment becomes relevant and that resistance is not a response to the environment (cf. Robson & Burns, 2011, for a detailed, though more complex, description of the experiment). One out of four tasks in the book that the students had to work on proceeds as follows:

“B) The relation between the use of antibiotics and the evolution of resistant bacteria can be explained by two hypotheses that Luria and Delbrück called the ‘hypothesis of
acquired immunity’ and the ‘mutation hypothesis’. Justify this wording and explain which hypothesis is supported by the results” (Erdmann, Paul, & Polzin, 2012, p. 34).

Following the introduction of the task, the students work in small groups and discuss the results after familiarizing themselves with the experiment. After a short break in the middle of the group work, the teacher provides further information to the class:

T: Small tip: Task B involves two hypotheses. This should ring a bell, since you are very familiar with the topics of acquired immunity and the mutation hypothesis. Think about it and then decide which names we can assign here? 00:06:38

In contrast to sequences 1a and 1b, the historical experiment, the task chosen to contrast the two hypotheses, and the teacher's suggestion to relate the hypotheses to the names of the proponents of evolutionary theories reveal her science teacher habitus and her positioning as a science expert. The teacher proposes a difference between the two hypotheses, of which one has to be falsified and one supported by the results. This already indicates a dualistic pedagogical heuristic of right and wrong, which is elaborated later.

The teacher terminates the group work and, after a passage about the description of the experiment, she asks the students to explain the two hypotheses:

T: What about the hypothesis of acquired immunity then? How would that look? What conclusions can be drawn from this about how resistance emerges? (3) Try to describe in your own words again how Lamarck would explain how bacteria can become resistant. (2) Anna. 00:17:16

Anna: The bacteria would develop this resistance very deliberately, probably also first in the petri dish when they encounter the phages, not before, or? 00:17:27

T: Because they are aware that it is beneficial to adapt [said in a laughing way]. This obviously means that it makes sense to develop resistance when coming in contact with something against which a resistance can develop. Acquired. And the acquired... Some become resistant and pass this on to their progeny, that is, the next generation of bacteria. What would Darwin say? 00:18:00 […]

Claudia: That the bacteria, which just accidentally acquired such a gene defect or such a gene change, can then simply survive and reproduce better. 00:18:46

T: Yes, that is correct in principle. What then would these bacteria have had to accidentally acquire for a gene defect, like Claudia said, so that it can survive better? Let's try to sort this out. Vanessa. 00:18:59

Vanessa: They would then have to become resistant. 00:19:01

T: So then resistance accidentally occurred through mutations. And as soon as they come into contact with antibiotics or bacteriophages, it is beneficial, that is, they have an increased ability to survive. That is what Darwin would say. 00:19:16 […]

T: Once we've gotten the picture, we might also be able to explain, if we think back to Darwin, what actually happened here and that the result is actually proof of Darwin's mutation-selection hypothesis. 0:21:18

The students differentiate the duality and polarization proposed by the teacher and the task. In interaction with the teacher, Anna parallels the hypothesis of acquired immunity with intentionality and Lamarck, and Claudia parallels the mutational hypothesis with randomness and Darwin.
However, the teacher's and the students' frameworks of orientation are complementary and not identical. This becomes apparent when Anna differentiates the aspect of intentionality and consciousness on the part of the bacteria, which adapt if the adaptation seems advantageous. This was not mentioned by the teacher or the task and reveals the underlying teleological orientation of the student. The laughter of the teacher emphasizes the perceived ridiculousness of this thought and discredits Lamarck's evolutionary theory. Consequently, the constructed duality between Darwin and Lamarck has the function to make a clear distinction between right and wrong, mechanistic and intentional, scientific and teleological. However, it can also be reconstructed that this polarization and reduction in complexity lead to a transformation of meaning and distortion of the scientific properties of the task through the interaction in the classroom. The hypothesis of acquired immunity is modified to form a hypothesis of intentionality. At the same time, the hypothesis of mutation is evaluated as correct and "what actually happened" without reference to tentativeness, thus suggesting a positivistic stance.

