Exploring the Role of Teacher Self-Efficacy and Personal Environmental Practices in Integrating Sustainability into Their Teaching: A Network Analysis of German Teachers

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The integration of sustainability and environmental conservation into school curricula has become increasingly important. Teachers are viewed as key actors in this process, often referred to as "change agents". Many are not specifically prepared for Education for Sustainable Development (ESD), and there is considerable variation in how explicitly or implicitly teachers address such topics in their teaching. Knowledge on interpersonal factors shaping this variability is still scarce, along with insights into their nomological net. Against this background, this study explores the relationships between teachers' incorporation of sustainability in their lessons, their self-and action-efficacy, personal attitudes, eco-anxiety, private engagement, and knowledge, alongside perceived student interest and pressure, and school awareness. We surveyed 419 teachers from various school types in Germany (M = 45 years, SD = 10.9; 68% female; average teaching experience = 16 years, SD = 9.9) relying on established scales and a knowledge test. The results revealed significant differences in how frequently teachers incorporated sustainability into their teaching, which were not systematically related to school type, gender, or teacher training. Network analyses highlighted that self-efficacy and private engagement, rather than teachers' knowledge, play a central role. Private engagement also showed high centrality indices and functioned as key bridge in the network, while high self-efficacy beliefs were particularly strongly tied to frequent ESD implementation in the classroom. We discuss how this points to both being two functionally different, but relevant points of interest for supporting teachers in incorporating sustainability in their lessons.

Keywords: sustainability, self-efficacy, motivation, teacher, education for sustainable development

Climate change is one of the greatest challenges for society today, necessitating a response not only from a political perspective but also from collective and individual efforts. In this context, Education for Sustainable Development (ESD) emerges as a transformative learning process aimed at equipping learners with the knowledge, skills, attitudes, and values necessary to address the complex challenges of sustainable development. These include climate change, biodiversity loss, poverty, and inequality. ESD empowers individuals to make informed decisions and take responsible actions for the environment, economic viability, and a fair society, both for present and future generations [1]. The global relevance of ESD is emphasized by its inclusion in the United Nations' Sustainable Development Goals (SDGs), especially Goal 4, which aims to ensure inclusive and equitable quality education. Therein, it is also emphasized that ESD should be integrated into all levels of education by 2030. This is considered essential for fostering the competencies required to create a sustainable future, such as critical thinking, problem-solving, and the ability to collaborate across cultural and disciplinary boundaries [2]

To this end, teachers are pivotal. As facilitators of learning, they are in a unique position to influence students' understanding and attitudes towards sustainability. Frequently, however, ESD is not yet embedded in common, national curricula. Moreover, and beside content specifications, teachers can act as "change agents" by integrating sustainability principles into their teaching practices, thereby fostering a culture of sustainabil-

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ity within their classrooms and broader school communities [3]. Note that ESD is a unique and complex approach, not just an implementation of new guidelines. As such, it requires comprehensive actions across the entire school and profoundly engages everyone involved, including teachers and students, whose lives and futures are directly affected by the issues comprised in ESD. Therefore, while general models of how teachers implement change can help grasping these issues, specific insights are necessary to better understand the variability between teachers in their integration of ESD into their lessons [4]. Such variability in between teachers is still little understood, including the surrounding nomological net. More specifically, the role of an ESD educator requires teachers to be well-prepared and confident in their ability to teach (complex and partly controverse) sustainability topics, likely requiring high efficacy beliefs to address these topics in their teaching. Besides that, following theorizing on competency models and educational psychology, various further factors can be considered as relevant for how teachers integrate ESD in their teaching, including personal factors such as attitudes, worries, private engagement, and knowledge, alongside perceived student interest and pressure, and school awareness. Accordingly, in the present research, we investigated interindividual differences in teachers' implementation of ESD in a broad sample of German school teachers and explored its nomological net with the aforementioned factors. By exploring these questions, we aim to identify relevant levers for understanding and enhancing the effectiveness of sustainability education. This not only contributes to the academic understanding of ESD but also provides practical insights for policymakers and practitioners aiming to promote sustainable practices in schools.

