Chapter 8
Transformative Teaching and Learning in Biology: Supporting Biodiversity Education for Promoting Sustainability

Eija Yli-Panula, Isabel Banos-González, Eila Jeronen, and Sandra Bueno-Férez

Abstract The planetary crisis requires an educational approach that seeks to comprehensively change people's knowledge, attitudes and values to support sustainable behaviour. Transformative education plays an important role in this process. When teaching is connected to students' everyday lives and values, as well as to the meanings of the community and includes critical discussion and reflection on personal assumptions and issues, this kind of teaching and learning opens new perspectives that can change the way they think and act. In this study, a systematic review was conducted to investigate the extent to which transformative teaching and learning have been conceptualised and put into practice in biology, specifically in biodiversity education (BE). The study was guided by two research questions: (i) How are the learning processes concerning transformative education supporting BE? (ii) What are the transformative teaching and learning methods used to promote BE? Our main finding was that prior learning is important for promoting transformative learning and disorienting dilemmas. Various teaching methods and strategies have been used, such as action learning, project and problem-based learning, teamwork, field trips and use of technological tools and discourses. This chapter also presents findings concerning learning outcomes, such as improvement of practical skills, positive long-term impact of technology on authentic problem-solving, change of attitude towards and positive assessment of biodiversity, impact of curricula and need for interdisciplinarity. The findings are discussed in connection with biodiversity, sustainability and transformative teaching and learning.

E. Yli-Panula (✉) · I. Banos-González
University of Turku, Turku, Finland

University of Murcia, Murcia, Spain
e-mail: eijyli@utu.fi

E. Jeronen
University of Oulu, Oulu, Finland

S. Bueno-Férez
University of Murcia, Murcia, Spain

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8.1 Introduction

Effective and timely actions are needed to curb climate change, biodiversity loss and environmental degradation, and to foster people's environmental awareness for a sustainable future (Mochizuki 2016). *Transformative education* has an important role to play in this, as the planetary crisis requires an educational approach that aims comprehensively to change knowledge, attitudes and values to support sustainable behaviour (Carr et al. 2018). According to the transformative paradigm, it is important to maintain and realise human potential in relation to the need to achieve and maintain social, economic and ecological well-being and recognising that they are part of the same dynamic (Sterling 2001). The entire education system, its members and society could benefit from teaching and learning that is consistent with transformative education, for example, in promoting sustainability transformation (Sterling et al. 2018).

In the last half-decade, educational researchers have offered numerous conceptions of what transformative education might look like. In one context, for example, transformative education is closely linked to the project of eradicating oppression and injustice, while in another, it is derived from phenomenological experience. Sometimes, transformative education refers to deep forms of learning in which students experience an expansion of value and meaning in relation to new scientific concepts and, sometimes, it is primarily concerned with learning how to learn (Yacek et al. 2020). In this study, transformative education is understood as an approach that offers students the opportunity to reflect on who they are, how they relate to the social world and who they want to be (Paul 2020; Yacek 2021). This endeavour is supported through transformative teaching and learning.

Transformative teaching is student- and competence-oriented, is rooted in transformative learning theory and engages with the normativity of research for sustainable development, as well as with experiences and inter- and transdisciplinary methods (Förster et al. 2019). In this study, it is also seen to be connected to students' everyday lives and values and community meanings (Osguthorpe and Jensen 2023). It promotes choices and develops expression and collaboration between teachers and students. Transformative teaching also requires teachers to reflect on and make decisions about what is defensible in relation to what is morally acceptable, just and caring (Osguthorpe and Jensen 2023). It emphasises teacher self--awareness and awareness of teaching goals and methods. Transformative teaching focuses on student-centred learning and uses active learning techniques and offers students, as individuals and as part of society, transformative learning situations (Osguthorpe and Jensen 2023).

Many educators refer to *transformative learning* as events that promote reflective learning in an environment that is relatively free from social and political constraints. Many researchers, on their part, describe transformative learning as a pedagogical philosophy. It is seen as a pedagogy that is consistent with transformative education, but distinct from critical pedagogy, progressive education and adult education. Some people use transformative learning and transformative education interchangeably (McWhinney and Markos 2003). In this study, transformative learning refers to events where students can examine their values and interests regarding the issues to be learned and possible to notice contradictions in their preconceptions (Osguthorpe and Jensen 2023). Critical discussion and reflection on personal assumptions and issues can lead to the transformation and adaptation of frames of reference or systems of meaning (Mezirow 1990, 1997; Fraser 2015). Learning experiences thus become a formative tool, providing new perspectives that can change the way students think and act (Mezirow 2009).

Transformative pedagogy is an approach that helps teachers and students develop their identity as whole individuals. It aims to develop cooperative social skills and knowledge of living together as a member of society, as well as individual socio--economic development (Farren 2019). Transformative pedagogy is based on moral--ethical concepts that guide stakeholders to work together to understand their own role and meaning in society (Farren 2019). It emphasises personal awareness and social change through action and critical reflection. It is important for educators to develop pedagogical skills that transform students into critical thinkers, problem solvers and innovators capable of applying learned information in the workplace and society as a whole. The study of Farren (2019) highlights the critical importance of transformational pedagogies in educating students to face the difficult problems of the twenty-first century.

According to Sterling (2010), 'environmental and sustainability education' is seen as a process by which the development of more sustainable lifestyles can be achieved. It combines theories of education and learning that, in turn, combine the best of liberal education with new ideas about transformative education, capacity building, creativity and adaptive leadership, which are considered crucial for sustainable development (Sterling 2008).

Sterling (2004, 2008, 2010, 2011, 2013) discusses transformative learning in the context of sustainability education, emphasising ecological and systems thinking to address sustainability challenges. According to both Sterling (2004) and Mezirow (1981), transformative learning is essential to achieving profound change in ways of thinking and acting and critical reflection. Both acknowledge the importance of social and cultural context in transformative learning. Transformative teaching focusing on student-centred learning uses active learning techniques and promotes critical reflection (Merzel 2023).

According to the Organisation for Economic Co-operation and Development (OECD 2018), education plays a fundamental role in developing the knowledge, skills, attitudes and values that enable people to contribute to and benefit from an inclusive and sustainable future. Nevertheless, O'Brien et al. (2013, p. 48) question whether it would be possible to achieve transformative learning without an axial

revolution to address 'the complex transdisciplinary challenges posed by global environmental change' and which allows individuals to question current assumptions and beliefs. In this sense, Sjöström and Eilks (2018) claim that the main goal of science education at all levels is to support the development of critical, socially aware and participatory citizens that can apply scientific knowledge and skills when solving complex sustainability challenges. Preventing the loss of biodiversity is one of these challenges that should be addressed, and pro-nature approach supported (UN 2022).

