

Managing biology learning for sustainability: Prospective teachers' perceptions and readiness

Ikmanisa Khairati *, Lufri, Festiyed, Mawardi, Usmeldi

Doctoral Program of Science Education, Faculty of Mathematics and Natural Science, Universitas Negeri Padang, Padang, West Sumatra, Indonesia

* Corresponding Author Email: ikmanisaa.khairati@gmail.com

Article Information	Abstract
Keyword: Prospective teachers; Biology learning; Perception; Readiness; Education for sustainable development Kata Kunci: Calon guru; Pembelajaran biologi; Persepsi; Kesiapan; Pendidikan untuk pembangunan berkelanjutan History: Received : 30/01/2025 Revised : 12/09/2025 Accepted : 18/09/2025 Published : 25/09/2025	Education for Sustainable Development (ESD) as a means to support the achievement of sustainability goals must become the core of the learning process. This is inherently connected to the crucial role of teachers in incorporating the concept of sustainability within the learning process. This research aims to gain insights into the perceptions and competencies of prospective teachers, reflecting their readiness to implement ESD into biology teaching. Referring to the Evidence for Policy and Practice Information and Co-ordinating Center (EPPI-Center) framework for systematic literature review in educational research, this study examines empirical studies from the Scopus electronic database published between 2015 and 2024, focusing on studies in the field of biology education and ESD. The review followed three main stages: determination of inclusion and exclusion criteria, keyword selection, and systematic categorization. Data analysis was conducted using a content analysis approach. The findings were categorized into four main themes: perceptions and self-efficacy; prospective teachers' competencies; ESD learning strategies for prospective teachers; and psychological and social factors. The results of this review provide evidence for identifying areas for future exploration aimed at improving the competencies of prospective teachers in implementing ESD. Abstrak. Education for Sustainable Development (ESD) sebagai upaya untuk mendukung pencapaian tujuan keberlanjutan, harus menjadi inti dari proses pembelajaran. Hal ini tentunya tidak terlepas dari peran penting guru dalam mengintegrasikan konsep keberlanjutan ke dalam proses pembelajaran. Penelitian ini bertujuan untuk mendapatkan wawasan tentang persepsi dan kompetensi calon guru yang mencerminkan kesiapan mereka dalam mengimplementasikan ESD ke dalam pembelajaran biologi. Mengacu pada kerangka kerja Evidence for Policy and Practice Information and Co-ordinating Center (EPPI-Center) untuk tinjauan literatur sistematis dalam penelitian pendidikan, penelitian ini mengkaji studi empiris dari database elektronik Scopus yang diterbitkan antara tahun 2015 hingga 2024, dengan fokus pada studi di bidang pendidikan biologi dan ESD. Tinjauan ini mengikuti tiga tahap utama: penentuan kriteria inklusi dan eksklusi, pemilihan kata kunci, dan kategorisasi sistematis. Analisis data dilakukan dengan menggunakan pendekatan analisis isi. Temuan dikategorikan ke dalam empat tema utama: persepsi dan kepercayaan diri; kompetensi calon guru; strategi pembelajaran ESD untuk calon guru; serta faktor psikologis dan sosial. Hasil kajian ini memberikan bukti untuk mengidentifikasi bidang-bidang yang perlu dieksplorasi di masa depan yang bertujuan untuk meningkatkan kompetensi calon guru dalam mengimplementasikan ESD.

A. Introduction

Education plays a crucial role in achieving the SDGs (Kioupi & Voulvoulis, 2019). The Education for All Global Monitoring Report edition 2013-2014 states that education has proven to change lives through teaching skills and transforming attitudes and behaviors in climate change mitigation and adaptation. Education in the sustainable development agenda concludes that the success of the SDGs leads to the success of achieving SDG No. 4 (Quality Education). The role of education in promoting sustainability is emphasized through the Global Action Programme on Education for Sustainable Development (ESD) by UNESCO, Sustainable Development Goal 4 (SDG 4) on quality education, the European Green Deal, the Finnish curriculum reform, and the Swedish Environmental Code (Ahmad & Sosa, 2025). The ESD objectives, particularly in biology learning, aim to equip students with the knowledge, attitudes, and skills to tackle complex sustainability challenges involving environmental, social, and economic dimensions. This requires active learning and transformative learning, initially oriented towards memorization, to transform into holistic understanding.

Education for Sustainable Development is explicitly recognized in the SDGs as part of Target 4.7 of the SDG on education, along with Global Citizenship Education (GCED), which UNESCO promotes as a complementary approach (Khoo & Jørgensen, 2021). ESD is an essential contribution to all efforts to achieve the SDGs, enabling individuals to contribute to sustainable development by promoting societal, economic, and political change as well as transforming their own behavior. Education for Sustainable Development mobilizes actions to achieve sustainability goals by increasing awareness and promoting a critical understanding of the SDGs (Abera, 2023; Yuan et al., 2022).

Aspects of ESD that must be considered in achieving sustainability include environmental, social, and economic aspects (UNESCO, 2017). Teachers and prospective teachers who do not have a background in ESD will struggle to integrate ESD into biology education. ESD is integrative and involves various disciplines and emphasizes fostering sustainability awareness and action competence (Eliyawati et al., 2024).

Several instructional models integrate ESD into biology learning. The first model adopts sustainable practical principles in biology education and technology in the form of laboratory practices (Shabrina et al., 2024). The second model adds ESD content to biology learning (Zguir et al., 2021; Novidsa et al., 2021). The third model uses sustainability questions that contain socio-scientific issues in biology learning (Riess et al., 2010).

Approaches that can be implemented to integrate ESD into biology learning holistically include

student-oriented, action-oriented, and transformative approaches (Aboytes & Barth, 2020; Avsec & Ferk Savec, 2021). Education for Sustainable Development-based biology learning can be conducted using the 3A approach (authentic learning, active learning, and action-oriented learning) (Cooper et al., 2024; Pratiwi et al., 2021; Tschantz et al., 2020), the 3C approach (context-based learning, case-based learning, and community-based learning), and the 3P approach (Phenomenon-based learning, Problem-based learning, and Project-based learning) (Cebrián et al., 2020; Saleem & Dare, 2023).

The goals of sustainable learning consist of cognitive, socio-emotional, and behavioral objectives (Hernandez Gonzalez, 2023). Assessment is adjusted to align with sustainable learning objectives that consider the SDGs and the ESD competencies to be achieved. There are eight key competencies that play an important role in thinking and acting for sustainable development, including system thinking competency, anticipatory competency, normative competency, strategic competency, collaboration competency, critical thinking competency, self-awareness competency, and integrated problem-solving competency (UNESCO, 2017).