Sequence 2b: Two opposing explanations of bird migration

(grade 12, advanced-level course, teacher's experience: 26 years; 20 students [17 F, 3 M]; Bach grammar school, small market town, period 5)

In this sequence, the teacher uses a dualistic pedagogical heuristic of right and wrong in a homologous way to that of the teacher in sequence 2a. Similarly, intentionality and mechanistic processes are contrasted as two opposing types of explanations for the evolution of traits.

At the beginning, the teacher asks the students to read a text presented in the textbook.

"Info Box: Final Thinking.

'Moles developed fossorial legs in order to dig better.' Statements like this initially seem plausible. However, a future event (improved digging) is given as the cause for an already existing object (fossorial legs). Scientifically, this isn't tenable, because causes must precede the effects." (Becker, Bokelmann, Krull, & Schäfer, 2012, p. 404)

Through the selection of this info-box, the teacher introduces the idea of teleology in terms of "final thinking," which is contrasted with scientific explanations involving cause–effect relations and their temporal connection. The normative background that is implicitly proposed is that explanations must be scientific. Moreover, the addressee of the explanation is constructed as a person who is ready to revise his or her initial teleological explanation.

After a short discussion about the info-box and addressing goal-directed explanations as problematic, the teacher introduces two opposing explanations, one intentional, one mechanistic:

T: Maybe another example to give you a better idea of this. A current phenomenon, migratory birds, they're flying south at the moment. Why do they do that? I'll give you two answers, and you can talk about these answers. Answer A, (.) they want to avoid the cold and lack of food in the winter here. That's why they fly south. (.) Answer B, (.) there's a hormonal change in their body, and that's why they experience migratory restlessness and have to escape. (9) Lara. 0:44:02

Lara: I would say that A's correct, 0:44:03

T: Can you explain? 0:44:06

Lara: I think that they just know that they can't get food and all that here, and that's why they fly elsewhere, where they know they'll find more food and everything, that's what I would say. 0:44:26
Okay, does anyone want to respond to Lara? Now nothing say something about it first. Pia: Answer A and everything that Lara said fits Lamarck's idea, because Lamarck also said that animals, for example a giraffe, grew a longer neck because it wanted to reach food, and the same thing with birds. They also fly away to get umm, to get food.

Melina: I think animals can't think that way, right? That they know, okay, winter's not great. I need to find summer. I don't think they can think that way. I think answer B must be correct because they have to receive something, some kind of signal to fly away.

Nico: Maybe a few birds just had a mutation back then, so that hormones were released, which is why they flew. Then they happened to fly south, those that stayed here mainly died out. Well, maybe just a few survived. And those that came back from the south reproduced and passed it on and that's how the population grew, in the sense that this characteristic that they had to fly when winter came increased.

The offer of two explanations involves the distinction between a right and a wrong answer. Whereas the first encompasses the consciousness of birds, the second is based on proximate causes and is formulated in a deterministic way. In Lara's response, the teleological bias becomes apparent and includes knowledge and conscious decisions regarding the birds' behavior. Pia parallels this understanding with the evolutionary theory of Lamarck, which is divergent from Lara's answer. Moreover, Melina and subsequently the teacher reject Lara's response. In the manner in which Melina addresses the answer and through the laughter of several students shortly after this passage, it is implicitly conveyed that Melina and some of the other students find the notion of consciousness of animals ridiculous. The incapability of animals to plan in a foresighted way is constructed as a deficit. In contrast to the presented teleological answer, the students are requested to explain the phenomenon of bird migration based on modern synthesis. Nico references random mutations, which happened to cause a release of hormones and subsequent migration, thus elaborating on the positive pole of the duality.

