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Fit to teach evolution? Pre- and in-service teachers' knowledge and acceptance of evolution

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ABSTRACT

Students need a clear grasp of evolution to understand biology and the world's current environmental crises. Science teachers are essential in fostering evolution knowledge in their students. Numerous European studies have shown that science teachers possess a broad spectrum of alternative conceptions of evolution, and their acceptance of evolution varies. School curricula increasingly include key concepts of evolution from early grades on. However, studies are limited that examine differences in understandings and acceptance of evolution in different country contexts. This study investigated the knowledge and acceptance of evolution in Swiss science teachers: 1352 pre- and in-service year K-9 teachers were surveyed using two established questionnaires (KAEVO 2.0 and ATEVO). The results showed that as a group, pre-service kindergarten and primary school teachers had a poor grasp of evolution, while pre-and in-service lower secondary school teachers had moderate knowledge. However, we found that knowledge of evolution varied a great deal across the groups and that teachers in all groups had a range of alternative conceptions of evolution. Acceptance of evolution was high for all groups. Given that currently, prospective teachers on some educational tracks do not study evolution at all, our findings have important implications for teacher education in the sciences.

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Evolution education; knowledge of evolution; alternative conceptions; acceptance of evolution; Switzerland

Background

Increasingly, teachers have to address controversial issues in science lessons, such as the climate crisis, the impact of consumer decisions on biodiversity, the use of antibiotics in human medicine and industrial farming, and how to deal with fake news (Hodson, 2003). Because understanding evolution is key to understanding these issues and making

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informed decisions about them, evolution must be taught in school (Harms & Reiss, 2019; Kampourakis, 2022).

Evolution is challenging to teach (e.g. Sickel & Friedrichsen, 2013; Ziadie & Andrews, 2018) and challenging for students to learn because students have naïve and often counterintuitive conceptions about evolutionary concepts (e.g. Coley & Tanner, 2012; Gregory, 2009; Nehm & Reilly, 2007). Effective instruction requires good teacher knowledge (Baumert et al., 2010; Hill et al., 2005; Sadler et al., 2013), which can come from school, teacher education, professional development, or teaching experience (Friedrichsen et al., 2009). There is evidence that a teacher's knowledge of a subject influences content choice and delivery (Gess-Newsome & Lederman, 1995). A teacher's value orientations, such as the value of scientific knowledge for society or acceptance of key scientific concepts and theories, also influence how they approach teaching specific subject matter (Trigwell et al., 1999). Hence, the weighting of evolution in the classroom is related to teachers' knowledge of evolution but also their acceptance of evolution (Großschedl et al., 2014; Nadelson & Nadelson, 2010; Nehm & Schonfeld, 2007). Many studies have measured science teachers' acceptance of evolution (see reviews, Kuschmierz et al., 2020b; Sickel & Friedrichsen, 2013). However, the relationship between knowledge and acceptance of evolution has not been clarified (Fiedler et al., 2024).

There are reasonable doubts that science teachers[1] of all tracks are sufficiently qualified during their studies at universities of teacher education to teach evolutionary concepts. Lagler and Wilhelm (2013) found a poor fit between biology courses on teacher training courses at university and curriculum-relevant content knowledge for Swiss science teachers. Also, depending on the educational track they follow, some prospective teachers do not study evolution at tertiary level. This could result in teachers passing their alternative conceptions of the subject on to their students (Yates & Marek, 2014). To date, there is no information available on how well Swiss teachers understand or how much they accept evolution.

Definition of terms: knowledge, understanding, and acceptance

The terms knowledge, understanding, and acceptance as they relate to the teaching of evolution have been operationalised by researchers in a variety of ways (Smith & Siegel, 2016; Southerland et al., 2001). In this article, knowledge is conceptualised following Shulman's (1986) category of subject matter content knowledge (CK): 'the amount and organisation of knowledge per se in the mind of the teacher' (p. 9). CK is distinct from pedagogical content knowledge (PCK; instructional strategies, common preconceptions) and pedagogical knowledge (PK) (Shulman, 1986). Here, knowledge of evolution is defined as the extent to which an individual agrees on scientific positions about evolutionary concepts and processes rather than alternative conceptions (Beniermann, 2019). As summarised by Smith and Siegel (2016), a 'student gains knowledge (via instruction, self-study, etc.) upon which she can build understanding (p. 486)'.

Beniermann et al. (2023) define acceptance of evolution as having a positive attitude toward evolution, where the attitude is a personal opinion about or assessment of a topic or fact. Acceptance of evolution is operationalised as the extent to which a person agrees that evolutionary processes explain the origin and diversity of species (Barnes et al., 2017). Smith and Siegel (2016) clarify the relationship between knowledge, understanding, and acceptance: 'Knowledge promotes/should lead to understanding. Understanding promotes acceptance […]' (p. 487); however, they stress that understanding may or may not lead to acceptance. A lack of acceptance may negatively affect knowledge and understanding (Bernhard et al., 2023).

Conceptualisation of the knowledge of evolution

The theory of evolution is central to the understanding of biology. It can serve as a unifying explanatory framework for what appear to be disparate phenomena (Kattmann, 1995). Evolution refers to the natural processes by which species evolve or go extinct over time, (long-term perspective) and populations adapt to environmental changes (short-term perspective). Evolutionary theory explains common ancestry, biological diversity, and evolutionary change (Kampourakis, 2020). According to Mayr (1982) and Gregory (2009), the three key principles that explain evolutionary change by natural selection are variation and its sources, heredity of certain traits, and differential reproduction and survival of offspring with heritable traits. The concepts of kinship and common ancestry, variability of organisms, adaptation and natural selection, variation, heredity, and genetic drift are key to understanding evolution (Lanka et al., 2023).

However, evolutionary principles are counterintuitive, and cognitive biases, as well as language, hinder the acquisition of scientifically correct concepts (e.g. Gregory, 2009; Harms & Reiss, 2019). Cognitive biases most likely arise from early childhood experiences and dispositions and result in informal theories that serve to make sense of the world (Bruckermann et al., 2021; Kelemen, 2019). Alternative conceptions may be classified via content areas (e.g. adaptation and natural selection, heredity) or their underlying causes, such as teleology, anthropomorphism, or Lamarckism. There can also be confusion about terms such as fitness or adaptation that have specific, different, meanings in everyday usage (Gregory, 2009). Missing conceptions (von Aufschnaiter & Rogge, 2010) may also be responsible for a lack of understanding. Finally, to understand evolution students must be familiar with threshold concepts such as randomness, probability, and temporal and spatial scales (Tibell & Harms, 2017).

Current state of research

Teachers' knowledge of evolution in Europe

There have been more than two dozen studies conducted on European pre-service (PST) and in-service (IST) science teachers' knowledge of evolution published since 2010 (for a review of studies conducted between 2010 and 2020 see Kuschmierz et al., 2020b). The results of these studies are only comparable to a limited extent since they employed different test instruments or modified versions thereof. Kuschmierz et al. (2020b) recommended a system to enable comparability between studies which employed different instruments by assigning percentage-oriented score categories used in the Knowledge About EVOlution instrument (KAEVO 2.0; Kuschmierz et al., 2020a) to other instruments. The resulting progression of knowledge categories aligned with the percentage of correct answers (high ≥90%, rather high ≥75%, moderate ≥60%, low

≥45%, very low ≤44%). These score categories are used in the following to interpret results of previous studies.

The results of four more recent studies into PST and IST knowledge of evolution (Aptyka & Großschedl, 2022; Fiedler et al., 2024; Fischer et al., 2021; Hartelt et al., 2022) can also be translated using this system and compared to those discussed in Kuschmierz et al. (2020b). Overall, research shows that most PSTs and ISTs in Europe have a low to very low knowledge of evolution (Figure 1; see Supplement 1 for study details).

