– Original Paper –

Moderate knowledge is not enough – a longitudinal study on knowledge and acceptance of evolution among pre-service science teachers

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ABSTRACT

Understanding evolution is crucial for comprehending biology and addressing contemporary biological crises. To teach evolution effectively, science teachers need profound content knowledge of evolution and a high acceptance of evolution. On average, across Europe, science teachers' knowledge of evolution is only low to moderate, while their acceptance levels vary. Switzerland has recently integrated fundamental concepts of evolution into school curricula, from early childhood education to secondary school. However, there is limited information on pre-service science teachers' knowledge and acceptance of evolution and the effectiveness of biology courses within teacher education programs in Switzerland. In a longitudinal (n = 32) and cross-sectional (n = 658) study spanning 3 years, the knowledge and acceptance of evolution among pre-service science and non-science teachers in Switzerland were surveyed using two established questionnaires (KAEVO 2.0 and ATEVO). The knowledge of evolution observed in pre-service science teachers increased throughout their studies. However, even upon completion of their studies, knowledge remained at a moderate level. The students still held persistent alternative conceptions, e.g. regarding the heredity of phenotype changes, variation, and fitness. The comparison group, without biology courses, exhibited low levels of knowledge at all measurement points. Both groups, however, demonstrated high levels of acceptance. The Model of Educational Reconstruction is discussed as an approach for teacher education to improve the effectiveness of teaching evolution, along with a stronger focus on professional orientation. Specifically, imparting school-relevant knowledge, considering students' alternative conceptions, and the repeated application of core concepts could contribute to increasing student learning outcomes.

Key words: science teacher education, longitudinal study, evolution

– Originalbeitrag –

Moderates Wissen reicht nicht aus – eine Längsschnittstudie zu Wissen und Akzeptanz von Evolution bei Lehramtsstudierenden

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ZUSAMMENFASSUNG

Evolutionswissen ist unerlässlich für ein Verständnis der Biologie und die Bewältigung aktueller biologischer Krisen. Um Evolution effektiv zu unterrichten, benötigen Naturwissenschaftslehrpersonen fundiertes fachliches Evolutionswissen (und fachdidaktisches Wissen) sowie eine hohe Akzeptanz der Evolution. Im europäischen Durchschnitt ist das Evolutionswissen von Naturwissenschaftslehrpersonen nur gering bis mäßig, während ihre Akzeptanz variiert. In die Schweizer Lehrpläne wurden kürzlich grundlegende Konzepte der Evolution von der Vorschule bis zur Sekundarstufe integriert. Es liegen jedoch nur wenige Informationen über das Wissen und die Akzeptanz von Evolution bei angehenden Naturwissenschaftslehrpersonen sowie über die Wirksamkeit von Biologiekursen in der Schweizer Lehrpersonenausbildung vor. In einer Studie über drei Jahre (Längsschnitt n = 32; Querschnitt n = 658) wurden das Wissen und die Akzeptanz von Evolution bei angehenden Schweizer Naturwissenschafts- und Nicht-Naturwissenschaftslehrpersonen mithilfe zweier etablierter Fragebögen (KAEVO 2.0 und ATEVO) erhoben. Das Evolutionswissen angehender Naturwissenschaftslehrpersonen nahm im Laufe ihres Studiums zu. Allerdings war es auch am Ende nur moderat und zeichnete sich durch hartnäckige alternative Vorstellungen aus, z.B. in Bezug auf die Vererbung von erworbenen Eigenschaften, Variation und Fitness. Die Vergleichsgruppe, die keine Biologiekurse besuchte, hatte zu allen Messzeitpunkten geringes Evolutionswissen. Beide Gruppen zeigten jedoch eine hohe Akzeptanz. Um die Effektivität der Lehre zu verbessern, werden das Modell der Didaktischen Rekonstruktion sowie eine stärkere Professionsorientierung für die Lehrpersonenausbildung diskutiert. Insbesondere die Vermittlung schulrelevanten Wissens, die Berücksichtigung alternativer Vorstellungen der Studierenden und die wiederholte Anwendung von Kernkonzepten in der Lehre könnten zur Erhöhung des Lernerfolgs der Studierenden beitragen.

Schlüsselwörter: Lehrer:innenbildung, Evolution, Längsschnittstudie

1 Introduction and Objective

Understanding evolution helps students grasp fundamental concepts about the diversity of life, adaptation, and the interconnectedness of all organisms. Knowledge of evolution is critical for addressing some of today's crises, such as climate change, habitat destruction, antibiotic resistance development, and the evolution of pathogens (Hodson, 2003). To develop evolutionary literacy (Kampourakis, 2022), students need biology teachers with profound subject-specific content knowledge (CK) as well as pedagogical content knowledge (PCK) and pedagogical knowledge (PK) (Shulman, 1986). However, empirical evidence concerning the knowledge of evolution of European science teachers[1] shows that, on average, their knowledge is only low to moderate (for an overview, see Kuschmierz et al., 2020b; Lanka, Hild & Beniermann, 2024) and not sufficient to foster a profound understanding of evolution in their students (Yates & Marek, 2014). Experienced teachers are difficult to recruit for professional development courses, and professional development often reaches only a few practising teachers (Autor:innengruppe Bildungsberichterstattung, 2022). Yet, an advancement in evolution education is possible through solid teacher education at university so that the next generation of science teachers can draw on scientifically adequate concepts and design effective learning environments. A prerequisite for successful teacher education is that the knowledge level of the pre-service science teachers (PSTs), and especially their alternative conceptions regarding evolutionary concepts, are known to tailor the courses to the participants' needs.

This paper presents data from a larger study investigating knowledge and acceptance of evolution among PSTs and in-service science teachers in Switzerland (Lanka et al., 2024). The findings discussed herein focus specifically on lower secondary PSTs (grades 7-9) over three years, contributing to the broader understanding of learning gains regarding evolution and possible changes in acceptance of evolution during teacher education. In Switzerland, evolutionary concepts were introduced as part of the curricula in compulsory schools about a decade ago (Conférence intercantonale de l'instruction publique de la Suisse romande et du Tessin [CIIP], 2010; Dipartimento dell'educazione, della cultura e dello sport [DECS], 2015; Deutschschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2015) and have only been taught for a few years in secondary schools (Lanka, Hild, Milani & Letouzey-Pasquier, 2022). A nationwide study on Swiss pre- and in-service science teachers (K-9) in 2022 demonstrated that knowledge of evolution was low for pre-service kindergarten and primary school teachers, while it was moderate for pre-and in-service lower secondary school teachers (Lanka et al., 2024). Lagler and Wilhelm (2013) found a lack of alignment between subject-specific biology courses for PSTs and the curriculum-relevant content knowledge required for Swiss science teachers. As acceptance was high for all these surveyed groups in the Swiss study, the findings indicate that science teacher education should be optimised to improve evolution education. To date, the effectiveness of teacher education in relation to evolutionary concepts has not been researched in Switzerland. Therefore, this study aims to assess the development of evolutionary concept knowledge and the acceptance of evolution of PSTs for lower secondary schools throughout a three-year teacher education program. We expect longitudinal data to provide a more accurate picture of the effectiveness of different courses in science teacher education than cross-sectional data.

2 Background

According to the principles of moderate constructivism (e.g. Riemeier, 2007), learning is a constructive, self-determined, individual, social, and situated process in which learners construct new concepts by building upon their preconceptions, knowledge, and beliefs. Teachers of all target groups, including teacher educators, need in-depth subject-specific CK (besides PCK and PK) to promote learning in their students. Alternative conceptions are common in science and pose significant learning difficulties (e.g. Duit & Treagust, 2003). Especially in the context of evolution, many scientific ideas and concepts are counterintuitive, and cognitive biases and common language usage impede the acquisition of scientifically adequate concepts (Gregory, 2009;

[1] For this article, the term *science teachers* refers to educators who teach or study to teach subjects such as biology, chemistry, and physics or solely biology unless the context requires specification.

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Harms & Reiss, 2019). Alternative conceptions of evolutionary principles can be categorised based on the subject matter they relate to (such as heredity, speciation, adaptation, and geological time) or on the underlying causes that give rise to them (such as teleology, anthropomorphism, Lamarckism). The instruction during teacher education is crucial in enabling PSTs to successfully develop CK in the field of evolution and overcome alternative conceptions (Ziadie & Andrews, 2018). The following section will focus mainly on European empirical findings regarding PSTs' knowledge and acceptance of evolution, which have been measured in over 2 dozen studies. However, the studies were conducted in fewer than ten countries, with a concentration in Germany and Turkey. The results of these studies are only partially comparable because they used different testing instruments or modified versions of them. Kuschmierz et al. (2020b) developed a system to interpret the knowledge and acceptance scores of frequently used instruments, enabling the comparison of findings across different studies. The categories have a descriptive function (categories: high, rather high, moderate, low, very low).

2.1 PSTs' knowledge and acceptance of evolution

PSTs' knowledge of evolution

European PSTs seem to have low knowledge of evolution, with the exception of German PSTs (Table 1; Kuschmierz et al., 2020b; Lanka et al., 2024). Studies which specifically mentioned the school levels PSTs aimed to teach revealed that PSTs with higher target levels had higher knowledge of evolution (Großschedl, Konnemann & Basel, 2014; Großschedl, Seredszus & Harms, 2018; Lanka et al., 2024). This relationship may be due to the different study programs for different school levels, with no or very few evolution learning opportunities for PSTs of lower levels

Table 1

Categorical overview of European PSTs' knowledge and acceptance of evolution as determined in studies from 2010 to 2024. Interpretation of the knowledge scores derived from different test instruments according to Kuschmierz, Beniermann and Graf (2020a)

Country	*n*	Knowledge level	Acceptance level	References
Czech Republic, Slovakia, Slovenia, Turkey	940	low		Šorgo et al. (2014)
Germany, Turkey	972	low	G: moderate to low, T: low to very low	Graf & Soran (2010)
Germany	309	moderate		Aptyka, Fiedler & Großschedl (2022)
	97	moderate	high	Beniermann (2019)
	206		high	Beniermann, Moormann & Fiedler (2023)
	68	low*		Fiedler, Tröbst & Harms (2017)*
	179	very low	high	Fiedler, Moormann & Beniermann (2024)
	51	moderate to high		Fischer, Jansen, Möller & Harms (2021)
	180	moderate	high	Großschedl, Konnemann & Basel (2014)
	212	moderate to high*	high	Großschedl, Seredszus & Harms (2018)
	67	low*	high	Hartelt, Martens & Minkley (2022)
	60	moderate	high	Nehm, Großschedl, Harms & Roshayanti (2013)
Greece	113	very low	moderate	Athanasiou, Katakos & Papadopoulou (2012)
	101	low		Athanasiou & Mavrikaki (2014)
	168		moderate	Athanasiou & Papadoupoulou (2012)
	120		moderate	Athanasiou (2022)

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Country	*n*	Knowledge level	Acceptance level	References
Slovenia	269	very low		Torkar & Šorgo (2020)
Switzerland	1063	low to moderate	high	Lanka et al. (2024)
Turkey	136	very low	moderate	Akyol, Tekkaya & Sungur (2010)
	415	very low		Akyol, Tekkaya, Sungur & Traynor (2012)
	147		moderate (near low*)	Deniz et al. (2011)
	126	very low	low	Deniz & Sahin (2016)
	75		low	Irez & Bakanay (2011)
	117	low*		Keskin & Köse (2015)
	35	low		Tekkaya et al. (2011)
	132		low	Yüce & Önel (2015)
UK (Scotland)	28		high*	Arthur (2013)

Note. For details on the studies see Lanka et al. (2024), Supplementary file 1. *Results from original publication.