Based on UNESCO (2017), there are 11 important issues in the implementation of ESD in school education. These issues include biodiversity, climate change, disaster risk reduction, cultural diversity, poverty reduction, gender equality, health improvement, sustainable lifestyles, peace and human safety, water, and sustainable population movement. The connection between biology education and sustainability aspects highlights the need for conservation efforts to protect ecosystems (Rushton & Walshe, 2022). Ecological concepts such as predator-prey dynamics and ecosystem resilience are crucial for sustainability (Thompson & Norris, 2021). Biology education emphasizes the impact of human activities on climate change, thus aiming to foster a relationship with nature, pro-environment actions, and conservation efforts.

One of the key competencies in ESD is system thinking. This competency encourages a deep understanding of complex scientific phenomena, especially in educational contexts that emphasize sustainability (Kordova et al., 2018), thinking equips students to analyze and understand multi-interactions within systems. As identified by Assaraf et al. (2013), six main indicators include identifying components and processes in a system, understanding relationships between components, recognizing dynamic relationships, making generalizations, uncovering hidden dimensions, and thinking temporally. Biology education promotes system thinking by teaching students to analyze and reason about systems as a whole, including their interactions and feedback mechanisms (Colucci-Gray et al., 2006;

Demssie et al., 2023; Momsen et al., 2022; Riess et al., 2010). Studies show that the application of ESD in biology education can enhance systemic thinking and problem-solving abilities, although the results vary among students (Saragih & Solihat, 2021). The integration of ESD with Problem-Based Learning (PBL), particularly on biodiversity topics, can improve students' science literacy (Shabrina et al., 2024).

Education for Sustainable Development emphasizes holistic understanding by viewing biology as an interconnected system. The holistic approach is supported by the Two-Eyed Seeing model, which combines scientific and holistic perspectives to enhance the learning process (Zeyer, 2024). The holistic approach in classroom activities and field trips increases ecological knowledge and environmental values, even though it does not significantly alter individuals' environmental values (Schneiderhan-Opel & Bogner, 2021). The memorization approach has been proven to fail in providing a holistic understanding because students are not accustomed to the systemic thinking required to comprehend complex concepts. Students can easily remember facts or steps through memorization but struggle to apply principles to new situations, such as predicting outcomes when variables change (Wenderoth et al., 2020; Wisinski & Yu, 2020). Students tend to be directed to memorize information without understanding the relationships between those concepts and real life. This results in students being unable to apply knowledge to solve real-world problems. For example, ecosystem material cannot be understood merely as knowledge about organisms, but also involves relationships among species, the environment, and human impacts (Mahanes et al., 2023).

Biology learning should not only focus on mastering scientific concepts but also on developing the skills, attitudes, and values that support sustainability in the real world (Zhai & Jackson, 2023). Biology education plays a central role in comprehensively addressing global issues such as pandemics, food security, and environmental sustainability (Akinwumi, 2023; Rushton & Walshe, 2022; Russell et al., 2022). Integrating ESD into biology learning impacts students' sustainability awareness (Setiawan et al., 2023). Teachers play a role in shaping students' attitudes and behaviors towards sustainability. Aspiring biology teachers need to have strong environmental knowledge and pro-environmental attitudes to effectively integrate ESD into their teaching practices.

Teachers' roles in the classroom can be influenced by their perceptions and readiness (Century, 2023). Positive teacher perceptions can contribute to improved learning outcomes (Tandler & Dalbert, 2020) and influence their beliefs about students' potential (Swanson et al., 2022). In the context of ESD, it is essential that teachers hold

positive perceptions of their own competence in implementing ESD principles. The previous study reveals that positive perceptions and motivation are critical indicators of teacher retention, which in turn impacts the quality of instruction in the classroom (Alexander et al., 2020).

The competencies possessed by teachers also indicate their readiness to implement ESD-oriented instruction and affect the extent to which sustainable learning practices can be integrated into the classroom (Timm & Barth, 2020). Additionally, social and psychological factors may influence teachers' sustainability-related attitudes and behaviors (Buettner et al., 2016; Nguyen-Van et al., 2021; Pimdee, 2020; Vukelić & Rončević, 2021). Prior research demonstrates that teachers' sustainability-oriented attitudes and behaviors can serve as role models for students, encouraging them to adopt similar practices in their daily lives (Almeida et al., 2018). This, in turn, contributes to the broader dissemination of sustainability values.

This review contributes to uncovering how the perceptions, competencies, and factors influence prospective teachers in implementing ESD into biology learning based on previous empirical studies, thus serving as a reference for further research.

B. Material and method

The study methodology refers to the Evidence for Policy and Practice Information and Co-ordinating Center (EPPI-Center) for systematic literature review in educational research (Bennett et al., 2005), with procedures divided into three stages as follows:

1) Determination of inclusion and exclusion criteria: At this stage, research articles relevant to biology education, pre-service teachers, and ESD (Education for Sustainable Development) are selected using established inclusion and exclusion criteria to identify articles utilized in this research (Bennett et al., 2005). The search is conducted through electronic databases to obtain relevant studies. This research scans scientific articles in the Scopus electronic database published between 2015 and 2024. Furthermore, the reviewed articles are limited to those published in English. This study focuses on research articles with the aim of reviewing peer-reviewed studies that present direct empirical data; therefore, document types such as reviews, conference articles, editorials, books, and book chapters are excluded. Selected articles with direct empirical data include information on perspectives and strategies for integrating ESD, as well as factors influencing pre-service teachers in implementing ESD into biology learning.

2) Keywording:

The articles obtained from the Scopus electronic database are listed to determine which articles can provide information on how ESD is integrated into

biology education. The initial keywords used for the search were "biology" and "learning" and "ESD" or "biology" and "education" and "ESD." These keywords are used to obtain comprehensive search results and to avoid missing relevant articles. In the initial search, limitations were only set on the year of publication. In subsequent searches, limitations were set in the subject area of social sciences as the research target being examined is educational research. The filtering procedures and search results are presented in Table 1 with two categories based on the keywords used, allowing other researchers to apply it systematically. Furthermore, the abstracts of the articles are scanned,

and those that do not meet the inclusion criteria are eliminated.

In the second search, the targeted articles were research articles, thus excluding other documents such as reviews, conference articles, editorials, books, and book chapters. Several articles obtained from the database were filtered out because they did not meet the inclusion criteria. The articles obtained with the keywords "biology," "education," and "ESD" were more numerous compared to the search using the keywords "biology," "learning," and "ESD," indicating that the keyword "education" captured more relevant articles than the keyword "learning."