Some researchers have investigated the differences between student teacher training for different educational levels (e.g. primary, lower secondary, upper secondary). Großschedl et al. (2014, 2018) discovered that students training to teach primary (PST_{1-6}) and lower secondary school (PST_{7-9}) had a moderate knowledge of evolution, while those training for upper secondary school (PST_{10-12}) had rather high knowledge. Großschedl et al. (2018) suggest that group PST_{10-12} knew more about evolution because their study programme had more science learning opportunities. Athanasiou et al. (2016) reported a similar progression of knowledge of evolution in ISTs in Greece: in-service kindergarten teachers (IST_K) had very low knowledge; IST_{1-6} had low, and IST_{7-9} had moderate levels of knowledge respectively. Hartelt et al. (2022)

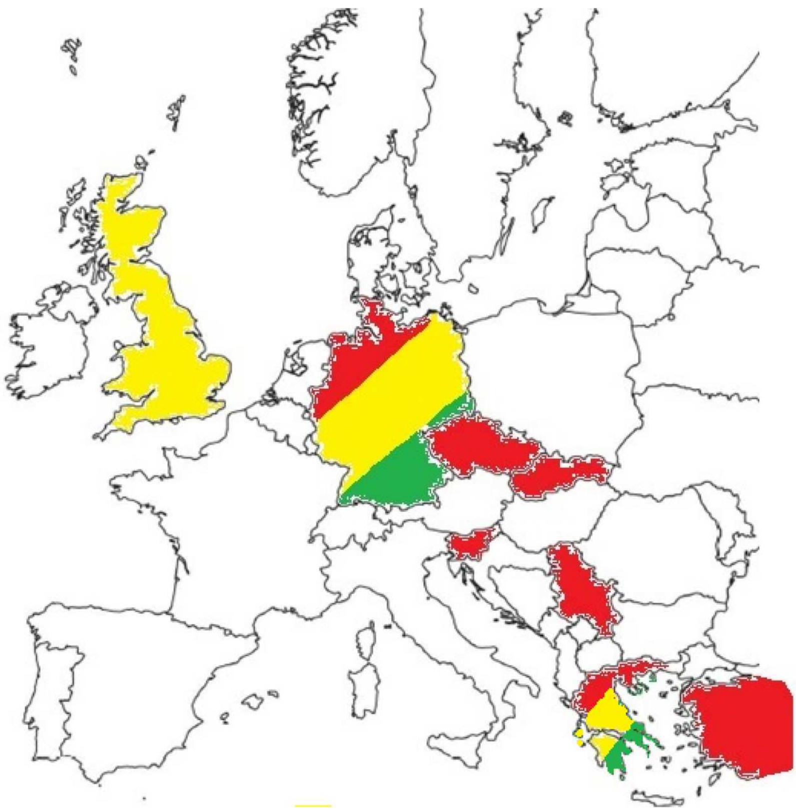

Figure 1. Categorical overview of European science teachers' knowledge of evolution as determined in studies from 2010 to 2023. Interpretation of the knowledge scores derived from different test instruments according to Kuschmierz et al. (2020b); categories of knowledge as rather high or high (green), moderate (yellow), and low or very low (red); for details on the studies see supplementary file 1.

studied German secondary school biology PSTs' and ISTs' knowledge of evolution and their ability to identify any alternate conceptions of evolution students had. About 60% of the items were answered correctly, on average. According to the scoring system (Table 2), ISTs had moderate knowledge, and PSTs had low knowledge of evolution. Participants with experience in teaching evolution had a significantly higher knowledge score than those without, and the ability to diagnose and deal with alternative conceptions correlated with the participants' knowledge.

Fischer et al. (2021) examined German biology upper secondary PSTs' CK and PCK of evolution. On average, 53% of the test items were answered correctly (interpretation: low knowledge). In a simulated classroom, virtual student answers were identified as scientifically correct or as alternative conceptions in around 90% of the answers. Being familiar with alternative conceptions students may have enables a teacher to ask questions that reveal them, thus facilitating interventions that promote student understanding. Nonetheless, the participants had problems diagnosing specific alternative conceptions (59% diagnostic rate; Fischer et al., 2021).

To our knowledge, to date no studies have been conducted on the knowledge of evolution of PSTs or ISTs in Switzerland.

Teachers' acceptance of evolution in Europe

As with knowledge of evolution, the acceptance of evolution by PSTs and ISTs has also been measured in more than two dozen European studies (Kuschmierz et al., 2020b). Issues with measuring acceptance have been highlighted by many researchers (see e.g. Barnes et al., 2019; Beniermann et al., 2023; Fiedler et al., 2024). Furthermore, once again, any comparison of the results of studies is complicated due to the use of different instruments or sections thereof, or different sampling methods. The Measure of Acceptance of the Theory of Evolution (MATE) developed by Rutledge and Warden (1999) established five score categories, ranging from very low to very high acceptance. Based on this scoring system Kuschmierz et al. (2020b) developed a system to compare the means of different acceptance instruments, like the category system created for the knowledge instruments. These score categories are used in the following to interpret results of previous studies. Overall, the acceptance of evolution among science teachers in Europe, apart from Turkey, is moderate to high (Figure 2; for details on the studies: Supplement 1).

Only a few studies on acceptance compared the educational tracks of science teachers. Großschedl et al. (2018) found high acceptance levels testing German biology PSTs of different education tracks, with significantly higher scores for PSTs_{10-12} than for $\text{PSTs}_{K\text{-}6}$. Athanasiou et al. (2016) found that acceptance increased with the educational level being taught: Early childhood and ISTs_{K} had a moderate score, while ISTs_{1-6} and ISTs_{7-9} had higher acceptance.

Hartelt et al. (2022) looked at how teaching experience affected German secondary school biology teachers' acceptance of evolution. PSTs, teachers in training, and ISTs had high acceptance levels. ISTs displayed significantly higher acceptance than teachers in training and PSTs. In line with the same authors' results about knowledge, the participants' professional teaching experience in years was significantly related to their acceptance of evolution. Downie et al. (2018) investigated whether the teaching experience of

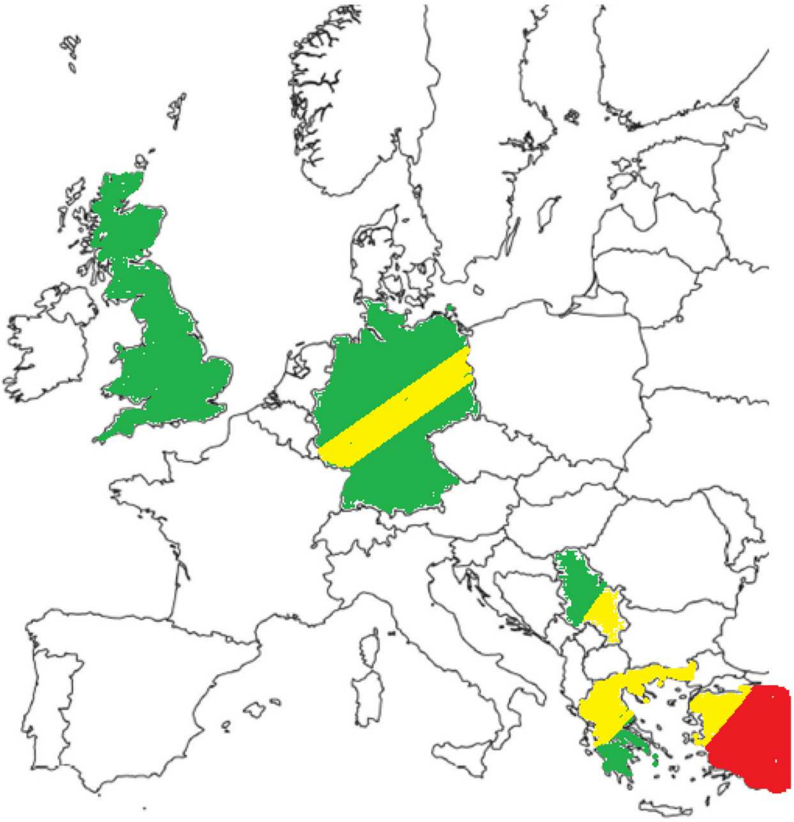

Figure 2. Categorical overview of European science teachers' acceptance of evolution as determined in studies from 2010 to 2023. Interpretation of the acceptance scores derived from different test instruments according to Kuschmierz et al. (2020b); categories of acceptance as rather high or high (green), moderate (yellow), and low or very low (red); for details on the studies see supplementary file 1.

Scottish biology ISTs affected acceptance. The authors judged that the study group broadly accepted evolution, however, there is no information about how professional experience may have influenced the acceptance of evolution.

As part of a study of Swiss secondary school students, Bernhard (2022) measured teacher acceptance of evolution. ISTs$_{7-9}$ (biology and philosophy) showed high acceptance rates, according to Bernhard's scoring system and the categories suggested by Kuschmierz et al. (2020b). To our knowledge, this is the only Swiss study examining the acceptance of evolution by teachers.

The relationship between knowledge and acceptance of evolution

The correlation between knowledge and acceptance of evolution has been examined with different test groups in numerous studies (see Fiedler et al., 2024, for a summary). However, the nature of the relationship between the two variables remains unclear. Most European studies have found a positive correlation between the two variables (Kuschmierz et al., 2020b; for details see Supplement 1). Beniermann (2019) demonstrated that the correlation coefficient between knowledge and acceptance increased with knowledge of evolution and education level, i.e. the correlation becomes stronger from lower secondary school students to biology PSTs. This finding confirms Sinatra's hypothesis that knowledge must be above a threshold level to affect acceptance (Sinatra et al., 2008). There is strong evidence that other variables such as knowledge of the nature of science (Graf & Soran, 2011; Nehm & Schonfeld, 2007), epistemological beliefs (Dunk et al., 2017), religiosity (Beniermann, 2019; Fiedler et al., 2024; Sickel & Friedrichsen, 2013), parental education and parental attitudes towards evolution (Barnes et al., 2017, 2019) also influence acceptance.