PSTs' alternative conceptions of evolution

Alternative conceptions significantly influence the learning of new concepts (for a compilation see Graf & Hamdorf, 2011; Gregory, 2009; Tibell & Harms, 2017). Various research findings have shown that teachers hold similar conceptions as their students (Chen, Sonnert, Sadler & Sunbury, 2020; Yates & Marek, 2014). Only a few studies on PSTs' knowledge of evolution mentioned above identified specific alternative conceptions and their frequency among the PSTs. PSTs often use teleological explanations, i.e. citing a purpose or a goal pursued by the organism itself or by a higher entity such as nature (Athanasiou, Katakos & Papadopoulou, 2012; Großschedl et al., 2018; Hartelt et al., 2022; Torkar & Šorgo, 2020). PSTs may refer to an internal need or a necessity as a driving force for adaptation (Großschedl et al., 2018; Hartelt et al., 2022; Torkar & Šorgo, 2020). This physical necessity for adaptation may occur automatically through the organism's reactions to the living conditions (Torkar & Šorgo, 2020). Anthropomorphic thinking, i.e. attributing human reasoning to non-living organisms, was detected by Torkar and Šorgo (2020). Typological conceptions that entail that individuals of a species share fixed, inherent characteristics and thus negate variation within populations were frequently found by Graf and Soran (2010). Besides natural selection, typological conceptions concern concepts about species, biological classifications, and fitness. The biological concept of fitness quantifies the reproductive output of an organism with a particular genotype relative to other genotypes (Gregory, 2009). PSTs' most common alternative conceptions regarding fitness include an individual's ability to adapt to new conditions in response to environmental changes, which indicates adaptation is understood in an everyday sense (Graf & Soran, 2010). The second most common response in the same study was the 'largest number of offspring', reflecting a basic comprehension of biological fitness (Gregory, 2009). Further alternative conceptions concern the heredity of phenotype changes, deep time, and mutations (e.g. Kuschmierz et al., 2020a). Tree reading seems to be a reading technique (procedural knowledge) rather than conceptual knowledge and can easily be acquired when taught (Hanisch & Eirdosh, 2023).

PSTs' development of knowledge of evolution during their studies

Only a few studies specifically studied PSTs' changes in knowledge of evolution in connection to teacher education courses with evolution content. Except for the first study mentioned, all were conducted in the US. Hanisch and Eirdosh (2023) developed and evaluated a semester-long course on evolution for primary school PST, implementing various pedagogical approaches. In the end, most participants could use key concepts of evolution adequately. PSTs improved their understanding of evolution in a 15-week science education course fostering conceptual change by examining the PSTs' own preconceptions and beliefs and focussing on micro- and macroevolution (Southerland & Nadelson, 2012). Similarly, PSTs with a bachelor's degree in biology showed significant learning gains in teacher

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knowledge of evolution and fewer alternative conceptions after a semester-long course on evolution (Nehm & Schonfeld, 2007). The lecturers used the pre-test knowledge results to structure course content and implemented various pedagogical approaches. In a study with biology majors (not PSTs), Nehm and Reilly (2007) compared active learning as an instructional strategy and using evolution as a common thread through all units vs. traditional lecture-style learning with evolution in one distinct unit. The first group of students achieved significant postcourse learning gains compared with the second. However, both groups still demonstrated inadequate postcourse levels of knowledge (Nehm & Reilly, 2007). In a professional development course with in-service teachers over an academic year, a strong focus was laid on content, active and collaborative learning, coherence with teaching situations in school, and alignment with the curriculum (Ha, Baldwin & Nehm, 2015). Teachers showed sustained large effect sizes for knowledge changes. As far as we know, there are no longitudinal studies on PSTs' changes in knowledge of evolution over several years of teacher education.

PSTs' acceptance of evolution

The acceptance of evolution among teachers influences whether and how evolution is taught. Teachers with a higher acceptance tend to teach evolution more often, allocate more instructional time to evolution education, and teach evolutionary topics such as deep time or phylogenetic trees rather than just natural selection as a single unit (Sickel & Friedrichsen, 2013). PSTs' acceptance in Europe varies depending on the cultural context (Kuschmierz et al., 2020b; Lanka et al., 2024). Overall, PSTs' acceptance is high to moderate, apart from Turkey (Table 1).

2.2 The Model of Educational Reconstruction

Prior knowledge and conceptions are the most important factors for constructing and integrating new knowledge (Komorek, Fischer, Moschner & Prediger, 2013). The Model of Educational Reconstruction (MER) (Duit, Gropengießer, Kattmann, Komorek & Parchmann, 2012; Kattmann, Duit, Gropengießer & Komorek, 1997) was first developed as a research model for science education and can provide a framework for improving teaching and learning science in teacher education. It is rooted in the German tradition of *Didaktik* (Heimann, Otto & Schulz, 1965; Klafki, 1958) and *Bildung*[2] and based on two central assumptions: Learning is not merely characterised by the subject matter to be taught but occurs in a situational context that must be created. Awareness of the students' perspective influences the reconstruction of the relevant subject matter (Kattmann et al., 1997; Van Dijk & Kattmann, 2007). In the reconstruction process, students' everyday and subject-specific knowledge, both constructs in their own right, equally serve as a foundation for developing teaching content.

The MER involves three components (Figure 1): (1) the clarification of competency requirements in the subject, (2) the clarification of the learners' perspective, and (3) the design and evaluation of instructional sequences. The clarification of competency requirements necessitates adopting an educational meta-perspective to not only represent the key concepts of science but also consider the significance of the subject matter in society and aspects of the nature of science. A vital feature of the MER is the process of elementarisation (*Elementarisierung*), which aims at identifying the core elements or concepts to be taught, and reducing the complexity of a particular subject matter in a way that makes it accessible and fruitful. The second key feature of the model is the analysis and subsequent integration of the students' perspective in reconstructing the instructional sequences. This analysis includes the learners' knowledge and skills, alternative conceptions, views on the subject matter, and affective factors such as interests and science-learning self-concepts. The construction of content structure for instruction proceeds from structuring the learning processes (deep structure) to arranging the lesson (surface structure) (Wilhelm & Kalcsics, 2017).

[2] Duit et al. (2012) note that *Didaktik* should not be equated with the English concept of "didactical", which refers to a very specific teaching style. Rather, "it concerns the analytical process of transposing (or transforming) human knowledge (the cultural heritage) like domain specific knowledge into knowledge for schooling that contributes to the above formation (Bildung) of young people" (p. 16).

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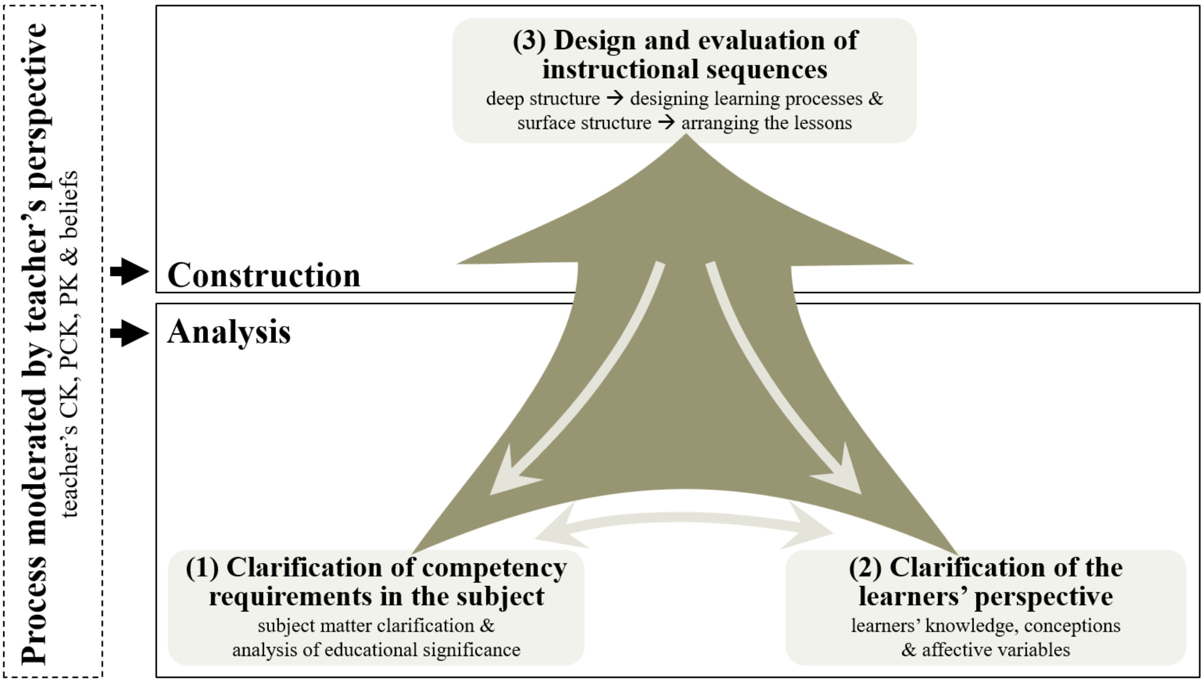

Figure 1. The three components of the Model of Educational Reconstruction (based on Duit et al., 2012; Tardent, 2020; Wilhelm & Kalcsics, 2017). The grey arrows indicate the recursive approach. The teacher's perspective moderates the analysis and the construction

Teacher's beliefs and professional knowledge play a crucial role in shaping the lesson planning process (Gess-Newsome, Southerland, Johnston & Woodbury, 2003). Empirical evidence suggests that teacher knowledge influences the quality of instruction (Baumert et al., 2010; Gess-Newsome & Lederman, 1993; Hill, Rowan & Ball, 2005; Sadler, Sonnert, Coyle, Cook-Smith & Miller, 2013), although positive learning outcomes seem to be diminished by the strength of alternative conceptions held by the learners (Sadler et al., 2013; Shulman, 1986). Teachers with a firm grasp of scientific concepts are more likely to identify and tackle students' alternative conceptions (Duit & Treagust, 2003; Hartelt et al., 2022). Chen et al. (2020) found that student performance is especially strong when teachers possess both CK and knowledge of their students' most common alternative conceptions. Evidence indicates that the level of teacher knowledge (Gess-Newsome & Lederman, 1995) and their beliefs (Idsardi et al., 2023) affect both the subject content that is taught and the methods used for instruction. More knowledgeable teachers were found to be more apt at the process of elementarisation, used more examples to tie teaching content together, and related teaching content to issues relevant to students (Gess-Newsome & Lederman, 1993). Teacher knowledge also determines whether and how evolution is addressed in the classroom (Sickel & Friedrichsen, 2013).

Using the MER to plan teacher education courses may be helpful in several respects. Teaching evolution at the university level has proved to be challenging (Kuschmierz et al., 2020b; Ziadie & Andrews, 2018). Therefore, lecturers at universities need to be aware of their students' existing (alternative) conceptions as well as their (non-)acceptance of evolution and address naïve or inaccurate understandings. Clarifying the PSTs' perspective includes analysing the significance of the subject content for the conceptual development of PSTs and for biology as a school subject. Besides elementarising the subject content for the PSTs, clarifying the subject requirements for the PSTs should focus on *in-depth school knowledge* (*vertieftes Schulwissen*; Riese et al., 2015), thus creating coherence between academic knowledge and the PSTs' career goals (John & Starauschek, 2018).