Table 1 Selection process on Scopus database

Selection process	Keywords including 'biology' and 'education' and 'ESD'	Keywords including 'biology' and 'learning' and 'ESD'
First search		
Keywords search in all fields	34	21
Second search		
Articles limited to English	33	20
Document type limited to article	25	14
Subject area limited to social sciences	23	12
Publication stage limited to final	22	11
Screening		
The abstracts of the articles in the second search were reviewed to assess whether the articles met the inclusion criteria	9	3

Subsequently, abstract screening was conducted on all of these articles. After performing abstract screening on each keyword pattern, a total of nine articles containing the keyword "education" and three articles containing the keyword "learning" were obtained. Since the three articles found with the keyword "learning" were the same articles also discovered in the search with the keyword "education," the total number of articles to be analyzed is nine. All articles are direct empirical data articles, with the earliest publication year being 2017, as shown in Figure 1.

3) Systematic categorization process:
The reviewed articles and the extracted information were tabulated consistently and structured to effectively manage the obtained information (Siddaway et al., 2019). The analyzed articles were coded based on the author's name, year of publication, article summary, keywords used, research objectives, participants and their countries, research methods, and the main themes of the research results, including perspectives of prospective teachers or strategies for implementing ESD-oriented learning. This research used a content analysis approach as an objective and systematic method (Neuendorf, 2017), categorizing the data. Content analysis allows for exploration of various topics and helps to identify specific concepts or themes reflected by the frequency of occurrence (Duriau et al., 2007).

C. Results and discussion

This study reviewed scientific articles indexed in the Scopus electronic database, covering the publication period from 2015 to 2024. Following the application of predetermined selection criteria, relevant articles pertaining to the variables under investigation were identified for the years 2017 to 2020, as well as 2022 and 2024. No relevant articles meeting the study criteria were found for the years 2015 to 2016, 2021, and 2023, as seen in Figure 1. The research article published in 2017 until 2019 consisted of only one article, as well as in 2024 (Büssing et al., 2018; Fanta et al., 2019; García-Fortes et al., 2024; Schuler et al., 2017).

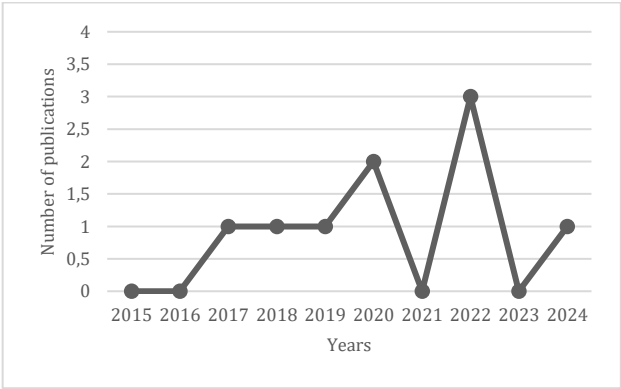


Figure 1 Number of publications

The highest number of publications occurred in 2022, with three empirical research articles (Handtke et al., 2022; Mandikonza, 2022; Purwianingsih et al., 2022). The country of origin of the reviewed research articles indicates that the available empirical research data comes only from a few countries, predominantly from developed countries, as can be seen in Figure 2. The identified empirical research data came from six countries, with the majority of the data presented in the research articles coming from Germany, which has a total of five articles (Büssing et al., 2018; Fanta et al., 2019; Handtke et al., 2022; Schuler et al., 2017; A. Weber et al., 2020).

The data presented comes from Indonesia, South Africa, and Spain, with each having one research article (García-Fortes et al., 2024; Mandikonza, 2022; Purwianingsih et al., 2022). Meanwhile, the data from Austria and Slovenia is included in one research article (Bezeljak et al., 2020).

Research Methods

The majority of the articles analyzed are quantitative studies, comprising for 67% of the total articles reviewed, namely nine articles, while 22% are qualitative studies, and 11% are studies with a mixed-method approach, as shown in Figure 3. The quantitative approach in empirical research predominantly uses survey studies employing questionnaires and quasi-experimental approaches. The qualitative approach uses descriptive qualitative study designs and qualitative interpretive case studies, with data collection instruments including observation, documentation, interviews, and lesson plan analysis (Mandikonza, 2022; Purwianingsih et al., 2022).

Furthermore, empirical research using a mixed-method approach combines quantitative and qualitative methods, with data collection utilizing Likert scale instruments and learning design analysis (García-Fortes et al., 2024). Participants The majority of participants in the analyzed research are undergraduate and graduate students, as shown in Figure 4. However, there are studies that feature a more diverse range of participants, such as the research by Handtke et al. (2022). A total of 88.8% of the research articles involved undergraduate students as research participants (Bezeljak et al., 2020; Büssing et al., 2018; Fanta et al., 2019; Handtke et al., 2022; Mandikonza, 2022; Purwianingsih et al., 2022; Schuler et al., 2017; A. Weber et al., 2020). In addition to undergraduate students, several studies also included graduate students (Bezeljak et al., 2020; Handtke et al., 2022).

Some studies not only involved prospective biology teachers but also included prospective teachers studying other fields such as geography, natural sciences, and politics (Fanta et al., 2019; Mandikonza, 2022; Purwianingsih et al., 2022; Schuler et al., 2017).