Context of the study

This section provides an overview of the educational system, teacher education programmes, and evolution in the curricula in Switzerland. Switzerland (>8.8 million inhabitants, 26% foreign residents) has four language regions and four national languages (percentage mother tongue: German 62%, French 23%, Italian 8%, and Romansh 0.5%). About 70% of the population declare a religion (33% Catholics, 21% Protestants, 6% Muslims) (BFS, 2023). The cantons oversee education.

Switzerland mandates 11 years of compulsory schooling starting at age four with two years of early childhood education, followed by five or six years of primary and three or four years of secondary school (Figure 3). After this, students continue their studies on one of two tracks, either a vocational and professional education and training programme or upper secondary school (academic track for higher education or specialised secondary school). About two-thirds of students pursue the non-academic route, which can also lead to a baccalaureate. About 40% of students get a baccalaureate (general, specialised, or vocational) (BFS, 2023).

Over 95% of PST study at universities of teacher education (Pädagogische Hochschulen, Figure 3) (SKBF, 2023). Admission to a teacher education programme requires a baccalaureate or an equivalent supplementary examination (e.g. university aptitude test). At present, only 35% of $PST_{K\text{-}6}$ have a general baccalaureate; over 45% of $PSTs_{K\text{-}6}$ graduate from a specialised upper secondary school and about 20% enter the teacher education programmes through other routes (e.g. a preparatory course). By contrast, almost 70% of $PSTs_{7\text{–}9}$ have a general baccalaureate. The lack of exposure to evolution in biology classes has implications for PSTs and ISTs: An unknown number of $PSTs_{K\text{-}9}$ have not been taught evolution in school.

Data derived from PISA suggest that $PSTs_{K\text{-}6}$ with a general or vocational baccalaureate perform weaker in maths and reading than the median of their respective groups. Only students with a specialised baccalaureate in pedagogy perform better than the group median. However, the median for the specialised baccalaureate is 80 points lower than that for the general baccalaureate, indicating that the academic performance of students with a specialised baccalaureate is generally lower (SKBF, 2023, pp. 302–303). These data suggest some adverse selection in the decision to study primary school teaching.

K-9 teacher education programmes in Switzerland are integrative rather than consecutive, giving PSTs teaching experience from the early stages of their studies. Preschool and primary teachers usually receive a bachelor's degree after three years and teach all

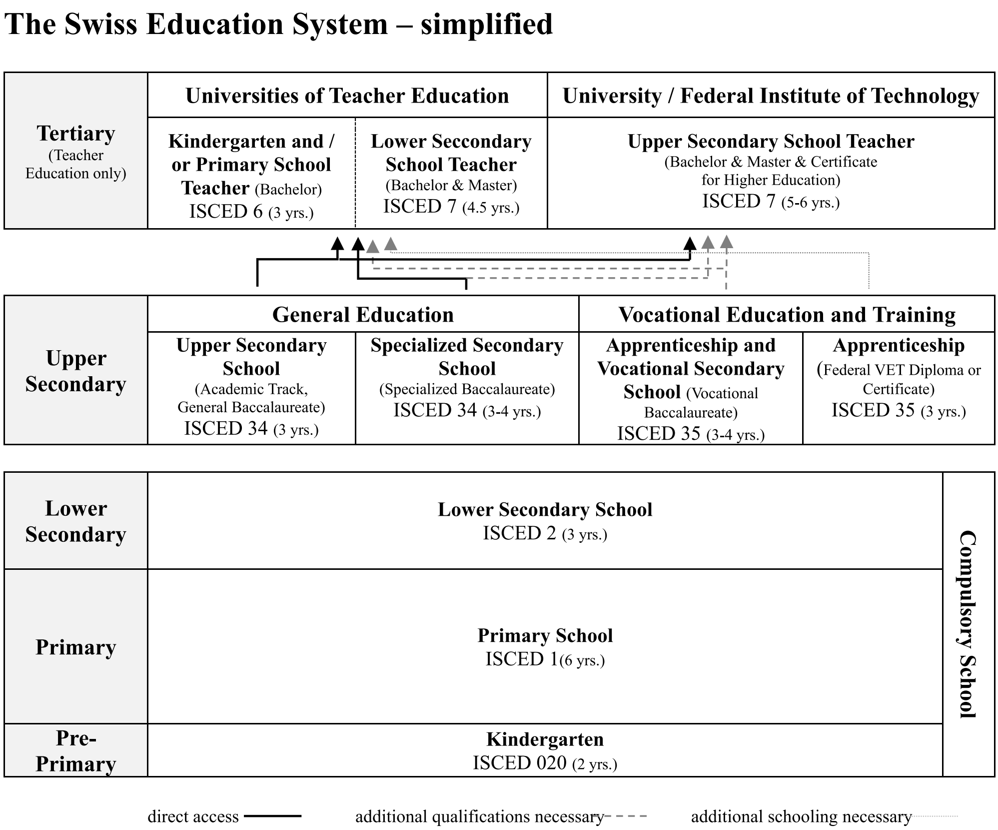

Figure 3. The Swiss education system based on the International Standard Classification of Education (ISCED; BFS, 2015) (simplified): Compulsory schooling and teacher education (based on BFS, 2023).

subjects. Lower secondary school teachers receive a master's degree after four and a half years of study and teach up to four subjects, with science as one subject. Upper secondary school teachers usually teach one or two subjects and must have a master's degree in their teaching subject from a regular university, plus a teaching diploma for higher education. The curricula for the teacher education programmes vary within the country. All PSTs have PK courses, however, PSTs$_{K\text{-}6}$ do not have courses in biology CK. Science PSTs$_{7–9}$ take CK courses in general biology or integrated biology courses with CK and PCK, but these may not teach key concepts of evolution.

In 2007 Switzerland harmonised its school systems (EDK, 2006) and adopted three regional curricula for the three large language regions (German: D-EDK, 2015; French: CIIP, 2010; Italian: DECS, 2015) for the 11 years of compulsory school. Until 2015 the key concepts of evolution were mostly absent from cantonal curricula, with just a few addressing limited aspects of evolution as an optional part of genetics or discussing evolution as an alternative to creation myths. The curriculum in Berne used to stipulate the equal treatment of the 'hypothesis of the origin of species and the beliefs of various religions' (Wilhelm, 2007, p. 183). Now the regional curricula introduce key concepts of evolution in preschool; by the end of primary school, students are expected to be familiar with concepts such as kinship and common ancestry of organisms, variability of living organisms, and adaptation. In lower secondary school, the evolutionary concepts mentioned above are to be developed and students are also taught about biological classification systems and evolutionary theory[2] (Lanka et al., 2023). Variation is not explicitly mentioned in any of the three curricula. Biology curricula in upper secondary schools vary from school to school and may or may not include evolution.

Research questions

This study aimed to provide baseline information for how well Swiss science teachers of years K-9 know and accept evolution. It was also designed to help identify when and how science teachers' knowledge of evolution can be improved by focusing on the educational track of the teacher education programme and teaching experience. The following research questions were investigated:

RQ1a What level of evolutionary knowledge do Swiss science teachers (K-9) have and how does it differ in the examined groups?

RQ1b What alternative conceptions of evolution can be identified in the examined groups?

RQ2 What is the level of acceptance of evolution by Swiss science teachers (K-9) and how does it differ in the examined groups?

RQ3 What is the relationship between knowledge and acceptance of evolution in Swiss science teachers and how does it differ in the examined groups?

Method

Measures

KAEVO 2.0 (Kuschmierz et al., 2020a) was used to assess evolutionary knowledge and alternative conceptions. The instrument has three subscales and includes fundamental concepts of evolution that are in the Swiss curricula: evolutionary adaptation and natural selection, heredity of phenotypic changes, tree reading, and speciation, including variation (KAEVO-A), mutations (KAEVO- B), and deep time (KAEVO-C).[3] KAEVO was selected because it was developed for secondary school and university students (Beniermann, 2019; Kuschmierz et al., 2020a) and therefore covered the topics required to assess secondary school teachers. It was also judged suitable for K-6 teachers who lay the foundation for a profound understanding of key evolutionary concepts. Plus, the instrument was validated using teacher trainees of biology.

Experts reviewed the KAEVO items with respect to the Swiss curricula. To address content validity, the questionnaire was extended with additional validated items from the Biological Evolution Literacy Survey (BEL survey; Yates & Marek, 2014), that explore recurring alternative conceptions (Table 1). These items focus on the intentionality, mechanisms, and nature of evolutionary processes.

The adapted questionnaire (Supplement 2) was piloted with 22 pre-service secondary school teachers in their last year of studies. Half of the KAEVO-B items (Kuschmierz et al., 2020a; items B1–B6) were subsequently excluded as they were shown to be non-selective and deemed by experts to be too simple for the target group.