2.3 Science Teacher Preparation Program and Study Context

PSTs in compulsory education in Switzerland (K-9) are trained almost exclusively at universities of teacher education (Swiss Coordination Centre for Research in Education [SKBF], 2023), where integrative and practice-oriented degree programs with

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courses focusing on PK, CK, and PCK, as well as practical training are offered (for details on the Swiss educational system and teacher education programs, see Lanka et al., 2024). At the university of teacher education, where the current study was conducted, pre-service lower secondary school teachers (grades 7-9) must take courses for four school subjects and complete a bachelor's and master's degree (comprising 270 credits in the European-Credit-Transfer-System [ECTS]; European Commission, n. d.). Science (biology, chemistry, and physics) counts as one integrative subject, just like social sciences (geography and history). PSTs take courses in science and three other subjects, such as math, social sciences, and sports[3]. Due to the four subjects and the strong practical focus, PSTs cannot be considered biology majors. Only 15% of the entire science teacher education program for PSTs is devoted to science and science education (CK and PCK; biology, chemistry, and physics), translating into around 68 90-minute lessons on biology or biology teaching for PSTs.

Details regarding CK and PCK course content and evolution-specific content for the PSTs are presented in Table 2. The biology CK lectures taken by the PSTs of this study were based on the disciplinary perspectives of biology as a university subject and taught by biologists. For the PCK courses, lecturers used the MER as a planning tool (Duit et al., 2012). The PCK lecturers tried to create horizontal coherence between school-relevant biological CK and PCK and promote reflective teaching practices among PSTs. They focused on the PSTs' competencies in elementarisation (see above), the students' perspectives, and how to create fruitful learning environments. Applying the MER to the PCK courses involved learning about common alternative conceptions in evolution, reflecting on one's conceptions, contrasting them with the scientifically adequate concepts in the context of constructivist learning theories, and discussing contexts of educational significance for the subject matters to be taught in school. The time allocated for evolution-specific content amounted to two 90-minute lessons each in the CK lecture and the PCK seminars. In addition, there were many references to evolutionary concepts in other PCK seminars since evolution is the unifying theme in biology.

Table 2

Overview of the biology CK and PCK courses for PSTs studying to become lower secondary science teachers with three other school subjects besides science – number of lessons and subject content

	CK course	**PCK courses**
Number of lessons	28 lectures (90-minutes each) plus 14 tutorials (90-minutes each)	26 seminars (90-minutes each)
ECTS	6	5
Subject content	molecules of life, cell biology, genetics, ontogeny, anatomy, physiology, ecology, evolution, plant biology	school-relevant key concepts, common alternative conceptions, interests, significant contexts, self-concepts, learning progressions, instructional strategies, and assessment in biology. Foundational educational principles such as aims in biology lessons, curriculum, the Model of Educational Reconstruction as a planning model, scientific inquiry, nature of science, modelling, original encounter, conducting excursions
Evolution-specific content	natural and sexual selection, life cycles, speciation, variation, convergence, phylogeny	conceptualisation of genetics and natural selection, alternative conceptions of evolution, levels of biological organisation, simulations on the impact of selection on evolutionary change

[3] Science and English cannot be studied together for a secondary school teaching degree at the participating university of teacher education. Some PSTs choose science as a subject because they do not want to or cannot study English or French (negative selection).

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3 Research Questions

Science teachers possess a range of alternative conceptions regarding evolution despite having taken CK and PCK courses during their studies. European PSTs' knowledge and acceptance levels of evolution have been measured in several countries, identifying common alternative conceptions. To date, Swiss science teachers' knowledge and acceptance of evolution have only been studied as part of the larger study (Lanka et al., 2024). Only a few studies worldwide have investigated the acquisition of evolutionary concepts throughout a teacher education program. We are unaware of any longitudinal study that measured the development of PSTs' knowledge and acceptance of evolution during teacher education and examined the persistence of alternative conceptions after the end of their studies. This research gap warrants further investigation into the development of PSTs' knowledge and its implications for the development of science teacher education. In this article, we examined knowledge and acceptance of evolution among PSTs and a comparison group of pre-service non-science teachers (PNSTs) over three years. PNSTs were used to establish a baseline for comparison and determine whether the expected learning gains were due to the biology courses or other factors. The following research questions guided our study:

> RQ1: How do knowledge and acceptance of evolution change among PSTs over the course of their studies?
>
> RQ2: Which alternative conceptions of evolution persist among these PSTs at the end of their studies?
>
> RQ3: What are the levels of knowledge and acceptance of evolution at various points during their studies among PSTs compared to a group of PNSTs?

The first two research questions focus on a group of PSTs over three years of studies. The third research question is examined using a larger cohort of PSTs as well as PNSTs.

4 Method

4.1 Measures

Data on knowledge and acceptance of evolution was gathered with two instruments (see Supplement Sections A and B): A slightly modified version (Lanka et al., 2024) of the Knowledge About EVOlution instrument (Kuschmierz et al., 2020a) was used to assess knowledge and alternative conceptions of evolution (with additional validated items from the Biological Evolution Literacy Survey; Yates, 2011)[4]. KAEVO 2.0 consists of multiple-choice items with a "don't know option" and covers fundamental concepts of evolution that reflect the secondary biology curricula of Switzerland (Lanka, Hild & Beniermann, 2023). Acceptance of evolution was measured with the subscale Attitudes Towards EVOlution – Evolution in General (ATEVO-EG; Beniermann, 2019; English version in Beniermann et al., 2021), which was extended with two additional items each from the Inventory of Student Evolution Acceptance instrument (I-SEA; Nadelson & Southerland, 2012), and the Generalized Acceptance of EvolutioN Evaluation (GAENE 2.0; Smith, Snyder & Devereaux, 2016). Participants were asked to express their personal agreement or disagreement with each item by choosing a response from a five-point rating scale (for details see Lanka et al., 2024). To interpret the test scores, the categorisation system devised by Kuschmierz et al. (2020b) was applied (Table 3). However, the assigned knowledge categories provide limited insight into which evolutionary concepts the participants understood and to what depth. Here, the results from RQ2 provide clarification, as they examine alternative concepts related to various evolutionary concepts. Moreover, sociodemographic data such as age, gender, semesters of study, subjects of study, and interest in biology, were collected. KAEVO 2.0 and ATEVO were initially developed for secondary and university students. Validation has been conducted for the subscales of KAEVO 2.0 and ATEVO, with documented evidence supporting their validity and reliability (Beniermann, 2019; Beniermann et al., 2023; Kuschmierz et al., 2020a).

[4] The three items from KAEVO-C measuring knowledge of deep time were not analysed for this paper.

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Table 3

Score categories for the knowledge score K (23 items) and the acceptance score A (eight items) surveyed in the presented study (interpretation based on Kuschmierz et al., 2020b)

Knowledge Score *K*	**Interpretation knowledge score**
22-23	high knowledge
19-21	rather high knowledge
15-18	moderate knowledge
11-14	low knowledge
0-10	very low knowledge

Acceptance score *A*	**Interpretation acceptance score**
35-40	acceptance
29-34	rather acceptance
20-28	indifferent position
14-19	rather rejection
8-13	rejection

4.2 Sample and Data Collection Procedure

The three-year study (2022-2024) presented in this paper involved PSTs and PNSTs from a large university of teacher education in the German-speaking part of Switzerland. The participants were in their first three years of studies in a 4.5-year teacher education program for lower secondary school teachers. Prior to obtaining the participants' consent, it was specified that the questionnaire was anonymous and that they could abort the completion of the questionnaire at any time. All participants received the same information on the purpose of the study and the same instructions.

The surveys consisted of the knowledge and acceptance scales at each of these three data collection points and took the participants around 25 minutes to complete. They were administered in both groups on three different occasions during the teacher education program (Figure 2). PSTs completed the questionnaire in their science courses and PNSTs in their English courses in the same weeks. T1 assessed PSTs' and PNSTs' school knowledge and acceptance of evolution at the beginning of teacher education, while T2 assessed knowledge and acceptance after the PSTs' biological CK examination, and T3 after the PSTs' biological PCK courses. T3 marks the end of the non-practical science teacher education for the PSTs.

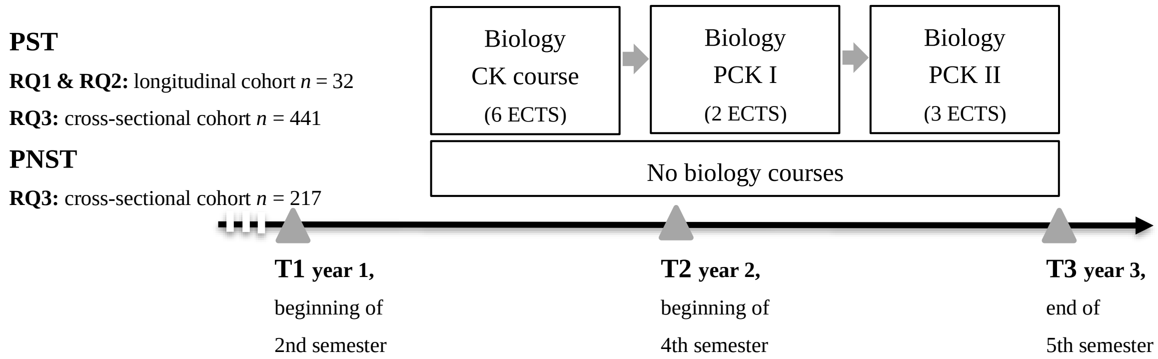

Figure 2. Study design for the longitudinal and the cross-sectional cohorts. Subject profile PST: pre-service lower secondary science; PNST: pre-service lower secondary non-science (English). Sequence of biology courses in the teacher education program for PSTs and number of credits. Data were collected at T1, T2, and T3 for three consecutive years (2022-2024)

During the three years in which the study was conducted, all cohorts of PSTs and PNSTs were surveyed at T1-T3, resulting in 441 PST ($n_{T1} = 144$, $n_{T2} = 158$, $n_{T3} = 139$) and 217 PNST ($n_{T1} = 73$, $n_{T2} = 83$, $n_{T3} = 61$) datasets (cross-sectional cohort). The three-year longitudinal study is based on 32 PSTs who were first surveyed in 2022. Those 32 PSTs are also part of the cross-sectional cohort. The longitudinal cohort represented the cross-sectional cohort of PSTs in terms of age, years of study, and interest in biology but contained more female than male students. The cross-sectional groups of PSTs and PNSTs were comparable in terms of age and years of study, but PNSTs had more female students and expressed less interest in biology. See Table 4 for the remaining participants after data cleansing for the demographic information.

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Table 4
Sample details of the participants after data cleansing. Each line contains data from T1, T2, and T3. PSTs with more than one year of teaching experience or more than one additional study year were excluded. Interest in biology was measured with the item "How interested are you in biological topics?"

Cohorts	**Number of participants** *n*	**Sex** (% female)	**Age** (years; *M* ± *SD*)	**Years of studies** (years; *M* ± *SD*)	**Interest in biology** (7 – very high, 1 – very low)
$PST_{longitudinal}$	**32**	**56**	**23.2** ± 3.0	**2.0** ± 0.2	**4.7** ± 0.9
$PST_{cross-sectional}$	**441**	**49**	**24.3** ± 4.5	**1.9** ± 0.8	**4.7** ± 1.0
PST_{2022}	144	53	24.4 ± 5.5	1.9 ± 0.7	4.9 ± .9
PST_{2023}	158	46	24.3 ± 3.9	2.0 ± 0.9	4.8 ± 1.0
PST_{2024}	139	48	24.1 ± 4.1	1.9 ± 0.8	4.5 ± 1.1
$PNST_{cross-sectional}$	**217**	**64**	**23.9** ± 5.6	**1.9** ± 0.8	**3.3** ± 1.3
$PNST_{2022}$	10	60	22.9 ± 3.1	2.9 ± 1.4	3.3 ± 1.1
$PNST_{2023}$	115	67	23.4 ± 4.7	1.8 ± 0.7	3.4 ± 1.3
$PNST_{2024}$	90	60	24.7 ± 6.7	1.9 ± 0.9	3.1 ± 1.3

For the longitudinal study (RQ1 and RQ2), PSTs created a self-generated identification code from the answers to four personal questions (mother's first name initial, mother's first name penultimate letter, sum of the participant's birthdate and birth month, participant's first name initial). The personal codes were matched across the three waves of data collection. There were 47 potential participants for the longitudinal cohort in the first year, i.e. participants who completed the survey at T1 and were present at T2 and T3 in the consecutive years. The employed code proved to be prone to errors, and especially the sum varied widely. Therefore, we allowed the codes to be fault-tolerant, accepting one position not to match (Audette, Hammond & Rochester, 2020), and used additional personal data such as gender, age, study year, and science or non-science cohort as additional information to ensure correct matches. Data loss was thus reduced from 50% to 30% (*n* = 32).