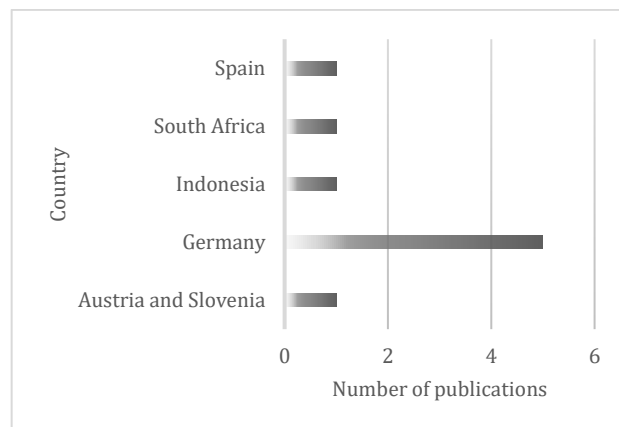


Figure 2 Country of origin of the articles

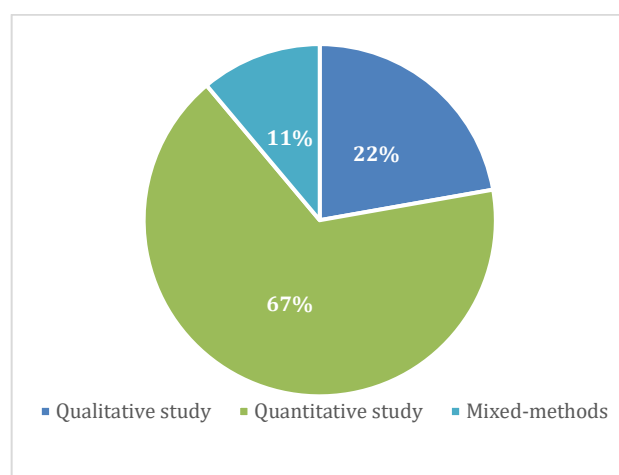


Figure 3 Methods of articles

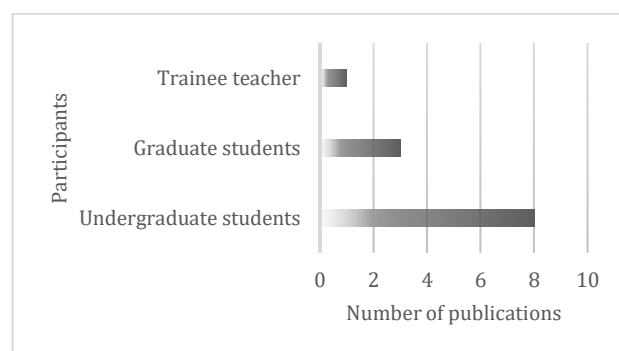


Figure 4 Participants of each publication

Themes

The empirical research analyzed was grouped into several main themes as shown in Table 2, which includes participants' views covering subcategories of perceptions and self-efficacy (García-Fortes et al., 2024; Handtke et al., 2022), competencies possessed by prospective teachers (Bezeljak et al., 2020; Mandikonza, 2022; Purwianingsih et al., 2022), models and strategies for ESD (Education for Sustainable Development) teaching for prospective teachers (Fanta et al., 2019; Mandikonza, 2022; Schuler et al., 2017) as well as social and psychological factors

(Büssing et al., 2018; A. Weber et al., 2020) that influence prospective teachers in practicing sustainability in daily life and how these factors can

affect their competencies in applying ESD in classroom learning. The table further presents the key findings of the reviewed studies.

Table 2 Major themes

Themes	Reference	Key findings
Perceptions and self-efficacy	García-Fortes et al. (2024)	Prospective teachers' perceptions of being able to apply ESD in learning, but contrary to their abilities
	Handtke et al. (2022)	Undergraduate students have a higher level of self-efficacy to implement ESD in education, compared to graduate students
Competency	Bezeljak et al. (2020)	Understanding is often skewed toward environmental aspects, while pedagogical principles of ESD are partially recognized
	Purwianingsih et al. (2022)	Prospective teachers demonstrated low levels of competence in TPACK-ESD
ESD learning models and strategies for prospective teachers	Fanta et al. (2019)	Technical, didactical, and combination of both approaches significantly fostering systems thinking of prospective biology teachers
	Mandikonza (2022)	Discussion and sharing insights in group learning help prospective teachers understand certain concepts
	Schuler et al. (2017)	Technical based, didactical based, or a combination of both could enhance student teachers' systems thinking skills
	Büssing et al. (2018)	Closeness psychologically to an issue and having a high motivation related to the conservation topic, creating a more positive attitude, greater enjoyment
Psychological and social factors	J. Weber et al. (2020)	The extended theory of planned behavior (TPB) model is suitable for predicting the intention to eat sustainable. Social and psychological factors influence prospective biology teachers' intentions to eat sustainably

This review aims to uncover information on how the research trends related to prospective teacher students and Education for Sustainable Development (ESD) have evolved over the past ten years through empirical studies published in Scopus-indexed journals. The review focuses on obtaining information from relevant previous empirical studies concerning the perspectives and readiness of prospective teacher students towards the implementation of ESD. This is examined in terms of the perceptions and competencies possessed by prospective teacher students. A review of the views of prospective teacher students is necessary because it can influence their competencies and the implementation of ESD in education (Cebrián & Junyent, 2015; Mogren et al., 2019).

This discussion begins with an exploration of the country of origin of articles that conduct studies relevant to the variables under study. The previous empirical studies retrieved show a fluctuating pattern, with the majority originating from Germany. The quantitative approach is the most commonly used method to gather information related to the views, competencies, models, and strategies of ESD for prospective teacher students, as well as the influence of social and psychological factors on the implementation of ESD.

Most empirical research on prospective teacher students, ESD, and biology education explores information from undergraduate students and generally focuses on the field of biology. Existing research also involves graduate students. Some of the analyzed empirical studies do not only involve

prospective biology teacher students but also prospective teacher students studying other fields such as geography, natural sciences, and politics. There are studies that involve trainee teachers; however, the data obtained from this participant group are still very limited, especially in the field of biology. The categorization of results from previous empirical studies consists of four main groups: perceptions and self-efficacy, competencies, models and strategies for ESD, and social and psychological factors. Each category is explained by the research findings.

Perceptions and self-efficacy

The perceptions expressed by biology prospective teachers in the study by García-Fortes et al. (2024) differ from the competencies they possess. Prospective teachers feel that they have the competence to implement ESD in education, but their competencies reflect otherwise. There are various challenges faced by prospective teacher students. This is evident from the suboptimal implementation of ESD in lesson planning. Additionally, prospective teachers also face challenges in assessing changes in student attitudes and behaviors regarding sustainability. This may be caused by the diverse mindsets demonstrated by students related to sustainability topics and their resistance to change (Marcos-Merino et al., 2020; Swaim et al., 2014). Difficulties are also identified in applying a holistic approach that considers social, economic, and political factors in education. This is different when using the surrounding environment as a source of learning. Nevertheless, utilizing the surrounding environment can help address challenges

related to abstract sustainability concepts (Yli-Panula et al., 2022). Furthermore, in the research by Handtke et al. (2022) a high level of self-efficacy is also shown by undergraduate biology prospective teachers in implementing ESD in education, especially among undergraduate students, who exhibit higher level of self-efficacy compared to graduate students.