Table 1. Items used to measure knowledge of evolution and alternative conceptions.

Evolutionary concepts	Number of items	Answer format	Original source	Reference
Evolutionary adaptation and natural selection, biological fitness, variation, speciation, tree reading, heredity of phenotype change	12	MC	KAEVO-A	Kuschmierz et al. (2020a)
Common alternative conceptions	5	T/F	BEL survey	Yates (2011)
Mutations	6	T/F	KAEVO-B	Kuschmierz et al. (2020a)
Deep time	3	Timeline estimation items	KAEVO-C	Kuschmierz et al. (2020a)

Note: MC: multiple choice; T/F: true or false items. One of the items from Yates (2011) was excluded from the evaluation for validity reasons. The results of the three deep time items are not presented in this paper.

Acceptance of evolution was assessed using a subscale of the Attitudes Towards EVOlution instrument (ATEVO-EG: evolution in general; Beniermann, 2019) and 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 et al., 2016) (Supplement 2). The clause 'Personally, I think that … ' ensured that participants knew that the section was about eliciting their opinions. It was added to the I-SEA and GAENE 2.0 items. Participants were asked to indicate to what extent they agreed or disagreed with each item by selecting a response on a five-point rating scale ('5' representing 'agree' to '1' representing 'disagree'). For an interpretation of the knowledge and acceptance scores, see Table 2.

All subscales of KAEVO 2.0 and ATEVO-EG were validated, and evidence for validity and reliability has been reported (Beniermann, 2019; Kuschmierz et al., 2020a; for ATEVO-EG as a single scale: Beniermann et al., 2023). KAEVO and ATEVO exist in 25 languages (Beniermann et al., 2021), including German, French, and Italian. Three trilingual science educators compared the three versions to the original English version and translated the additional items into the three languages, and back.

Sample and data collection procedure

An online questionnaire consisting of the knowledge and acceptance items described above was created. It was available in three languages. Lecturers from several Swiss universities of teacher education were asked to distribute the questionnaire to their students (PSTs). Filling out the questionnaire was either integrated into a science education course or students were provided with a link to the questionnaire with the request for completion. To reach ISTs, an appeal to complete the questionnaire was published in

Table 2. Score categories for the Knowledge score K (23 items) and the Acceptance score A (eight items) surveyed in the present study (interpretation based on Kuschmierz et al., 2020b).

Knowledge score *K*	Interpretation knowledge score	Acceptance score *A*	Interpretation acceptance score
22–23	High knowledge	35–40	Acceptance
19–21	Rather high knowledge	29–34	Rather acceptance
15–18	Moderate knowledge	20–28	Indifferent position
11–14	Low knowledge	14–19	Rather rejection
0–10	Very low knowledge	8–13	Rejection

teacher newsletters in several cantons and an email request for participation was sent to former PSTs$_{7–9}$ from a large university of teacher education. All participants received the same instructions and participation was voluntary.

A total of 1433 PSTs and ISTs completed the questionnaire between March and June 2022. Most participants were PSTs$_{K\text{-}6}$ ($n = 1063$, average age 23.7). The second largest group was PSTs$_{7–9}$ with science as one of their subjects ($n = 210$, average age 25.0). PSTs indicating that they had more than one year of teaching experience were excluded. The group IST$_{K\text{-}6}$ ($n = 19$) was excluded due to its small size. The group IST$_{7–9}$ ($n = 90$, average age 33.9) had an average of three years of experience teaching biology. ISTs$_{7–9}$ without science as a subject or without teaching experience in biology and ISTs$_{10–12,}$ were excluded. After data cleansing, 1352 participants remained for analysis (Table 3).

Statistical analysis

Quantitative data from the questionnaires was summarised using descriptive statistics in SPSS (IBM version 28.0.1.0). A knowledge sum score (K), based on 23 items, was calculated (see Beniermann et al., 2021) (score range 0–23). Acceptance was measured using eight items, generating a mean acceptance score (A) (score range 8–40). The internal consistency of the adapted knowledge and acceptance instruments was tested. Two items (A13 and D8) were excluded to increase reliability ($\alpha_K = .818$; $\alpha_A = .842$). The sum scores K and A were calculated without A13 and D8.

Results

RQ1a: Knowledge of evolution

The total sample of Swiss PSTs and ISTs, and group PST$_{K\text{-}6}$ had a low knowledge of evolution ($K_{total} = 13.01$; $K_{PSTK\text{-}6} = 11.85$). Groups PST$_{7–9}$ and IST$_{7–9}$ had moderate knowledge ($K_{PST7–9} = 16.78$; $K_{IST7–9} = 17.10$) (Figure 4).

Only two of the 1352 participants answered all 23 knowledge items correctly. A Kruskal-Wallis test showed that there were significant differences between the knowledge scores of the three groups ($H(2) = 305.6$, $p < .001$). A post-hoc Mann-Whitney U test showed that PST$_{7–9}$ and IST$_{7–9}$ had significantly higher knowledge than PST$_{K\text{-}6}$ ($p <$ 0.01, strong effect for both comparisons); the knowledge sum scores of PST$_{7–9}$ and IST$_{7–9}$ did not differ significantly (Table 4).

Table 3. Sample details of the participants included in the study after data cleansing.

Subgroup	PST$_{K\text{-}6}$	PST$_{7–9}$	IST$_{7–9}$
Number of participants *n*	1063	210	79
Sex (% female)	77%	52%	50%
Age (years; $M \pm SD$)	23.7 ± 4.4	25.0 ± 6.4	33.9 ± 9.1
Years of studies (years; $M \pm SD$)	2.1 ± .085	1.9 ± 1.00	Not applicable
Teaching experience (years; $M \pm SD$)	None	None	2.8 ± 1.2
Language region (% German, French, Italian)	64% German 19% French 17% Italian	97% German 3% Italian	100% German

Note: PST$_{K\text{-}6}$: pre-service primary teachers; PST$_{7–9}$: pre-service lower secondary teachers; IST$_{7–9}$: in-service lower secondary teachers.

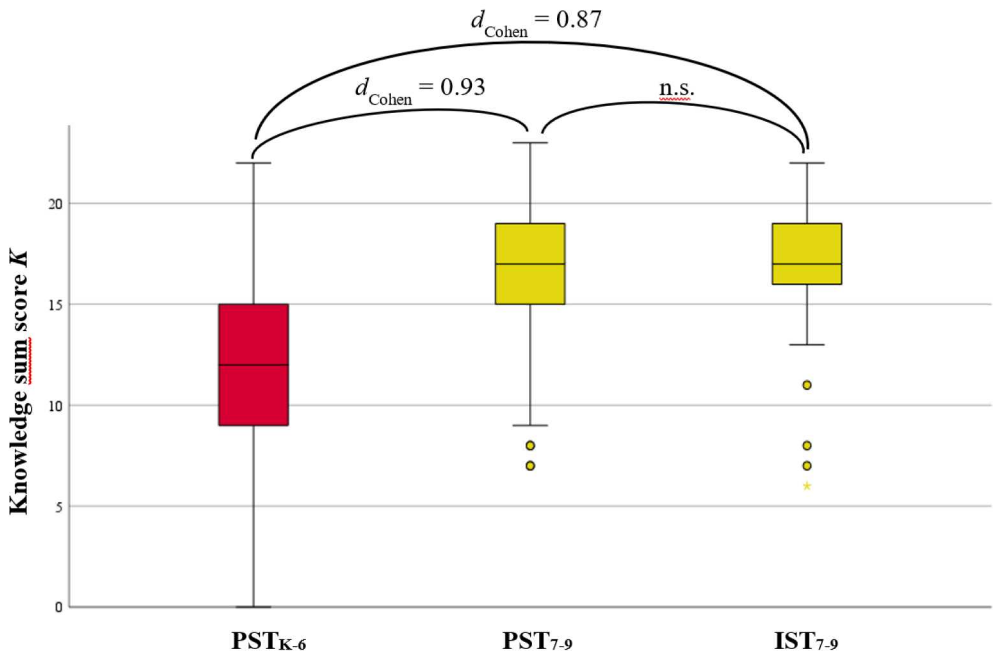

Figure 4. Evolution knowledge sum scores *K* and interpretation thereof for the three subgroups $PST_{K\text{-}6}$ ($n = 1063$), $PST_{7–9}$ ($n = 210$) and $IST_{7–9}$ ($n = 79$). Red: low knowledge, yellow: moderate knowledge (interpretation according to Kuschmierz et al., 2020b). Circles indicate moderate, asterisks indicate extreme outliers. For knowledge scores according to knowledge categories see Supplement 2.

Table 4. Mann-Whitney U Test for significant differences in knowledge sum scores *K* among $PST_{K\text{-}6}$ ($n = 1063$), $PST_{7–9}$ ($n = 210$), and $IST_{7–9}$ ($n = 79$).