Loss of biodiversity at all levels, including species extinction and functional and phylogenetic levels of diversity erosion, can lead to the breakdown of ecosystems (Van Weelie and Wals 2002). However, this risk is hardly understood by the general public because of its complexity and ambiguity (Renn 2008). This situation has arisen through both the lack of empathy or connection with nature (Pyle 2003), and the lack of knowledge about biological diversity and conservation (Heberlein 2013). Educators can contribute to the solution to this problem and its prevention by teaching students about biodiversity and biodiversity protection in an engaging way. Previous studies have shown that many factors, such as peoples' experiences of species, are related to species conservation motivation (Eyster et al. 2022). Teaching about biodiversity, for example, at the regional level, can motivate both teachers and students towards conservation efforts (Lavorel and Morel-Deville 2010).

Based on an environmental and sustainability education approach, biodiversity education could guide students into the understanding and analysing of the many meanings and dimensions of biodiversity and encourage the construction of knowledge applied to solving problems in various contexts (Navarro-Perez and Tidball 2012). Students benefit also of having the opportunity to develop critical skills and increase their awareness of scientific and non-scientific aspects of biodiversity. In addition, education should emphasise the importance of biological diversity, responsibility towards nature and action for the protection of biodiversity (Kollmuss and Agyeman 2002). The goal is to understand the various factors, interpretations and uses of biodiversity that are relevant, to make students aware of and to understand their own ecological, economic, ethical, spiritual and cultural values, and to make them recognise the relationship between biodiversity and human well-being (Lindemann-Matthies et al. 2009). Biodiversity education (BE) is thus considered a useful educational approach when teaching issues on ecosystems and sustainable development. It emphasises the importance of understanding the values of biodiversity and the responsible attitude towards living nature and the urgency of action for biodiversity conservation (UNESCO 2017; Wolff 2022). In this context, the goal of transformative education is to promote the skills needed to implement a sustainability breakthrough (Odell et al. 2019). The document 'Education for the Sustainable Development Goals' highlights transformative teaching and it calls for 'a transformative, action-oriented pedagogy that supports self-directed learning, participation and collaboration, problem orientation, interdisciplinarity and transdisciplinarity'

(UNESCO 2017, p. 2). This transformative approach is closely related to education for sustainability (EfS), which represents a comprehensive educational vision and emphasises the cognitive, social, emotional and functional learning of sustainability at all educational levels (UNESCO 2017). In this sense, for Sterling (2010), 'transformative learning' means a quality of learning that is deeply engaging, and touches and changes deep levels of values and believes through a process of realisation and recognition. For developing active citizenship and enable people's participation it is necessary to continue research on BE and EfS from the perspective of a transformative approach at all educational levels.

In these times, when climate change has caused widespread adverse impacts and related losses and damages to nature and people (IPCC 2023), and biodiversity across the world is deteriorating at rates unprecedented in human history (CBD 2022, p. 1), the key question for education is how it can support sustainable development regarding biodiversity. Although a fair amount of research has been published on transformative education and EfS, only a few studies have examined and reflected on the kind of teaching and learning (T/L) strategies that can be used to support BE in promoting sustainability. Therefore, we conducted a systematic review to analyse the state of the matter, considering that systematic reviews offer the opportunity to explore, survey, question and improve the published evidence in the field of interest (Monroe et al. 2019).

8.2 Theoretical Framework

In this theoretical framework, the focus is on transformative pedagogy. In the school culture, transformative learning plays a key role in promoting social processes among students and in the entire school community (Bivens et al. 2009; Mogren 2019). Transformative learning means developing students' participation, agency and solutions (Stevenson et al. 2012). Participation and agency are related to joint planning and visioning of the future, as well as critical thinking and reflection (Tilbury 2007). Transformative learning from the view of biodiversity can mean, for example, how everyone as an individual and community member can actively work to protect biodiversity and promote a sustainable use of it. This is shown, for example, in the study of Wickenberg et al. (2022), in which the interaction between committed individuals and stakeholder groups, as well as participation in collaborative learning and integrative and reflexive knowledge production, led to doing better things concerning nature-based solutions. In terms of teaching and other activities, this means a strong commitment to sustainable practices and sustainability education and the adoption of sustainability competencies (Collins-Figueroa 2012). At the learner level, it is essential to critically examine one's own assumptions and beliefs, to take emotions into account and to be aware of and tolerate contradictions.

8.2.1 The Need for Transformative T/L

T/L plays a key role in developing society members that support sustainability. For this, it is necessary that T/L processes are transformative. However, what is meant by transformative T/L? Already in the 1980s, the American social scientist Jack Mezirow developed an adult learning theory on transformation and defined 'transformative learning' as 'learning that transforms problematic frames of reference—sets of fixed assumptions and expectations (mental habits, meaning perspectives, mindsets)—to make them more inclusive, discriminating, open, reflective and emotionally capable of change' (Mezirow 2003, p. 58). Furthermore, in one of his early papers, Mezirow (1981) specified some key features of transformative learning, focusing on the following:

(i) Learning processes (how people learn): These encompass a number of elements that are evolutionary, recursive and spiral in nature (Taylor 1997) and aimed at changing entrenched beliefs that might impede learning, leading individuals to critical reflection and a commitment to action.
(ii) The results (what they learned): These are what students are able to do and think at the end of the learning period after being integrated into disciplinary and professional contexts (Mezirow 1981).
(iii) The conditions (how to improve the students' learning): These are external and internal conditions and factors that influence the students' ability to participate in a learning situation.

Conceptualisations of transformative learning encompass various individual and social purposes such as empowerment, ecological awareness, social action, citizenship and democracy (Rodríguez and Barth 2020). For some authors, contributing to a more significant social change (or transformation) through education makes transformative learning attractive and necessary for EfS (Rodríguez and Barth 2020). Mezirow argued that through transformative learning, individuals may learn to reflect on hidden experiences, preconceptions, values and assumptions, to think critically and freely engage in rational discourses (Mezirow 1990, 1991).

According to UNESCO (2017), there is a need for a 'transformative pedagogy' that awakens students' critical awareness and enables them to become active transformers of their own reality. Based on previous research on transformative T/L, we recognise that this process involves creating dynamic relationships between teachers, students and also shared knowledge in ways that promote student learning and personal growth (Blake et al. 2013). In contrast to traditional education, which involves the transfer of information from teachers to students, transformative education involves teachers as agents who guide students in the process of development as learners and individuals (Slavich and Zimbardo 2012). Therefore, it is important to examine teachers' strategies and students' responsibilities in shaping their own and their peers' learning experiences. For all these reasons, it can be said that *transformation* has become a central objective in educational policies in the twenty-first century (UNESCO 2017).

8.2.2 EfS and Education for Biodiversity

EfS aims to teach people to be aware of current socio-ecological problems and to make appropriate actions towards environmental responsibility (Aarnio-Linnanvuori 2019). In order to achieve this aim, students should be motivated and aware of values, as well as able to put sustainability ideas into practice (Banos-González et al. 2021). Although many educational efforts have already been undertaken, EfS still remains a challenge. Researchers have recommended alternative approaches to traditional teaching that emphasise the personal relevance of content, acknowledge students' emotions and integrate the socio-economic and scientific dimensions of the problem (Chawla and Cushing 2007; Trott 2019). The teaching of biology is closely related to the content of EfS. This content exists especially in the fields of biology, ecology, biodiversity and conservation (Jeronen et al. 2017). These authors recommend that teaching about biological phenomena related to socio-scientific issues, such as biodiversity or climate change, has an integrative and interdisciplinary approach to ensure that the topic is thoroughly taught and learned.