Competency

Research by oleh Purwianingsih et al. (2022) shows that the competencies of prospective teachers in TPACK-ESD are still categorized as low. The study explains that improving ESD competencies requires relevant program interventions implemented over a longer period. Nevertheless, ESD training can significantly enhance TPACK-ESD competencies (Brandt et al., 2022; Novidsa et al., 2021). The study by Bezeljak et al. (2020) also shows that prospective teachers recognize several pedagogical principles of ESD and the Sustainable Development Goals (SDGs). Active learning principles and transformative education have been acknowledged, but there is still a lack of understanding regarding the interconnection between sustainability aspects, namely environmental, social, and economic aspects. However, regarding environmental aspects in sustainable development, prospective teachers have a good understanding and often link ESD with environmental education. This can be explained as the concept of sustainability is often associated with environmental aspects, while social and economic aspects are often neglected (Borg & Gericke, 2021; Lavey, 2024). A perspective that considers social, economic, and environmental aspects needs to be mastered by teachers to create learning with a holistic approach, which can be practiced by applying interdisciplinary learning methods and case studies (Gorski et al., 2023; Greenland et al., 2023; Sánchez-Carrillo et al., 2021).

Education for Sustainable Development learning models and strategies for prospective teachers

Thinking systemically is one of the key competencies in ESD (UNESCO, 2017). This competency must not only be mastered by students but also by teachers as educators. Research by Fanta et al. (2019) shows the intervention conducted significantly fostering systems thinking of prospective biology teachers. Consisted of three different courses, i.e. technical course (focusing on technical fundamentals of system science), didactic course (focusing on didactical fundamentals for teaching systems thinking), and mixed course, combination of the two previous courses, both technical and didactical fundamentals.

Schuler et al. (2017) explain that the enhancement of prospective teachers' systems thinking skills also increases when participating in courses based on technical, didactic, or a combination of both. These approaches not only improve systems thinking skills but also the Pedagogical Content

Knowledge (PCK) of prospective teachers. This insight is necessary because teachers' content and pedagogical knowledge play a crucial role in enhancing students' systems thinking skills (Rosenkränzer et al., 2017; Streiling et al., 2021).

Mandikonza (2022) shows that discussion and sharing insights in group learning help prospective teachers understand certain concepts. This is because experienced prospective teachers can assist their peers in understanding the material. This is relevant to social constructivism theory, which encourages student engagement, discussion, and knowledge exchange, thereby fostering active interaction in learning. Additionally, the development of teachers' professional competencies in implementing ESD can be assisted by using references, such as modules that integrate theory and practice (Brandt et al., 2019) which can serve as a guideline for teachers in implementing ESD in their teaching.

Psychological and social factors

As an integral factor of competency in teaching relevant learning topics, research by J. Weber et al. (2020) shows how social and psychological factors influence prospective biology teachers' intentions to eat sustainably. Intention to eat sustainably affected by positive attitudes, high subjective norm, and high perceived behavioral control, which is the variables of the theory of planned behavior (TPB). Furthermore, the closeness to nature and positive altruistic concern (the extended variables of TPB) affect the attitudes and intentions of prospective teachers to adopt sustainable eating habits. This indicates that the nutritional behavior of prospective teachers may influence their desire to teach the topic (Weber et al., 2021). In short, the extended TPB model is suitable for predicting the intention to eat sustainably (A. Weber et al., 2020). Furthermore, research by Büssing et al. (2018) indicates that when an issue is psychologically close to prospective teachers and they have a high motivation related to the conservation of specific species, it creates a more positive attitude, greater enjoyment (Büssing et al., 2020) and a feeling of greater capability in teaching sustainability issues. Thus, it can be understood that behavioral patterns, intentions, psychological closeness, and the motivation of prospective teachers can be potential factors that influence the implementation of ESD-based learning. This review indicates that further research is needed to explore additional factors that positively influence the implementation of ESD in teaching by prospective teachers, as well as other competencies and models or approaches that can be applied to improve the competence of prospective teachers in applying ESD.

Based on the analysis of existing empirical studies, it can be understood that prospective teachers' perceptions and self-efficacy levels often do not align with their actual ability to implement Education for Sustainable Development (ESD) in classroom practice.

Furthermore, several studies have proposed strategies to enhance prospective teachers' systems thinking skills—one of the core competencies in ESD—through technical, didactical, or combination of both approaches. In addition, collaborative discussions and the sharing of insights in group learning settings have been shown to support prospective teachers in developing a deeper understanding of key concepts. This aligns with the principles of humanizing pedagogy, which is increasingly recognized as a relevant approach within the ESD framework. The analysis also highlights that social and psychological factors can significantly influence positive attitudes and the adoption of sustainability-related behaviors among prospective teachers.

The results of this analysis can serve as a foundation for enhancing teacher quality through teacher education programs in higher education. This includes conducting needs and competency analyses, implementing appropriate strategies, and determining effective interventions to strengthen teachers' ability to design learning experiences aligned with the principles of Education for Sustainable Development (ESD), thereby supporting the achievement of sustainability objectives.

D. Conclusion

This study presents a systematic review of research on prospective teachers and ESD. Based on the review of prospective teachers' perceptions and competencies, it was found that while they have high self-efficacy in implementing ESD, this contradicts their actual competencies. Strategies that can be implemented in learning process to enhance one of the core competencies in ESD; systems thinking skills; include technical, didactical, and combination of both approaches. Enhancing the understanding of prospective teachers can also be achieved through discussions and the exchange of ideas in group learning settings. The review findings also indicate that social and psychological factors are potential influences on the implementation of ESD-based learning. Furthermore, the insights gained from this systematic review can serve as a foundation for future researchers to conduct studies related to the implementation of ESD in biology learning.