4.3 Statistical analysis

Quantitative data from the questionnaires following the method outlined in Beniermann et al. (2021) were summarised using descriptive statistics in SPSS (IBM version 29.0.2.0). For RQ1 and RQ3, a knowledge sum score (*K*), derived from 23 items, was calculated (score range 0-23). Acceptance sum scores (*A*) were assessed by summing the individual scores of all items (1-5) on the scale (score range 8-40). For RQ2 (alternative conceptions at the end of the participants' studies), knowledge items answered incorrectly at T3 by 25% or more of the participants of the longitudinal cohort were considered. Descriptive statistics were employed to summarise the data, including the calculation of the percentage of correct responses alongside the identified alternative conceptions. To track changes in the prevalence of alternative conceptions, the percentage of incorrect responses at T1 and T3 were compared.

5 Results

RQ1: How do knowledge and acceptance of evolution change among pre-service science teachers over the course of their studies? (longitudinal cohort)

On average, knowledge of evolution *K* can be interpreted as moderate for all three data collection points for the longitudinal cohort (K_{T1} = 16.41 ± 2.35; K_{T2} = 17.34 ± 2.21; K_{T3} = 18.22 ± 1.86; Figure 3). However, knowledge scores differ significantly between T1, T2, and T3 (Friedman test: p<.001), with an increase over time. The Wilcoxon signed-rank test revealed a significant difference in knowledge scores between T1 and T2 (Z = 2.440, n = 32, p = .015) and T2 and T3 (Z = 2.820, n = 32, p = .005), with strong effects (Figure 3a).

Acceptance of evolution remained high throughout data collection (A_{T1} = 36.37 ± 4.75; A_{T2} = 35.84 ± 5.68; A_{T3} = 36.06 ± 6.11; Figure 3b), and a Friedman's test indicated no significant differences in acceptance across the three testing points (p = .461).

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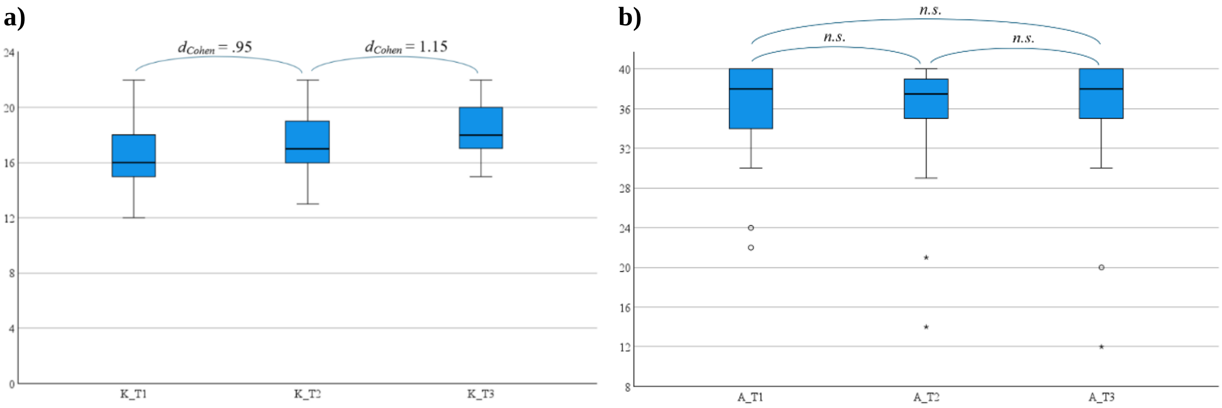

Figure 3. a) Evolution knowledge sum scores *K* for the longitudinal cohort PSTs (*n* = 32; score range 0-23); interpretation: moderate knowledge; statistical test: Wilcoxon signed-rank test. b) Evolution acceptance sum scores *A* for the longitudinal cohort PSTs (*n* = 32; score range 8-40); interpretation: high acceptance; statistical test: Friedman test. Circles indicate moderate, and asterisks indicate extreme outliers

RQ2: Which alternative conceptions of evolution persist among pre-service science teachers at the end of their studies? (longitudinal cohort)

By time point T3, the PST practically no longer had any alternative ideas regarding adaptation and mutation (for correct answers of all knowledge items in per cent for T1 and T3: Supplement Section A). Areas in which they still had alternative conceptions will be further examined below. *Scope of the theory of evolution*: A quarter of the participants think the theory of evolution (A12) explains the origin of life. *Heredity of phenotype changes*: Almost all participants answered correctly that missing tails in the parental generation have no effect on the offspring after one generation (A7). However, around 28% adhered to the conception that phenotypically altered traits do influence the offspring after multiple generations (A8) (Figure 4).

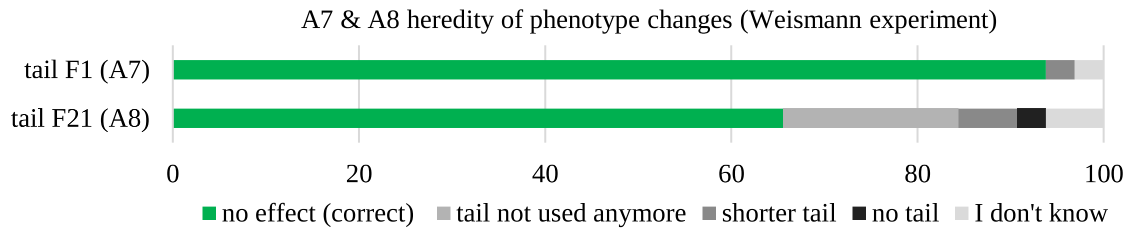

Figure 4. Percentage of correct answers and alternative conceptions on the heredity items A7 and A8 for PSTs (longitudinal cohort, *n* = 32) at T3. The five response options are shown in the legend

Speciation, including variation: Concerning the reencounter of two geographically separated subpopulations of lizards (A4), 60% of PSTs correctly chose the answer, indicating that how the two groups might develop is not predictable. The most common alternative conception was that a differential development would only be possible in two substantially different environments (28%), followed by the conception of differential development without specification (13%) (Figure 5).

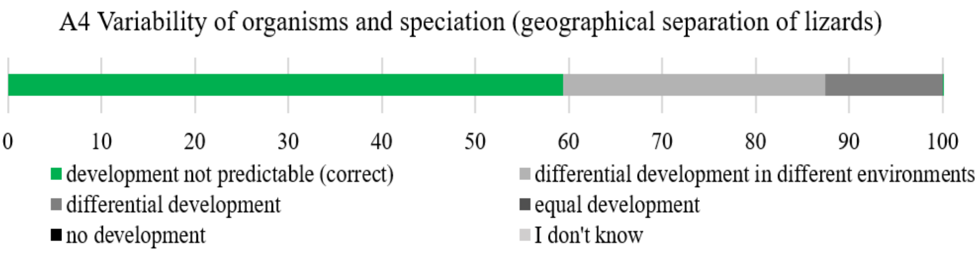

Figure 5. Percentage of correct answers and alternative conceptions on the speciation item A4 for PSTs (longitudinal cohort, *n* = 32) at T3. The six response options are shown in the legend

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Biological fitness: The alternative conception of "largest number of offspring" was slightly more represented (47%) than the correct concept, "largest number of adult offspring" (44%) (A2, Figure 6). Only 9% seem to adhere to the alternative conception of "only the strongest survive", choosing "able to adapt after a fire".

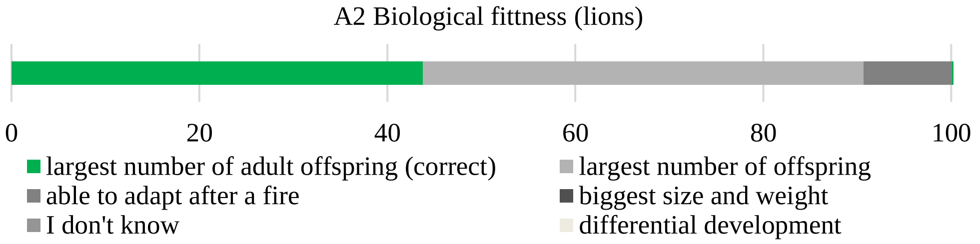

Figure 6. Percentage of correct answers and alternative conceptions on the biological fitness item A2 for PSTs (longitudinal cohort, n = 32) at T3. The five response options are shown in the legend

Human evolution: Around 47% correctly identified humans as the closest ancestors of chimpanzees (A11). A large group (31%) ticked "I don't know".

Tree reading: Only 22% could identify the time axis and the direction of time in a phylogenetic tree (A9.1, Figure 7). 25% of the participants followed the "backbone" of the tree from the common ancestor to the tips, while 22% solely focused on the tips connected to the backbone, disregarding the common ancestor. Concerning kinship (A9.2, Figure 8), only 9% could correctly identify close relatives by looking at the last common ancestor. The majority (44%) used proximity at the tips to indicate kinship, while 31% favoured the equal length of branches for kinship.

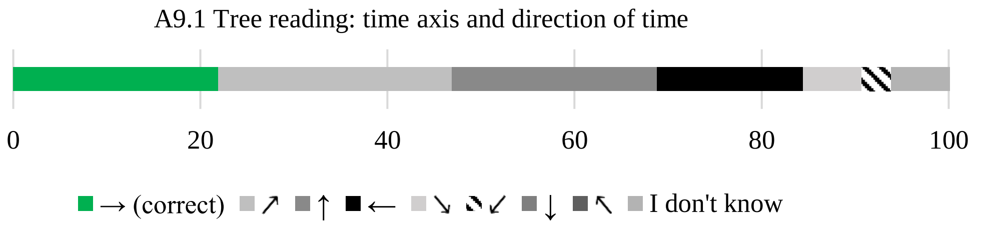

Figure 7. Given phylogenetic tree and percentage of correct answers and alternative conceptions on the tree reading item A9.1 for PSTs (longitudinal cohort, n = 32) at T3. The nine response options are shown in the legend

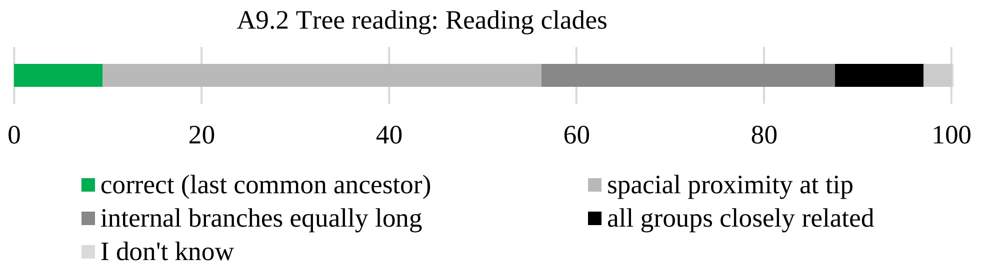

Figure 8. Percentage of correct answers and alternative conceptions on the tree reading item A9.2 for PSTs (longitudinal cohort, n = 32) at T3. The seven original response options are pooled into five options the legend

RQ3: What are the levels of knowledge and acceptance of evolution at various points during their studies among pre-service science teachers compared to a group of pre-service non-science teachers? (cross-sectional cohorts)

In the cross-sectional cohorts of PSTs, the level of knowledge of evolution can be interpreted as moderate ($K_{PST\text{-}T1}$ = 14.83; $K_{PST\text{-}T2}$ = 16.41; $K_{PST\text{-}T3}$ = 18.10; Table 5), the PNSTs' knowledge as low ($K_{PNST\text{-}T1}$ = 12.23; $K_{PNST\text{-}T2}$ = 12.67; $K_{PNST\text{-}T3}$ = 13.69; Table 5).