In their study, Van Weelie and Wals (2002) reflected on the complexity of the concept of biodiversity and the lack of an explicit definition of it and pointed out that it is important to contextualise the term in teaching situations. They highlighted that it is beneficial for learner's understanding if biodiversity is linked with real contexts such as political, scientific and media sources when these contexts are used as educational resources. Through this contextualisation, students become aware of the conflict of interest underlying the conservation issue. Contextualisation facilitates critical reflection on the normative aspects of socio-scientific issues typical of transformative T/L.

8.2.3 Principles and Teaching Methods in EfS and Biodiversity

To achieve the goals of EfS, several researchers recommend active, memorable and experiential teaching methods, through which students learn to discuss their own choice of values and critically evaluate phenomena and information sources (Maina 2004). These methods include problem-based learning and outdoor education (Jeronen et al. 2017), collaborative learning (Volet et al. 2013) and inquiry-based learning (Hakkarainen and Sintonen 2002).

Problem- or project-based learning (PBL) is a set of instructional strategies that empower students to conduct research, integrate theory and practice and apply knowledge (Savery 2006). Students start from a problem setting to define their own learning objectives. For Chin and Chia (2004), 'learning in this way [PBL] is useful and motivating as students learn while looking for solutions to problems. Students actively participate and learn in the context in which the knowledge will be used' (p. 708). In PBL, students collect and work with information with the purpose to solve a problem; therefore, problems are presented at the beginning of the

intervention. Thus, the order is reversed from traditional teaching methods, which introduce problems only after that the students have learned the necessary body of knowledge.

Outdoor education (OE) takes place when T/L activities 'are organised in authentic, often natural environments, where students can connect their theoretical thinking with experiences of various kinds of real nature' (Jeronen et al. 2017, p. 5). It includes general interdisciplinary aspects of the world outside the classroom, including experiential education and outdoor environmental education (Jeronen et al. 2009). Borsos et al. (2022) argued that this methodology is successful and effective only when the teacher can guide students through an active, transformative learning process. In addition, various learning environments, which could be meaningful to the student, and the current and contextualised tasks used in PBL and OE support self-efficacy, autonomy, engagement and meaningful learning, and encourage creativity and flexibility (Turner and Fulmer 2013).

Collaborative learning is considered an active process that results in knowledge of higher quality than that produced by an individual. The increasing importance of solving complex problems and building knowledge in modern society emphasises the need for collaborative activities and environments in schools to foster learning (Volet et al. 2013). This is especially the case for socio-environmental issues such as biodiversity conservation.

Inquiry-based learning, in its part, is well suited to the context of collaborative learning, as students' mutual interactions make it possible to achieve a deeper and higher level understanding. This action is important in solving complex socio-environmental problems when working towards a more sustainable lifestyle (Hakkarainen and Sintonen 2002).

Therefore, in this chapter, we set out to clarify whether these transformative T/L methods are used to promote BE in primary and secondary education and teacher education.

8.3 Objective and Research Questions

An important question concerning T/L in biology is how transformative T/L approaches can support BE for promoting sustainability. Therefore, in this study, we conducted a systematic review to investigate the extent to which transformative T/L have been conceptualised and put into practice in biology and, specifically, in BE. In addition, we intended to collect evidence from previous studies on how to promote transformative learning in relation to the studied content.

This study was guided by the following research questions:

1. How do the learning processes concerning transformative education support the BE presented in primary and secondary education and in teacher education?
2. What transformative T/L methods are used to promote BE in primary and secondary education and teacher education?

To answer these research questions, we analysed the characteristics of the transformative teaching methods (TTM) used in research literature and the implications of TTM for the teaching of biology.

8.4 Material and Methods

In this section, the data collection, processing and analyses of the selected articles are described in detail in order to answer the research questions. A systematic literature review (SLR) was conducted to understand the relationships between transformative T/L, sustainability education and BE. The SLR was conducted on all available peer-reviewed articles published in English and Spanish (also in Finnish, but none was found) that explicitly focused on transformative learning, sustainability and BE. SLR represents a typical method for mapping the field and tracking recent developments in both the educational sciences and the science of sustainability (Spangenberg 2011).

In this work, we followed the SLR approach described by Sánchez-Meca and Botella (2010), and the PRISMA 2020 statement (Page et al. 2021). First, the research objectives and questions were established, followed by the locations of the empirical studies. In the identification phase, the inclusion and exclusion criteria of the studies were defined. The following aspects were included in SLR: (a) an identification of the study designs admissible for review; (b) a definition of the types of programmes, treatments or interventions intended to be investigated; (c) a definition of the study participants' characteristics; (d) a determination of the statistical data that the studies provide to calculate the effect sizes; and (e) an identification of how the outcome variables were to be measured (duly graded performance tests, self-report measures, etc.). Finally, in the SLR, the language in which the study was written and the time range of the articles were considered. An SLR is about providing a systematic and replicable search and analysis strategy that is fully documented and transparent (Sánchez-Meca and Botella 2010).

The SLR conducted in this study followed three steps: (1) data collection, (2) data processing and coding and (3) data analysis, which yielded a bibliometric view that combines quantitative and qualitative analyses of the learning process, results and conditions.

8.4.1 Data Collection

To provide a complete sample universe, searches were performed in electronic, scientific databases such as Scopus, Web of Science (WOS) and ERIC, which are considered among the most enriched and popular academic databases. The search strategy was based on a systematic organisation, categorisation and selection of keywords related to transformative T/L in biology, sustainability and BE. We used

a single broad search term instead of a series of discrete search terms. The keyword terms used in the literature search were as follows: TITLE-ABS-KEY (Transformative) AND (teach* OR learn*) AND (biodiversity OR biology) AND (education).

Based on these keywords, a common search strategy was developed for the consulted databases, adapting it to the characteristics of the given platform. Depending on the requirements of each database, the search fields were basically limited to the titles, abstracts and keywords of the articles. The following criteria were used to select the articles for in-depth analyses: (a) scope: national and international research, (b) period: 2012–2022, (c) target groups: primary and secondary school students and education of future biology teachers and (d) languages: English, Finnish and Spanish.

The review was limited to scholarly papers published in peer-reviewed journals because these have undergone rigorous review and are therefore higher quality documents. The authors were aware of the existence of other types of documents that could have been analysed, such as theses, research reports, books and book chapters and conference proceedings, but they were not included in the final SLR.

8.4.2 Data Processing and Coding

This study focuses on T/L methods to promote transformative learning, sustainability education and BE in primary and secondary school and teacher education. A raw database was created from the sample universe (n = 130), which included all available bibliographic data, the abstract and the full text. Additional variables were added to better capture the nature of the contributions (e.g. target groups, date of study and language). Coding was performed iteratively by selecting first the abstracts and then the full articles using an inductive coding approach. Then, 31 documents that did not meet the study date criteria (2012–2022) were excluded. After this filtering, 35 documents were excluded on the basis of the type of ineligible document (e.g. book chapters, notes and editorials), along with three documents that did not meet the language criteria (Fig. 8.1).

