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Author(s): Daneshpour, Hosein; Kwegyir-Afful, Ebo

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Analysing Transdisciplinary Education: A Scoping Review

Hosein Daneshpour¹ · Ebo Kwegyir-Afful²

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Abstract

The present study sheds light on transdisciplinary education through the application of a scoping literature review, as a lack of a comprehensive synthesis in this area is evident. Thus, the overview frames and outlines the scattered research that has been fulfilled until now in this field. As a result, within transdisciplinary education, medical and adolescent themes form the main scopes, while within sustainable transdisciplinary education, pedagogical design, socio-efficiency, and philosophy are the major themes. Furthermore, the present study contributes to the understanding of transdisciplinary education by highlighting the avenues for future research. Consequently, the translation of transdisciplinary teaching practices to comparable languages and an increase of transparency in the application and reporting of the transdisciplinary design steps are suggested.

Keywords Transdisciplinary · Pedagogy · Teacher education · Teaching · Innovation

1 Introduction

The dominant approach in the current university and educational system is based on a single-disciplinary style, though various attempts and experiments have been conducted to shift the education towards interdisciplinary or transdisciplinary approaches in order to better meet real-world expectations (Fortuin & Van Koppen, 2016; Knuuttila, 2013). A similar drawback in the building blocks of teaching guidelines through siloed pedagogical competencies can be observed (Jordan et al., 2008). Tackling this challenge requires a rigorous combination of modern pedagogy, facilitators, and different views (Klaassen, 2018).

The history of the transdisciplinary model goes back to the year 1840 to the term “consilience”, which refers to a “jumping together of knowledge by linking facts across disciplines to develop a common explanation” (Glittenberg, 2004, p. 8), where the author anticipated the demand for a more rigorous learning process by interweaving knowledge of humanity and natural science. Nonetheless, the first observation of the term, transdisciplinary, dates back to the year 1982 (Glittenberg, 2004). Meanwhile, some studies noted the challenges of

✉ Hosein Daneshpour
H.daneshpour@gmail.com

¹ School of Professional Teacher Education, Oulu University of Applied Sciences, Yliopistokatu 9, 90570 Oulu, Finland

² School of Technology and Innovations, University of Vaasa, Vaasa, Finland

the siloed educational system, the barriers to merging different disciplines, and the essential competencies (e.g., Hansmann et al., 2009; Smith & Christie, 2004). Generally, the issue of transdisciplinary education requires opening the closed boundaries of the subjects or disciplines for integration “to see a variety of situations as like each other” (Jakobsen & Bucciarelli, 2007, p. 299). Likewise, Hammer and Söderqvist (2001) highlighted that the vital measures in experimental transdisciplinary teachings are the improvement of the student awareness of various disciplinary terminologies and expressions to ease communications and the development of critical thinking in students to grow their capabilities to view the world from different angles. Similarly, Grey and Connolly (2008) explained the difficulty of transdisciplinary education by stating, “coming together is a beginning; keeping together is progress; working together is success” (p. 102). This educational paradigm needs an integrated model of education and a cooperative team and commitments from various academic units and authorities in order to combine different curricula (McDaniel et al., 2008). However, a variety of academic disciplines have not yet systematically engaged with the transdisciplinary approach (Collin, 2009; Meneses & McNeese, 2007). Nevertheless, the development of integrated curricula as an emerging phenomenon is gaining considerable attention in the advanced educational systems needing integration across disciplines (Lam et al., 2013).

Accordingly, three main types of collaboration and integration between different disciplines can be determined: multidisciplinary, interdisciplinary, and transdisciplinary (Huutoniemi et al., 2010). A multidisciplinary approach is considered as independent works on different facets of a topic within the boundary of each discipline, while a transdisciplinary approach is an overlapping collaboration of theories, concepts, and shared problems (Ferguson-Patrick et al., 2018). Thus, the degree of unity of theories, methods, concepts, knowledge, values, and aims increases, respectively, from multidisciplinary to interdisciplinary, and then to transdisciplinary (Alvargonzález, 2011). Nevertheless, there is also an ambiguity in the interdisciplinary definition, as it can cover a wide range of interactions, such as simple communications up to integrated methodologies and epistemologies (Chowdhary et al., 2014; Fam et al., 2020). For instance, the following definition for interdisciplinary can be extracted: “a side by side of disciplines”, which is also equivalent to the multidisciplinary concept (Baumgärtner et al., 2008, p. 386). Although the lack of consensus about the transdisciplinary definition is visible in some academic works (for instance, Gero (2017) considered the transdisciplinary approach as a subcategory of an interdisciplinary approach), the study of the development of the process of transdisciplinary education distinguishes it from the interdisciplinary process through integrated leadership and shared missions in the social context (Otis-Green et al., 2009). Simply speaking, interdisciplinary is considered as the cooperation of scientific disciplines, while transdisciplinary is the interrelationship of science and society (Alvargonzález, 2011).

Furthermore, a transdisciplinary approach is a vital factor to fulfil the sustainable development goals determined by the United Nations (Pennington et al., 2020). Although the notion of sustainable development was coined in the year 1987, it will be imposing further complexity to decision systems, including education, considering that new dimensions and features are still being added to the sustainable development concept by research scholars, replacing the traditional triple bottom lines of society, environment, and economics (Gaziulusoy & Boyle, 2013; Hamdouch & Zuideau, 2010). Accordingly, new concepts and systems need to be shaped or integrated into the educational process that also make the traditional triangle of passive education (content, teacher, and student) invalid (Steiner & Posch, 2006). Therefore, the demand for sustainability has made the teaching scenarios more complicated since a variety of

new methods, lenses, and competencies should merge to make teaching schemes more career-relevant and ensure that they meet the new expectations (Brown et al., 2017).

According to the simulated case study of Fromhold-Eisebith et al. (2009), shifting the education governance towards transdisciplinarity needs to cope with several contradictions, such as tradition vs innovation, single vs together, inside vs outside. Accordingly, an interactive transdisciplinary educational system demands an active and purposeful interaction of students, teachers, and stakeholders (Carpenter et al., 1998). The core concept of this systematic education framework depends on both the maturity of the process of innovation (e.g., collaborative learning towards the acquisition of knowledge) and the degree of stakeholders' involvement (Kekes & Mylonakou, 2006). Nevertheless, the measurement of the success of transdisciplinary teaching has been a debatable issue, mainly depending on variation in the intended goals and aims of teaching and on methodological weaknesses (Jahangiri et al., 2008). For instance, Lambert and Monnier-Barbarino (2005) determined related achievement criteria through the level of students' evolution, such as the capability to translate disciplinary knowledge into the language of another discipline, or curiosity and analysis of obstacles to sharing the new concepts and paradigms.

In the process of operationalising transdisciplinary education, simulating a model of an actual situation is a crucial step (Aeberhard & Rist, 2009). However, there is not enough existing empirical evidence regarding models of transdisciplinary learning implementation (Nash, 2008). A model as a toolbox, or "toy model", can aid the transdisciplinary teaching process, which is also affected by sustainability complexity (Baumgärtner et al., 2008, p. 389). Accordingly, complexity in transdisciplinary education is regarded as a wicked problem and is characterised as uncontrollable, unique, and unpredictable due to the variety of stakeholders' perspectives (Valdés et al., 2019). As a general educational policy, implementing "reflective practice" in the transdisciplinary education process can ease this complexity issue (Bore & Wright, 2009, p. 241). The critical components of reflexive teaching and learning are the theoretical models used to systematically evaluate the scientific facets of the transdisciplinary process and the know-how of bridging the gap between the theory and practice (Fortuin & Van Koppen, 2016). Meanwhile, McGregor (2017) recommends inquiry-based pedagogy, which is mainly based on the interactive enquiries of students in a collaborative learning environment, as an impactful strategy for the transition towards transdisciplinary teaching. Hence, to meet the real expectations of education and society, a change-oriented pedagogy based on collaboration and reflexive approaches is essential (Whelan & Lawthom, 2009). Table 1 depicts an outline of the facets of multi-, inter-, and transdisciplinary approaches.

This paper is structured as follows. The next section explains the methodology of the study. Subsequently, we discuss the main body of the review in three phases. First, the evaluation of transdisciplinary teaching and education without contributing to sustainable development is presented. This is followed by an exploration of transdisciplinary teaching and sustainability. Finally, pragmatic views are presented. The study is finalised by a discussion and recommendations for future research.

2 Method

The literature review is considered as one of the key tools for classifying and synthesising a group of different studies from diverse disciplines and methodologies that contribute to a similar domain of problems and scientific gaps (Teixeira et al., 2012). Meanwhile, a scoping review mainly summarises an area and offers a snapshot of a specific

Table 1 Outline of multidisciplinary, interdisciplinary, and transdisciplinary dimensions

	Multidisciplinary	Interdisciplinary	Transdisciplinary
Degree of overlap of different disciplines	Minimum	Moderate	Maximum
Condition of each discipline boundary for integration	Minimum openness	Moderate flexibility for integration	Philosophically (and methodologically and theoretically) open and merged
Aim and outcome of education and learning process	Within the boundary of a single discipline (minimum potential to address the real-life problems)	Integrated objective and collaboration between different disciplines	Real-life problems
Degree of involvement of stakeholders	Not required	Minimum, or not required	A vital requirement. However, some scholarly works have considered it for the integration of initially separated disciplines to generate a new scientific discipline or paradigm (Pennington et al., 2020)
Level of expected innovative outcomes	Less	Advantageous	Maximum
Potential to contribute to the sustainable development dimensions (with further complexity respectively)	The traditional triple bottom lines of sustainable development (e.g., Hamdouch & Zuideau, 2010)	Business and organisational level (e.g., Pennington et al., 2020)	Sustainable innovation (e.g., Gaziulusoy & Boyle, 2013)
Methodological orientation	Mono methods	Mix methods	Mixed (abductive) and pragmatic approach

area of literature, without judgement about the quality, while striving to draw a rapid map of the circumstances (Barbeau et al., 2018). Thus, scoping reviews, in contrast to systematic reviews, provide a broader overview of the studies (McEvoy et al., 2015). Moreover, a scoping review can be a precursor to a systematic review (Munn et al., 2018).