E. References

- Abera, H. G. (2023). The role of education in achieving the sustainable development goals (SDGs): A global evidence based research article. *International Journal of Social Science and Education Research Studies*, 3(01), 67-81. DOI: <https://doi.org/10.55677/ijssers/v03i1y2023-09>
- Aboytes, J. G. R., & Barth, M. (2020). Transformative learning in the field of sustainability: A systematic literature review (1999-2019). *International Journal of Sustainability in Higher Education*, 21, 993–1013. DOI: <https://doi.org/10.1108/ijshe-05-2019-0168>
- Ahmad, L., & Sosa, M. (2025). *Teaching design for sustainable futures: community, construction, and creativity*. Taylor & Francis. Retrieved from <https://www.taylorfrancis.com/books/edit/10.4324/9781003495444/teaching-design-sustainable-futures-lina-ahmad-marco-sosa>
- Akinwumi, I. O. (2023). Biology education: A panacea to global environmental challenges. *European Journal of Training and Development Studies*, 10(2), 44–56. DOI: <https://doi.org/10.37745/ejtds.2014/vol10n24456>
- Alexander, C., Wyatt-Smith, C., & Plessis, A. E. Du. (2020). The role of motivations and perceptions on the retention of inservice teachers. *Teaching and Teacher Education*, 96, 103186. DOI: <https://doi.org/10.1016/j.tate.2020.103186>
- Almeida, S. C., Moore, D., & Barnes, M. L. (2018). Teacher identities as key to environmental education for sustainability implementation: A study from Australia. *Australian Journal of Environmental Education*, 34, 228–243. DOI: <https://doi.org/10.1017/ae.2018.40>
- Assaraf, O. B., Dodick, J., & Tripto, J. (2013). High school students' understanding of the human body system. *Research in Science Education*, 43, 33–56. DOI: <https://doi.org/10.1007/s11165-011-9245-2>
- Avsec, S., & Ferik Savec, V. (2021). Pre-service teachers' perceptions of, and experiences with, technology-enhanced transformative learning towards education for sustainable development. *Sustainability*, 13(18), 10443. DOI: <https://doi.org/10.3390/su131810443>
- Bennett, J., Lubben, F., Hogarth, S., Campbell, B., & Robinson, A. (2005). *A systematic review of the nature of small-group discussions aimed at improving students' understanding of evidence in science*. In: *Research Evidence in Education Library*. Retrieved from <http://eppi.ioe.ac.uk/>
- Bezelsjak, P., Scheuch, M., & Torkar, G. (2020). Understanding of sustainability and education for sustainable development among pre-service biology teachers. *Sustainability (Switzerland)*, 12(17), 6892. DOI: <https://doi.org/10.3390/SU12176892>
- Borg, F., & Gericke, N. (2021). Local and global aspects: Teaching social sustainability in Swedish Preschools. *Sustainability*, 13(7), 3838. DOI: <https://doi.org/10.3390/SU13073838>
- Brandt, J. O., Bürgener, L., Barth, M., & Redman, A. (2019). Becoming a competent teacher in education for sustainable development: Learning outcomes and processes in teacher education. *International Journal of Sustainability in Higher Education*, 20(4), 630–653. DOI: <https://doi.org/10.1108/IJSHE-10-2018-0183>
- Brandt, J. O., Barth, M., Hale, A., & Merritt, E. (2022). Developing ESD-specific professional action

- competence for teachers: Knowledge, skills, and attitudes in implementing ESD at the school level. *Environmental Education Research*, 28, 1691–1729. DOI: <https://doi.org/10.1080/13504622.2022.2064973>
- Buettner, C. K., Jeon, L., Hur, E., & Garcia, R. (2016). Teachers' social-emotional capacity: factors associated with teachers' responsiveness and professional commitment. *Early Education and Development*, 27, 1018–1039. DOI: <https://doi.org/10.1080/10409289.2016.1168227>
- Büssing, A., Dupont, J., & Menzel, S. (2020). Topic specificity and antecedents for preservice biology teachers' anticipated enjoyment for teaching about socioscientific issues: Investigating universal values and psychological distance. *Frontiers in Psychology*, 11, 1536. DOI: <https://doi.org/10.3389/fpsyg.2020.01536>
- Büssing, A. G., Schleper, M., & Menzel, S. (2018). Do pre-service teachers dance withwolves? Subject-specific teacher professional development in a recent biodiversity conservation issue. *Sustainability (Switzerland)*, 11(1), 47. DOI: <https://doi.org/10.3390/su11010047>
- Cebrián, G., & Junyent, M. (2015). Competencies in education for sustainable development: Exploring the student teachers' views. *Sustainability (Switzerland)*, 7(3), 2768–2786. DOI: <https://doi.org/10.3390/su7032768>
- Cebrián, G., Palau, R., & Mogas, J. (2020). The smart classroom as a means to the development of ESD methodologies. *Sustainability*, 12(7), 3010. DOI: <https://doi.org/10.3390/su12073010>
- Century, J. (2023). The power of teachers' perceptions. *Phi Delta Kappan*, 104(6), 44–49. DOI: <https://doi.org/10.1177/00317217231161540>
- Colucci-Gray, L., Camino, E., Barbiero, G., & Gray, D. (2006). From scientific literacy to sustainability literacy: An ecological framework for education. *Science Education*, 90(2), 227–252. DOI: <https://doi.org/10.1002/sce.20109>
- Cooper, M. M., Caballero, M. D., Carmel, J. H., Duffy, E. M., Ebert-May, D., Fata-Hartley, C. L., Herrington, D. G., Lavery, J. T., Nelson, P. C., & Posey, L. A. (2024). Beyond active learning: Using 3-Dimensional learning to create scientifically authentic, student-centered classrooms. *Plos One*, 19(5), e0295887. DOI: <https://doi.org/10.1371/journal.pone.0295887>
- Demssie, Y. N., Biemans, H. J. A., Wesselink, R., & Mulder, M. (2023). Fostering students' systems thinking competence for sustainability by using multiple real-world learning approaches. *Environmental Education Research*, 29(2), 261–286. DOI: <https://doi.org/10.1080/13504622.2022.2141692>
- Education for All Global Monitoring Report. (2013). *2013 Education for All global monitoring report: teaching and learning for development*. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000219171_eng
- Eliyawati, Widodo, A., Kaniawati, I., & Fujii, H. (2024). *Penerapan ESD dalam pembelajaran IPA*. Bandung: UPI Press.
- Fanta, D., Braeutigam, J., & Riess, W. (2019). Fostering systems thinking in student teachers of biology and geography—an intervention study. *Journal of Biological Education*, 54(3), 226–244. DOI: <https://doi.org/10.1080/00219266.2019.1569083>
- García-Fortes, M. Á., Banos-González, I., & Esteve-Guirao, P. (2024). ESD action competencies of future teachers: Self-perception and competence profile analysis. *International Journal of Sustainability in Higher Education*, 25(8), 1558–1580. DOI: <https://doi.org/10.1108/IJSHE-07-2023-0323>
- Gorski, A., Ranf, E.-D., Badea, D., Halmaghi, E.-E., & Gorski, H. (2023). Education for Sustainability—Some bibliometric insights. *Sustainability*, 15(20), 14916. DOI: <https://doi.org/10.3390/su152014916>
- Greenland, S., Saleem, M., Misra, R., Nguyen, N., & Mason, J. (2023). Reducing SDG complexity and informing environmental management education via an empirical six-dimensional model of sustainable development. *Journal of Environmental Management*, 344, 118328. DOI: <https://doi.org/10.2139/ssrn.4402064>
- Handtke, K., Richter-Beuschel, L., & Bögeholz, S. (2022). Self-efficacy beliefs of teaching ESD: A theory-driven instrument and the effectiveness of ESD in German Teacher Education. *Sustainability (Switzerland)*, 14(11), 6477. DOI: <https://doi.org/10.3390/su14116477>
- Hernandez Gonzalez, F. (2023). Exploring the affordances of place-based education for advancing sustainability education: The role of cognitive, socio-emotional and behavioural learning. *Education Sciences*, 13(7), 676. DOI: <https://doi.org/10.3390/educsci13070676>
- Khoo, S., & Jørgensen, N. J. (2021). Intersections and collaborative potentials between global citizenship education and education for sustainable development. *Globalisation, Societies and Education*, 19(4), 470–481. DOI: <https://doi.org/10.1080/14767724.2021.1889361>
- Kioupi, V., & Voulvoulis, N. (2019). Education for sustainable development: A systemic framework for connecting the SDGs to educational outcomes. *Sustainability (Switzerland)*, 11(21), 6104. DOI: <https://doi.org/10.3390/su11216104>
- Kordova, S. K., Frank, M., & Miller, A. N. (2018). Systems thinking education—seeing the forest through the trees. *Systems*, 6(3), 29. DOI: <https://doi.org/10.3390/systems6030029>
- Lavey, W. (2024). Sustainability evolved for experts but students fell behind: Teaching interrelated social, economic and environmental goals.