	U	*z*	*p*	d_{Cohen}
$PST_{K\text{-}6}$ vs. $PST_{7–9}$	38374.0	−15.076	< 0.01	0.93
$PST_{K\text{-}6}$ vs. $IST_{7–9}$	12614.0	−10.409	< 0.01	0.87
$PST_{7–9}$ vs. $IST_{7–9}$	7839.5	−.724	0.469	

The answers to the KAEVO-A subscale, which tests for knowledge of adaptation and natural selection, heredity of phenotypic changes, tree reading, speciation, and some alternative conceptions, showed that group $PST_{K\text{-}6}$ had very low knowledge and $PST_{7–9}$ and $IST_{7–9}$ had moderate knowledge. The differences between group $PST_{K\text{-}6}$ and groups $PST_{7–9}$ and $IST_{7–9}$ were significant (*U*-test; $p < 0.01$ for both comparisons); there was no significant difference between $PST_{7–9}$ and $IST_{7–9}$. All three groups scored higher on knowledge of mutations (KAEVO-B), with $PST_{K\text{-}6}$ showing moderate knowledge and $PST_{7–9}$ and $IST_{7–9}$ demonstrating high knowledge. Again, the group $PST_{K\text{-}6}$ had significantly lower knowledge than $PST_{7–9}$ and $IST_{7–9}$ (*U*-test; $p < 0.01$ for both comparisons), while $PST_{7–9}$ and $IST_{7–9}$ did not differ significantly in what they knew about mutation (Supplement 2).

RQ1b: Alternative conceptions

The low knowledge sum scores *K* of PSTs and ISTs indicate that participants in all groups have some alternative conceptions, which are briefly presented in this section (see Table 5 for percentage of correct answers for each knowledge item).

Table 5. Item content, evolutionary concept, answer format and percentage of correct answers for knowledge items for the three subgroups $PST_{K\text{-}6}$ (pre-service kindergarten and primary teachers); $PST_{7–9}$ (pre-service lower secondary teachers); $IST_{7–9}$ (in-service lower secondary teachers).

No.	Item content	Evolutionary concept	Answer format	Correct answers in % (*n*) $PST_{K\text{-}6}$	$PST_{7–9}$	$IST_{7–9}$
A1	Evolution of modified leaves of Venus fly trap	Adaptation	MC	45.5 (*n* = 1063)	81.0 (*n* = 210)	86.1 (*n* = 79)
A3	Evolution of higher running speed of cheetahs	Adaptation	MC	60.7 (*n* = 1063)	89.0 (*n* = 210)	96.2 (*n* = 79)
A5	Evolution of shell colours of banded snails	Adaptation	MC	58.0 (*n* = 1063)	92.9 (*n* = 210)	92.4 (*n* = 79)
A6	Evolution of cacti thorns	Adaptation	MC	47.3 (*n* = 1063)	83.8 (*n* = 210)	88.6 (*n* = 79)
A14	Adaptation of a single individual	Adaptation	T/F	49.1 (*n* = 1052)	78.4 (*n* = 208)	70.9 (*n* = 79)
A16	Adaptation of a single individual	Adaptation	T/F	20.3 (*n* = 1055)	52.9 (*n* = 210)	60.8 (*n* = 79)
A7	Weismann experiment on mice part I	Heredity of phenotype changes	MC	85.3 (*n* = 1063)	97.1 (*n* = 210)	96.2 (*n* = 79)
A8	Weismann experiment on mice part II	Heredity of phenotype changes	MC	43.3 (*n* = 1063)	63.8 (*n* = 210)	74.7 (*n* = 79)
A9.1	Cladistic relationships among organisms: time axis	Tree reading	MC	12.8 (*n* = 1011)	21.9 (*n* = 210)	22.8 (*n* = 79)
A9.2	Cladistic relationships among organisms: interpreting the tips	Tree reading	MC	8.4 (*n* = 722)	10.5 (*n* = 210)	17.7 (*n* = 79)
A4	Separation and reunion of a lizard population	Speciation including variation	MC	21.5 (*n* = 1062)	47.4 (*n* = 209)	48.1 (*n* = 79)
A10	Evolution of a rabbit population after an ice age	Speciation including variation	MC	64.8 (*n* = 1056)	69.5 (*n* = 210)	74.7 (*n* = 79)
A2	Biological fitness of lions	Biological fitness	MC	15.9 (*n* = 1062)	33.3 (*n* = 210)	35.4 (*n* = 79)
A15	Survival of the fittest	Biological fitness	T/F	36.3 (*n* = 1063)	76.7 (*n* = 210)	64.6 (*n* = 79)
A11	Ancestor of humans and chimpanzees	Human evolution	MC	48.5 (*n* = 1060)	53.3 (*n* = 210)	62.0 (*n* = 79)
A12	Evolution theory	General alternative conception	T/F	51.9 (*n* = 1063)	64.3 (*n* = 210)	55.7 (*n* = 79)
A17	Evolution leads to improvement	General alternative conception	T/F	66.9 (*n* = 1058)	85.2 (*n* = 210)	75.9 (*n* = 79)
B7.1	Mutations happen randomly	Mutations (randomness)	T/F	57.2 (*n* = 1063)	94.3 (*n* = 210)	96.2 (*n* = 79)
B7.2	Mutations controlled by organism	Mutations (randomness)	T/F	78.1 (*n* = 1063)	96.7 (*n* = 210)	100.0 (*n* = 79)
B7.3	Mutations are always negative	Mutations (effects)	T/F	93.3 (*n* = 1063)	98.1 (*n* = 210)	100.0 (*n* = 79)
B7.4	Mutation effects can be neutral	Mutations (effects)	T/F	72.1 (*n* = 1063)	95.7 (*n* = 210)	96.2 (*n* = 79)
B7.5	Mutations normally don't occur in living beings.	Mutations (conditions)	T/F	76.7 (*n* = 1063)	97.1 (*n* = 210)	98.7 (*n* = 79)
B7.6	Mutations independent of environmental changes	Mutations (conditions)	T/F	75.8 (*n* = 1063)	96.7 (*n* = 210)	96.2 (*n* = 79)

Note: Items A1–A11, B7.1–B7.6 (Kuschmierz et al., 2020a), A13–A17 (Yates, 2011), A12 (self-developed); item A13 was excluded after CFA.

Evolutionary theory (item A12): Just over 50% of the sample understood the scope of evolutionary theory. Over a third ($PST_{K\text{-}6}$ 44.0%, $PST_{7–9}$ 32.6%, $IST_{7–9}$ 40.5%) believe it explains the origin of life.

Adaptation and natural selection (items A1, A3, A5, A6, A16): These items were designed to reveal teleological, anthropomorphic, and Lamarckian conceptions, and the idea of an *automatic* adaptation (Figure 5). Whereas groups $PST_{7–9}$ and $IST_{7–9}$ seem to have a grasp of evolutionary concepts and revealed few alternative conceptions

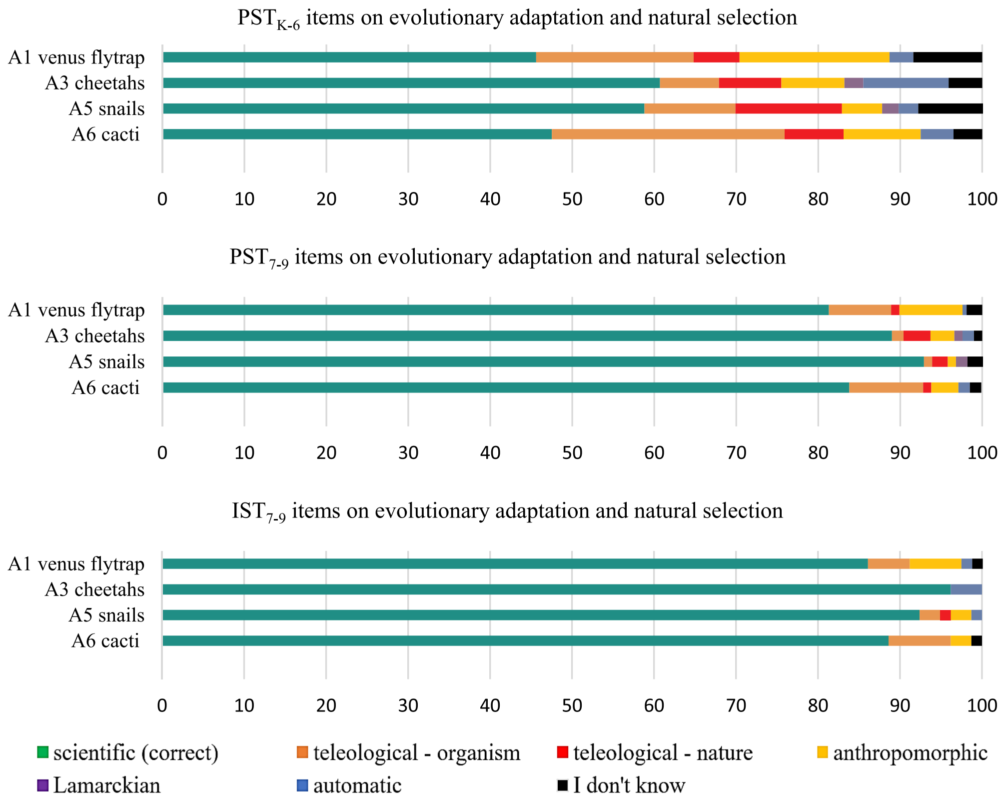

Figure 5. Percentage of correct answers and alternative conceptions on evolutionary adaptation and natural selection per subgroup. A1 Venus flytrap, A3 cheetahs, A5 snails, A6 cacti ($PST_{K\text{-}6}$ $n = 1063$, $PST_{7–9}$ $n = 210$; $IST_{7–9}$ $n = 79$). The answer option Lamarckian was only given in the zoological items.