Finally, the teacher concludes this passage:

So, the term adaptation is always used in a goal-oriented way, right? A mother says to her child, adapt yourself a little, okay? That you change something yourself, that you actively change something in a goal-oriented way – that's the point we have in our heads which doesn't fit here and will get us off track here. It's basically the same misconception that Lamarck had. I'm saying misconception in quotation marks, it's in all of us and is really hard to get rid of.
differentiates it in a way that students' conceptions are difficult to change. In this sequence, the proposed incorrectness of final reasoning is elaborated by all students but Lara.

The effect of the polarization is that from a knowledgeable historical perspective, Lamarck is discredited through the parallelization with the students' conceptions and fallacious reasoning. Consequently, the reduction in complexity leads to a transformation of the scientific content regarding scientific progress. This is homologous to sequence 2a because from today's perspective, previous theories are discredited.

**Summary of comparative analyses**

Regarding the way the teacher and the students address intentionality and evolutionary principles, the comparative analyses of the four sequences reveal the frameworks of orientations of the agents and thus two different types of how the teaching habitus and the learning habitus are related. On an explicit level, in all four sequences, intentionality and evolutionary principles, such as randomness of mutations, are addressed in the context of adaptations to the environment. The teachers of sequences 1a and 1b let the students explore the phenomena in an inductive way, and on an implicit level, they propose compatibility between scientific mechanisms and intentionality in an ambiguous way. Intentions play a more important role than do randomness and mechanistic processes, resulting in a teleological construction of an organism or need-based, anthropomorphic explanations of the development of flightless birds. The embedment of scientific phenomena in an everyday context, such as a game-like activity or analogies with human needs, sets the ground. The students react to these habitual characteristics of the teacher in a complementary way by reproducing these teleological structures. They use the model as a game rather than a scientific tool and engage in a need-based design of traits. Similarly, in sequence 1b, the allusion of the teacher to intentionality evokes teleological and Lamarckian explanations. The students' conceptions are not perturbed or corrected but rather confirmed by the teacher because the teacher and the students both hold a teleological orientation. The explicit use of scientific terms, such as mutation, masks this implicit teleological interaction.

In contrast, the teachers in sequences 2a and 2b have a scientifically structured teaching habitus and problematize the complex scientific content through the construction of an unambiguous duality and incompatibility of scientific explanations and teleology. This difference is introduced in a deductive way and is embedded either in an historic experiment with two opposing hypotheses or two opposing explanations for a natural phenomenon. The difference between intentionality and chance is differentiated into two opposing horizons: intention and Lamarck's theory as wrong and unimaginable vs. chance, evolutionary mechanisms and Darwin's theory and modern evolutionary synthesis as correct and scientific. Consequently, the polarization reduces complexity for the students, and the students take up this difference and discuss the issue of teleology critically and reject teleological explanations. At the same time, this duality is enacted in a complementary way as a differentiation between right and wrong answers following the logic of achievement within the school system, in which the asymmetric teacher-student relation leads to an evaluation of the students' answers. Moreover, this duality has the effect that scientific progress is distorted in a positivistic way as precedent evolutionary theories are discredited and today's knowledge is not introduced as tentative, thus, introducing scientific content in a reductive way.

6 | DISCUSSION

Regarding the research question, how teleological explanations emerge in science classroom interactions about evolution and how teachers and students situationally address emerging teleology, we conclude from our analyses that the teachers' framework of orientation strongly influences the learning environment and hence the opportunities of the students to engage in teleological actions and explanations or to reflect upon them in a critical way. The observation that some teachers hold
ambiguous orientations themselves regarding the relation between evolutionary and teleological explanations is in line with the finding of Nehm and Schonfeld (2007) that some teachers explain evolutionary phenomena in a teleological or Lamarckian way. From our analyses, we argue that this can be problematic for the interactions with the students if classroom materials, such as a model that illustrates randomness, are used by the teacher in a teleological way and invite the students to engage in teleological actions and explanations, for example, constructing an organism in a teleological, need-based way. Based on our results, we can see no indication that the students are aware of the teacher “breaking the rules” of scientific norms when using teleological metaphors, as suggested by Lemke (1990, p. 134) and Taber and Watts (1996). Moreover, this suggests that the issue of teleology is not only a matter of using mistakeable teleological formulations; rather, both students and teachers may hold deeply rooted teleological understandings, which manifest themselves not only in the use of words but also in tacit actions in the classroom. To some extent, this finding supports the evaluation of teleology as an obstacle in understanding and explaining evolutionary processes (Evans et al., 2012; Kampourakis & Zogza, 2008; Kelemen, 2012; Sinatra et al., 2008). However, a clear distinction between teleological and scientific explanations led to a reduction in complexity, discrediting previous theories, and a positivistic stance. Although this allowed the students to critically reflect on teleology, the students readily adopted the polarization and the learning environment did not offer opportunities to reflect on tentativeness in scientific progress.