After an in-depth analysis of the thematic relevance of the remaining 61 articles, they were classified into four large distinctive research areas in the sample universe, and then 52 articles were excluded in areas (i–iv), as follows:

(i) Higher education in general: University-level contributions in undergraduate or graduate programmes (n = 6 were deleted).
(ii) Non-formal or informal learning: Encompasses research on learning environments that are not directly linked to formal educational institutions and programmes (n = 16).
(iii) Policy and guidelines: Mainly cover conceptual elaborations on policies and general discourses on education and their links with sustainability and BE (n = 30).

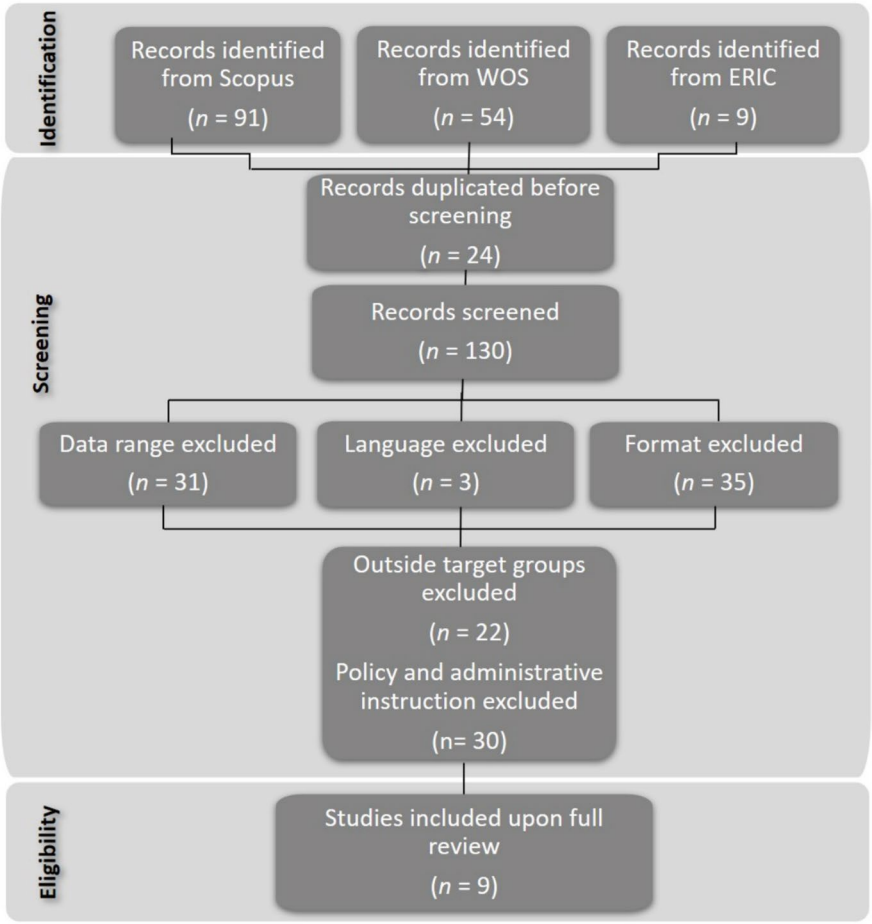

Fig. 8.1 Flow diagram of the review selection process. (Modified after PRISMA, 2020)

(iv) Educational programmes: Programmes for future teachers and students in primary and secondary education (n = 9), which represent the core sample of our study.

To ensure the reliability of the SLR, all three co-authors were involved in the article screening. Two authors reviewed the title, abstract and keywords of each article, coding the article as 'accept', 'reject', or 'further review' based on the inclusion criteria. A third author reviewed any articles coded 'further review' or whose coding by the other co-authors did not match. Articles that were still considered for inclusion underwent full-text analysis by two of the co-authors, with the third co-author again reviewing any cases of disagreement. Finally, the evaluation of inter-rater reliability was completed with adequate agreement among the three authors ($\kappa = 0.7$) (Landis and Koch 1997).

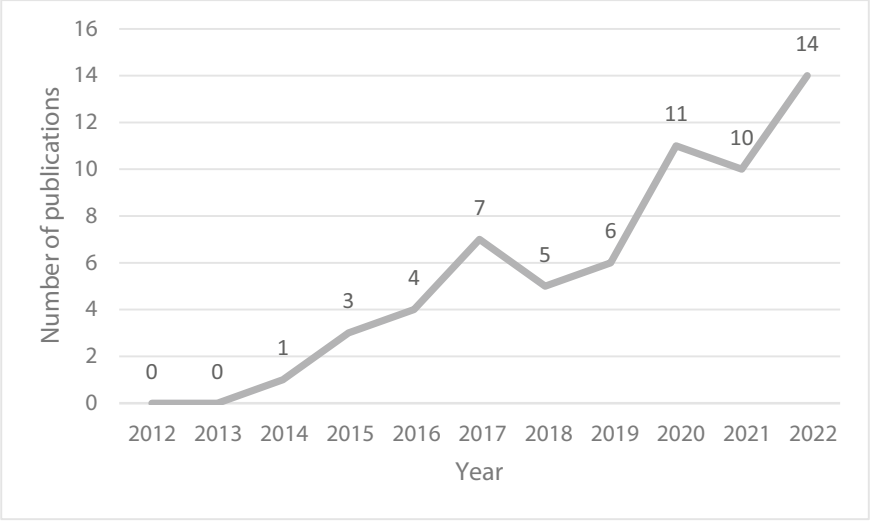

Fig. 8.2 Evolution in the number of publications found between 2012 and 2022

8.4.3 Data Analyses of the Selected Articles

The most relevant content of the nine studies were recorded (Fig. 8.2), including the year of publication, location, target population and theme of the study; the transformative teaching or learning and type of intervention or strategies followed in the study; the type of data collection and the results obtained and evaluated.

8.4.4 Understanding the Sample Universe

A raw data set, which included the identified articles, was obtained from each database consisting of 154 publications (91 from Scopus, 54 from WOS and nine from ERIC). Article screening revealed duplicates because the databases presented overlaps. After removing the duplicates (n = 24), we retrieved a raw sample of 130 publications (Fig. 8.1). Then, the raw sample was initially screened using the predefined inclusion and exclusion criteria.

In this study, the focus was on articles on transformative T/L and BE for promoting sustainability and dedicated to primary and secondary students and future teachers. It represents 14.8% of the found contributions (9/61 articles; Fig. 8.1).

During the data processing and coding, the following observations were made. In the study period, the number of articles found in relation to transformative T/L and education for biodiversity was increasing, with the highest number of publications found in 2022 (Fig. 8.2). The annual average for the studied period 2012–2022 was 5.4 articles.