(proportion of correct answers: $PST_{7–9}$ 86.7%, $IST_{7–9}$ 90.8%), only 53.2% of $PST_{K\text{-}6}$ answered correctly. Teleological distractors were most attractive ($PST_{K\text{-}6}$ 24.9%, $PST_{7–9}$ 6.5%, $IST_{7–9}$ 5.8%). Anthropomorphic and Lamarckian conceptions were mainly evident in the group $PST_{K\text{-}6}$ (12.3%). Botanical contexts (A1 Venus flytrap, A6 cacti) elicited more alternative conceptions than zoological ones (A3 cheetahs, A5 snails). A comparison of acquisition (A1 trapping leaves) and loss of a trait (A6 cacti leaves) in the two botanical items showed no differences.

Over two-thirds of the sample agreed with the statement ‘According to evolutionary theory, individuals adapt to their environment’ (A16), revealing that they understand adaptation in an everyday sense rather than a scientific way of populations changing over time (correct answers A16: $PST_{K\text{-}6}$ 20.3%, $PST_{7–9}$ 52.9%, $IST_{7–9}$ 60.8%).

Inheritance of acquired traits (A7, A8): The prevalence of understanding adaptation in the everyday sense aligns with the results of the two items designed to elicit conceptions of inheritance of acquired traits (Weismann experiment). Although 87.9% of the sample agreed that removing the tail of a mouse has no effect on the offspring’s tail after one generation, 48.2% said it had an effect after 21 generations (Figure 6). Even 24.0% of $IST_{7–9}$ seemed to believe Lamarckian ideas of inheritance of acquired traits over the course of multiple generations.

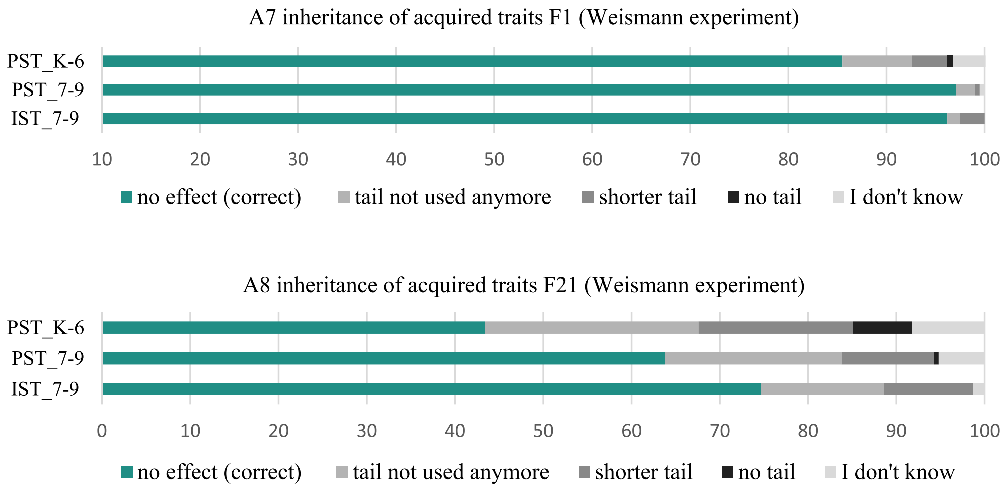

Figure 6. Percentage of correct answers on the heredity items A7 and A8 (Weismann experiment) per subgroup ($PST_{K\text{-}6}$ $n = 1063$, $PST_{7–9}$ $n = 210$, $IST_{7–9}$ $n = 79$).

Tree reading (items A9.1, A9.2): The tree reading items assessed whether participants could accurately interpret evidence for evolution as depicted in a phylogenetic tree. In all three groups, most responded that the temporal direction was along the 'backbone' of the tree from today back to the common ancestor, followed by the option from the 'backbone' towards the tips (correct answers A9.1: $PST_{K\text{-}6}$ 12.8%, $PST_{7–9}$ 21.9%, $IST_{7–9}$ 22.8%). Over a quarter of $PST_{K\text{-}6}$ (29.2%) answered 'I don't know'. Only a minority grasped that to establish kinship, one needs to look at the last common ancestor (correct answers A9.2: $PST_{K\text{-}6}$ 8.4%, $PST_{7–9}$ 10.6%, $IST_{7–9}$ 17.7%). Again, many $PSTs_{K\text{-}6}$ (31.7%) answered 'I don't know'. The most attractive distractors were those with spatial proximity of the descendants at the tips and where internal branches of the cladogram were of equal length.

Speciation, including variation (item A4): About a quarter of respondents (27.1%) selected the correct answer that it would be impossible to predict how two populations of one lizard species that had been geographically split thousands of years ago would evolve (correct answers A4: $PST_{K\text{-}6}$ 21.5%, $PST_{7–9}$ 47.4%, $IST_{7–9}$ 48.1%). The distractor selected most often was that the subpopulations would only have evolved differently if the two environments had differed substantially. The second most common answer was that they would have evolved in different ways (Figure 7).

Biological fitness (item A15): The alternative conception *only the strongest survive* is more prevalent in $PST_{K\text{-}6}$ than in the other two groups (correct answers A15: $PST_{K\text{-}6}$ 36.3%, $PST_{7–9}$ 76.7%, $IST_{7–9}$ 64.6%). Only a few respondents in each group correctly applied the concept to answering the questions about lions (correct answers A2: $PST_{K\text{-}6}$ 15.9%, $PST_{7–9}$ 33.3%, $IST_{7–9}$ 35.4%). The distractors *adaptation of an individual to changing conditions* and *largest number of offspring* were equally attractive for the full sample (Figure 8).

Mutations (items B7.1–B7.6): The KAEVO-B subscale, which covered the hereditary nature of mutations, consisted of true or false questions with an option to select 'I don't know'. Again, the percentage of correct answers for KAEVO-B items was much higher

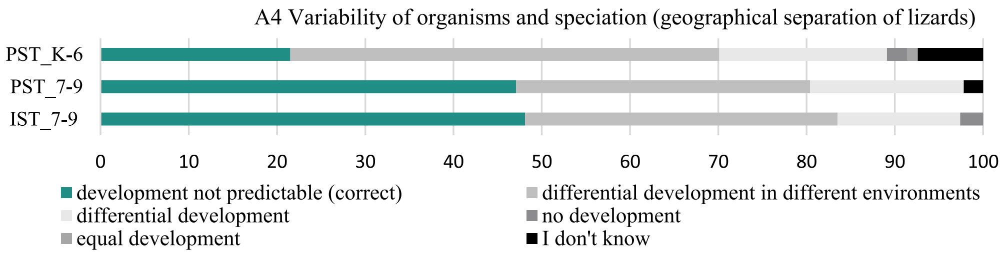

Figure 7. Percentage of correct answers on the speciation item A4 per subgroup (PST_{K-6} A4 $n = 1062$, A10 $n = 1056$; $PST_{7–9}$, A4 = 209, A10 $n = 210$, $IST_{7–9}$ $n = 79$).

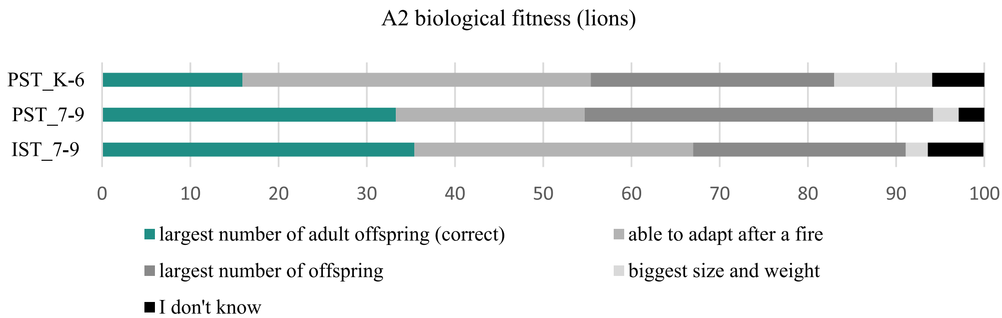

Figure 8. Percentage of correct answers on biological fitness item A2 per subgroup (PST_{K-6} A2 $n = 1062$; $PST_{7–9}$ $n = 210$, $IST_{7–9}$ $n = 79$).

for $PST_{7–9}$ and $IST_{7–9}$ than for PST_{K-6}. The greatest gap in knowledge between PST_{K-6} and the other two groups concerns the concept of the randomness of mutations (correct answers B7.1: PST_{K-6} 57.2%, $PST_{7–9}$ 94.3%, $IST_{7–9}$ 96.2%).