Consequently, a scoping review considers a predetermined set of criteria to generate a comprehensive search to answer a specific research question while leading to the transparency and reliability of the results (Coemans & Hannes, 2017). The general criteria are the number and type of papers that should be included in the analysis to offer a rapid unbiased review (Stevenson et al., 2017). The contribution of systematic review to the analysis of transdisciplinary education has been endorsed in extant scholarly works (Bellamy et al., 2013). Accordingly, our broad research question has been: What are the status and overview of the extant scholarly works related to transdisciplinary teaching and education?

This study is based on a review of peer-reviewed articles, while our analysis strives to make a distinction between the transdisciplinary approach as a “research methodology” and the transdisciplinary approach as a “teaching” method (e.g., Fam et al., 2020). The EBSCOhost database has been used to collect the samples required for the synthesis. The primary selection process has been based on the Boolean search method, and the search terms were “transdisciplinary” on Title; AND “teaching” on Subject OR “education” on Subject/Source OR “pedagogy” on Subject OR “students” on Abstract. Thus, we have focused on contributions that have stated the transdisciplinary term at the title of the papers. This initial search of the articles formed 458 potential results after the year 2010 (as shown in the Prisma diagram in Fig. 1).

The review framework follows a five-step scoping strategy: identification of research question, recognising related studies, selection, charting, and reporting the results (Arksey & O’Malley, 2005; Marcheschi et al., 2018). Consequently, different criteria were considered to select the final group of the involved papers. For the reliability and validity of this study, the following (peer-reviewed) databases have been included: Elsevier, Sage, Springer, Taylor & Francis, Wiley, and Emerald. Results such as editorial commentaries, personal views, conference papers, poster presentations, and duplicated results, were excluded. Therefore, 69 articles were finally included in the review process.

Then, the main filter was by the inclusion of the “sustainability” term in the content of included papers, reducing the total to 33 out of 69. However, a group of the 36 papers without contribution to the sustainable development evaluated as well, to provide a comparative view of how sustainable development as a more recent phenomenon has impacted the transdisciplinary study trends.

In the next stage, we have filtered the pragmatic approach of the chosen literature by the “triangulation” term to answer: What, practically, can we do? (e.g., Huutoniemi et al., 2010). Varpio et al. (2017) have defined triangulation as using multiple types of data, investigators, methods, theories, and philosophies to cover the reliability, accuracy, and validity of the teaching or study. However, incorporation of the “triangulation” filter revealed no explicit contribution to the pedagogical triangulation, and just a few papers involved it as a “research” methodology (not a teaching method/strategy). Thus, we have implemented a separate search string by “triangulation” on Title and “teaching” on Subject that resulted in 13 papers, while four articles were found relevant. Hence, the scoping review acted as a precursor for the last step, which is a systematic judgement about the articles (Peters et al., 2015).

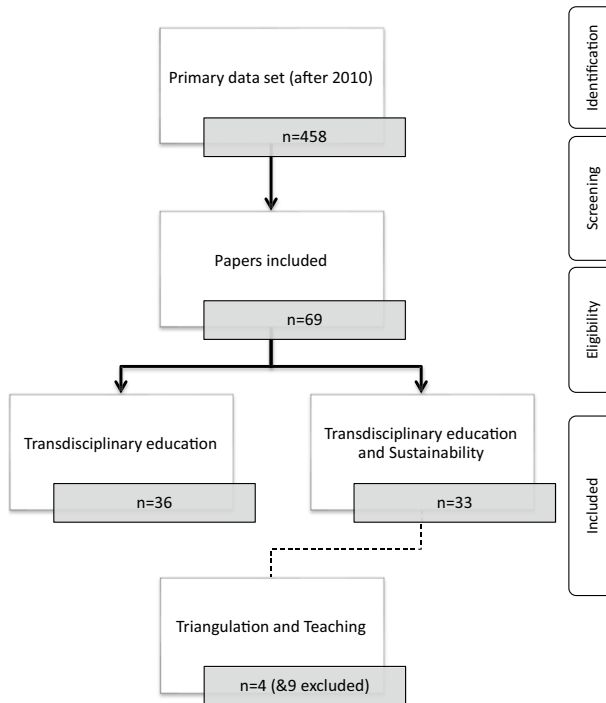


Fig. 1 Scoping review process

3 Results

3.1 Transdisciplinary Teaching and Education

This section illustrates the scope of transdisciplinary teaching and education, without contribution to sustainable development. The evaluation in Table 2 has revealed relationships between transdisciplinary education and different key themes. Therefore, the assessment in this section has resulted in the following major scopes: medical, adolescent, art, pedagogical design and planning, language, socio-efficiency, and special education. A summary of the findings and a brief explanation of each scope are presented in Table 3. The scoping of the included papers was done mainly via the subject and context explanations provided by EBSCOhost.

3.2 Transdisciplinary Education and Sustainable Development

Following the complex nature of transdisciplinarity, the impact of the multidimensional aspect of sustainability can be observed in this section (Table 4). Technically, designing education for sustainability requires tackling real-life problems that are beyond a simple academic practice, which requires a shift towards the collaborative and integrated model of learning and education (Bootsma et al., 2014). Aneas (2015) has defined sustainable transdisciplinary education as a collection of maps and socio-cultural perspectives that can

Table 2 Overview of transdisciplinary teaching and education scopes

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Medical	Brazile et al., (2018)	Medical Teacher	USA	Leadership; Entrepreneurship; Engineering; Interprofessional relations	Highlights the need for toolboxes to enhance the productivity of collaborations among students, such as “design thinking” skills. However, the students’ values and professional goals are considered the most influential factors for innovation and collaboration
	Wijma et al., (2018)	Disability and Rehabilitation	Belgium	Grounded theory; Management; Education	Develops a framework for effective transdisciplinary education through a team that “collaborate intensively, with flexible boundaries and roles, learn simultaneously, and have a shared ... view” (p. 2182). However, the superiority of the transdisciplinary approach over the single-disciplinary method is remarked for future studies
	Carroll et al., (2014)	The Journal of Law, Medicine & Ethics	USA	Social aspects; Collaborative learning; Vocational guidance	Recommends the mentality of humility, openness, and expansion of the zone of learners by including a wider variety of people and connectors or “dabblers”, to overcome the main barriers, such as funding, publication channels, a lack of mentors, and indicators of success
	Doid (2014)	The Journal of Academic Librarianship	USA	Behavioural health, Collaboration; Medical home	Uses the context of Librarian in the health service as a means of “critical information literacy” to develop an integrated model of different disciplines. The “critical information literacy” is an integrative view towards comprehension and reconsideration of information with different political and social backgrounds and across the disciplines
	Bellamy et al., (2013)	Research on Social Work Practice	USA	Best practices; Training methods; Educational policy	Illustrates a model to integrate the research, practice, and communications by adopting the concept of evidence-based practice, consisting of five steps: asking a practical question, acquiring the evidence, appraising the quality, applying the evidence, and analysing outcomes
	Gassman et al., (2012)	Health Promotion Practice	USA	Evaluation; Methods; Psychological factors	Discusses the challenge of transdisciplinary studies through a multilevel framework
	Montgomery et al., (2012a)	Nursing Clinics	USA	Simulations; Health care reform; Outcomes	Highlights the lack of multilevel perspectives (administrative, teaching, and national). Meanwhile, defines the main competencies for the success of the transdisciplinary curriculum as values, responsibilities, communication, and teamwork
	Montgomery et al., (2012b)	Gender Medicine	USA	Computer simulation; Women’s education; Pilot projects	Simulated trainings can foster the development of transdisciplinary education; meanwhile, active participation of a leader or a project committee (e.g., of different faculties) is vital

Table 2 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Adolescent	Silverman et al., (2010)	Early Childhood Education Journal	USA	Services for children with disabilities; Social integration; Mentoring	Presents a model based on: the provision of a positive image and mindset about inclusion through flexibility, preparation by valuing the diversity and uniqueness among students, and orientation of practices towards the further collaboration of families
	Cahill (2011)	NJ: Drama Australia Journal	Australia	Public health; Systems theory; Social change	Combines systematic thinking and reflection-based methods (e.g., games, role play) to generate an epistemological transdisciplinary tool
	Souto-Manning et al., (2019)	Review of Research in Education	USA	Equal education; Social bias; Teaching methods; Culturally relevant education	Introduces the key principles that can transform the adolescents' teaching practices, such as "young children's learning is varied", while emphasising equity (emancipatory) in the classroom (p. 267)
	Emans et al., (2010)	Journal of Adolescent Health	USA	Career planning and development. Evidence-based; Financial	Argues that the impact of macro and meso levels (such as social and political factors) can significantly affect the creation of a suitable culture for teaching
	Sanches-Ferreira et al., (2015)	Childhood Education	Portugal	Parents; Students with disabilities; Human services	The contribution of play-based assessment as a simulation of the real-life condition has been considered for developing transdisciplinary practices, which defines human development through a complex interaction of "individuals and the contextual systems" (p. 301)
	Cumming and Wong (2012)	Australasian Journal of Early Childhood	Australia	Early intervention; Teaching teams; Interdisciplinary teams	Recommends effective measures for teamwork as: sharing common goals and philosophies and reflection through open and frank conversation among the team members
	Land et al., (2018)	World Futures	Canada	Play-based assessment; Social psychology; Politics	Answers the question of "what kinds of collaborations does our transdisciplinary labour demand?" (p. 573) through vulnerability, accountability, and personal practice (Praxis)