Most of the articles included secondary school students (A2, A4, A5 and A8) and future biology or science teachers (A3, A7 and A9), respectively, and A1 included both groups as a collaborative team (Table 8.1). Transformative learning in BE played a lesser role in learning and research than in EfS. Hence, only few studies have addressed BE in any of the theoretical uses of transformative learning.

8.5 Findings

In this section, findings of transformative learning processes are presented according to unintentional and foreseen situations and critical reflection. Also, the methods and strategies connected to transformative teaching and learning outcomes are related to sustainability and biodiversity.

8.5.1 Findings Concerning Transformative Learning Processes

The first finding was the importance of prior conceptions. Four articles explicitly investigated prior perspectives and worldviews (A1, A3, A8 and A9). The rest of the articles mentioned prior learning as part of participants' general background and experiences related to biodiversity. Among the former four, the A1 article argued that learning is an active and dynamic process that occurs through experience. On the other hand, the A3 article explored the problem of not considering emotional and motivational variables to advance in professional development programmes for future biology teachers when they address conservation issues such as the natural remigration of the grey wolf in Germany. In A9, the preconceived ideas of anthropocentrism as domination over nature in the emulation of the subject were dismantled. This means that environment preservation cannot be achieved from the prevailing selfish perspective of the human species but, according to A9, it should be based on the improvement of the conditions of human life. Finally, A8, by means of an interpretive phenomenological analysis based on a qualitative research approach, aimed to understand the lived experiences of secondary school students during their first year of A-level study through the theoretical lens of the threshold concept (TC) framework. For A8, TC is likely to be transformative, occasioning ontological and epistemological shifts in the learner's view of the world and, potentially, their own identity.

The second finding was the occurrence of disorienting dilemmas. The reviewed articles showed various situations in which such disorienting dilemmas can occur (Rodríguez and Barth 2020).

(i) *Structured and unintentional situations*: These refer to planned learning activities in which educators do not deliberately trigger a dilemma; rather, owing to

Table 8.1 The analysed articles ($n = 9$)

Article code	Authors (year)	Study location	Participants	Data collection	Study theme
A1	Harnisch et al. (2014)	Illinois (USA)	Collaborative teams composed of graduate teaching scholars in education, secondary students and high school teachers	Unstructured interviews Surveys at the beginning and end of the service	Science and mathematics education
A2	Ortega--Torres and Moncholí (2021)	Valencia (Spain)	96 ninth-grade students	Group research dossier Expert experimentation dossier Exhibition products with co-evaluation	Albufera biodiversity study
A3	Büssing et al. (2018)	Germany	120 pre-service biology teachers	Questionnaire on contextual factors and their motivation to teach on the subject	Biodiversity conservation of sustainable development
A4	Zoller (2015)	Israel	Tenth-grade high school, undergraduate and graduate students	Pre-post questionnaires Observations in class Interviews	Sustainability
A5	Salami (2015)	Nigeria	274 upper secondary education students	Observation verification Rating scale of the activities Achievement test	Study of plant and animal nutrition
A6	Rüdisser et al. (2017)	Austria	548 students, aged between 6 and 20 years	Identification template Project database	Watching and monitoring of butterfly species
A7	Bezeljak et al. (2020)	Slovenia and Austria	60 biology students and 60 pre-service biology teachers	Survey with open and Likert-type questions	Sustainable development and education for sustainability
A8	Dunn (2019)	United Kingdom	Six high school students from a biology class	Class diaries Semi-structured interviews	Biology education
A9	Vasquez et al. (2020)	Venezuela	Future teachers from various disciplines	Stories and reflections on an educational process that adopted the science, technology and society (CTS) approach	Education for sustainable development and biodiversity of the semi-arid territory

the nature of the activity, the student experiences such a dilemma. Examples include new learning environments such as interdisciplinary environments at work (A1). In A4, students found situations in which they could participate in change processes and establish new social relationships.

(ii) *Structured and foreseen situations*: These refer to cases in which the disorienting dilemma is planned and deliberately induced during educational interventions to challenge students' frames of reference by asking critical questions such as those in A5. In this work, a modified laboratory learning environment was used, which had a significant positive impact on students' use of science process skills.

(iii) *Critical reflection:* Three types of reflections were identified:

- Reflection on content encompasses the analysis of information, concepts, values and norms that promote critical thinking; they are collaborative and create knowledge, such as those in A1, which was aimed at creating engaging collaborative learning environments. In addition, A7 was aimed at identifying knowledge and understanding of sustainable development and EfS among future biology teachers from Slovenia and Austria, and comparing the results between the two countries.
- Reflection on the process refers to assessing the way in which learning experiences are developed. In the process, it is vital to provide participants with frequent opportunities for feedback, reflection and idea modification. This is the case of A2, in which one main finding was from the reflection and teamwork of four secondary school teachers involved in the project 'We explain the Albufera' and students' reflections about the change produced by the methodology, with challenge-based learning.
- Reflection on premises occurs when learners assess the assumptions that underlie their thoughts, beliefs, attitudes, actions and behaviours. In the context of teacher education, A3 highlighted the importance of educating future teachers to reflect on values and transform them into more sustainable ways of living and teaching.

8.5.2 Findings on Teaching Methods and Strategies

Among the teaching methods or types of intervention, eight were differentiated. One was *action learning*. For Rodríguez and Barth (2020), the transformation process is sometimes followed by the adoption of sustainable behaviours as part of the designed experiments. In A9, teachers were urged to get rid of traditional educational standards and assume commitment to doing and relearning in a flexible process of high creativity. It is 'a requirement of social commitment, not a promise, where ethics, honesty and transparency are put ahead, that the embryos take their steps and follow their course towards sustainability' (A9, p. 4).

Project- or problem-based learning is another method that occurs in the analysed articles. In A2, the didactic sequence designed for the interdisciplinary project about Albufera was structured in accordance with challenge-based learning methods. This is linked to a goal that promotes students' active participation through the need to use higher order cognitive skills (HOCS) to achieve greater depth in learning. Moreover, A4 developed methodologies for the promotion of HOCS; for example, students, not teachers, ask the questions, solve problems that require their systems and evaluative thinking and decision-making skills in high schools and colleges in Israel.

Teamwork was also present in the included articles. Several references are available to this type of work. For example, in A1, various collaborative T/L teams were formed among National Science Foundation graduate teaching fellows in the K-12 education programme, which 'not only provided space for the exchange of ideas, but also fostered collaboration, community and mutual learning and teaching between educators and students' (A1, p. 7). In A2, the cooperative technique of the Aronson puzzle was developed (Aronson and Bridgeman 1996). Following this, each student belonging to the initial core group was assigned various roles to form five groups of experts according to their affinities and interests.

Use of technological tools was observed in A1, A4 and A5. Through GK-12, meaningful technologies and collaborative teaching models are integrated for students to learn science. A *modified laboratory learning environment* was demonstrated in A5. The study of this article examined the impact of a modified laboratory learning environment, particularly on secondary school students' science process skills. The students designed and conducted experiments on two research topics, animal and plant nutrition, with the help of trained research assistants under a researcher's supervision. *Field trips* were represented in two articles. Both A2 and A6 used field trips to create transformative learning contexts or environments that support the students' learning and motivation.