RQ 2: Acceptance of evolution

On average, Swiss science teachers accept evolution ($A = 34.76$, $n = 1352$; Figure 9). A Kruskal-Wallis test showed, however, that there were significant differences between the three groups ($H(2) = 54.131$, $p < .001$). A post-hoc Mann-Whitney-U-test revealed that PST_{K-6} had significantly lower acceptance scores than $PST_{7–9}$ ($p < 0.01$, weak effect) and $IST_{7–9}$ ($p < 0.01$, medium effect); $PST_{7–9}$ and $IST_{7–9}$ also differed significantly in their acceptance of evolution ($p = 0.003$, weak effect) (Table 6).

The percentage of participants who reject evolution or take an indifferent view is around 10% for PST_{K-6} and around 5% for the other two groups. In group $IST_{7–9}$, which is the group with teaching experience, 88.2% fully accept evolution (Supplement 2). Table 7 gives the item formulations, mean, and standard deviation for the acceptance items for the three groups.

RQ3: Relationship between knowledge and acceptance of evolution

A Spearman correlation coefficient was calculated to evaluate the relationship between knowledge K and acceptance A of evolution. There was a significant moderate positive correlation between K and A for the full sample ($r_{K\text{-}A} = .351$, $p < 0.001$, 2-tailed, $n =$

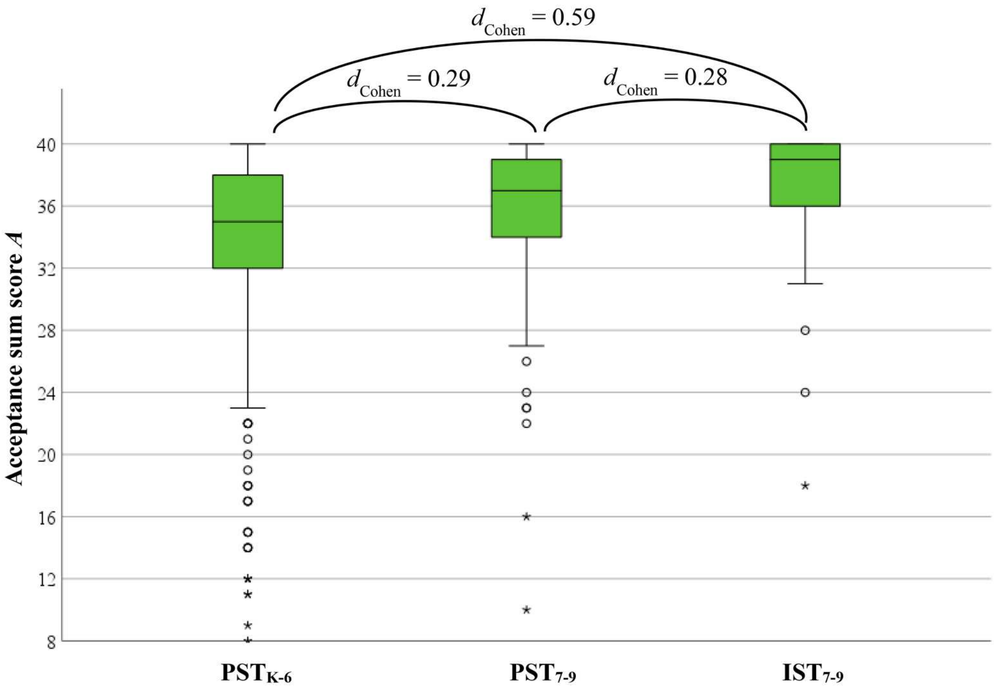

Figure 9. Evolution acceptance sum scores *A* and interpretation thereof for the three subgroups PST_{K-6} ($n = 999$), $PST_{7–9}$ ($n = 201$) and $IST_{7–9}$ ($n = 76$). Green: acceptance (interpretation according to Kuschmierz et al., 2020b). Circles indicate moderate, asterisks indicate extreme outliers.

Table 6. Mann-Whitney U Test for significant differences in acceptance sum scores *A* among PST_{K-6} ($n = 999$), $PST_{7–9}$ ($n = 201$), and $IST_{7–9}$ ($n = 76$).

	U	*z*	*p*	d_{Cohen}
PST_{K-6} vs. $PST_{7–9}$	79806	−4.614	< 0.01	0.29
PST_{K-6} vs. $IST_{7–9}$	21914	−6.177	< 0.01	0.59
$PST_{7–9}$ vs. $IST_{7–9}$	5887	−2.985	0.003	0.28

1352) and for PST_{K-6} ($r_{K\text{-}A} = .335$, $p < 0.001$, 2-tailed, $n = 999$). By contrast, the relationship between *K* and *A* was not significant for $PST_{7–9}$ ($r_{K\text{-}A} = .032$, $p < 0.647$, 2-tailed, $n = 201$) or $IST_{7–9}$ ($r_{K\text{-}A} = .206$, $p < 0.74$, 2-tailed, $n = 76$).

Discussion

The main aim of this study was to investigate the level of knowledge and acceptance of evolution in Swiss science teachers of different educational tracks. The study also aimed to identify common alternative conceptions of evolution and explore the relationship between knowledge and acceptance of evolution.

Knowledge of evolution

Swiss science teachers' knowledge of evolution is low to moderate. Our results are in line with those compiled by Kuschmierz et al. (2020b) and others published since 2020. The

Table 7. Item content, mean and standard deviation ($M \pm SD$) for acceptance items for the three subgroups $PST_{K\text{-}6}$ (pre-service primary teachers); $PST_{7–9}$ (pre-service lower secondary teachers); $IST_{7–9}$ (in-service lower secondary teachers) on a five-point rating scale ranging from '1' representing 'disagree' to '5' representing 'agree'.

No.	Item content	$M \pm SD$ (n)		
		$PST_{K\text{-}6}$	$PST_{7–9}$	$IST_{7–9}$
D1	Living organisms developed over billions of years	4.45 ± 0.03 (n = 1046)	4.53 ± 0.07 (n = 210)	4.76 ± 0.08 (n = 79)
D2	Adaptations explicable by the theory of evolution	4.38 ± 0.03 (n = 1046)	4.58 ± 0.05 (n = 208)	4.66 ± 0.10 (n = 78)
D3	Living animals and plants developed from earlier species	4.54 ± 0.24 (n = 1043)	4.73 ± 0.04 (n = 210)	4.92 ± 0.03 (n = 79)
D4	Living organisms are the result of evolutionary processes billions of years ago	4.41 ± 0.03 (n = 1040)	4.62 ± 0.06 (n = 207)	4.82 ± 0.07 (n = 78)
D5	Fossils are evidence that living organisms change over time	4.31 ± 0.03 (n = 1040)	4.50 ± 0.06 (n = 209)	4.78 ± 0.05 (n = 78)
D6	No evidence that species evolved from ancestral forms (recoded)	3.88 ± 0.03 (n = 1040)	4.08 ± 0.08 (n = 210)	4.32 ± 0.13 (n = 78)
D7	The theory of evolution applies to plants, animals, and humans	4.18 ± 0.03 (n = 1040)	4.48 ± 0.06 (n = 207)	4.63 ± 0.10 (n = 78)
D9	Evolution is a good explanation of how humans first emerged	4.18 ± 0.03 (n = 1049)	4.18 ± 0.07 (n = 209)	4.45 ± 0.10 (n = 79)

Note: Items D1–D4 (Kuschmierz et al., 2020a), D5–D6 (Nadelson & Southerland, 2012), D7 and D9 (Yates, 2011); item D8 was excluded after CFA.

knowledge level of Swiss PSTs is comparable to that of some cohorts of German or Greek PSTs; Swiss ISTs' knowledge is similar to that of British or German ISTs (Figure 1; Supplement 1).