The analyses reveal that the relation between intentionality and randomness was somewhat problematic. In recent publications, randomness is considered to be a threshold concept – a troublesome abstract concept – that explains many scientific phenomena, such as evolutionary change, once it is properly understood (Ross et al., 2010; cf. Fiedler, Tröbst, & Harms, 2017; Tibell & Harms, 2017). In the context of evolution, variation through mutations and genetic recombination and, to some extent, selection is based on randomness, making discussion of this concept inevitable for evolution classes (Tibell & Harms, 2017). However, students frequently state that environmental conditions cause advantageous mutations in a directional instead of a random process (Robson & Burns, 2011). In sequence 1a, it is the teacher who introduces the need for a directional mutation. Randomness is considered a less plausible explanation for biological phenomena because students associate randomness with inefficiency, while the biological systems are considered highly efficient (Garvin-Doxas & Klymkowsky, 2008). Furthermore, for many students, random is paralleled with purposeless (Mead & Scott, 2010a). Therefore, randomness as a counterintuitive concept is not taken into account, whereas purposeful explanations may be more appealing. Consequently, randomness and teleology are related, and a lack of understanding of randomness is assumed to lead to teleological explanations (Tibell & Harms, 2017). In relation to our theoretical framework, we consider the teleological orientation to be part of tacit knowledge, whereas the counterintuitive and abstract concept of randomness often remains part of explicit knowledge. The efficiency of randomness cannot be experienced within social interactions and needs to be understood on an abstract level. By contrast, the students in sequence 1a experience the random drawing of numbers as an active endeavor through their participation. The distinction between implicit and explicit knowledge (Bohnsack, 2010; Mannheim, 1982) may help us to understand why the explicit (scientific) knowledge acquired in science classes may not guide actions as much as incorporated implicit knowledge does. From a sociological perspective, this distinction may also make plausible the coexistence of intuitive conceptions and elaborate scientific understandings (cf. Martens, 2015; Martens & Gresch, 2018) and may help to explain why scientific explanations are not likely to replace intuitive explanations (cf. Evans, 2008).

Regarding the relation between intuitive and scientific explanations in the study, the context of the tasks in the learning environment needs to be discussed critically because different contexts evoke
intuitive and scientific explanations to different extents (Ha, Lee, & Cha, 2006; Nehm & Ha, 2011; Tamir & Zohar, 1991). Intentional explanations (Ha et al., 2006, cited after Nehm & Ha, 2011) and anthropomorphic explanations (Tamir & Zohar, 1991) are more frequently related to the evolution of animals than of plants. Ha et al. (2006, cited after Nehm & Ha, 2011) report a higher degree of teleological explanations in the context of plants than animals, whereas Tamir and Zohar (1991) report an equal distribution. Goal-driven and need-based explanations of students are also observed in the context of cells, though the taxon was not systematically controlled in the study (Kampourakis & Zogza, 2008). Regarding the contexts used by the teachers in our study, the contexts of fish, birds, and bacteria may induce teleological explanations to a different extent. However, from previous research on contexts, we cannot draw a clear conclusion but rather only cautious assumptions. Compared to the bacteria context, the fish context may be more likely to induce explanations involving intentionality, but the inability to fly and migration in birds do not vary as much regarding the context. Moreover, we argue that all learning environments include materials that could potentially support learning about the causal mechanisms: a lottery model to introduce the relevance of randomness, pictures illustrating a peculiar evolutionary phenomenon, a historical experiment proving random mutations or a text introducing final thinking. From our analyses, we conclude that the teaching habitus plays a crucial role and that the way the materials are used based on the teacher's orientation is most relevant for the learning process. Furthermore, we suggest that the teacher's choice to include a specific taxon or phenomenon as an element of the learning materials can be reflected as part of his framework of orientation and his teaching habitus.