The *integrative learning of science, technology and society (STS) approach* was presented in A9. In this case, the approach was used for transformative and critical environmental EfS to achieve meaningful and collaborative learning among the participants.

Discourse was the eighth finding. Some authors referred to the stage of discourse as a process of sharing knowledge and practices related to biodiversity conservation (A6) or experiences of participation in a community activity (A9).

8.5.3 Findings of the Learning Outcomes

Five issues regarding learning outcomes were presented in the articles included in this review. One issue is the *improvement of practical skills, and the increase of new knowledge related to sustainability and biodiversity* (Table 8.2). In the study reported in A6, authors investigated about systematically collected data by trained students, together with their teachers, on the occurrence of diurnal butterflies. The

Table 8.2 Summary of the findings about learning outcomes in the SLR

Learning outcomes	Citation
Improvement of practical skills and increase of new knowledge related to sustainability and biodiversity	A5. Salami (2015) A6. Rüdisser et al. (2017) A7. Bezeljak et al. (2020)
Positive long-term impact of technology when used for authentic problem solving	A1. Harnisch et al. (2014)
Change of attitude and positive assessment of biodiversity issues to improve teaching and learning	A2. Ortega-Torres and Moncholí (2021) A3. Büssing et al. (2018) A6. Rüdisser et al. (2017)
Impact of the curricula on the teaching and learning about sustainability and biodiversity education	A4. Zoller (2015) A7. Bezeljak et al. (2020)
The need for interdisciplinarity	A7. Bezeljak et al. (2020) A9. Vasquez et al. (2020)

participants gradually gained experience, 'sometimes even turn[ed] into experts' (p. 685). According to the authors, this kind of participation could substantially contribute to the successful implementation of biodiversity monitoring programmes. In A5, a modified laboratory learning environment had a significant positive impact on students' use of science process skills. Scientific process skills were learned and acquired by students in environments that encourage thinking and enthusiasm for working and discovering new things. The results also showed that the process skills of low-achieving students improved significantly when they were taught in a modified laboratory setting. Meanwhile, A7 revealed that less than half of the future biology teachers who answered the questionnaire had a good understanding of the environmental aspects of sustainability, but most lacked an understanding of the interconnections between the environmental, economic and social dimensions.

The *positive long-term impact of technology when used for authentic problem solving* (A1) was presented to create engaging experiences for both students and teachers. The A1 article demonstrated the fundamental integration of meaningful technologies (e.g. informatics and visualisation tools) and collaborative teaching models for student-learners to develop critical scientific literacy in primary and secondary school classrooms.

Change of attitude and positive assessment of biodiversity issues to improve T/L were the key findings reported in A2 and A3. The connection between the selection of adequate contexts (e.g. the returning wolves to the region) and the attitudes, enjoyment and perceived behavioural control of future teachers to teach about the issue was demonstrated in A3. This positive attitude and increased motivation of future teachers might be a stepping stone to strengthening BE in schools, leading to a more sustainable future for everyone. A2 described changes in students' interest in science and attitudes due to the transformation of a field trip into an interdisciplinary project. This positive assessment by the students was considered a good predisposition towards new projects, as described by A2. On the other hand, A6 found that 87% of the students reported a high degree of interest and enjoyment in

participating in the butterfly observation project. Thus, the authors concluded that the project could enthuse more individuals for nature observation and biodiversity issues.

The *impacts of the curricula on T/L about sustainability and BE* were differentiated in A7. The article described that future biology teachers had little awareness of the complexity of sustainability issues and even less awareness of social and intergenerational equity. For this reason, the authors argued to convert biodiversity and sustainability into cross-cutting issues, which could benefit both the natural and social sciences education and also in humanities. A4 criticised the fact that contemporary science education in secondary and high school education is mainly disciplinary. This article also described a slow shift from disciplinary teaching at the undergraduate level to interdisciplinary learning oriented to higher order cognitive skills.

The *need for interdisciplinarity* was also identified. A9 showed that integrative learning of STS for the theme of biodiversity allowed for achieving the transversality of environmental education, and meaningful and collaborative learning between students and teachers. This integration is achieved in multidisciplinary and transversal teaching to build alternatives for sustainable local development. In addition, A7 reported that future biology teachers, despite having a good understanding of the environmental aspects of sustainability, lacked an understanding of the interconnections between the environmental, economic and social dimensions, which are essential for active T/L approaches in the fields of sustainability and BE.

8.6 Discussion

In this section, we first discuss the sample universe and, second, the main RQs. Third, we discuss the main learning outcomes found in the literature and, finally, we summarise what we learnt from the review.

8.6.1 Understanding the Sample Universe

The transformative learning theory in EfS and BE has become an emerging field of research, as evidenced by the increasing trend in the number of publications over the last few years. In this study, the focus was on articles referring to transformative T/L and BE in promoting sustainability.

Rodríguez and Barth (2020) suggested that transformative learning has become an attractive theory used in the field of EfS, although it often lacks deep enough analyses. However, in the field of education for biodiversity, the results obtained in this study do not confirm this idea, apparently because of the limited number of papers. Nevertheless, this idea seems to be proven for other fields such as social learning and sustainability (Reed et al. 2010; Taylor 1997). The complexity of this

problem could lie in the unpredictability and subjectivity of the results of experiences related to transformative learning and in the methodological and ethical implications when evaluating those results.

8.6.2 Transformative T/L and BE

Dewey (1938) suggested that learning is based on continuous reflection on lived experiences. This statement is supported by A1, which emphasised the importance of active and dynamic processing of experiences in learning situations. The authors of A1 used the threshold concept framework as a transformative approach to learning, which is based on the idea that in the process of change, learners are awakened to new ways of seeing and become ready to let go of their prevailing perceptions (Land and Rattray 2017). The learning of the concepts, such as photosynthesis or biodiversity, can bring about ontological and epistemological changes in learners' worldviews and, possibly, their own identities.

Understanding the importance of biodiversity is a prerequisite for nature conservation. In this sense and from the perspective of EfS, it is important to consider students' personal experiences, emotions and motivation (Chawla and Cushing 2007). According to A3's conclusions, the professional development programmes for future biology teachers have neglected this view.

On the other hand, the preconceived notions about anthropocentrism are dismantled in A9. The authors of A9 suggested that nature and biodiversity conservation cannot be achieved from an anthropocentric point of view; but could be based on personal experiences and conducted as collective activities that acknowledge unsustainability and are aimed at creating a just and equal society and viable ecological conditions. Weinberg et al. (2020) argued that education is a critical element in a global transformation towards sustainability and is urgently needed to stabilise socio-ecological systems worldwide.