Group $PST_{K\text{-}6}$ had low knowledge of evolution, while $PST_{7–9}$ had moderate knowledge. Our findings are of particular concern as primary school teachers lay the groundwork for the acquisition of more complex concepts of evolution such as diversity and adaptation in secondary school (Lanka et al., 2023). Großschedl et al. (2014, 2018) found a similar relationship for primary, lower, and upper PSTs in Germany: those aiming for upper secondary school outperformed the other two groups in their knowledge of evolution. Athanasiou et al. (2016) observed the same pattern for Greek ISTs. Although the teacher education programmes of Greece, Germany, and Switzerland are quite different, our findings indicate that the educational track of a teacher education programme has an impact on the PSTs' knowledge. Watts (2021) hypothesised that a rejection of evolution and poor or non-existent opportunities to learn about it result in a lack of knowledge. Since the acceptance level of all three groups in our study is high, our results suggest that the latter may be the case.

There are several reasons for the different knowledge levels found in our study. Unlike $PSTs_{7–9}$, $PSTs_{K\text{-}6}$ do not have specific biology CK courses during their teacher training programme. Thus, $PSTs_{K\text{-}6}$ need to rely on their secondary school knowledge to teach evolution. By contrast, $PSTs_{7–9}$ do learn about evolution during their studies at a university of teacher education. The secondary school background may be another variable that affects the participants' knowledge scores. Swiss universities of teacher education attract prospective primary school teachers with below-average academic performance levels (measured through PISA test scores; SKBF, 2023, pp. 302–303). The proportion of PSTs with a general baccalaureate, which indicates higher academic performance compared to students from vocational secondary school, is higher for $PSTs_{7-9}$ than for $PSTs_{K-6}$. The multiple routes for qualifying for admission to teacher training programmes in Switzerland means some prospective teachers might never have studied biology at the upper secondary level.

$PSTs_{7-9}$ did not score significantly lower on the knowledge test than IST_{7-9}, with an average of three years of teaching experience. This might be because some ISTs had only taught evolution topics once or twice. Regarding PCK of evolution, Hartelt et al. (2022) found that ISTs diagnosed alternative conceptions correctly more often than PSTs and that teaching experience was positively correlated with diagnostic ability. However, the authors acknowledged that it was impossible to determine which factor, experience of teaching the topic, professional experience, CK, or acceptance of evolution was most important for diagnosing and dealing adequately with student conceptions. Empirical data about the significance of teaching experience for professional knowledge is inconclusive (Großschedl et al., 2015). Nehm et al. (2009) found no difference in the knowledge of evolution of biology and non-biology teachers with two years of teaching experience. Großschedl et al. (2014) demonstrated that teaching experience did not have an effect on knowledge of evolution (CK) but did affect PCK. We believe that teaching experience should make a difference if, as is the case for Swiss $PSTs_{K-6}$, evolution is not included in the teacher education. Unfortunately, we cannot compare K-6 teachers with and without teaching experience due to the small sample size of IST_{K-6} in our study.

The low to moderate knowledge level of science teachers as measured in this study, is not good enough for the planning and execution of effective lessons on evolution. It poses the risk that teachers' incorrect or alternative beliefs may be transmitted to their students (Sickel & Friedrichsen, 2013; Yates & Marek, 2014). Both PSTs and ISTs displayed a variety of alternative conceptions. The observed alternative conceptions of the key concept of adaptation were primarily teleological. Other studies have shown that teleological conceptions are prevalent (e.g. Beniermann, 2019; Kuschmierz et al., 2020a; Nehm & Schonfeld, 2007). Zoological contexts (A3, A5) elicited more correct answers than botanical contexts (A1, A6) (Großschedl et al., 2018).

About 50% of the sample believed that persistent phenotypic alterations affect the offspring (A7, A8), revealing a lack of understanding about the genetic basis of the process of adaptation and the difference between phenotype and genotype (Hammann, 2019). It could also suggest a fundamental misunderstanding of the temporal scale of evolution (Tibell & Harms, 2017).

The tree reading items (A9.1, A9.2) differ from other knowledge items because they test a reading technique (procedural knowledge) rather than conceptual knowledge. Participants unfamiliar with evolutionary trees struggled to give an answer, as shown by the high number of 'I don't know' responses for the two items. Unlike finding an explanation for the development of antibiotic resistance or the success of invasive species, tree thinking is not part of everyday life. Thus, we could be dealing here with missing conceptions (von Aufschnaiter & Rogge, 2010) or misinterpretations rather than misconceptions (Gregory, 2009).

The speciation item (A4) reveals the common alternative conception that the environment alone drives evolution, regardless of the genetic makeup of the populations. The key concept of variation, for which an understanding of organisational levels is essential, seems to be absent. This finding is backed by a study on learning trajectories for concepts of evolutionary change by Zabel and Gropengiesser (2011), which showed that variation within a population is difficult to understand.

Alternative conceptions about biological fitness reflect well-known empirical results (e.g. Beniermann, 2019; Graf & Soran, 2011). These can be the result of lived experiences or arise from not being able to differentiate between the everyday and the scientific meaning of the term fitness. However, a third of the participants chose the distractor *largest number of offspring*, indicating a fundamental understanding of biological fitness (Gregory, 2009).

All three groups scored highest on the items about mutation (KAEVO-B). The good performance might be due to the lower item difficulty of KAEVO-B compared to KAEVO-A (Kuschmierz et al., 2020a).

Acceptance of evolution

Acceptance of evolution by Swiss science teachers was high. This result is in line with empirical data from other European countries. Acceptance is particularly high in countries culturally and religiously similar to Switzerland (Figure 2). It also appears to be an important personal characteristic of teachers, as it is associated with a willingness to fully integrate evolutionary concepts into their teaching (Nehm & Schonfeld, 2007; Sickel & Friedrichsen, 2013). The three groups $PST_{K\text{-}6}$, $PST_{7–9}$, and $IST_{7–9}$ differed significantly in their level of acceptance. Großschedl et al. (2014, 2018) found a similar pattern for different educational tracks, with weak effects in pre-service primary, lower, and upper secondary school teachers. Hartelt et al. (2022) and Athanasiou et al. (2016) reported higher acceptance rates in ISTs than in PSTs. The participants' acceptance of evolution showed a significant positive correlation with their overall professional experience in years (Hartelt et al., 2022). However, due to the use of different measuring instruments and conceptualisations of acceptance, the comparisons must be interpreted cautiously.

Relationship between knowledge and acceptance of evolution

Although the acceptance scores for all three groups were high, there were differences in their knowledge scores. Our results indicate a correlation between knowledge and acceptance of evolution for the full sample and group $PST_{K\text{-}6}$, but not for $PST_{7–9}$ and $IST_{7–9}$. However, the three subgroups differed considerably in size as well as the variance in their knowledge scores *K*. An evaluation of studies on the relationship between knowledge and acceptance by secondary school students, university students, and PSTs, revealed an ambiguous relationship between the two factors (Fiedler et al., 2024). Religiosity stands out as the primary factor for predicting whether individuals will accept or reject evolution (Fiedler et al., 2024).

Limitations

Various limiting factors are important when interpreting the results. Although religiosity is important in the interplay between knowledge and acceptance, the study did not ask about it. Religion is a sensitive topic in Swiss society and including questions about belief could have resulted in much fewer responses. Our sample of IST_{7-9} may not be representative of the population of Swiss science teachers. Because participants were recruited by means of newsletters and emails to former students, knowledgeable teachers may have been more likely to participate. The different modes of completing the survey (in a science education course or at home) may have also biased the results. The knowledge instrument was chosen to enable comparisons with other studies. However, this was the first time this adapted version was used. To be able to arrive at more statistically sound statements about alternative conceptions and examine these in different contexts, additional items would be required to create scales for more alternative conceptions. Qualitative data would give greater insight into alternative or missing conceptions about adaptation, heredity of phenotypic changes, tree reading, and speciation.

Implications

Other factors, such as teachers' religiosity and their understanding of the nature of science should be investigated to further elucidate the relationship between knowledge and acceptance of evolution. Also, a proper longitudinal study of pre-service teachers where a cohort of science PSTs and a comparison group with non-science PSTs are examined several times during their course of study would provide a more accurate picture of the influence of teacher education on knowledge and acceptance of evolution.

The weight given to evolution in the K-9 curricula poses a chance for students to develop a good understanding of evolution and acquire the skills to interpret and respond to current environmental crises. However, the results of our study show that science teachers have an inadequate knowledge base for teaching this topic. The current structure of science teacher training (K-9) is designed so that teachers must primarily rely on their knowledge of evolution from school, as there is little or no CK taught in university courses. In reality, a significant portion of PSTs have been taught little about evolution during their school years. Moreover, teacher education programmes in Switzerland strongly focus on PK, while PCK is also needed for efficient teaching. The data on alternative conceptions of evolution collected in this study could be used in teacher education programmes to revise courses and teach students about common alternative conceptions.

Notes

1. For this study, science teachers are defined as teachers who teach or study to teach science, including biology, no matter whether the subject is called science, or 'nature, humans and society'.
2. Genetic drift is not part of the three Swiss K-11 curricula.
3. The three items from KAEVO-C measuring knowledge of deep time were not analysed for this paper.

Disclosure statement

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

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Ethics statement

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 prior to 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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