Table 2 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Art	Romanski (2019)	Art Education	USA	Teaching methods; Story telling; Elementary education	The application of art and narrative pedagogy is considered as a key driver of the transformation of the STEM (Science, Technology, Engineering, and Mathematics) curriculum
	Ananthakrishnan and Collins (2019)	Studies in Theatre and Performance	India	Digital technology; Drawing; Intercultural	Proposes the ideology of “democratisation” to clarify the flexibility that a transdisciplinary platform can offer for openness towards different perspectives, thus “engendering open-mindedness and the plurality of vision in all students is a pedagogical priority” (p. 128)
	Costantino (2018)	Art Education Policy Review	USA	STEM education; Educational technology; Creative inquiry	Suggests that transdisciplinary curricula should be based on problem-solving, critical inquiry, and creative hands-on learning methods (e.g., the tools presented by Scott and Michèle (1999) to develop a higher level of thinking)
	Liao (2016)	Art Education	USA	STEM; Assignments; Creativity	Artmaking is considered as a pillar in the hands-on learning process. Thus, STEM is regarded as an opportunity to implement the transdisciplinary approach in individual classroom experiments, rather than extensive projects that require fundamental and infrastructure changes in schools
Pedagogical design and planning	Dobozy (2017)	Technology, Knowledge and Learning	Australia	Constructivism; Emotional intelligence; Technology uses in education	The application of transdisciplinary pre-designed lessons, as a template, can deliver a more creative teaching strategy. Generally, these templates can provide a subject-free teaching framework for various disciplines
	Wagner et al., (2014)	Innovations in Education and Teaching International	USA	Creative ability; Problem-based learning; Higher education	Focuses on the epistemological aspect of transdisciplinary education and presents the strategies for effective collaboration, such as clear and open communication, trust and respect, and critical thinking
	Lodge et al., (2017)	Technology, Knowledge and Learning	Australia	Data interpretation; Higher education; Educational research	Introduces a conceptual model for the transdisciplinary learning ecosystem, and explores the development of a new discipline of “learning analytics”, and raises the need for further empirical research in this area
	Samaras et al., (2014)	Journal of Transformative Education	USA	Transformative learning; Independent study; Theory practice relationship	Discusses the importance of “reflective practice” for the personal transformation of teachers to bridge the gap between the theory and practice

Table 2 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Language	Johnson (2019)	The Modern Language Journal	USA	Education of teachers; Sociocultural factors; Second language acquisition	Presents a conceptual multilevel framework as micro (human level), meso (institute), and macro (ideology); by emphasising the “cognitive development” and “lived experience” of the teacher as a pre-condition to the success of transdisciplinary education (p. 168)
	Hall (2019)	The Modern Language Journal	USA	Knowledge level; Interaction; Social influences	Extends the transdisciplinary framework of “second language acquisition” by offering new terms of “repertoire”, “semiotic resources”, and “semiotic register” to emphasise the significance of the social context for the development of the language knowledge
	Ortega (2013)	Language Learning	USA	Intellectual disciplines; Trend analysis; Second language instruction	Defines the significance of transdisciplinarity for the “second language acquisition” education through sharing common goals with other disciplines, and reframing the “second language acquisition” discipline boundaries to contribute to the other language science goals and meet the various theoretical needs
	Sánchez-Martín and Seloni (2019)	Journal of Second Language Writing	USA	Academic dissertations; Mentoring in education; Reflexivity	Links the transdisciplinary mentoring to the “engaged” model of pedagogy that needs interaction between the mentor and mentee, based on mutual trust and commitment to generate real learnings
Socio-efficiency	Gülliland and Hatilovich (2017)	Archival Science	USA	Human rights; Memory; Anthropology	Has shown the lack of attention to the transdisciplinary pedagogy for the archival studies, and to address this gap has implemented a combination of practices in a university course, such as reflective, group-assignment, and experimental exercises
	Yu (2016)	Teaching and Training for Global Engineering	USA	Communication & culture; Training of engineers; Ethics	Offers a new pedagogical method by combining two different epistemological paradigms to explain the intercultural interactions needed by students in their working conditions. This method can pedagogically benefit engineering studies as it can integrate dimensions of the design and basic science (e.g., systems thinking and analytical abilities)
	Schinekus and Jovanovic (2013)	Journal of Economic Methodology	Canada	Financial markets; Risk; Pluridisciplinarity	Shows how a multidisciplinary field of study can evolve into a transdisciplinary subject. The study explains that integration between two different disciplines requires a shared language (pidgin) as a means of communication

Table 2 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Special education	Evans (2017)	Australian Social Work	Australia	Reflection; Early intervention; Theory	Explains a transdisciplinary team model (key worker) that needs to open different disciplines' boundaries for integration. Determining this context as "super-complex", explains that the only suitable model to address this need can be a family-centred transdisciplinary team. Nevertheless, the need for further transparency in the development process of the transdisciplinary approach has been remarked
Doctoral studies	Bargerhuff et al., (2012) McDaniels and Skogsberg (2017)	International Journal of Inclusive Education New Directions for Higher Education	USA USA	School Policy, Inclusion; Disabilities Scholars; Doctoral students; University faculty	Introduces the potential of the transdisciplinary team as a service model to tackle the challenge of diversity Suggests reforming the "scholarship of practice" to divert and leverage the attempts towards societal needs and expectations while demanding further creativity. Incorporation of the scholarship of practice in the educational process can make the epistemology of students open and extend the active collaborations with colleagues and stakeholders to "re-create new models" for transdisciplinarity (p. 81). The idea of "scholarship of practice" recommends the scholars not only as users of knowledge, but also as key partners in the generation, integration, and training processes
Philosophy	Vanasupa et al., (2012)	Innovative Higher Education	USA	Theory of knowledge; Teacher collaboration; Mental models theory	Considers the disciplinary habits of mind as a barrier for transdisciplinary collaborations, and by application of two theories (leadership model and causality) discusses the criteria for the success of the collaborations, such as an egalitarian against hierarchy, shared values, and the reflection practice
Neuroscience	García Carrasco et al., (2015)	Learning, Media and Technology	Spain	Experiential learning; Learning processes; Resilience	The systemic concept of "plasticity" (autonomy, vulnerability, and resilience) connects neuroscience as a donor to other educational disciplines. The plasticity notion is considered as an ability to adapt in response to external or internal factors
Mathematics	Robertson and Graven (2018)	The International Journal on Mathematics Education	South Africa	Mathematical concepts; Second language learning; Classroom communication	Implements a transdisciplinary framework to assess the classroom dialogues by applying three conceptual lenses of psychology, sociology, and linguistics

Table 3 Summary of the findings of the transdisciplinary teaching and education scopes

Scopes	A concise explanation of the scope (includes but not limited to)	Number of findings
Medical	Pain management; Behavioural health; Mental health; Syndemic; Healthcare system	8
Adolescent	Youth participation; Child and youth care; Child disability	7
Art	Drawing; Creative inquiry; Creativity; Theatre education	4
Pedagogical design	Integrated curriculum; Problem-based learning; Learning analytics; Transformative pedagogy; Higher education	4
Language	Conversation analysis; Second language acquisition; Rhetoric	4
Socio-efficiency	Integrated economic added value and social impact; Human rights; Societal stakeholders; Diaspora; Cultural heuristics; Financial economics	3
Special education	Inclusive education; Disability	2
Others (doctoral studies, philosophy, neuro-science, mathematics)	-	4
Total		36

be used to observe real-life problems from different angles. Furthermore, the success of the transdisciplinary program also depends on the degree of collaboration with stakeholders (Meyer et al., 2017). The teachers' stance in teaching sustainable development through an "innovative pedagogy" is a leading factor in promoting the epistemic change of transdisciplinary education into a shared learning process among science and stakeholders (Jia et al., 2019, p. 167). Similarly, two different forms of pedagogy can be recognised as extrinsically motivated (e.g., "fear of failure") for the traditional subject-oriented teaching approach, and intrinsically motivated to enable the deep understanding that can provide the "hope for success" of sustainable transdisciplinary education by considering a holistic and global view in confronting sustainability challenges (Nordén, 2018, p. 11–12). Tackling this complexity requires methods and curricula that integrate isolated scientific knowledge and society in the process of learning and in the production of knowledge (Clark & Button, 2011).

Meanwhile, as the transdisciplinary education strategy is problem-solving-oriented, having a pragmatic approach in the transdisciplinary education process is a requirement (Di Giulio & Defila, 2017). Abson et al. (2017) have offered four systematic leverage points as a practical (pragmatic) approach to tackle the complex sustainability challenges as parameters, feedbacks, design, and intent. Hence, the implementation of systematic leverage points is essential in the transformation towards sustainable transdisciplinary education (Fam et al., 2020). Although the systematic thinking concept has been sufficiently developed in the educational systems, which can help students obtain a holistic view of sustainability, the pedagogical methods for developing the competencies to "get things done" and collectively map and design the strategies for evolution towards transdisciplinary education have not been adequately discussed, which enables the students to recognise and resolve the conflicts between the sustainable and traditional values and goals (Remington-Doucette et al., 2013, p. 410). Consequently, the application of pilot projects and case studies have been suggested for this purpose as they enhance students' interactions with actual problems (Bimpitsos & Petridou, 2012; Hugill & Smith, 2013). The pilot transdisciplinary teaching models can systematically support and develop the required competencies for transdisciplinary learning, such as "building knowledge and understanding of the environment", "building connection and empathy with living things", and "developing deeper understanding" as equally suggested in Bloom's taxonomy for the levels of learning as "remember & understand", "apply & analyse", and "evaluate & create" (Wallace, 2019, p. 313). In addition, conceptual and pilot learning models can generate a common language for the operationalisation and paradigm shift management of transdisciplinary education (Danish et al., 2019; Wallace, 2019). Since paradigm shift management requires an "Agile" problem-solving environment (Reme et al., 2015), the application of maturity models for transdisciplinary education can also address this need (Wagner et al., 2014).