8.6.2.1 Transformative Learning Processes

According to the SLR performed by Rodríguez and Barth (2020) about transformative learning in the field of sustainability, structured and unintentional situations, structured and foreseen situations and critical reflection are areas of concern, since they can contain confusing dilemmas. Through various learning environments, students' self-efficacy, autonomy, commitment and meaningful learning can be fostered and their creativity and flexibility are encouraged (Turner and Fulmer 2013). Social relationships and collaborative learning can result in jointly processed knowledge, which is important when discussing environmental issues (Huang and Lajoie 2023).

Structured and foreseen situations of disorienting dilemma such as a modified laboratory learning environment were evident from the data reported in A5. This

dilemma seemed to have a significant positive impact on the students' use of science process skills (SPS) such as thinking and research skills, including basic and integrated process skills (Elmas et al. 2018). Basic process skills create a foundation for learning integrated (more complex) skills. They consist of observing, guessing, measuring, communicating, classifying and predicting. Integrated process skills include variable control, operationalisation, formulating hypotheses, interpreting data, conducting experiments and designing models (Elmas et al. 2018). SPS is used in problem solving, critical thinking, understanding concepts (Candrasekaran 2014), and in supporting students to understand and solve everyday life problems and cope with global challenges (Abungu et al. 2014), such as biodiversity loss and climate change.

In our SLR, we identified three types of critical reflections: reflection on learning content and results, reflection on the learning processes and reflection on premises of students' assumptions. Reflection related to learning conditions, learning processes, content and results is typical for transformative learning (Mezirow 1981). Thus, education aims to increase individual empowerment, ecological awareness and social activity (Rodríguez and Barth 2020). Reflecting on premises concerns students' assumptions that underlie their thoughts, beliefs, attitudes, actions and behaviours. The results in A3 emphasised that in teacher education, it is important that future teachers reflect on their values to become aware of norms and to change their practice (including teaching activities) to be more sustainable. This transformative pedagogy can also awaken students' critical awareness and enable them to become active transformers of their own reality according to the goal of the UNESCO (2017).

8.6.3 Teaching Methods and Strategies

Teaching methods are important because they affect all types of learning in cognitive, affective and psychomotor areas (Karami et al. 2012). In this SLR, we identified the following types of learning: action learning, problem-based learning, teamwork, information and communication technology, laboratory work, field trips and integrative learning of STS and discourse.

Approaches to problem-solving involve acting and reflecting upon the results (Reynolds 2011), which may facilitate the development of problem-solving processes and simplifying the solutions developed by the team. In A9, teachers were encouraged to abandon traditional teaching methods and to apply flexible action learning that developed creativity. The results of A6 also suggested that citizen science projects related to biodiversity conservation could promote public engagement and provide transformative learning situations.

Problem-based learning and project-based learning are active learning methods, by which students solve questions related to, for example, their own lives, as in the interdisciplinary Albufera project (A2). The goal in A2 was to support the students' HOCS from the perspective of deep learning. A4 had the same goal, but students,

not teachers, presented questions and solved problems that required systems thinking and decision-making skills. According to Fuglei (2014), problem-based learning is an especially useful method of transformational education. As an active-learning method, it can support structural changes in students' thoughts, feelings, actions and consciousness, which can permanently change the way they view and behave in the world.

In the articles analysed in our SLR, teamwork was found among the T/L methods. Teamwork includes the collaborative effort of a group to achieve a common goal or to complete a task in the most effective and efficient way (Salas et al. 2008). In A1, various collaborative T/L teams were formed among the National Science Foundation graduate teaching fellows in the K-12 education programme, which fostered collaboration community and mutual learning and teaching between educators and students. In A2, the collaborative technique of the Aronson puzzle was used.

Regarding laboratory work in science and biology education, Gericke et al.'s (2023) systematic review showed that one of its main purposes is to provide students with conceptual and theoretical knowledge to support them in learning scientific concepts and, through scientific methods, in understanding the nature of science. In A5, authors stated that a modified laboratory learning environment might enhance this kind of learning, as was the case in the animal and plant nutrition study. Laboratory work also provides students with the opportunity to experience science by using scientific research procedures. To achieve meaningful learning, Ottander and Grelsson (2006) stated that scientific theories and their application methods should be experienced by students. Moreover, laboratory work should encourage the development of the students' analytical and critical thinking skills and their interest in science.

The purpose of field trips is usually to provide students with experiences outside their everyday school issues, as the aim is to observe things in their natural state and possibly collect samples (Jeronen et al. 2017). According to our SLR findings, a field trip is meant to create transformative learning environments that serve to support students' learning and motivation. Liefländer and Bogner (2018) argued that when a field trip includes problem-based activities, learning by doing, exploring real-life phenomena and sensory engagement, it significantly improves students' interest, knowledge, attitudes and behaviour in relation to sustainable development. According to Borsos et al. (2022), field trips should be an integral part of education at all educational levels. The integrative learning of STS approach was used in A9 for transformative and critical environmental EfS to achieve meaningful and collaborative learning among the participants.

As defined by Van de Walle et al. (2014), a classroom discourse includes 'the interactions between all the participants that occur throughout a lesson' (p. 20). When discussing the protection of diversity (A6) and participation in community activities (A9), information and practices related to these topics can be shared. This is important from the point of view of understanding scientific knowledge and the development of scientific thinking. Knowledge of species and species identification are fundamental prerequisites of understanding biodiversity, ecosystems and ecological sustainability, according to Palmberg et al. (2018) and Randler (2008). The

studies of these authors showed that teachers' and student teachers' knowledge of species and species identification and their interest in nature in an ecological context have significantly declined. One possible reason is that students' scientific vocabulary varies considerably. Some students have a good command of the terminology of biology and the complex meanings associated with biological terms, whereas others struggle with these terms and do not master even the threshold concepts enough to explain the relationships and meanings between the phenomena (Mouton and Rootman-Le Grange 2020).

It can be concluded that after the in-depth analysis of the nine selected articles, the most common methodologies used when considering transformative learning were based on problem-based learning and outdoor activities.

8.6.4 Learning Outcomes

The key findings to enhance transformative learning in relation to biodiversity and EfS in this SLR study were as follows: improvement of practical skills and increase of new knowledge related to sustainability and biodiversity, positive long-term impact of technology when used for authentic problem solving, change in attitude and positive assessment of biodiversity issues to improve T/L, impact of the curricula on T/L about sustainability and BE and the usefulness of interdisciplinarity.

Developing practical skills and adding new knowledge related to sustainable development and biodiversity enhanced transformative learning. For example, students' ability and participation in gathering systematically information about the occurrence of diurnal butterflies significantly contributed to the success of diversity monitoring programmes (A6). For its part, the modified laboratory learning environment had a significant positive effect on the development and use of students' natural science process skills (A5). Active T/L processes appeared to develop higher order learning and practical skills (Elmas et al. 2018). On the other hand, our findings show that most student teachers lacked an understanding of the connections between the environmental, economic and social dimensions of sustainability. Without knowledge of the relationship between human beings and nature, it seems difficult to understand the structure and function of ecosystems (life-supporting systems on Earth) and the principles of biodiversity and its role in maintaining sustainability (Randler 2008).