Several limitations of the study need to be addressed. Although we can reconstruct the knowledge of the teacher and the students to some extent, this can only be done with regard to the observable interactions. We cannot draw conclusions about individual conceptual changes, as in pre–post designs, or obtain knowledge about students who do not participate in the interactions. However, we can observe how explicit and implicit knowledge emerge in the interactions and shape the learning environment for all students in the classroom. Furthermore, the study design and sampling strategy aim at reconstructing different types of interactions through the maximization of contrast. However, this approach does not allow conclusions about the representability of the reconstructed types. Other types of dealing with teleology, for example, in other scientific contexts or creationist regions, must be identified by extending the sample size (Glaser & Strauss, 1967). Moreover, we have focused on whole-class discussions in this article. In addition, nonpublic discussions in the classroom, such as in small groups and pairs, should be examined to account for students' heterogeneous orientations.

6.1 Implications for teaching and learning evolution

Sequences 2a and 2b in our study provide examples of how the teacher constructs the differences between mechanistic and intentional, scientific and teleological. This was done by referencing the historical theories of Lamarck and Darwin, paralleling teleological conceptions and Lamarckism (see Kampourakis & Zogza, 2007, for a detailed distinction between teleological student conceptions and Lamarck's theory of evolution). Such a reflection on the differences between teleology and causality on an abstract level has been suggested by various scholars (Bartov, 1981; González Galli & Meinardi, 2011; Jensen & Finley, 1996; Richardson, 1990; Trommler et al., 2018) because students are not sufficiently capable of discriminating between them at the level of etiology (Trommler et al., 2018). From the viewpoint that a teleological bias is implicit, such reflection requires the students to explicate their ways of thinking on a metacognitive level (González Galli & Meinardi, 2011). However, despite the distinction between different types of conceptions, the teachers did not include a metacognitive perspective focusing on the students' own initial concepts. Rather, this remains
abstract, as the students' actual preconceptions are not made transparent, and the classes do not reflect upon individual progress. Consequently, we suggest relating a distinction between causal and teleological explanations with metacognitive considerations. In addition to this metacognitive perspective, we suggest that focusing on the contrast between the legitimate use of teleological explanations in everyday life and mistakable teleological explanations in science — in addition to focusing on linguistic differences, such as the use of teleological words or conjunctions — may further help students to discriminate between teleological formulations and causal explanations (Bartov, 1981; Trommler et al., 2018). However, this distinction does not take into account that scientists themselves often use teleological formulations despite thorough scientific knowledge (Abrams & Southerland, 2001). Furthermore, the analysis of functions is an important aspect of biological research, particularly to describe the organization of biological systems (Trommler et al., 2018; Wouters, 2013). However, investigating how this subtle — and simultaneously complex — distinction between legitimate functional explanations and illegitimate teleological explanations can be accomplished in science classes remains a desideratum, and it is necessary to investigate how this distinction would be recontextualized by the students. Furthermore, it is suggested that teleological explanations be examined not only in the context of evolution but also in ecology, ethology, and human physiology — disciplines that emphasize a systemic understanding and thus focus on functions within a system.