Following the sustainable development goals, the relationship between quality education and sustainability can be reinforced by the transdisciplinary paradigm (Cervantes et al., 2018). Therefore, transdisciplinary education can provide a worthwhile contribution to the social movement towards sustainability (McClam & Flores-Scott, 2012). For example, entrepreneurship education as a transdisciplinary change agent can question the siloed norms of universities and generate innovative solutions for further economic and social sustainability, which requires education systems that develop innovative and intellectual mindsets (Nandan & Scott, 2013). Consequently, the transdisciplinary educational attitude needs to be ecologically literate and environmentally aware, and this can occur via a focusing on the cooperative spirit of education and cognitive openness to shift the systematic thinking towards practice and address the complexity of transdisciplinary education through an ongoing process of re-learning (Vargas-Madrazo, 2018). These transversal

competencies, such as cooperation, creativity, and entrepreneurship skills, cross the boundary of different disciplines and are necessary for the future development process of the transdisciplinary curriculum (Eronen et al., 2019). Meanwhile, to inject the sense of creativity and innovation, the art discipline needs to be integrated with the other curricula, such as science, technology, and engineering, which can significantly contribute to the realization of transdisciplinary education (Biberhofer & Rammel, 2017). Hence, this incorporation with art can offer a new educational paradigm and raise awareness about sustainable development's social and environmental facets (Guyotte et al., 2014).

Consequently, the synthesis in this stage (Table 5) has identified the key scopes as pedagogy design and planning, socio-efficiency, philosophical, medical, doctoral studies, and adolescent. Meanwhile, the alteration of contributions to the interdisciplinary or transdisciplinary-based journals is relatively visible, and this is derived from the nature of sustainable development. Contrary to the previous section, the contribution of the medical and adolescent domains have decreased; instead, pedagogical design and socio-efficiency have received increasing attention as essential pillars of sustainable development.

3.3 Pragmatic Transdisciplinary Teaching Approaches: Implications for Future Practice

As mentioned in the method section of this paper, triangulation is a crucial step for the implementation of transdisciplinary research and education. However, the synthesis in the previous section has shown the scattered and non-transparent efforts and instructions regarding transdisciplinary education, e.g., the “zone of absolute transparency” (Vargas-Madrado, 2018, p. 19), or “certain practices in academic contexts were not transparent or easily accessible” (Sánchez-Martín & Seloni, 2019, p. 31). For instance, among the selected articles, only one paper implicitly contributes to teaching through triangulation methods, as “mix and phase forms of disciplinary training and exposure...quadrangulation” (Kemp & Nurius, 2015, p. 138). Meanwhile, a few other studies have mentioned the importance of triangulation from the “research” methodology point of view. Thus, due to a lack of qualified contributions, we fulfilled a supplementary search string by “triangulation” and “teaching” terms to base this crucial section. Two main categories of contributions are recognisable here: similarly, the majority of extracted papers (nine) have shown the application of triangulation as a research method in the assessment of teaching scenarios; however, only four articles have implemented triangulation as a “teaching” method, as follows.

The case study of Rennie et al. (2011) has implemented a theoretical triangulation practice in the classroom. The theoretical triangulation has been highlighted as a more rigorous way towards an integrated teaching style. The authors have considered this method as a lever to balance between the traditional disciplinary curriculum and the integrated approach. The study explained that the application of different theoretical perspectives can affect learning outcomes and “enables students’ knowledge to be represented as grounded in their experiences, relationships, and contexts, and drawing from, but not bounded by the constraints of, the traditional disciplines” (Rennie et al., 2011, p. 144). Thus, the study has applied three different lenses: first, as an “integrated perspective” by following the theory of “knowing-how-to-do” or “deep understating”, as it is contrary with the disciplinary-based learning; second, a traditional “discipline-based perspective” by incorporation of constructivism theory; third, a “sources-of-knowledge” lens by valuing the external sources of the knowledge, such as stakeholders, to replicate a pragmatism scenario (pp. 148–152).

Table 4 Overview of sustainable transdisciplinary teaching and education

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Pedagogy design and planning	Fam et al., (2020)	Higher Education Quarterly	Australia	Problem solving; Teamwork; Communication skills	The main contradictions between the traditional and future model of university education are (i) the alignment between individual and group interests, (ii) the lack of co-design, methodological, and philosophical issues to meet the expectations of the transdisciplinary notion that oppose the disciplinary model, (iii) the tension between research and learning processes including social stakeholders that are also under the influence of the limitation of time, and (iv) prioritising and dealing with the emerging uncertainty and multidimensional nature of transdisciplinary education, which demands additional efforts
	Eronen et al., (2019)	The Curriculum Journal	Finland	Problem-based learning; Core curriculum; Competency-based education	Proposes a teaching curriculum to meet the objectives of sustainable development. Accordingly, their experiment is mainly based on "students' questions and their concerns" (p. 3) rather than specific subject-based teaching
	Fortuin and Van Koppen (2016)	Environmental Education Research	Netherlands	Teaching methods; Reflection; values; Cross cultural studies	The success of transdisciplinary education is linked to the reflexivity skills of the students in different levels, such as general sustainability science, real condition experiments, and individual norms and values
	Madrazo et al., (2018)	World Futures	Mexico	Eco-literacy; Eco-pedagogy; Participatory action research	Education can be based on the three elements of re-learning, eco-literacy, and reflection to generate the important pedagogical components of creativity, spiritual awareness, and connection to the universe (Praxis)
	Evans (2015)	Policy Futures in Education	USA	Teacher collaboration; Transformational leadership; College faculty	Emphasises the significance of combining the practice, theory, and reflection (Praxis) by the collaboration of faculty members and upper leadership
	Remington-Doucette et al., (2013)	International Journal of Sustainability in Higher Education	USA	Interdisciplinary education; Academic programs; Curriculum research	Defines the key components of sustainable transdisciplinary education as systems thinking and strategic competencies for competitive advantages. Thus, for the future designing of curricula, suggests keeping the major as a traditional academic program while merging with a minor program in sustainability. (Similarly see: Di Giulio & Defila, 2017; Biberhofer & Rammel, 2017; Meyer et al., 2017; Jia et al., 2019)
	Hugill and Smith (2013)	Digital Creativity	UK	Curriculum planning; Digital technology; Higher education research	The critical factor in shaping the transdisciplinary programs is fostering the learners' creativity, as it can develop the transferable skills across disciplines, such as communication
Bimptios and Petridou (2012)	European Journal of Training and Development	Greece	Educational change; Training methods; Performance factors	Highlights the great potential of implementation of the transdisciplinary experiments at the governmental level to expedite the development of the crucial managerial competencies needed to tackle the complexities of global problems	

Table 4 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Socio-efficiency	Strong et al., (2016)	Mind, Culture, and Activity	USA	Science education; Educational change; Sociocultural factors	Puts forwards the notion of “critical transdisciplinary” for the epistemological development of the cross-disciplinary process by emphasising the collaborative style of education (Praxis)
	McClam and Flores-Scott (2012)	Teaching in Higher Education	USA	Social movements; Teaching; Higher education	Has implemented a conceptual practice to examine the condition of current discipline-based academia (through Foucault theory of disciplining power). As a result, highlighted opening the thoughts for learning beyond a single discipline and realising “how we know what we know within our disciplines and what we do not or cannot know within those same disciplines” (p. 241), by practicing with the real-life complex problems
	Nandan and Scott (2013)	Administration in Social Work	USA	Diffusion of innovations; Outcome-based education; Organisational structure	Suggests a roadmap for the success of the transdisciplinary programs as the exploration of the needs and ideas by emphasising the role of stakeholders to form a “new cognitive paradigm”; implementation and connecting the key resources and drivers (e.g., staff, performance measurements, funds, policies, and leadership), and finally launching the program
	Bootsma et al., (2014)	Corporate Social Responsibility and Environmental Management	Netherlands	Real-world learning; Stakeholders; Value added	Has focused on the aspect of curriculum development for the transdisciplinary programs by including the (outside-in) stakeholders, such as inviting guest lecturers or industrial managers. In addition, by involving inside-out views, since students need to observe the outside through real-world problems. Moreover, including a collaborative form by focusing on the co-creation mechanism

Table 4 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Philosophy	Aneas (2015)	Studies in Higher Education	Spain	Humanity; Awareness; Technology education	Transdisciplinary education requires a shift in the epistemology of the current educational system, such as moving from linearity to nonlinearity, university-based to real practices, and tradition to a hybrid disciplinary approach
	Collado-Ruano et al., (2019)	Studies in Philosophy and Education	Ecuador	Culture; Learning; Theory of knowledge	Transdisciplinary teaching can be defined through the “good living” philosophy, which can link the human with the planet by considering the three elements of education as: self-training, training in a societal context, and eco-training by considering the environmental factors
	Vargas-Madrado (2018)	World Futures	Mexico	Social responsibility; Epistemological awareness; Self-knowledge	Sustainable knowledge can be shaped through eco-pedagogical practice, which is based on the co-creation mindset and supports the key pillars of education as: physical, emotional, and mental and spiritual awareness. Thus, it defines transdisciplinary education as “learn to know, learn to do, learn to live together, and learn to be” (p. 15)
	Cervantes et al., (2018)	World Futures	Mexico	Theory of knowledge; Complexity; Community	Considering the current ecological crisis, it has shifted the level of the university interactions towards a universal pedagogical outlook and has suggested a major change in the currently disrupted epistemology of the universities to restructure the knowledge production in “all levels with human interaction” (p. 263)
Medical	Reme et al.,(2015)	Public Health Reports	USA	Occupational Health; Course evaluation; Student attitudes	Highlights the relevant success factors as: the incorporation of different stakeholders, and loyalty to the transdisciplinary ethic, such as respect, openness, and tolerance. On the contrary, the main challenges are the lack of systematic support to the new curriculum, the levels of willingness of the students, and team working challenges
	Weiss et al., (2020)	Journal of Autism and Developmental Disorders	USA	Collaborative teaming; Implementation science; Interprofessional collaboration	The lack of transdisciplinary knowledge among teachers has been mentioned as one of the key reasons. Thus, the authors recommend the pre-service training for teachers
	Kuo et al., (2017)	Health Promotion Practice	USA	Public health; Program development; Professional development	The transdisciplinary context has been discussed through a multilevel model approach to empower the interactions of the academic units and the community at different levels