Learning occurs when people solve problems in authentic contexts and participate in community activities. Thus, authentic learning can be considered closely related to problem solving and other community practices. Consequently, authentic learning can support students to become members of the culture and participate in meaningful practices (Cho et al. 2015), especially when the fundamental integration of meaningful technologies (e.g. informatics and visualisation tools) takes place and when student learners develop critical scientific literacy in primary and secondary school classrooms. The positive long-term impact of technology can lead to transformative learning when used for authentic problem solving.

The findings of this study show that the choice of context has meaning for the relationships between teachers' attitudes, enjoyment and perceived behaviour and students' increased interest in science through their participation in an interdisciplinary field project, such as the butterfly observation project, which fostered transformative T/L. According to previous studies (Duerden and Witt 2010; Palmberg et al. 2018), people's knowledge about nature and interest and experiences in nature influenced their values and emotions regarding nature. Transformative learning touches and changes deep levels of values and attitudes through realisation and recognition (Sterling 2011) and could therefore motivate teachers in more value--based T/L about biodiversity.

Another finding of this study was the impact of curricula on T/L about sustainability and biodiversity. Some education experts have noted that most twenty-first--century students are still being taught by teachers using twentieth-century pedagogical practices in nineteenth-century school organisations (OECD 2019). The transition from traditional teaching methods to interdisciplinary learning and teaching methods has been slow. This may be partly because the concepts of sustainability and sustainability education are difficult for both teachers and students to understand (Pathan et al. 2013). In addition, the need for thinking of issues as an entity is fundamental, and the ability to systems thinking is essential. Systems thinking is a way of understanding the world as a complex system, in which everything is connected to everything else (Palmberg et al. 2018). It supports the identification of the interrelationships of various biophysical and social factors in a given environment (Sterling 2003). It is a way of thinking that enables a person to understand their role from a holistic perspective. Learning situations offer encounters in which teachers and students can learn from each other and build paths to a sustainable future together through open discourse.

Finally, it is important to point out some of the shortcomings of this review. The reduced number of papers included is considered a limitation of this study. It might be due, on the one hand, to the difficulty of implementing the theory of transformative learning and, transforming results may become visible much later or not at all. On the other hand, to the specificity of the content, education for biodiversity conservation, we argue that for future research on biodiversity transformative T/L, it would be prudent to note that more empirical research is needed in the areas of teacher education and formal learning other than higher education. This review can be considered a starting point from which potential articles that we might have missed (and future articles) can be integrated into the sample universe. Finally, this study warrants the need to develop good methods and tools that can provide insights into transformative learning processes and outcomes.

8.6.5 What We Can Learn from this Review

A change in 'conventional' pedagogical practices towards practices that seek impactful learning results both individually and socially is necessary. Various pedagogical endeavours such as problem- or project-based learning have been made in

interdisciplinary and intercultural settings. However, introducing these methods and settings can cause unexpected dilemmas. Therefore, before embarking on these processes, it is essential to consider both the disorienting dilemmas that can arise during learning interventions and the individuals' prior learning experiences. In addition, the social norms and emotional charge inherent in environmental issues can lead to problematic situations.

Social norms can reduce the discussion of environmental issues and affect environmental behaviour, such as electricity consumption and recycling (Jachimowicz et al. 2018). If the students think that their peers do not support their environmental views, they will avoid discussing the topic. A recent systematic review of social determinants of climate change research highlights the need to better understand the effects of social network members on an individual's climate change behaviour (Tam et al. 2021).

Research on emotions has in its part shown how personal emotional attitudes differently affect the decision-making of individuals (Peters et al. 2006). Today, information is lacking on the effects of emotions on environmental behaviour due to the complex nature of environmental issues such as climate change. According to Latkin et al. (2021), avoiding the topic of climate change is negatively related to citizens' willingness to participate in climate change actions. Possibly the reason is that people avoid discussing topics that they do not feel they can influence. Understanding the role of emotions is very important in the current situation, when environmental decisions will be made, for example, about curbing climate change (Xie et al. 2019) and environmental policy (Smith and Leiserowitz 2014). Decisions related to these topics may have long-term consequences, and people's emotional reactions can strongly influence their attitudes and actions (Davidson and Kecinski 2022). One the one hand, positive feelings such as empathy and concern for nature can motivate individuals to participate in, for example, recycling or in supporting conservation efforts (Berenguer 2007). On the other hand, negative emotions such as fear or denial can prevent environmental actions or leads to unsustainable practices (Büssing et al. 2018). The findings of the study reveal the importance of planning educational interventions to create supportive learning conditions as a space for reflection and discourse, and social and collaborative interactions. The need for interdisciplinarity was one important finding of this study. Biodiversity can be taught and learned meaningfully in, for example, environmental education using collaborative learning. However, such active teaching methods require a good understanding of the connections between the environmental, economic and social dimensions of sustainability. For this reason, topics related to sustainability should be added to all teacher education subjects. Moreover, time for practical training and teaching experiences should be increased in teacher education programmes to develop teachers' pedagogical content knowledge concerning biodiversity and sustainability (Großschedl et al. 2015) to support transformative teaching and learning.

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Eija Yli-Panula, PhD, is a senior researcher (emerita) at the University of Turku, Finland and is acting as a Visiting Professor at the University of Murcia, Spain. She is an Associate Professor in sustainability education and also in aerobiology at the University of Turku. In addition to education she has a degree in biology and geography. Her research interests are in sustainability education, e.g. teacher competencies in science education, in didactics of biology and geography and in teacher education. Yli-Panula has acted as an editor for national (Publications of the Finnish Research Association of Subject Didactics) and international journals and special issues, and she has published several international scientific articles and book chapters. She has been part of international scientific research groups and networking groups.

Isabel Banos-González, PhD, is a lecturer in the Department of Didactics of Experimental Sciences at the Faculty of Education (University of Murcia, UM). She is main researcher of the 'E013-02 Research and innovation in science education' research group of the UM. She has a strong background in environmental science. Her PhD was in the field of Ecology, and she has worked as secondary school teacher. Her particular interest relies on sustainability education. Isabel has published in both natural and educational science journals, as well as chapters and books.

Eila Jeronen, PhD, is emerita in biology and geography didactics at the University of Oulu in Finland. She is also associate professor in environmental education at the University of Oulu, in biology education at the University of Lapland in Finland and in sustainable development education at the University of Helsinki in Finland. In addition, she has Ph.L. and M.Sc. degrees in biology and teacher certificate in biology and geography in the University of Oulu. Her research interest includes science education, environmental education, and sustainability education. She has supervised dissertation theses and published and worked as an editor in international journals, an editor-in-chief in Natura (the Finnish journal of Biologian ja maantieteen opettajien liitto) and in multicultural projects in several countries.

Sandra Bueno-Férez, MSc, is a part time teacher in science education at the Faculty of Education in the University of Murcia and she also does research in teacher training. She has a technical profile developed over 20 years in the field of water management, as well as formal training as a science teacher. Her research is mainly based on the competencies in primary education towards sustainability and in relation to the current socio-ecological problems.