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Table 5

Knowledge sum scores K (n, M ± SD) among PSTs and PNSTs (cross-sectional cohort) for the three data collection points, T1, T2, and T3, and the three consecutive years of data collection

Survey year	Subject profile	K_{T1}			K_{T2}			K_{T3}		
		n	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***
2022	PST	55	15.76	3.024	55	16.44	3.46	28	18.50	2.22
	PNST	2	-	-	1	-	-	7	-	-
2023	PST	43	13.86	3.71	57	16.58	3.17	51	17.86	2.58
	PNST	39	11.85	4.10	49	13.10	3.73	27	13.26	3.63
2024	PST	46	14.61	3.61	46	16.15	3.04	60	18.12	2.24
	PNST	32	12.66	4.03	33	11.94	4.91	27	14.04	4.81
2022-2024	PST	**144**	**14.83**	**3.50**	**158**	**16.41**	**3.22**	**139**	**18.10**	**2.36**
	PNST	**73**	**12.23**	**4.02**	**83**	**12.67**	**4.25**	**61**	**13.69**	**4.28**

Kruskal-Wallis test results indicated no significant differences among the three cohorts (2022, 2023, 2024) for PSTs and PNSTs, except for PSTs at T1 ($K_{PST-2022-T1}$, $K_{PST-2023-T1}$, $K_{PST-2024-T1}$, $H(2) = 6.41$, $p = .04$). For the further comparisons, the cohorts were pooled. There were significant differences in the knowledge scores *K* between the three data collection points T1, T2, and T3 for PSTs (K_{PST-T1}, K_{PST-T2}, K_{PST-T3}, $H(2) = 73.09$, $p < .001$; Mann-Whitney-U-Test, $p < 0.001$ for all three comparisons; Table 6) and no significant differences for PNSTs. PSTs and PNSTs show significant differences in knowledge of evolution at all three data collection points (Table 7).

Table 6

Mann-Whitney-U-Test for significant differences in knowledge sum scores K among PSTs (cross-sectional cohort) between the data collection points T1-T2 and T2-T3, with effect sizes reported

Differences in knowledge sum scores *K*	***U***	***z***	***p***	d_{Cohen}
$K_{T1} – K_{T2}$	8267.5	−4.123	<.001	.486
$K_{T2} – K_{T3}$	7484.5	−4.777	<.001	.571

Table 7

Mann-Whitney-U-Test for significant differences in knowledge sum scores K between PSTs and PNSTs (cross-sectional cohort) for the data collection points T1, T2, T3, with effect sizes reported

Differences in knowledge sum scores *K*	***U***	***z***	***p***	d_{Cohen}
K_{T1}	3242.0	−4.626	<.001	.659
K_{T2}	3182.0	−6.591	<.001	.933
K_{T3}	1550.0	−7.192	<.001	1.169

PSTs and PNSTs accept evolution (Table 8), with no significant differences between the two groups (Mann-Whitney-U test). Kruskal-Wallis test results indicated no significant differences in acceptance among the three cohorts (2022, 2023, 2024) for PSTs and PNSTs, nor significant differences at different testing points T1, T2, and T3.

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Table 8

Acceptance sum scores A (n, M ± SD) among PSTs and PNSTs (cross-sectional cohort) for the three data collection points, T1, T2, and T3, and the three years of data collection

Survey year	Subject profile	A_{T1}			A_{T2}			A_{T3}		
		n	***M***	***SD***	***n***	***M***	***SD***	***n***	***M***	***SD***
2022	PST	55	36.42	4.08	55	35.38	4.82	28	36.14	3.44
	PNST	2	-	-	1	-	-	7	-	-
2023	PST	43	36.09	4.40	57	35.26	5.95	51	37.06	3.99
	PNST	39	35.51	4.72	49	35.94	4.72	27	34.96	5.34
2024	PST	46	34.48	6.28	46	36.28	4.26	60	36.42	5.75
	PNST	31	35.29	5.25	33	34.30	5.69	27	33.96	7.52
2022-	PST	**144**	**35.70**	**5.01**	**158**	**35.60**	**5.10**	**139**	**36.60**	**4.73**
2024	PNST	**72**	**35.49**	**4.88**	**83**	**35.29**	**5.13**	**61**	**34.84**	**6.24**

6 Discussion

Extensive empirical research in evolution education has examined fundamental concepts, alternative conceptions, and the acceptance of evolution in science teachers (for an overview see Harms & Reiss, 2019; Sickel & Friedrichsen, 2013). In many of these studies, it was found that the existing evolutionary knowledge of teachers is not sufficient for successful evolution education (e.g. Fischer et. al., 2021; Hartelt et al., 2022; Yates & Marek, 2014) and that acceptance varies depending on the cultural context (for a review see Kuschmierz et al., 2020b). Teacher education provides an opportunity to equip the next generation of teachers with a solid understanding of evolution. However, to our knowledge, no studies have examined the development of knowledge and acceptance of evolution among PSTs during their studies. Therefore, our research was guided by the following aim: We pursued to investigate the relations between learning opportunities of PSTs and their knowledge and acceptance of evolution before, during, and after their studies. We recruited PNSTs as a comparison group to make causal inferences on the effectiveness of the biological courses.

RQ1: Changes in knowledge and acceptance of evolution among pre-service science teachers throughout their studies

On average, knowledge of evolution can be interpreted as moderate throughout the PSTs' studies, with small but significant learning gains after the CK and the PCK courses. Acceptance of evolution is already high as PSTs start their studies and remains stable. The knowledge scores are comparable to PSTs' knowledge found in other studies; acceptance scores are high like those measured in PSTs with a similar cultural background (e.g. Aptyka et al., 2022; Großschedl et al., 2014, 2018; Nehm et al., 2013).

The test instrument KAEVO, which was originally developed for secondary school students, covers evolutionary concepts relevant to the Swiss curriculum. Future teachers should, therefore, choose scientifically correct answers for most, if not all items. The categorisation of test scores allows for a rough comparison of participants' knowledge levels (Kuschmierz et al., 2020b). The category *moderate* indicates that the participants were unable to correctly answer some of the items, which suggests that they do not fully master all evolutionary concepts. However, the categorisation does not provide any information about which specific evolutionary concepts the participants have securely understood.

The reasons for the relatively low learning gains after the CK course could be as follows: In the CK lectures, evolution was not treated as the central theme of biology (Nehm & Reilly, 2007) but as one distinct unit of academic biology. In-depth school knowledge (Riese et al., 2015) for secondary school and personally relevant contexts played practically no role. The teaching method for evolution subject matter was almost exclusively in the traditional lecture-style format. In a meta-analysis of studies on the effect of active learning versus traditional lecturing on student performance in STEM subjects, on average, active learning leads to significantly higher scores in exams and concept inventories (Freeman et al., 2014).

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Due to the strongly university-oriented curriculum, the PSTs may not have seen the relevance of the CK lectures for their future professional field (John & Starauschek, 2018), which is teaching secondary school students and fostering evolutionary literacy in them (Kampourakis, 2022). PSTs' own alternative conceptions or commonly held conceptions were not addressed. On the other hand, PSTs showed significant learning gains in evolutionary CK after the PCK courses. This might be attributed to the following aspects in the PCK courses: PSTs' alternative conceptions and those common among secondary students were explicitly discussed. A key strategy in effectively assisting students in modifying inadequate conceptions is to guide them in recognising the limitations of their initial conceptions, thus facilitating the construction of more scientifically valid concepts (Duit & Treagust, 2003). Additionally, the method of elementarisation was employed and practised by the PSTs, highlighting core concepts of evolution and constructing conceptual frameworks. The core concepts were actively applied in selected, meaningful, and relevant educational contexts, and useful applications of evolutionary concepts were demonstrated through concrete examples. Furthermore, aspects of evolution were addressed in other contexts as well, with evolution as a unifying theme for the PCK courses. In both, CK and PCK courses, the amount of instructional time dedicated to evolutionary content may simply have been too low for PSTs to fully understand evolution.

RQ2: Alternative conceptions among pre-service science teachers at the end of their studies

Almost all students have knowledge about the concepts of adaptation and mutation. Nevertheless, it should be noted that most participants already correctly used the concepts at T1. However, in contrast to the PSTs' initial knowledge of adaptation at T1, contexts and the gain or loss of traits no longer played a role at T3. The fact that only 84% answered the single-choice items A14 and A16 on adaptation correctly may partly be due to the wording of the items. Both items require close reading. A14 contains a negative wording ("Evolution cannot cause an organism's traits to change within its lifetime"), while A16 only triggers those who are familiar with the alternative conception that evolutionary changes occur at the population level ("According to the theory of evolution, individual organisms adapt to their environments"). We also suspect that at T3, the stereotypical adaptation items (A1, A3, A5, A6) were too easy for the students. In open-ended tasks, differences in fully understanding adaptation would likely become apparent. Other alternative concepts, such as variation, fitness, and heredity of phenotype change, proved to be more persistent. The conception that phenotypic alterations must affect the offspring after some time is very common (A8). This suggests a lack of comprehension regarding the hierarchical levels of genotype and phenotype (Hammann, 2019) and the process of adaptation itself. The alternative conceptions favoured in the speciation item (A4) point to the absence of variation as a core concept for evolutionary change. The most common conception is the selective environment as the crucial driver of evolution. The difficulty of acquiring the concept of variation has been demonstrated by Zabel and Gropengießer (2011) in their study on learning trajectories for evolutionary change. The biological fitness item answers (A2) align with established empirical findings. However, it must be pointed out here that almost 50% of the PSTs selected the most common distractor (largest number of offspring), implying a basic understanding of fitness (Gregory, 2009). The fact that the percentage of correct answers dropped from T1 to T3 suggests guessing rather than a solid understanding of the concept. Guessing may have also played a role in answering the tree reading items (A9.1 and A9.2), which are indispensable tools in evolution education (Schramm & Schmiemann, 2019). The seemingly plausible answers regarding the time axis and the closest related taxa are evenly distributed. The tree reading items may indicate missing conceptions rather than alternative conceptions (von Aufschnaiter & Rogge, 2010). During the survey, participants from both groups expressed that they had no idea how to read such trees.

Possible reasons for inadequate conceptions could be that the evolutionary concepts were not taught in the courses or that the instructional time was too brief (e.g. tree reading). As mentioned above, engaging with one's own alternative conceptions fosters learning (Duit & Treagust, 2003). John and Starauschek (2021) postulate that "Alltagsvorstellungen bei sich zu erkennen, deshalb als ein eigener Teilaspekt eines professionsbezogenen Fachwissens aufgefasst werden [sollte]. Dies erfordert die explizite

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Auseinandersetzung der Studierenden mit den eigenen Fehl- oder Alltagsvorstellungen“ (p. 25).[5]
However, it must be noted that the multiple-choice format does not allow for the diagnosis of coexisting normative and non-normative ideas. The format does not require recall and application of causally central features but merely recognition of familiar ideas (Opfer, Nehm & Ha, 2012). Eliciting explanations in open-ended questions would most likely reveal that significantly fewer PSTs can apply the concepts correctly.