Table 4 (continued)

Theme	Reference	Journal	Affiliation of the first author	Focus area	Contribution summary
Doctoral studies	Kemp and Nurius (2015)	Journal of Teaching in Social work	USA	Competency-based education; Capacity building; Scaffolding	Proposes a roadmap for the initiation, navigation, and maturity of transdisciplinary education
	Muhar et al., (2013)	Journal of Cleaner Production	Australia	Doctoral programs; Comparative studies; University & College administration	By remarking the significance of transdisciplinarity in meeting the needs of society, has noted the leading success factors such as support of the university leaders, funding availability, capabilities of the supervisors, and reforming the administrative affairs
	Costley and Prizzolato (2018)	Studies in Continuing Education	UK	Education policy; Experiential learning; Theory of knowledge	Innovation is the key item in pedagogy to increase the capacity and rigour of transdisciplinary education. Furthermore, reflexivity is a crucial element in forming a transdisciplinary team to address sustainability, as the core of its logic is to value different insights and trustworthy cooperation
Adolescent	Carmel et al., (2013)	Early Years	Australia	Educational policy; Educational change; Reflection	Discusses the significance of leadership to accelerate the transdisciplinary practices and suggests the appreciation of multiple perspectives, respectful relationships, and critical thinking ability
Doctoral studies	Wallace (2019)	International Research in Geographical and Environmental Education	Australia	Program effectiveness; Consciousness raising; Experiential learning	Relates the concept of transdisciplinary education and sustainable development through a garden-based learning program, as it can potentially make the students ecologically literate. The notion of eco-literacy focuses on the "relationships and connectedness", or in other words, systematic thinking
	Norden (2018)	Environmental Education Research	Sweden	Teaching methods; Teacher attitudes; Cognitive processes	Has studied the significance of the deep learning method (meaningful understanding), which is closely related to the level of the motivation of students
Art	Guyotte et al., (2014)	Art Education	USA	Creativity; STEM education; Educational practices	Suggests a framework to enhance the transdisciplinary education outcomes, consisting of: creative thinking by considering the philosophy of the whole problem-solving process as an artistic work, empathising with the diversity of audiences, looking at the world from the point of view of others, and engaging with the community to cope with the sociotechnical facet of sustainable development
	Clark and Button (2011)	International Journal of Sustainability in Higher Education	USA	STEM education; Teacher student relationships; Environmental education	Remarks the cognitive impact of art integration in the development of transdisciplinary curricula
Energy	Danish et al., (2019)	Journal of Cleaner Production	Japan	Global warming; Sustainable energy; Air pollution	Illustrates a new educational paradigm by combining a multilevel model, life cycle policy, and mix of methods to offer an innovative transdisciplinary model
Language	Dehdad (2019)	Interchange: a Quarterly Review of Education	Iran	Creativity; Cultural awareness; Social justice	Discusses sustaining the education (English majors) by shifting towards a new paradigm through applying complexity theory as an adaptive system that focuses on the integration of methods and openness to the outside world

Table 5 Summary of the findings of the sustainable transdisciplinary teaching and education scopes

Scope	A concise definition of the scope (includes but not limited to)	Number of findings
Pedagogy design and planning	(as mentioned in Table 3)	12
Socio-efficiency	(as mentioned in Table 3)	4
Philosophy	Models of knowledge; Complexity; Environmental awareness; Long-life education; Epistemological awareness; Collaboration	4
Medical	(as mentioned in Table 3)	3
Doctoral studies	Doctoral education; Practice-based doctorate; Curriculum design	3
Adolescent	(as mentioned in Table 3)	3
Others (art, energy, language)	-	4
Total		33

Meanwhile, further investigations by application of other theoretical frameworks have been recommended.

A similar study by Van Drie and Dekker (2013) has used three theoretical perspectives to demonstrate and comprehend the complexity of interactions in the classroom. The study argued that triangulation can facilitate the interactions of the teacher, the student, and the teaching subjects and also seeks the relationship between the quality of lessons and applications of theoretical triangulation by the teacher. Therefore, their study has used three theoretical lenses in the classroom as improving the interactive discourse by the teacher taking the constructivism approach of asking thought-provoking questions, facilitating and interpreting the questions, collaborating, and appreciating the contributors' efforts; conceptual development through the cognitivism and critical realism approaches; and collaborative reasoning through argumentations, and application of meta-concepts (e.g., facts, causes, and consequences). Likewise, Schul (2015) has demonstrated the application of pedagogy triangulation. This case has integrated three different approaches to making the teaching subject (history) more interesting for the students. The author, by using the term of tradition, has shown the application of three different theories as inquiry-based, reflectivity, and traditional lecturing, and the author has noted the related weaknesses and strengths of each one. Meanwhile, Gran et al. (2010) have noted the impact of triangulation in the assessment and feedback tasks of teachers in the medical discipline.

4 Discussion and Future Research Avenues

The above scoping review revealed that the previous experiences and practices carried out in transdisciplinary teaching are relatively varied and dispersed. Moreover, there is no transparency about how case studies and pilot projects have been designed and fulfilled. Generally, in the circumstances that the lack of transparency is a barrier in the development of methodological processes (e.g., abductive design), the application of a common reporting guideline is suggested, for example, by describing the sequence, justifications for the choice of approach, and limitations (O' Cathain et al., 2008).

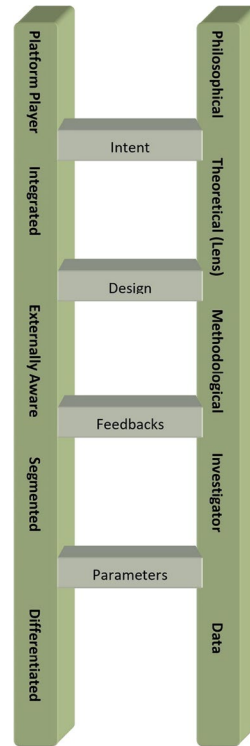
Likewise, as discussed in the previous section, a lack of attention to the triangulated pedagogy was observed. However, awareness about the application of triangulation as a “research” method for assessment in the teaching context is more recognisable (e.g., Drouin et al., 2015; Durif-Bruckert et al., 2015). The application of triangulation as a “research” method is outside of the scope of this study; nevertheless, the following studies have applied triangulation as a research method. Clark and Jasaw (2014) have implemented data and method triangulation to check the reliability of assessment in education by including students, staff, and stakeholders. Likewise, Schaap et al. (2011) have utilised a multi-method triangulation, such as concept maps, interviews, and reflection practices, to evaluate students’ competency development in vocational education. Similarly, Varpio et al. (2017) conceptually elaborate different types or steps of triangulations, such as data, investigator, method, lens, and philosophical; however, their study is non-empirical and theory driven. Similarly, the works of Fotheringham, 2010, Ling et al., 2018, Park et al., 2016, and Scheffer et al., 2011 can be categorised in the same way.

Furthermore, systematic and design thinking have been implemented as a pillar in many of the conducted cases. Accordingly, applying maturity models as a change medium can tackle the complexity of transdisciplinary education (Enkel et al., 2020; Kekes & Mylonakou, 2006). Similarly, one of the key areas of discussions in transdisciplinary education studies is mainly related to the co-creation and collaborative value creation with stakeholders in an innovative environment. Despite the booming trends in innovation studies that have addressed educational-related issues, the contribution of open innovation as a megatrend in innovation studies to transdisciplinary teaching has not been appropriately studied (Lucia et al., 2012). Open innovation as a governance mechanism can encourage and leverage the interactions of the internal and external collaborations and can create further synergy between an educational organisation and its stakeholders (West et al., 2014). Likewise, by offering the strategic element of change management, the business model of open innovation can provide agility for the paradigm shift management in transdisciplinary education (Chesbrough, 2006). The maturity levels of open innovation (e.g., Chesbrough, 2006) merge the process of innovation with stakeholders while also matching the corresponding triangulating steps (Bechara & Van de Ven, 2011) and can be defined as follows:

- (1) Differentiated (the lowest level), e.g., some scattered innovations are fulfilled in a teaching institute by ad hoc activities; versus Data triangulation.
- (2) Segmented, e.g., the innovation process is planned by a leader for a long-term horizon; versus Investigator triangulation.
- (3) Externally aware, e.g., the role of stakeholders is recognised with awareness about the external innovations; versus Methodological triangulation.
- (4) Integrated, e.g., internal and external innovations are integrated into the educational roadmap and aligned with stakeholders; versus Theoretical triangulation.
- (5) Platform player (the highest level), e.g., the teaching scenario and stakeholders are interconnected, and as innovation is the main criterion, all academic units will support this strategy; versus Philosophical triangulation.

Figure 2 presents a maturity model consisting of pillars of open innovation and triangulation maturity as well as steps of systematic leverage points.

Fig. 2 Transdisciplinary teaching maturity: consists of two pillars of open innovation and triangulation and steps of leverage points in the systematic and design thinking



5 Conclusion

The present study aims to weave a network of the varied practices and contributions to transdisciplinary teaching and education that have been fulfilled until now. The dominated model in academia does not encourage the transdisciplinary approach. Therefore, the current educational system can be illustrated as a one-way funnel that every student should go through to reach a specific level of professionalism, which is considered a barrier to the development of transdisciplinary education.

Real-life problems contain abundant ambiguities and uncertainties, necessitating a learning and education process that connects different disciplines such as art, science, technology, and engineering to yield problem-based and creative learning approaches. However, the lack of solid guidance in the extant academic literature for implementing pilot transdisciplinary experimenting is notable. Nonetheless, teachers can play an essential role in this process, and the unique opportunity of transdisciplinary education can be initially enhanced by reshaping teachers' interpretations of pedagogy, or "how teachers learn to teach", considering the incorporation of science and society, explicitly (Johnson, 2019, p. 172). In a transdisciplinary team, members are not considered as "jack(s) of all trades", but rather should be able to "draw on the expertise of others" (Cumming & Wong, 2012, p. 133).