In further research, we suggest using the theoretical and methodological framework presented in this article to analyze the interactions in the classroom that emerge from intervention concepts suggested in the science education literature about teleology. Most approaches focus on a conceptual change through the presentation of conflicting evidence. Such a presentation may be through historical experiments (Jensen & Finley, 1996) or through reflecting on the evolution of traits without apparent function and traits that would be useful but do not exist (Kampourakis, Palaiokrassa, Papadopoulou, Pavlidi, & Argyropoulou, 2012; Zohar & Ginossar, 1998). González Galli and Meinardi (2011) discuss, controversially, whether the analogy might foster or reduce teleological explanations. As our analyses reveal, even learning materials that focus on randomness can be used in a teleological way by the teacher and the students. Therefore, it is important to analyze the ways in which learning materials have the potential to be used in a nonintended, complementary way in the classroom or if they involve further obstacles. In general, we argue that it is more important to focus on the reflection of the habitus of the teacher in professional development rather than identifying plausible learning materials because the way the material is introduced strongly influences the learning environment of the students. The results of the present study highlight the importance of reflecting on teachers' teleological orientations and considering teleology as more than just a student conception. Therefore, transcripts and video sequences are used to discuss with preservice teachers how teachers deal with teleological explanations (Steinwachs & Gresch, submitted). The reconstruction of different types of interactions allows preservice or in-service teachers to contrast different approaches more systematically and to focus on potential problems when dealing with teleological explanations.

In our study, neither the teacher nor the students made reference to creationism because in Germany, creationist beliefs are rather rare and not expected to be predominant in science classrooms, while attitudes toward evolutionary theory are generally positive (Konnemann, Ashhoff, & Hammann, 2016). Despite these favorable conditions for teaching evolution, we argue, based on our results, that science education faces the challenge of addressing teleology as a cognitive constraint. In addition to teleology, creationist beliefs are described as a major challenge to the teaching of
evolution in many countries, including the United States (Glaze & Goldston, 2015). Despite this difference in the role of religious discussions in science education, we suggest that the theoretical framework regarding a tacit dimension of teleology can also be useful in analyzing classroom interactions in a context where creationism is abundant. Regarding the cognitive development of children, it has been argued that teleological thinking is linked with the intentionality constraint, a predisposition to assume an intentional agent, and moreover, creationist beliefs (Evans, 2001; Sinatra et al., 2008). However, the dissemination of creationist beliefs is not only based on cognitive predispositions but also on social processes (Evans, 2001). While 8- to 10-year-old students exclusively hold creationist views independent of their background, most 11- to 13-year olds hold the views of their religious community and their parents (ibid.). Consequently, we suggest analyzing the interactions in the classroom from a sociological perspective to take into account the role of religious and nonreligious communities. Regarding controversy in the classroom, the role of the teacher and the students may be investigated, looking at the asymmetry and the positioning of the teacher and the students.

6.2 Implications for research on classroom interactions in science education

Based on these results and our theoretical framework, we argue, in line with Mason (2007), that the analysis of conceptual understanding in the science classroom needs to integrate both a socio-cultural and a cognitive perspective. As we demonstrated, scientific knowledge is co-constructed in interactions in the classroom, and the context of the learning environment plays a crucial role, whereas simultaneously, an intuitive cognitive bias of the agents can be shown, which influences the interactions. We suggest that the sociology of knowledge (Bohnsack, 2010; Mannheim, 1982) may contribute to building a “bridge” between cognitive and socio-cultural approaches in the field of conceptual change, as Mason (2007, p. 3) demands. On the one hand, the framework states that knowledge is co-constructed through common experiences in “conjunctive spaces of experiences” (Bohnsack, 2010, p. 105). This is consistent with the approaches of socio-cultural studies. On the other hand, we argue in line with Taber and García-Franco (2010), who investigated conceptual understanding from a cognitive perspective, that the distinction between theoretical (explicit) and a-theoretical (tacit) knowledge is valuable to understand knowledge construction. Here, the framework provides a sociological foundation for this distinction rather than a purely cognitive approach.