RQ3: Levels of knowledge and acceptance of evolution among pre-service science teachers compared to pre-service non-science teachers
PSTs start their studies with significantly higher evolutionary knowledge than PNSTs, which suggests that the university of teacher education, where the study was conducted, attracts potentially suitable candidates as prospective science teachers. Compared to the PNSTs’ low knowledge scores, the PSTs’ increase in knowledge sum scores from T1 to T3 indicates that their knowledge gain can be attributed mainly to the biology courses. However, knowledge sum scores also increased slightly in PNSTs from T1 to T3. This could be partially attributed to memory effects caused by increased familiarity with the measurements, increased comfort with the tasks, or learning something about evolution in non-university contexts (Becker & Schmiedek, 2022). Multiple tests of varying difficulty should ideally be used to measure the same characteristics to minimise memory effects in longitudinal or quasi-longitudinal studies. A ceiling effect might have skewed the results for some items (e.g. adaptation and mutation). It is also possible that participation in the study increased interest in the topic and that PSTs and PNSTs independently engaged with the given problems. An indication of this possibility is the observation that after each testing session, the participants of both groups, PSTs and PNSTs, explicitly asked for the answers and explanations for the problems (which were not provided).
The acceptance of evolution is high for both PSTs and PNSTs, with no significant differences between them. This result is in line with high acceptance rates of evolution in similar cultural contexts (Kuschmierz et al., 2020b; Lanka et al., 2024).

Limitations
Even if the study allows deeper insight, it is important to mention that our study was not a proper intervention study. Although the CK and PCK courses were taught by the same individuals with the same materials over three consecutive years, the instruction of the evolution sequences was not designed as an intervention. The repeated use of the same instrument likely distorted the data (see remarks above regarding the memory effect). The knowledge test measures facets of evolutionary concepts and alternative conceptions, but the test format introduces potential bias and allows for limited nuanced responses. Qualitative data would provide a deeper understanding of alternative conceptions, including adaptation, variation, heredity of phenotype changes, tree reading, speciation, and any missing conceptions. Lastly, the sample size of the longitudinal cohort was very small, thus limiting the statistical power compared to a large-scale cross-sectional study.

Implications
Our study provides important insights for biology lecturers in teacher education. Despite around 68 lessons (90-minutes) in CK and PCK in biology, the PSTs’ knowledge of evolution remains moderate, and a range of alternative conceptions persist. This implies that teacher education programs should consider restructuring their curriculum to give evolution a more prominent and integrated role. A greater focus on specific school knowledge should already be emphasised in the CK course to make content more relevant and contextualised for the PSTs’ future professional role. The chosen forms and contexts of learning should enable PSTs to recognize and address their alternative conceptions. Greater coherence should be established between CK and PCK courses.
The persistent alternative conceptions identified in this study could be further examined using qualitative methods to permit more effective teaching. Ad-

[5] Recognising everyday conceptions in oneself should therefore be seen as a distinct aspect of CK. This requires students’ explicit engagement with their own misconceptions and everyday conceptions (translation by the authors).

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ditionally, it would be valuable to investigate the importance PSTs attribute to evolution education and how well prepared they feel to teach evolution. To investigate how the learning process regarding evolution knowledge could be specifically promoted, it would be interesting to conduct a real intervention study, comparing traditional lecture-based instruction with a solid profession-oriented subject-specific education based on the MER. Moreover, our study only examined students' evolution knowledge at the beginning, during, and after their studies. Empirical findings indicate that threshold concepts (Tibell & Harms, 2017) and an understanding of the nature of science (Graf & Soran, 2010; Nehm & Schonfeld, 2007) play a significant role in developing evolution-related concepts. A follow-up study should investigate the understanding of the nature of science to make targeted adjustments in teacher education.

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Conflicts of Interest
The authors declare no conflict of interest.

Data Availability Statement
The data supporting this study's findings are available from the corresponding author upon reasonable request.

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Compliance with Ethical Standards
The participation was voluntary and anonymous. All participants were informed about the study's objectives and the use of the data. No harm resulted from non-participation. Since students participated voluntarily and chose to participate or not before the survey, we assumed implicit informed consent. Ethical guidelines as prescribed by the European Commission (2021), the German Research Foundation (2023) and the Office for Human Research Protections (2023) were followed during the planning and conducting of the study.

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Supplement

Section A: Knowledge About EVOlution instrument (KAEVO 2.0 without items B1-B6; Kuschmierz et al., 2020a) with additional items to measure alternative conceptions. A12 self-developed, A13-A17 from the Biological Evolution Literacy Survey (BEL; Yates, 2011). Percentage of responses for PSTs (longitudinal cohort) included.

Section B: Attitudes Towards EVOlution instrument (ATEVO-EG; Beniermann, 2019]) with additional items. C5 and C6 from the Inventory of Student Evolution Acceptance instrument (I-SEA; Nadelson & Southerland, 2012); C7 and C9 from the Generalized Acceptance of EvolutioN Evaluation (GAENE 2.0; Smith, Snyder & Devereaux, 2016).

***Section C*:** German version of the questionnaire

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Section A: Knowledge items with percentage of responses for PSTs at T1 and T3

For each knowledge item, the percentage of PSTs who selected each answer option at the testing times T1 and T3 is provided in brackets next to the options (longitudinal cohort, *n* = 32). If none of the participants chose a particular answer option, that option is left blank. The correct answer option is indicated in **bold** for clarity.

Preliminary information for the survey

Please read the informational texts and answer options carefully. Then, select the answer that you believe is correct from a scientific perspective. Important: only mark one answer per question!

A1 Venus flytraps are carnivorous plants. They occur in soil with only few nutrients. With the help of specifically adapted trapping leaves, they can also feed on insects by catching them. Therefore, the supply of nutrients is enhanced, and the plants can grow. How did the leaves evolve over time?

a. Some Venus flytraps recognised the nutrient deficiencies and transformed their leaves into trapping leaves in response. As a result, they could also feed on insects and survived with greater ease. T1 : 12.5%

b. Because of the nutrient deficiency, the Venus flytraps automatically developed trapping leaves. Hence, they had a survival advantage.

c. Nature has adapted the Venus flytraps to the nutrient-deficient soil so they can grow better.

d. Some Venus flytraps randomly had trapping leaves and additionally were able to consume insects on the nutrient-deficient soil. Therefore, more Venus flytraps with trapping leaves were able to survive and reproduce. T1 = 84.4%; T3 = 100%

e. In order to grow better, the Venus flytraps adapted to the nutrient-deficient soil. T1 = 3.1%

f. I do not know.

A2 Biologists often use the term «fitness» when speaking of evolution. Below are descriptions of four male lions.

Which lion would you consider the fittest? Please check in the table below.

Name	**George**	**Ben**	**Spot**	**John**	I do not know.
Length with tail	3 m	2.55 m	2.7 m	**2.7 m**	
Weight	173 kg	160 kg	162 kg	**160 kg**	
Number of cubs fathered	19	25	20	**20**	
Age of death	13 years	16 years	12 years	**9 years**	
Number of cubs surviving to adulthood	13	14	14	**19**	
Comments	George was very large and very healthy. The strongest lion.	Ben had the largest number of females in his harem.	When the area that Spot lived in was destroyed by fire, he was able to move his pride to a new area and change his feeding habits.	**John was killed by an infection resulting from a cut in his foot**	
The «fittest» lion is:	T1 = 6.3%	T1 = 46.9% T3 = 46.9%	T1 = 21.9% T3 = 9.4%	**T1 = 25% T3 = 43.8%**	**T1 = 6.3%**

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A3 When chasing their prey, cheetahs are able to run up to 104 km/h. In comparison, their ancestors were only able to reach a speed of 32 km/h.
How did the ability to run fast evolve in cheetahs?

a. In order to catch more prey, the cheetahs adapted their speed. — T1 = 3.1%

b. Some cheetahs were randomly faster and were able to catch more prey. Therefore, more of the faster cheetahs were able to survive and reproduce. — **T1 = 93.8%; T3 = 100%**

c. Nature has adapted the running speed of cheetahs so they can catch more prey.

d. Some ancestors of the cheetahs recognised that they could not catch enough prey. Hence, they increased their running speed. As a result, they were able to catch more prey and survive with greater ease.

e. Because they were able to catch more prey this way, the running speed increased automatically. Hence, they had a survival advantage.

f. Some ancestors of the cheetahs recognised that they could not catch enough prey. Hence, they trained in order to run faster.

g. I do not know. — T1 = 3.1%

A4 A group of lizards lives in a valley. Due to an earthquake, a deep and broad canyon is created. From then on, the canyon separates the lizards' habitat (living space). Consequently, the group of lizards is split into two smaller groups. After several thousand years, the canyon closes at one point, and lizards from both of the separated groups share a habitat (living space) once again.
How would the groups have evolved?

a. Both groups would have evolved in the same direction - one could not distinguish them.

b. A different evolution of both groups would only be possible if the two separated habitats (living spaces) were very different. — T1 = 46.9%; T3 = 28.1%

c. It cannot be predicted how the groups would have evolved. — **T1 = 28.1%; T3 = 59.4%**

d. Neither group would have evolved; everything would be just as before.

e. Both groups would have evolved in different directions - one could easily distinguish the two groups from each other. — T1 = 25%; T3 = 12.5%

f. I do not know.

A5 The shells of banded snails can have different colours. Snails with darker shells frequently live in forests, where the ground tends to be brown. Lighter-coloured snails more frequently live in meadows, where this colour is a better camouflage. Therefore, they can hide better from their enemies, the song thrushes.
How did this happen?

a. Since this was a better way to hide from the song thrushes, the light-coloured snails changed their former colour automatically. Hence, they had a survival advantage.

b. Nature has adapted the light-coloured snails to their habitat (meadows), so they are better camouflaged.

c. Some dark-coloured snails recognised that they needed to change their colour to have better camouflage. Therefore, they ate more light-coloured food in order to change their shells into a lighter colour.

d. To have better camouflage, the dark-coloured snails adapted to the habitat (meadow).

e. Some dark-coloured snails recognised that they had to change their colour to have better camouflage. Therefore, they changed their colour. As a result, they were eaten less frequently and were able to survive more easily.

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f. Some snails randomly had a lighter colour and were not spotted so easily (in the meadow) by the song thrushes. Therefore, more light-coloured snails were able to survive and reproduce. **T1 = 100%; T3 = 100%**

g. I do not know.

A6 There is little water in deserts. Throughout the day, it is hot and the sun shines with great intensity. For many plants, this is bad because they lose a lot of water due to the heat and the dry air. From cacti with leaves, first cacti with smaller leaves and then leafless cacti with thorns evolved. How did this happen?

a. In order to lose less water, the cacti adapted to the desert habitat.

b. Some cacti with leaves recognised that they were losing too much water. Hence, they shrank their leaves. As a result, they were losing less water and were able to survive more easily. T1 = 3.1%

c. Some cacti randomly had smaller leaves and were losing less water in the desert. Consequently, more cacti with smaller leaves were able to survive and reproduce. **T1 = 96.9%; T3 = 100%**

d. The cacti had smaller leaves automatically because they were losing less water in the desert this way. Hence, they had a survival advantage.

e. Nature has adapted the cacti to their desert habitat, so they lose less water.

f. I do not know.