Despite the rigour of the transdisciplinary approach, still, it would be the decision of the educational institutes to choose a strategy that suits their contexts and benefits best; by questioning the degree of integration and collaboration through these: what are the nature of the problems that are going to be solved and what kind of solutions or outcomes are expected, and the corresponding methods and available resources.

Accordingly, fruitful transdisciplinary learning should be in interaction with the society and stakeholders and involves the research in the societal background, encouraging the integration process to shift the disciplinary paradigm.

Nonetheless, one of the limitations in this paper is due to the definitions of the previous works regarding the transdisciplinary and interdisciplinary terms. As discussed in the Introduction section, some previous studies have interchangeably used the interdisciplinary and transdisciplinary terms, though there is a clear difference between these two. Furthermore, the maturity model that we have presented in this study is considered as a prototype and an informal scaling, so further empirical testing is required. Accordingly, full systematic reviews on different dimensions of the transdisciplinary education scopes are suggested for future research.

Data Availability The datasets analysed during the current study are available in the EBSCOhost platform.

Code Availability Not applicable.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare that they have no conflict of interest.

References

- Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*(1), 30–39.
- Aeberhard, A., & Rist, S. (2009). Transdisciplinary co-production of knowledge in the development of organic agriculture in Switzerland. *Ecological Economics*, *68*(4), 1171–1181.
- Alvargonzález, D. (2011). Multidisciplinarity, interdisciplinarity, transdisciplinarity, and the sciences. *International Studies in the Philosophy of Science*, *25*(4), 387–403.
- Ananthakrishnan, B., & Collins, J. (2019). Against a hierarchy of expressive means; arguments for new pedagogies in performer education in India and the UK. *Studies in Theatre and Performance*, *39*(2), 113–131.
- Aneas, A. (2015). Transdisciplinary technology education: A characterisation and some ideas for implementation in the university. *Studies in Higher Education*, *40*(9), 1715–1728.
- Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32.
- Barbeau, P., Wolfe, D., Yazdi, F., Rice, D. B., Dube, C., Kanji, S., ... & Hutton, B. (2018). Comparative safety of bowel cleansers: protocol for a systematic review and network meta-analysis. *BMJ open*, *8*(6), 1–8
- Bargerhuff, M. E., Cole, D. J., & Teeters, L. (2012). Using a transdisciplinary model to address inequities in field placements for teacher candidates with disabilities. *International Journal of Inclusive Education*, *16*(2), 185–206.
- Baumgärtner, S., Becker, C., Frank, K., Müller, B., & Quaas, M. (2008). Relating the philosophy and practice of ecological economics: The role of concepts, models, and case studies in inter- and transdisciplinary sustainability research. *Ecological Economics*, *67*(3), 384–393.
- Bechara, J., & Van de Ven, A. H. (2011). Triangulating philosophies of science to understand complex organizational and managerial problems. *Research in the Sociology of Organizations*, *32*(2), 343–364.

- Bellamy, J. L., Mullen, E. J., Satterfield, J. M., Newhouse, R. P., Ferguson, M., Brownson, R. C., & Spring, B. (2013). Implementing evidence-based practice education in social work: A transdisciplinary approach. *Research on Social Work Practice, 23*(4), 426.
- Biberhofer, P., & Rammel, C. (2017). Transdisciplinary learning and teaching as answers to urban sustainability challenges. *International Journal of Sustainability in Higher Education, 18*(1), 63–83.
- Bimpitsos, C., & Petridou, E. (2012). A transdisciplinary approach to training: Preliminary research findings based on a case analysis. *European Journal of Training and Development, 36*(9), 911–929.
- Bootsma, M. C., Vermeulen, W. J., Van Dijk, J., & Schot, P. P. (2014). Added value and constraints of transdisciplinary case studies in environmental science curricula. *Corporate Social Responsibility and Environmental Management, 21*(3), 155–166.
- Bore, A., & Wright, N. (2009). The wicked and complex in education: Developing a transdisciplinary perspective for policy formulation, implementation and professional practice. *Journal of Education for Teaching, 35*(3), 241–256.
- Brazile, T., Hostetter Shoop, G., McDonough, C. M., & Van Citters, D. W. (2018). Promoting innovation: Enhancing transdisciplinary opportunities for medical and engineering students. *Medical Teacher, 40*(12), 1264–1274.
- Brown, M., Benson, G. O. G., Keel, R., Mahoney, E., Porter, J., & Thompson, J. (2017). Seeking Northlake: Place, technology, and public as enabling constraints for urban transdisciplinary research. *Cities, 60*, 314–322.
- Cahill, H. (2011). Drama as transdisciplinary practice: Using systems thinking tools to generate new stories about HIV. *NJ; Drama Australia Journal, 35*(1), 15–33.
- Carpenter, S. L., King-Sears, M. E., & Keys, S. G. (1998). Counselors + educators + families as a transdisciplinary team = more effective inclusion for students with disabilities. *Professional School Counseling, 2*(1), 1096–2007.
- Carroll, L., Ali, M. K., Cuff, P., Huffman, M. D., Kelly, B. B., Kishore, S. P., Narayan, K. V., Siegel, K. R., & Vedanthan, R. (2014). Envisioning a transdisciplinary university. *The Journal of Law, Medicine & Ethics, 42*(s2), 17–25.
- Cartmel, J., Macfarlane, K., & Nolan, A. (2013). Looking to the future: Producing transdisciplinary professionals for leadership in early childhood settings. *Early Years, 33*(4), 398–412.
- Cervantes, E. R., Vargas-Madrado, E., & Corona García, M. (2018). Epistemological transformation for a sustainable and transdisciplinary university: The experience at the university of veracruz. *World Futures, 74*(4), 257–264.
- Chesbrough, H. (2006). *Open business models: How to thrive in the new innovation landscape*. Harvard Business Press.
- Chowdhary, B., Liu, X., Yerrick, R., Smith, E., & Grant, B. (2014). Examining science teachers' development of interdisciplinary science inquiry pedagogical knowledge and practices. *Journal of Science Teacher Education, 25*(8), 865–884.
- Clark, B., & Button, C. (2011). Sustainability transdisciplinary education model: Interface of arts, science, and community (STEM). *International Journal of Sustainability in Higher Education, 12*(1), 41–54.
- Clark, G., & Jasaw, G. S. (2014). Evaluating team project-work using triangulation: Lessons from communities in northern Ghana. *Journal of Geography in Higher Education, 38*(4), 511–524.
- Coemans, S., & Hannes, K. (2017). Researchers under the spell of the arts: Two decades of using arts-based methods in community-based inquiry with vulnerable populations. *Educational Research Review, 22*, 34–49.
- Collado-Ruano, J., Madroñero-Morillo, M., & Álvarez-González, F. (2019). Training transdisciplinary educators: Intercultural learning and regenerative practices in Ecuador. *Studies in Philosophy and Education, 38*(2), 177–194.
- Collin, A. (2009). Multidisciplinary, interdisciplinary, and transdisciplinary collaboration: Implications for vocational psychology. *International Journal for Educational and Vocational Guidance, 9*(2), 101–110.
- Costantino, T. (2018). STEAM by another name: Transdisciplinary practice in art and design education. *Arts Education Policy Review, 119*(2), 100–106.
- Costley, C., & Pizzolato, N. (2018). Transdisciplinary qualities in practice doctorates. *Studies in Continuing Education, 40*(1), 30–45.
- Cumming, T., & Wong, S. (2012). Professionals don't play: Challenges for early childhood educators working in a transdisciplinary early intervention team. *Australasian Journal of Early Childhood, 37*(1), 127–135.
- Danish, M. S. S., Senjyu, T., Zaheb, H., Sabory, N. R., Ibrahim, A. M., & Matayoshi, H. (2019). A novel transdisciplinary paradigm for municipal solid waste to energy. *Journal of Cleaner Production, 233*, 880–892.