- International Journal of Sustainability in Higher Education*, 25(6), 1180-1197. DOI: <https://doi.org/10.1108/ijshe-07-2023-0327>
- Mahanes, S. A., Sorte, C. J. B., & Bracken, M. E. S. (2023). The functional effects of a dominant consumer are altered following the loss of a dominant producer. *Ecology and Evolution*, 13(8), e10342. DOI: <https://doi.org/10.1002/ece3.10342>
- Mandikonza, C. (2022). Collaborative learning experiences and development of capabilities among first-year pre-service teachers learning Cell Biology concepts. *Social Sciences and Humanities Open*, 5(1), 100254. DOI: <https://doi.org/10.1016/j.ssaho.2022.100254>
- Marcos-Merino, J., Corbacho-Cuello, I., & Hernández-Barco, M. (2020). Analysis of sustainability knowingness, attitudes and behavior of a spanish pre-service primary teachers sample. *Sustainability*, 12, 7445. DOI: <https://doi.org/10.3390/su12187445>
- Mogren, A., Gericke, N., & Scherp, H. Å. (2019). Whole school approaches to education for sustainable development: A model that links to school improvement. *Environmental Education Research*, 25(4), 508-531. DOI: <https://doi.org/10.1080/13504622.2018.1455074>
- Momsen, J., Speth, E. B., Wyse, S., & Long, T. (2022). Using systems and systems thinking to unify biology education. *CBE—Life Sciences Education*, Summer, 1-11. DOI: <https://doi.org/10.1187/cbe.21-05-0118>
- Neuendorf, K. A. (2017). *The content analysis guidebook* (2nd ed.). SAGE Publications, Inc.
- Nguyen-Van, P., Stenger, A., & Tiet, T. (2021). Social incentive factors in interventions promoting sustainable behaviors: A meta-analysis. *PLoS ONE*, 16(12), e0260932. DOI: <https://doi.org/10.1371/journal.pone.0260932>
- Novidsa, I., Purwianingsih, W., & Riandi, R. (2021, March). Technological pedagogical content knowledge (TPACK) prospective biology teacher in integrating education for sustainable development (ESD) in their learning planning. In *Journal of Physics: Conference Series* (Vol. 1806, No. 1, p. 012163). IOP Publishing. DOI: <https://doi.org/10.1088/1742-6596/1806/1/012163>
- Pimdee, P. (2020). Antecedents of Thai student teacher sustainable consumption behavior. *Heliyon*, 6(8), e04676. DOI: <https://doi.org/10.1016/j.heliyon.2020.e04676>
- Pratiwi, E. D., Masykuri, M., & Ramli, M. (2021). Active learning strategy on higher education biology learning: A systematic review. *Tadris: Jurnal Keguruan dan Ilmu Tarbiyah*, 6(1), 75-86. DOI: <https://doi.org/10.24042/tadris.v6i1.7345>
- Purwianingsih, W., Novidsa, I., & Riandi, R. (2022). Program for integrating education for sustainable development (ESD) into prospective biology teachers' technological pedagogical content knowledge (TPACK). *Jurnal Pendidikan IPA Indonesia*, 11(2), 219-228. DOI: <https://doi.org/10.15294/jpii.v11i2.34772>
- Riess, W., Mischo, C., Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal of Science Education*, 32(6), 705-725. DOI: <https://doi.org/10.1080/09500690902769946>
- Rosenkränzer, F., Hörsch, C., Schuler, S., & Riess, W. (2017). Student teachers' pedagogical content knowledge for teaching systems thinking: effects of different interventions. *International Journal of Science Education*, 39, 1932-1951. DOI: <https://doi.org/10.1080/09500693.2017.1362603>
- Rushton, E. A. C., & Walshe, N. (2022). Climate change, sustainability and the environment: The continued importance of biological education. In *Journal of Biological Education* (Vol. 56, Issue 3, pp. 243-244). Taylor & Francis. DOI: <https://doi.org/10.1080/00219266.2022.2116843>
- Russell, A. E., Aide, T. M., Braker, E., Ganong, C. N., Hardin, R. D., Holl, K. D., Hotchkiss, S. C., Klemens, J. A., Kuprewicz, E. K., & McClearn, D. (2022). Integrating tropical research into biology education is urgently needed. *PLoS Biology*, 20(6), e3001674. DOI: <https://doi.org/10.1371/journal.pbio.3001674>
- Saleem, A., & Dare, P. S. (2023). Unmasking the action-oriented ESD approach to acting environmentally friendly. *Sustainability*, 15(2), 1675. DOI: <https://doi.org/10.3390/su15021675>
- Sánchez-Carrillo, J., Cadarso, M., & Tobarra, M. (2021). Embracing higher education leadership in sustainability: A systematic review. *Journal of Cleaner Production*, 298, 126675. DOI: <https://doi.org/10.1016/j.jclepro.2021.126675>
- Saragih, L., & Solihat, R. (2021). The implementation of ESD into biology learning to equip students with ESD competencies of systemic thinking and problem-solving. In *Journal of Physics: Conference Series* (Vol. 1806, No. 1, p. 012158). IOP Publishing. DOI: <https://doi.org/10.1088/1742-6596/1806/1/012158>
- Schneiderhan-Opel, J., & Bogner, F. X. (2021). Cannot see the forest for the trees? Comparing learning outcomes of a field trip vs. a classroom approach. *Forests*, 12(9), 1265. DOI: <https://doi.org/10.3390/f12091265>
- Schuler, S., Fanta, D., Rosenkraenzer, F., & Riess, W. (2017). Systems thinking within the scope of education for sustainable development (ESD)—a heuristic competence model as a basis for (science) teacher education. *Journal of Geography in Higher Education*, 42(2), 192-204. DOI: <https://doi.org/10.1080/03098265.2017.1339264>
- Setiawan, H., Surtikanti, H. K., Kusnadi, K., & Riandi, R. (2023). Sustainability awareness, engagement, and perception of indonesian high school students during sustainability project based learning