Regarding the socio-cultural approach, we raise the further question of whether teachers and students can belong to a scientific community, an aim discussed by many science educators (Bowen, 2005; Lemke, 1990; cf. Kelly, 2014). We argue from a systems theory perspective (Luhmann, 2002) P and complementary, as evident from all sequences, and that the habitus of the teacher and the students are based on different social experiences. In addition, the learning environment of the third teacher seems scientific through the analysis of an historical experiment, but the analyses reveal that the teachers of sequences 2a and 2b do not hold a purely scientific orientation. The manner in which they address evolutionary theories does not fully reflect the merits of previous scientific progress or the tentativeness of scientific knowledge. Therefore, the orientations of teachers shape interactions in a way that is not necessarily equal to interactions in the scientific community. Based on our theoretical framework and the findings of Bowen (2005) regarding structural differences between school and science communities, we argue that school science is inevitably peculiar.

Regarding the sociology-based framework of implicit or tacit knowledge, we suggest that it can also be useful in analyzing classroom interactions in different contexts of science education research. In addition to the context of teleology and creationism discussed above, the students’ as well as the teacher's implicit understanding of the NOS and epistemology may influence the learning process. As argued by Clough (2006) and Oliveira et al. (2012), the teacher transports an implicit meaning: “Ever present in
science content and science teaching are implicit and explicit messages regarding the NOS. The issue is not whether science teachers will teach about the NOS, only what image will be conveyed to students.” (Clough, 2006, p. 464). Speaking in the terminology of the sociology of knowledge (Bohnsack, 2010), the teacher may hold an implicit orientation toward science as a positivistic rather than a tentative endeavor. Even a teaching unit that explicitly addresses NOS may then be taught in a recontextualized and thus positivistic way – comparable to using the lottery model, which addresses the aspect of randomness in the evolutionary process in a teleological way. The teacher's problematic implicit orientation may then be elaborated by the students, who are prone to intuitive conceptions as part of their framework of orientation. Similarly, in the field of socio-scientific issues, we suggest that implicit knowledge plays an important role because in addition to (explicit) factual knowledge, cultural beliefs, and normative values need to be taken into account (e.g., Zeidler, Sadler, Simmons, & Howes, 2005), and such beliefs and values are, to some extent, a result of socialization processes and form the framework of orientation of the agents. Moreover, moral judgments can be intuitive judgments, and people have difficulty explicitly articulating the reasons for their choices (Haidt, 2001), which is in line with the notion of an implicit orientation and may explain why theoretical knowledge alone may not guide our actions. In the context of education for sustainable development as one area of socio-scientific issues, Kater-Wettstädt (2017) uses the framework of the sociology of knowledge to reconstruct how the students address their limited knowledge about the issue, the different perspectives of involved stakeholders and calls to action. In addition to the fields of evolution, the NOS and socio-scientific issues, the sociological framework also allows addressing issues of equity and access to scientific knowledge (cf. review of Kelly, 2007) because cultural aspects of the students, and the positioning of the teacher and the students, can be analyzed. Consequently, we argue that the theoretical framework presented in this article is applicable to many fields of science education research and may enrich our understanding of the tacit knowledge base of the agents and classroom interactions.

ACKNOWLEDGMENTS
The authors would like to thank Prof. Dr. Marcus Hammann and the reviewers for their critical review of the manuscript and their valuable comments. Moreover, the authors would also like to thank the documentary method interpretation groups in Frankfurt am Main and Münster, in particular Prof. Dr. Barbara Asbrand, for the discussion of our interpretations.

ENDNOTES

1The interpretations are based on the German transcripts, which were then translated.
2All names anonymized.
3At 0:48:30, the first video file ends, and the second video file starts at 0:00:00.

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**How to cite this article:** Gresch H, Martens M. Teleology as a tacit dimension of teaching and learning evolution: A sociological approach to classroom interaction in science education. *J Res Sci Teach.* 2019;56:243–269. [https://doi.org/10.1002/tea.21518](https://doi.org/10.1002/tea.21518)