- Dehnad, V. (2019). Sustainable transdisciplinary future for English majors in Iran by implementing a new paradigm. *Interchange: A Quarterly Review of Education*, 50(1), 77–96.
- Di Giulio, A., & Defila, R. (2017). Enabling university educators to equip students with inter-and transdisciplinary competencies. *International Journal of Sustainability in Higher Education*, 18(5), 630–647.
- Dobozy, E. (2017). The pre-designed lesson: Teaching with transdisciplinary pedagogical templates (TPTs). *Technology, Knowledge and Learning*, 22(2), 143–150.
- Dold, C. (2014). Critical information literacy: A model for transdisciplinary research in behavioral sciences. *The Journal of Academic Librarianship*, 40(2), 179–184.
- Drouin, M., Stewart, J., & Van Gorder, K. (2015). Using methodological triangulation to examine the effectiveness of a mentoring program for online instructors. *Distance Education*, 36(3), 400–418.
- Durif-Bruckert, C., Roux, P., Morelle, M., Mignotte, H., Faure, C., & Moumjid-Ferdjaoui, N. (2015). Shared decision-making in medical encounters regarding breast cancer treatment: The contribution of methodological triangulation. *European Journal of Cancer*, 24(4), 461–472.
- Emans, S. J., Austin, S. B., Goodman, E., Orr, D. P., Freeman, R., Stoff, D., Litt, I. F., Schuster, M. A., Haggerty, R., Granger, R., & Irwin, C. E., Jr. (2010). Improving adolescent and young adult health-training the next generation of physician scientists in transdisciplinary research. *Journal of Adolescent Health*, 46(2), 100–109.
- Enkel, E., Bogers, M., & Chesbrough, H. (2020). Exploring open innovation in the digital age: A maturity model and future research directions. *R&D Management*, 50(1), 161–168.
- Eronen, L., Kokko, S., & Sormunen, K. (2019). Escaping the subject-based class: A Finnish case study of developing transversal competencies in a transdisciplinary course. *The Curriculum Journal*, 30(3), 264–278.
- Evans, S. (2017). The social worker as transdisciplinary professional: A reflective account. *Australian Social Work*, 70(4), 500–507.
- Evans, T. L. (2015). Transdisciplinary collaborations for sustainability education: Institutional and intra-group challenges and opportunities. *Policy Futures in Education*, 13(1), 70–96.
- Fam, D., Clarke, E., Freeth, R., Derwort, P., Klaniecki, K., Kater-Wettstädt, L., Juarez-Bourke, S., Hilser, S., Peukert, D., Meyer, E., & Horcea-Milcu, A. I. (2020). Interdisciplinary and transdisciplinary research and practice: Balancing expectations of universities as ‘problem solvers.’ *Higher Education Quarterly*, 74(1), 19–34.
- Ferguson-Patrick, K., Reynolds, R., & Macqueen, S. (2018). Integrating curriculum: A case study of teaching Global Education. *European Journal of Teacher Education*, 41(2), 187–201.
- Fortuin, K. P. J., & Van Koppen, C. S. A. (2016). Teaching and learning reflexive skills in inter-and transdisciplinary research: A framework and its application in environmental science education. *Environmental Education Research*, 22(5), 697–716.
- Fotheringham, D. (2010). Triangulation for the assessment of clinical nursing skills: A review of theory, use and methodology. *International Journal of Nursing Studies*, 47(3), 386–391.
- Fromhold-Eisebith, M., Freyer, B., Mose, I., Muhar, A., & Vilsmaier, U. (2009). Creating regional futures: A scenario-based inter-and transdisciplinary case study as a model for applied student-centred learning in geography. *Journal of Geography in Higher Education*, 33(3), 409–431.
- García Carrasco, J., Hernández Serrano, M. J., & Martín García, A. V. (2015). Plasticity as a framing concept enabling transdisciplinary understanding and research in neuroscience and education. *Learning, Media and Technology*, 40(2), 152–167.
- Gassman, R. A., Agle, J., Johnston, J. D., Middlestadt, S. E., van Puymbroeck, M., & YoussefAgha, A. H. (2012). Catalyzing transdisciplinary studies in public health: A college health survey and data platform. *Health Promotion Practice*, 13(1), 90–97.
- Gaziulusoy, A. I., & Boyle, C. (2013). Proposing a heuristic reflective tool for reviewing literature in transdisciplinary research for sustainability. *Journal of Cleaner Production*, 48, 139–147.
- Gero, A. (2017). Students’ attitudes towards interdisciplinary education: A course on interdisciplinary aspects of science and engineering education. *European Journal of Engineering Education*, 42(3), 260–270.
- Gilliland, A. J., & Halilovich, H. (2017). Migrating memories: Transdisciplinary pedagogical approaches to teaching about diasporic memory, identity and human rights in archival studies. *Archival Science*, 17(1), 79–96.
- Glittenberg, J. (2004). A transdisciplinary, transcultural model for health care. *Journal of Transcultural Nursing*, 15(1), 6–10.
- Gran, S. F., Braend, A. M., & Lindbaek, M. (2010). Triangulation of written assessments from patients, teachers and students: Useful for students and teachers? *Medical Teacher*, 32(12), e552–e558.
- Grey, M., & Connolly, C. A. (2008). “Coming together, keeping together, working together”: Interdisciplinary to transdisciplinary research and nursing. *Nursing Outlook*, 56(3), 102–107.

- Guyotte, K. W., Sochacka, N. W., Costantino, T. E., Walther, J., & Kellam, N. N. (2014). STEAM as social practice: Cultivating creativity in transdisciplinary spaces. *Art Education*, 67(6), 12–19.
- Hall, J. K. (2019). The contributions of conversation analysis and interactional linguistics to a usage-based understanding of language: Expanding the transdisciplinary framework. *The Modern Language Journal*, 103, 80–94.
- Hamdouch, A., & Zuindeau, B. (2010). Sustainable development, 20 years on: Methodological innovations. *Journal of Environmental Planning and Management*, 53(4), 427–438.
- Hammer, M., & Söderqvist, T. (2001). Enhancing transdisciplinary dialogue in curricula development. *Ecological Economics*, 38(1), 1–5.
- Hansmann, R., Crott, H. W., Mieg, H. A., & Scholz, R. W. (2009). Improving group processes in transdisciplinary case studies for sustainability learning. *International Journal of Sustainability in Higher Education*, 10(1), 33–42.
- Hugill, A., & Smith, S. (2013). Digital creativity and transdisciplinarity at postgraduate level: The design and implementation of a transdisciplinary masters programme and its implications for creative practice. *Digital Creativity*, 24(3), 191–207.
- Huutoniemi, K., Klein, J. T., Bruun, H., & Hukkinen, J. (2010). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, 39(1), 79–88.
- Jahangiri, L., Mucciolo, T. W., Choi, M., & Spielman, A. I. (2008). Assessment of teaching effectiveness in US dental schools and the value of triangulation. *Journal of Dental Education*, 72(6), 707–718.
- Jakobsen, A., & Bucciarelli, L.L. (2007). Transdisciplinary variation in engineering curricula. Problems and means for solutions. *European journal of engineering education*, 32(3), 295–301.
- Jia, Q., Wang, Y., & Fengting, L. (2019). Establishing transdisciplinary minor programme as a way to embed sustainable development into higher education system. *International Journal of Sustainability in Higher Education*, 20(1), 157–169.
- Johnson, K. (2019). The relevance of a transdisciplinary framework for SLA in language teacher education. *The Modern Language Journal*, 103, 167–174.
- Jordan, A., Carlile, O., & Stack, A. (2008). *Approaches to learning: a guide for teachers: a guide for educators*. Glasgow, UK: McGraw-Hill Education.
- Kekes, I., & Mylonakou, I. (2006). Syneducational transactions among students, parents, educators and policy makers: The transdisciplinary program SYNTHESIS. *Interactive Learning Environments*, 14(1), 35–54.
- Kemp, S. P., & Nurius, P. S. (2015). Preparing emerging doctoral scholars for transdisciplinary research: A developmental approach. *Journal of Teaching in Social Work*, 35(1–2), 131–150.
- Klaassen, R. (2018). Interdisciplinary education: A case study. *European Journal of Engineering Education*, 43(6), 842–859.
- Knuuttila, T. (2013). Science in a new mode: Good old (theoretical) science versus brave new (modified) knowledge production? *Science & Education*, 22(10), 2443–2461.
- Kuo, A. A., Sharif, M. Z., Prelip, M. L., Glik, D. C., Albert, S. L., Belin, T., McCarthy, W. J., Roberts, C. K., Garcia, R. E., & Ortega, A. N. (2017). Training the Next Generation of Latino Health Researchers: A multilevel, transdisciplinary, community-engaged approach. *Health Promotion Practice*, 18(4), 497–504.
- Lam, C. C., Alviar-Martin, T., Adler, S. A., & Sim, J. B. Y. (2013). Curriculum integration in Singapore: Teachers' perspectives and practice. *Teaching and Teacher Education*, 31, 23–34.
- Lambert, R. D., & Monnier-Barbarino, P. (2005). Transdisciplinary training in reproductive health through online multidisciplinary problem-solving: A proof of concept. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, 123(1), 82–86.
- Land, N., Gulamhusein, S., Scott, A., & Coon, E. (2018). Transdisciplinary conversations in child and youth Care. *World Futures*, 74(7–8), 572–594.
- Liao, C. (2016). From interdisciplinary to transdisciplinary: An arts-integrated approach to STEAM education. *Art Education*, 69(6), 44–49.
- Ling, C., Fuller, A., Taylor, L., & Johnson, H. (2018). Triangulation of multifactorial assessment: Bringing objectivity to objective structured clinical examination evaluation. *Clinical Simulation in Nursing*, 16, 40–47.
- Lodge, J. M., Alhadad, S. S., Lewis, M. J., & Gašević, D. (2017). Inferring learning from big data: The importance of a transdisciplinary and multidimensional approach. *Technology, Knowledge and Learning*, 23(3), 385–400.
- Lucia, Ó., Burdio, J. M., Acero, J., Barragán, L. A., & Garcia, J. R. (2012). Educational opportunities based on the university-industry synergies in an open innovation framework. *European Journal of Engineering Education*, 37(1), 15–28.