A7 At the end of the 19th century, the zoologist August Weismann conducted the following experiment: He completely cut off the tail of mice in order to determine which consequences this might have on the mice‘s direct offspring.
What would the mice‘s offspring look like?

a. On average, their tails would be slightly shorter than their parents’. T1 = 3.1%; T3 = 3.1%

b. They would still have a tail, which would not be used anymore.

c. They would have no tail.

d. Cutting off the tails would not have an effect on the offspring’s tail length. **T1 = 96.9%; T3 = 93.8%**

e. I do not know. T3 = 3.1%

A8 Assuming that Mr. Weismann would also have cut off the tails of the offspring and their descendants, etc., for a total of 20 generations.
What would the mice of the 21st generation look like?

a. On average, their tails would be significantly shorter than their parents’ tails from the first generation. T1 = 18.8%; T3 = 6.3%

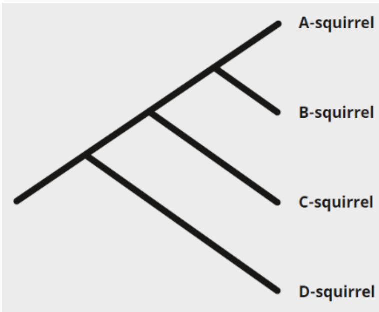
b. They would still have a tail, which would not be used anymore. T1 = 21.9%; T3 = 18.8%

c. They would have no tail. T3 = 3.1%

d. Cutting off the tails would not have an effect on the offspring’s tail length. **T1 = 53.1%; T3 = 65.6%**

e. I do not know. T1 = 6.3%; T3 = 6.3%

A9 The figure (on the right) shows the evolution of fictional squirrel species.



A9.1 Tick the time arrow, which represents the real timeline.

↑	↓	→	←	↗	↙	↘	↖	I do not know.
☐	☐	☐	☐	☐	☐	☐	☐	☐
a	b	**c**	d	e	f	g	h	i

a T1 = 3.1%; T3= 3.1%
b T1 = 12.5%; T3 = 25%
c T1 =15.6%; T3 = 21.9%
d T1 = 6.3%
e T1 = 15.6%; T3 = 5.6%
f T1 = 34.4%; T3 = 21.9%
g T1 = 3.1%, T3 = 6.3%
h -
i T1 = 9.4%; T3 =6.3%

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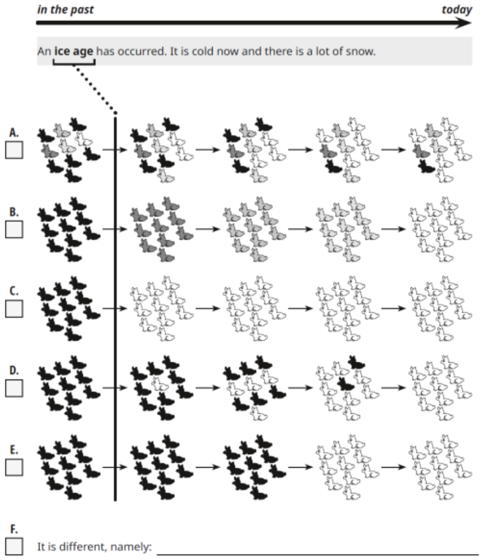
A9.2 The figure shows a family tree of the relationship between four different squirrel species. Which of the following statements corresponds to the family tree?
C-squirrels are …

a. … most closely related to A-squirrels. — a T1 = 15.6%; T3 = 31.3%
b. … most closely related to B-squirrels. — b T1 = 9.4%
c. … most closely related to D-squirrels. — c T1 = 3.1%; T3 = 3.1%
d. … as closely related to A as to B-squirrels. — **d T1 = 12.5%; T3 = 9.4%**
e. … as closely related to B as to D-squirrels. — e T1 = 40.6%; T3 = 43.8%
f. … as closely related to A as to B and D-squirrels. — f T1 = 12.5%; T3 = 9.4%
g. I do not know. — g T1 = 6.3%; T3 = 3.1%

A10 Which of the illustrated long-term developments after the ice age is the most likely?



a T1 = 65.6%; T3= 87.5%
b T1 = 3.1%
c -
d T1 = 31.3%; T3 = 9.4%
e -
f T3 = 3.1%

A11 Which of the species is the closest relative to the chimpanzee? — T1 = 12.5%; T3 = 3.1%
a. gorilla — **T1 = 46.9%; T3 = 46.9%**
b. human — T1 = 12.5%; T3 = 6.3%
c. orang-utan — T1 = 3.1%; T3 = 12.5 %
d. baboon — T1 = 25%; T3 = 31.3%
e. I do not know.

A12-A17[6] The following statements are either true or false. Please decide on only one answer per statement (answer options: true / false / I do not know).

For the following items only the **correct responses** are given.

A12 Evolution explains the origin of life. — **T1 = 59.4%; T3 = 71.9%**

A14 Evolution cannot cause an organism's traits to change within its lifetime. — **T1 = 78.1%; T3 = 84.4%**

A15 'Survival of the fittest' basically means that 'only the strong survive.' — **T1 = 71.9%; T3 = 84.4%**

A16 According to the theory of evolution, individual organisms adapt to their environments. — **T1 = 50%; T3 = 84.4%**

A17 Evolution always results in improvement. — **T1 = 81.3%; T3 = 90.6%**

[6] Item A13 was excluded after CFA (wording: «Evolution is a totally random process».)

B7.1-B7.6 The following statements are either true or false. Please decide on only one answer per statement (answer options: true / false / I do not know).

B7.1	Mutations happen randomly.	**T1 = 90.6%; T3 = 100%**
B7.2	Mutations are usually controlled by the plants and animals themselves.	**T1 = 96.9%; T3 = 100%**
B7.3	Mutations are always negative.	**T1 = 100%; T3 = 100%**
B7.4	Mutations can be neutral in their effects.	**T1 = 100%; T3 = 97%**
B7.5	Under normal conditions, mutations do not occur in living beings.	**T1 = 96.9%; T3 = 93.8%**
B7.6	Mutations can take place independently of environmental changes.	**T1 = 96.9%; T3 = 96.9%**

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Section B: Acceptance items

C1-C9[7] Please indicate to what extent you agree with the following statements about evolution (answer options: agree / somewhat agree / undecided / somewhat disagree / disagree).

In my personal opinion, …

C1 ... the entire world of living organisms has developed over billions of years.

C2 ... the adaptations of living organisms to their environments can be explained by the theory of evolution.

C3 ... the animals and plants we know today have developed from earlier species.

C4 ... the modern living organisms are the result of evolutionary processes which occurred over billions of years.

C5 … there are a large number of fossils found all around the world that support the idea that organisms change over time.

C6 … there is little or no observable evidence to support the theory that describes how one species of organism evolves from another ancestral form.

C7 … the theory of evolution applies to all plants and animals, including humans.

C9 … evolution is a good explanation of how humans first emerged on the earth.

[7] C8 was excluded after CFA (wording: «… nothing in biology makes sense without evolution»).

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Section C: German version of the questionnaire

Bitte lesen Sie sich die Informationstexte und die Antwortmöglichkeiten aufmerksam durch. Kreuzen Sie danach die Antwort an, die Ihrer Meinung nach aus Sicht der Wissenschaft richtig ist. Wichtig: Nur ein Kreuz pro Aufgabe setzen!

A1 Venusfliegenfallen sind fleischfressende Pflanzen. Sie kommen auf Böden mit nur wenigen Nährstoffen vor. Mit Hilfe ihrer speziell umgebildeten Fangblätter können sie sich zusätzlich von Insekten ernähren. Dadurch ist die Nährstoffversorgung verbessert und die Pflanzen können wachsen. Wie haben sich die Fangblätter im Laufe der Zeit entwickelt?

a. Einige Venusfliegenfallen bemerkten den Nährstoffmangel und bildeten daraufhin die Blätter zu Fangblättern um. Dadurch konnten sie sich zusätzlich von Insekten ernähren und besser überleben.
b. Die Venusfliegenfallen bekamen aufgrund des Nährstoffmangels automatisch Fangblätter. Somit hatten sie einen Überlebensvorteil.
c. Die Natur hat die Venusfliegenfallen an den nährstoffarmen Boden angepasst, damit sie besser wachsen können.
d. Einige Venusfliegenfallen hatten zufällig so etwas wie Fangblätter und konnten sich auf dem nährstoffarmen Boden zusätzlich von Insekten ernähren. Deshalb konnten mehr Venusfliegenfallen mit Fangblättern überleben und sich fortpflanzen.
e. Die Venusfliegenfallen haben sich an den nährstoffarmen Boden angepasst, damit sie besser wachsen können.
f. Ich weiss es nicht.

A2 Biolog:innen verwenden oft den Begriff „Fitness“, wenn sie von Evolution sprechen. In der folgenden Tabelle werden Ihnen vier männliche Löwen vorgestellt.
Welcher Löwe ist der fitteste? Bitte unten in der Tabelle ankreuzen.

Name	**George**	**Ben**	**Spot**	**John**	Ich weiss es nicht.
Länge mit Schwanz	3 m	2.55 m	2.7 m	2.7 m	
Gewicht	173 kg	160 kg	162 kg	160 kg	
Anzahl der Nachkommen	19	25	20	20	
Todesalter	13 Jahre	16 Jahre	12 Jahre	9 Jahre	
Anzahl der Nachkommen, die erwachsen geworden sind.	13	14	14	19	
Kommentare	George war sehr gross, sehr gesund, der stärkste Löwe.	Ben hatte die grösste Anzahl an Weibchen in seinem Harem.	Als die Gegend, in der Spot lebte, durch Feuer zerstört wurde, war er in der Lage, in eine neue Umgebung zu ziehen und seine Fressgewohnheiten zu ändern.	John starb an einer Infektion, die durch einen Schnitt an seinem Fuss ausgelöst wurde.	
Der fitteste Löwe ist					

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A3 Geparde können bis zu 104 km/h laufen, wenn sie ihre Beute jagen. Ihre Vorfahren konnten dagegen nur eine Geschwindigkeit von 32 km/h erreichen.
Wie hat sich die schnellere Laufgeschwindigkeit entwickelt?
a. Die Geparde passten ihre Geschwindigkeit an, damit sie mehr Beute fangen können.
b. Einige Geparde waren zufällig schneller und konnten mehr Beute fangen. Deshalb konnten mehr schnelle Geparden überleben und sich fortpflanzen.
c. Die Natur hat die Laufgeschwindigkeit der Geparde angepasst, damit sie mehr Beute fangen können.
d. Einige Vorfahren der Geparde merkten, dass sie nicht genug Beute fangen konnten. Daher wurden sie schneller und sie konnten sie mehr Beute fangen und besser überleben.
e. Die Laufgeschwindigkeit erhöhte sich automatisch, weil sie so mehr Beute fangen konnten. Somit hatten sie einen Überlebensvorteil.
f. Einige Vorfahren der Geparde merkten, dass sie nicht genug Beute fangen konnten. Daher trainierten sie und wurden immer schneller.
g. Ich weiss nicht.

A4 In einem Tal lebt eine Gruppe von Eidechsen. In Folge eines Erdbebens entsteht eine tiefe und breite Schlucht, die den Lebensraum der Eidechsen fortan trennt. Dadurch wird auch die Gruppe in zwei kleinere Gruppen geteilt. Nach vielen 1000 Jahren schliesst sich die Schlucht an einer Stelle wieder und die Eidechsen aus den beiden getrennten Gruppen teilen wieder einen gemeinsamen Lebensraum. Wie würden sich die Gruppen entwickelt haben?
a. Die beiden Gruppen hätten sich in die gleiche Richtung entwickelt - man könnte sie nicht voneinander unterscheiden.
b. Eine unterschiedliche Entwicklung der beiden Gruppen wäre nur möglich, wenn die beiden getrennten Lebensräume sehr unterschiedlich waren.
c. Es ist nicht vorhersehbar, auf welche Weise sich die Gruppen entwickelt hätten.
d. Die beiden Gruppen hätten sich auf keinen Fall in irgendeiner Art und Weise entwickelt, alles ist wie vorher.
e. Die beiden Gruppen hätten sich in verschiedene Richtungen entwickelt, man könnte sie gut voneinander unterscheiden.
f. Ich weiss nicht.