- implementation in biology education. *Jurnal Penelitian Pendidikan IPA*, 9(6), 4227–4236. DOI: <https://doi.org/10.29303/jppipa.v9i6.3971>
- Shabrina, A., Suhartini, S., & Huang, T. C. (2024). Problem-based learning tool integrated with education for sustainable development on biodiversity topic to improve science literacy. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 12(2), 338–353. DOI: <https://dx.doi.org/10.24815/jpsi.v12i2.36218>
- Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annu. Rev. Psychol.*, 70, 747–770. DOI: <https://doi.org/10.1146/annurev-psych-010418>
- Streiling, S., Hörsch, C., & Riess, W. (2021). Effects of teacher training in systems thinking on biology students—An intervention study. *Sustainability*, 13(14), 7631. DOI: <https://doi.org/10.3390/SU13147631>
- Swaim, J., Maloni, M., Napshin, S., & Henley, A. (2014). Influences on student intention and behavior toward environmental sustainability. *Journal of Business Ethics*, 124, 465–484. DOI: <https://doi.org/10.1007/S10551-013-1883-Z>
- Swanson, J. D., Brock, L., Van Sickle, M., Gutshall, C. A., & Curby, T. W. (2022). Teacher perceptions as an entry point for talent spotting and development. *Journal for the Education of the Gifted*, 45(3), 238–270. DOI: <https://doi.org/10.1177/01623532221105311>
- Tandler, N., & Dalbert, C. (2020). Always look on the bright side of students: does valence of teacher perceptions relate to students' educational performance? *Social Psychology of Education*, 23, 1121–1147. DOI: <https://doi.org/10.1007/s11218-020-09573-z>
- Thompson, P., & Norris, P. (2021). *Sustainability and Ecology, in Sustainability*. Oxford University Press. DOI: <https://doi.org/10.1093/wentk/9780190883249.003.0003>
- Timm, J., & Barth, M. (2020). Making education for sustainable development happen in elementary schools: the role of teachers. *Environmental Education Research*, 27, 50–66. DOI: <https://doi.org/10.1080/13504622.2020.1813256>
- Tschantz, A., Seth, A. K., & Buckley, C. L. (2020). Learning action-oriented models through active inference. *PLoS Computational Biology*, 16(4), e1007805. DOI: <https://doi.org/10.1371/journal.pcbi.1007805>
- UNESCO. (2017). Education for sustainable development goals (SDGs). In *European Conference on Educational Research 2017*. UNESCO. DOI: <https://doi.org/10.54675/CGBA9153>
- Vukelić, N., & Rončević, N. (2021). Student teachers' sustainable behavior. *Education Sciences*, 11(12), 789. DOI: <https://doi.org/10.3390/educsci11120789>
- Weber, A., Büssing, A. G., Jarzyna, R., & Fiebelkorn, F. (2020). Do German student biology teachers intend to eat sustainably? Extending the theory of planned behavior with nature relatedness and environmental concern. *Sustainability (Switzerland)*, 12(12), 4909. DOI: <https://doi.org/10.3390/SU12124909>
- Weber, A., Hahn, S., & Fiebelkorn, F. (2021). Teach what you eat: Student biology teachers' intention to teach sustainable nutrition. *Journal of Nutrition Education and Behavior*, 53(12), 1018–1027. DOI: <https://doi.org/10.1016/j.jneb.2021.07.012>
- Weber, J. M., Lindenmeyer, C. P., Liò, P., & Lapkin, A. A. (2020). *Teaching sustainability as complex systems approach: A sustainable development goals workshop*. *International Journal of Sustainability in Higher Education*, 22(8), 25–41. DOI: <https://doi.org/10.1108/IJSHE-06-2020-0209>
- Wenderoth, M. P., Scott, E., Jackson, M., Cerchiara, J., Moon, S., McFarland, J., & Doherty, J. (2020). Developing a learning progression in physiology to characterize how students reason about ion movement. *The FASEB Journal*, 34(S1), 1. DOI: <https://doi.org/10.1096/fasebj.2020.34.s1.09744>
- Wisinski, J., & Yu, A. (2020). Is the Bloom taxonomy level of student-generated exam-style questions predictive of exam performance? *The FASEB Journal*, 34(S1), 1. DOI: <https://doi.org/10.1096/fasebj.2020.34.s1.03999>
- Yli-Panula, E., Jeronen, E. K., & Mäki, S. (2022). School culture promoting sustainability in student teachers' views. *Sustainability*, 14(12), 7440. DOI: <https://doi.org/10.3390/su14127440>
- Yuan, X., Yu, L., Wu, H., She, H., Luo, J., & Li, X. (2022). Sustainable development goals (SDGs) priorities of senior high school students and global public: Recommendations for implementing education for sustainable development (ESD). *Education Research International*, 2022(1), 2555168. DOI: <https://doi.org/10.1155/2022/2555168>
- Zeyer, A. (2024). Scientific holism: A synoptic (“two-eyed seeing”) approach to science transfer in education for sustainable development, tested with pre-service teachers. *Sustainability*, 16(6), 2279. DOI: <https://doi.org/10.3390/su16062279>
- Zguir, M. F., Dubis, S., & Koç, M. (2021). Embedding education for sustainable development (ESD) and SDGs values in curriculum: A comparative review on Qatar, Singapore and New Zealand. *Journal of Cleaner Production*, 319(June), 128534. DOI: <https://doi.org/10.1016/j.jclepro.2021.128534>
- Zhai, X., & Jackson, D. F. (2023). *A pedagogical framework for mobile learning in science education* (R. J. Tierney, F. Rizvi, & K. B. T.-I. E. of E. (Fourth E. Ercikan, Eds.; pp. 215–223). Elsevier. DOI: <https://doi.org/10.1016/B978-0-12-818630-5.13037-4>