- Madrazo, C. N., Vigil, A. S., & Hernández, L. C. (2018). Experiencing the mastership in transdisciplinary studies for sustainability. *World Futures*, *74*(4), 246–256.
- Marcheschi, E., Von Koch, L., Pessah-Rasmussen, H., & Elf, M. (2018). Home setting after stroke, facilitators and barriers: A systematic literature review. *Health & Social Care in the Community*, *26*(4), e451–e459.
- McClam, S., & Flores-Scott, E. M. (2012). Transdisciplinary teaching and research: What is possible in higher education? *Teaching in Higher Education*, *17*(3), 231–243.
- McDaniel, A. M., Champion, V. L., & Kroenke, K. (2008). A transdisciplinary training program for behavioral oncology and cancer control scientists. *Nursing Outlook*, *56*(3), 123–131.
- McDaniels, M., & Skogsberg, E. (2017). The scholars we need: Preparing transdisciplinary professionals by leveraging the scholarship of practice. *New Directions for Higher Education*, *178*, 71–83.
- McEvoy, E., MacPhail, A., & Heikinaro-Johansson. . (2015). Physical education teacher educators: A 25-year scoping review of literature. *Teaching and Teacher Education*, *51*, 162–181.
- McGregor, S. (2017). Transdisciplinary pedagogy in higher education: Transdisciplinary learning, learning cycles and habits of minds. *Transdisciplinary Higher Education* (pp. 3–16). Springer.
- Meneses, K. D., & McNees, P. (2007). Transdisciplinary integration of electronic communication technology and nursing research. *Nursing Outlook*, *55*(25), 242–249.
- Meyer, J., Mader, M., Zimmermann, F., & Çabiri, K. (2017). Training sessions fostering transdisciplinary collaboration for sustainable development. *International Journal of Sustainability in Higher Education*, *18*(5), 738–757.
- Montgomery, K., Griswold-Theodorson, S., Morse, K., Montgomery, O., & Farabaugh, D. (2012a). Transdisciplinary simulation: Learning and practicing together. *Nursing Clinics*, *47*(4), 493–502.
- Montgomery, K., Morse, C., Smith-Glasgow, M. E., Posmontier, B., & Follen, M. (2012b). Promoting quality and safety in women's health through the use of transdisciplinary clinical simulation educational modules: Methodology and a pilot trial. *Gender Medicine*, *9*(1), S48–S54.
- Muhar, A., Visser, J., & Van Breda, J. (2013). Experiences from establishing structured inter-and transdisciplinary doctoral programs in sustainability: A comparison of two cases in South Africa and Austria. *Journal of Cleaner Production*, *61*, 122–129.
- Munn, Z., Peters, M. D., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology*, *18*(143), 1–7.
- Nandan, M., & Scott, P. A. (2013). Social entrepreneurship and social work: The need for a transdisciplinary educational model. *Administration in Social Work*, *37*(3), 257–271.
- Nash, J. (2008). Transdisciplinary training: Key components and prerequisites for success. *American Journal of Preventive Medicine*, *35*(2), S133–S140.
- Nordén, B. (2018). Transdisciplinary teaching for sustainable development in a whole school project. *Environmental Education Research*, *24*(5), 663–677.
- O'Cathain, A., Murphy, E., & Nicholl, J. (2008). The quality of mixed methods studies in health services research. *Journal of Health Services Research & Policy*, *13*(2), 92–98.
- Ortega, L. (2013). SLA for the 21st century: Disciplinary progress, transdisciplinary relevance, and the bi/multilingual turn. *Language Learning*, *63*, 1–24.
- Otis-Green, S., Ferrell, B., Spolum, M., Uman, G., Mullan, P., Baird, R. P., & Grant, M. (2009). An overview of the ACE Project—advocating for clinical excellence: Transdisciplinary palliative care education. *Journal of Cancer Education*, *24*(2), 120–126.
- Park, N. K., Chun, M. Y., & Lee, J. (2016). Revisiting individual creativity assessment: Triangulation in subjective and objective assessment methods. *Creativity Research Journal*, *28*(1), 1–10.
- Pennington, D., Ebert-Uphoff, I., Freed, N., Martin, J., & Pierce, S. A. (2020). Bridging sustainability science, earth science, and data science through interdisciplinary education. *Sustainability Science*, *15*, 647–661.
- Peters, M. D., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. *International Journal of Evidence-Based Healthcare*, *13*(3), 141–146.
- Reme, S. E., Caban-Martinez, A. J., Young, J., Arlinghaus, A., & Gray, G. (2015). A model for development and delivery of a graduate course in transdisciplinary research. *Public Health Reports*, *130*(5), 552–558.
- Remington-Doucette, S. M., Connell, K. Y. H., Armstrong, C. M., & Musgrove, S. L. (2013). Assessing sustainability education in a transdisciplinary undergraduate course focused on real-world problem solving. *International Journal of Sustainability in Higher Education*, *14*(4), 404–433.
- Rennie, L. J., Venville, G., & Wallace, J. (2011). Learning science in an integrated classroom: Finding balance through theoretical triangulation. *Journal of Curriculum Studies*, *43*(2), 139–162.

- Robertson, S. A., & Graven, M. (2018). Using a transdisciplinary framework to examine mathematics classroom talk taking place in and through a second language. *ZDM: The International Journal on Mathematics Education*, 50(6), 1013–1027.
- Romanski, N. (2019). Reigniting the transformative power of puppets through narrative pedagogy, contemporary art, and transdisciplinary approaches in art education. *Art Education*, 72(4), 36–42.
- Samaras, A. P., Karczmarczyk, D., Smith, L., Woodville, L., Harmon, L., Nasser, I., Parsons, S. A., Smith, T. M., Borne, K., Constantine, L. S., & Mendoza, E. R. (2014). The shark in the vitrine: Experiencing our practice from the inside out with transdisciplinary lenses. *Journal of Transformative Education*, 4, 368–388.
- Sanches-Ferreira, M., Linder, T., Lopes-dos-Santos, P., Silveira-Maia, M., & Alves, S. (2015). Portuguese parents' perceptions of transdisciplinary play-based assessment. *Childhood Education*, 91(4), 300–306.
- Sánchez-Martín, C., & Seloni, L. (2019). Transdisciplinary becoming as a gendered activity: A reflexive study of dissertation mentoring. *Journal of Second Language Writing*, 43, 24–35.
- Schaap, H., De Bruijn, E., Van der Schaaf, M. F., Baartman, L. K. J., & Kirschner, P. A. (2011). Explicating students' personal professional theories in vocational education through multi-method triangulation. *Scandinavian Journal of Educational Research*, 55(6), 567–586.
- Scheffer, C., Tausche, D., & Edelhäuser, F. (2011). I wish I had a physician like that: The use of triangulation on the way towards a patient-centred medical education. *Patient Education and Counseling*, 82(3), 465–467.
- Schinckus, C., & Jovanovic, F. (2013). Towards a transdisciplinary econophysics. *Journal of Economic Methodology*, 20(2), 164–183.
- Schul, J. (2015). Pedagogical triangulation: The mergence of three traditions in history instruction. *The Social Studies*, 106(1), 24–31.
- Scott, R.B.R. & Michèle, R.B. (1999). *Sparks of Genius. The thirteen thinking tools of the world's most creative people*. New York: Houghton Mifflin Harcourt.
- Silverman, K., Hong, S., & Trepanier-Street, M. (2010). Collaboration of teacher education and child disability health care: Transdisciplinary approach to inclusive practice for early childhood pre-service teachers. *Early Childhood Education Journal*, 37(6), 461–468.
- Smith, A. R., Jr., & Christie, C. (2004). Facilitating transdisciplinary teamwork in dietetics education: A case study approach. *Journal of the American Dietetic Association*, 104(6), 959–962.
- Souto-Manning, M., Falk, B., López, D., Barros Cruz, L., Bradt, N., Cardwell, N., McGowan, N., Perez, A., Rabadi-Raol, A., & Rollins, E. (2019). A transdisciplinary approach to equitable teaching in early childhood education. *Review of Research in Education*, 43(1), 249–276.
- Steiner, G., & Posch, A. (2006). Higher education for sustainability by means of transdisciplinary case studies: An innovative approach for solving complex, real-world problems. *Journal of Cleaner Production*, 14(9–11), 877–890.
- Stevenson, R. B., Lasen, M., Ferreira, J. A., & Davis, J. (2017). Approaches to embedding sustainability in teacher education: A synthesis of the literature. *Teaching and Teacher Education*, 63, 405–417.
- Strong, L., Adams, J. D., Bellino, M. E., Pieroni, P., Stoops, J., & Das, A. (2016). Against neoliberal enclosure: Using a critical transdisciplinary approach in science teaching and learning. *Mind, Culture, and Activity*, 23(3), 225–236.
- Teixeira, E. S., Greca, I. M., & Freire, O. (2012). The history and philosophy of science in physics teaching: A research synthesis of didactic interventions. *Science & Education*, 21(6), 771–796.
- Valdés, R.M.T., Santa Soriano, A., & Almendros, C.P. (2019). The transference of theoretical models to productive transdisciplinary intersections in public relations management: eight case studies addressing wicked problems. *Public Relations Review*, 45(5), 101799.
- Van Drie, J., & Dekker, R. (2013). Theoretical triangulation as an approach for revealing the complexity of a classroom discussion. *British Educational Research Journal*, 39(2), 338–360.
- Vanasupa, L., McCormick, K. E., Stefanco, C. J., Herter, R. J., & McDonald, M. (2012). Challenges in transdisciplinary, integrated projects: Reflections on the case of faculty members' failure to collaborate. *Innovative Higher Education*, 3, 171–184.
- Vargas-Madrado, E. (2018). Contemplative dialogue as the basis for a transdisciplinary attitude: Ec literacy toward an education for human sustainability. *World Futures*, 74(4), 224–245.
- Varpio, L., Ajjawi, R., Monrouxe, L. V., O'Brien, B. C., & Rees, C. E. (2017). Shedding the cobra effect: Problematising thematic emergence, triangulation, saturation and member checking. *Medical Education*, 51(1), 40–50.
- Wagner, T., Baum, L., & Newbill, P. (2014). From rhetoric to real world: Fostering higher order thinking through transdisciplinary collaboration. *Innovations in Education and Teaching International*, 51(6), 664–673.

- Wallace, H. (2019). Transdisciplinary learning in a kitchen garden: Connecting to nature and constructing a path to ecoliteracy? *International Research in Geographical and Environmental Education*, 28(4), 309–323.
- Weiss, D., Cook, B., & Eren, R. . (2020). Transdisciplinary approach practicum for speech-language pathology and special education graduate students. *Journal of Autism and Developmental Disorders*, 1–18.
- West, J., Salter, A., Vanhaverbeke, W., & Chesbrough, H. (2014). Open innovation: The next decade. *Research Policy*, 43(5), 805–811.
- Whelan, P., & Lawthom, R. (2009). Transdisciplinary learning: Exploring pedagogical links between feminisms and community psychology. *Feminism & Psychology*, 19(3), 414–418.
- Wijma, A. J., Speksnijder, C. M., Crom-Ottens, A. F., Knulst-Verlaan, J. C., Keizer, D., Nijs, J., & van Wilgen, C. P. (2018). What is important in transdisciplinary pain neuroscience education? A qualitative study. *Disability and Rehabilitation*, 40(18), 2181–2191.
- Yu, H. (2016). Teaching cultural heuristics through narratives: A transdisciplinary approach. In K. S. Amant (Ed.), *Teaching and training for global engineering: Perspectives on culture and professional communication practices* (pp. 219–238). Wiley-IEEE Press.

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