A5 Die Häuser von Bänderschnecken können unterschiedliche Farben haben. Im Wald, wo der Untergrund eher braun ist, leben häufiger Schnecken mit dunklen Häusern. Schnecken, die hell sind, leben vermehrt auf Wiesen, wo ihre Farbe eine bessere Tarnung darstellt. So sind sie vor ihren Feinden, den Singdrosseln, besser versteckt.
Wie kam es dazu?
a. Die hellen Schnecken änderten ihre vorherige Farbe automatisch, weil sie so besser vor den Singdrosseln getarnt waren. Somit hatten sie einen Überlebensvorteil.
b. Die Natur hat die hellen Schnecken an den Lebensraum der Wiese angepasst, damit sie besser getarnt sind.
c. Einige dunkle Schnecken erkannten, dass sie die Farbe ändern mussten, damit sie besser getarnt waren. Daher frassen sie mehr helle Nahrung, damit sich ihr Haus hell färbt.
d. Die vorher dunklen Schnecken haben sich an den Lebensraum der Wiese angepasst, damit sie besser getarnt sind.
e. Einige dunkle Schnecken erkannten, dass sie die Farbe ändern mussten, damit sie besser getarnt waren. Daher veränderten sie allmählich ihre Farbe. Dadurch wurden sie seltener gefressen und konnten besser überleben.
f. Einige Schnecken waren zufällig heller und konnten auf der Wiese von den Singdrosseln nicht so gut gesehen werden. Deshalb konnten mehr helle Schnecken überleben und sich fortpflanzen.
g. Ich weiss nicht.

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A6 In Wüsten gibt es wenig Wasser. Tagsüber ist es heiss und die Sonne scheint stark. Das ist für viele Pflanzen schlecht, denn aufgrund der Hitze und der trockenen Luft verlieren sie über die Blätter sehr viel Wasser. Aus Kakteen mit Blättern sind erst Kakteen mit kleineren Blättern und dann blattlose Kakteen mit Dornen entstanden.
Wie kam es dazu?

a. Die Kakteen haben sich an den Lebensraum der Wüste angepasst, damit sie weniger Wasser verlieren.
b. Einige Kakteen mit Blättern merkten, dass sie zu viel Wasser verloren. Deshalb verkleinerten sie nach und nach ihre Blätter. Dadurch verloren sie weniger Wasser und konnten besser überleben.
c. Einige Kakteen hatten zufällig kleinere Blätter und verloren in der Wüste weniger Wasser. Deshalb konnten mehr Kakteen mit kleinen Blättern überleben und sich fortpflanzen.
d. Die Kakteen hatten automatisch kleinere Blätter, weil sie dadurch weniger Wasser in der Wüste verloren. Somit hatten sie einen Überlebensvorteil.
e. Die Natur hat die Kakteen an den Lebensraum der Wüste angepasst, damit sie weniger Wasser verlieren.
f. Ich weiss nicht.

A7 Ende des 19. Jahrhunderts führte der Zoologe August Weismann folgendes Experiment durch: Er schnitt Mäusen die Schwänze komplett ab, um festzustellen, welche Auswirkungen dies auf die direkten Nachkommen haben würde.
Wie müssten die Kinder dieser Mäuse aussehen?

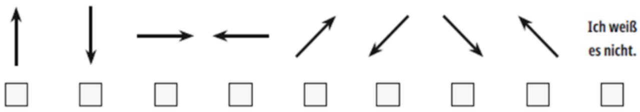
a. Ihre Schwänze wären im Durchschnitt etwas kürzer als die Schwänze der Eltern.
b. Sie hätten noch einen Schwanz, der aber nicht mehr benutzt wird.
c. Sie hätten gar keinen Schwanz.
d. Das Abschneiden hätte keinen Effekt auf die Schwanzlänge der Kinder.
e. Ich weiss nicht.

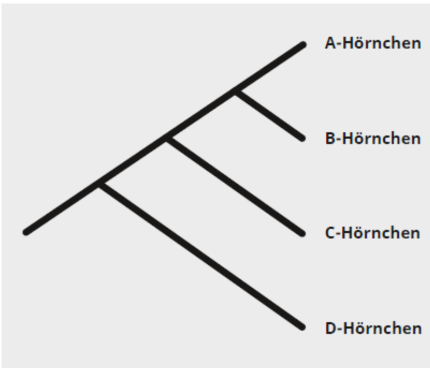
A8 Nehmen wir an, Herr Weismann hätte auch den Nachkommen wieder die Schwänze abgeschnitten und deren Nachkommen auch usw., das ganze insgesamt 20 Generationen lang.
Wie müssten die Mäuse der 21. Generation aussehen?

a. Ihre Schwänze wären im Durchschnitt deutlich kürzer als die Schwänze der Eltern aus der ersten Generation.
b. Sie hätten noch einen Schwanz, der aber nicht mehr benutzt wird.
c. Sie hätten gar keinen Schwanz.
d. Das Abschneiden hätte keinen Effekt auf die Schwanzlänge der Kinder.
e. Ich weiss nicht.

A9

A9.1 Die Abbildung stellt die zeitliche Entwicklung fiktiver Hörnchenarten dar. Kreuzen Sie den Zeitpfeil unten an, der die reale Zeitachse repräsentiert.





A9.2 Die Abbildung zeigt einen Stammbaum mit der Verwandtschaft zwischen vier verschiedenen Hörnchenarten. Welche der folgenden Aussagen entspricht dem Stammbaum?
C-Hörnchen sind mit …

a. … A-Hörnchen am nächsten verwandt.

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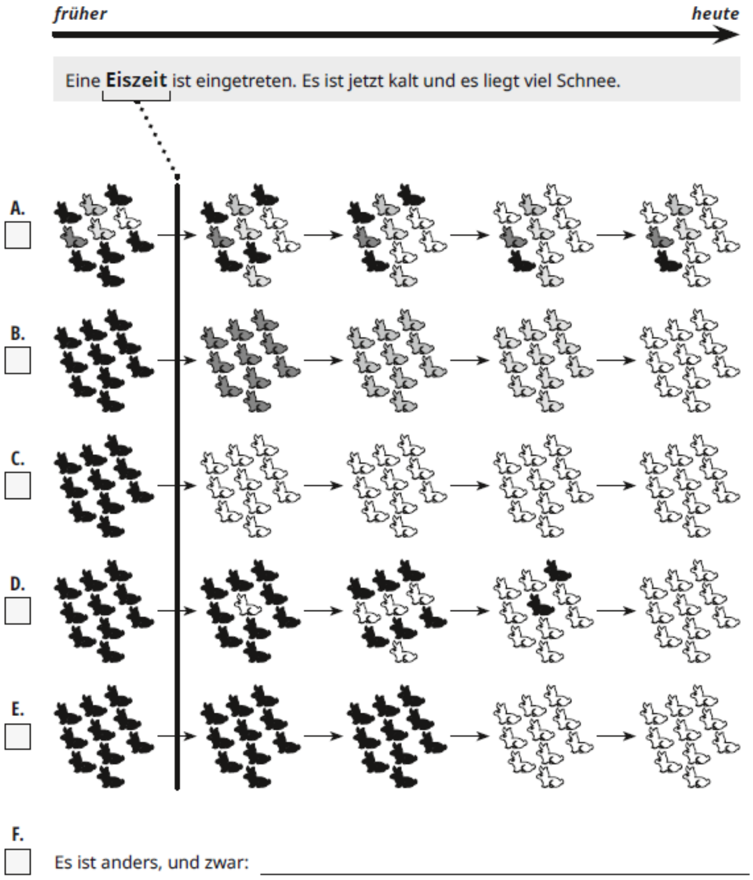
b. … B-Hörnchen am nächsten verwandt.
c. … D-Hörnchen am nächsten verwandt.
d. … A-Hörnchen und B-Hörnchen gleich nah verwandt.
e. … B-Hörnchen und D-Hörnchen gleich nah verwandt.
f. … A-Hörnchen, B-Hörnchen und D-Hörnchen gleich nah verwandt.
g. Ich weiss nicht.

A10 Welche der dargestellten langfristigen Entwicklungen ist nach dem Eintreten der Eiszeit die wahrscheinlichste?



A11 Welche der unten aufgeführten Arten ist am nächsten mit dem Schimpansen verwandt?
a. Gorilla
b. Mensch
c. Orang-Utan
d. Pavian
e. Ich weiss es nicht.

A12-A17[8] Kreuzen Sie bitte an, ob Sie die Aussagen als wahr oder falsch erachten (Auswahlmöglichkeiten wahr / falsch / Ich weiss nicht):
A12 Die Evolutionstheorie erklärt die Entstehung des Lebens.
A14 Evolution bewirkt nicht, dass sich die Merkmale eines Individuums während seines Lebens ändern.
A15 „Survival of the fittest“ bedeutet, dass die Stärksten überleben.
A16 Laut der Evolutionstheorie passen sich Individuen an ihre Umwelt an.
A17 Evolution führt immer zu einer Verbesserung.

[8] Item A13 wurde nach der CFA ausgeschlossen (Wortlaut: „Evolution ist ein völlig zufälliger Prozess“).

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B7.1-B7.6 Kreuzen Sie bitte an, ob Sie die Aussagen als wahr oder falsch erachten (Auswahlmöglichkeiten wahr / falsch / Ich weiss nicht):

B7.1 Mutationen ereignen sich zufällig.

B7.2 Mutationen werden normalerweise von den Tieren und Pflanzen selbst gesteuert.

B7.3 Mutationen sind immer negativ.

B7.4 Mutationen können in ihren Auswirkungen neutral sein.

B7.5 Mutationen kommen bei Lebewesen unter normalen Bedingungen nicht vor.

B7.6 Mutationen können unabhängig von Umweltveränderungen stattfinden.

C1-C9[9] Bitte geben Sie an, inwieweit Sie den folgenden Aussagen zur Evolution zustimmen (Auswahlmöglichkeiten: Ich stimme zu / Ich stimme eher zu / unentschieden / Ich stimme eher nicht zu / Ich stimme nicht zu).

Ich persönlich bin der Meinung, dass…

C1 ... sich die ganze Welt der Lebewesen im Laufe von Milliarden Jahren entwickelt hat.

C2 ... die Anpassungen der Lebewesen an ihre Lebensräume mit der Evolutionstheorie erklärt werden können.

C3 ... die Tiere und Pflanzen, die wir heute kennen, sich aus früheren Arten entwickelt haben.

C4 ... die heutigen Lebewesen das Ergebnis evolutionärer Prozesse sind, die über Milliarden von Jahren stattgefunden haben.

C5 … dass es auf der ganzen Welt eine grosse Zahl an Fossilfunden gibt, die das Konzept stützen, dass Organismen über lange Zeiträume zu neuen Arten evolvieren.

C6 … dass es kaum oder keine Beweise für die Theorie gibt, die beschreibt, wie eine Art aus einer anderen Art evolviert ist.

C7 … dass die Evolutionstheorie für alle Pflanzen und Tiere, einschliesslich des Menschen, zutrifft.

C9 …. dass Evolution eine gute Erklärung dafür ist, wie sich Menschen auf der Erde entwickelt haben.

[9] D8 wurde nach der CFA ausgeschlossen (Wortlaut: „… dass nichts in der Biologie Sinn macht ohne Evolution“).

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