ESD and Role of Teachers as "Change Agents"

The comprehensive scope of ESD subsumes addressing critical global challenges such as climate change, biodiversity loss, environmental degradation, and economic instability. To this end, ESD reflects an integrated perspective to foster a holistic understanding of sustainability. This is considered as essential for developing the necessary attitudes and values that underpin sustainable living and for promoting behaviors that support environmental integrity, economic viability, and social justice [5]. Accordingly, embedding ESD into school curricula involves a broad approach that transcends traditional disciplinary boundaries.

In practice, the formal embeddedness of ESD into school curricula varies significantly across different countries and educational systems [6]. Some nations have developed comprehensive national frameworks and policies that mandate the inclusion of ESD across all levels of education; most have not [6]. Many countries are still developing such frameworks, facing challenges like insufficient resources and limited policy support [7]. In Germany, ESD is not yet systematically formally anchored but is increasingly integrated into educational landscapes [8, 9]. Accordingly, this provides a suitable foundation for investigating differences between different teachers.

The whole-institution approach advocated by UNESCO [1] emphasizes the need for ESD to stretch across all aspects of school life, including governance, operations, and community engagement. Specifically, this approach encourages schools to model sustainable practices, such as reducing energy consumption, promoting recycling, and engaging with local communities on sustainability initiatives [similar to universities, see 10]. By doing so, schools have the potential to create an environment that, through the collective actions of teachers and students, supports and reinforces the principles of sustainability, providing a living example for students and staff.

While this makes it clear that multiple, person- and institution-based factors matter for the incorporation of ESD in schools, it is also clear that individual teachers are central to the successful implementation of ESD [11]. As facilitators of learning, they are ideally positioned to shape students' understanding and attitudes towards sustainability. By integrating sustainability principles into their teaching practices, teachers can further strengthen a culture of sustainability within their classrooms and extend it to the broader school community [12]. This role of teachers as "change agents" is particularly vital for the success of ESD, as they are responsible for translating educational policies and curricula into meaningful learning experiences for students. However, there is arguably substantial variability in how teachers incorporate ESD into their teaching, with significant interindividual differences in both the explicit and implicit integration of sustainability topics [13]. These interindividual differences in how teachers integrate sustainability and environmental conservation into their teaching and the reasons for teachers (not) to do so are still barely understood [13]. Identifying how teachers successfully integrate sustainability education into their teaching practice is considered as key research aim [4], to which end particularly

quantitative insights are called for [14]. Teacher competence models and insights from educational psychology provide grounds to draw potential reasons and sources for interindividual differences.

Multiple theoretical models outline the competencies teachers need for effectively integrating Education for Sustainable Development (ESD) into their lessons. These models, including UNESCO's Competency Framework for ESD, UNECE's key competencies, and the European Competence Framework for Educators on ESD, were explicitly formulated regarding teacher competencies; others [e.g., 15, 16] have been adapted for educators. Common aspects across these models include a solid foundation of teachers' sustainability knowledge, practical application skills, and fostering of positive attitudes and behaviors toward sustainability [16-18]. Accordingly, the models emphasize the importance of self-and action-efficacy and knowledge. For example, system thinking enhances self-efficacy by helping teachers understand and explain complex sustainability issues. Besides that, personal aspects like attitudes and worries are also relevant to teaching sustainability, as a personal commitment to sustainability influences teaching practices [15]. Additionally, teachers' private engagement with sustainability outside the classroom reinforces behaviors aligned with ESD principles, promoting authenticity and commitment in teaching. Further, from an educational psychology perspective, it is also important to consider aspects of the social context of teaching, such as perceived student interest and student pressure. Finally, as previously stated, school awareness of sustainability is expected to impact teaching [1]. It reflects the broader social and institutional context in which teachers operate. Perceived student interest and pressure can significantly drive a teacher's motivation to integrate ESD, while school awareness reflects level of institutional support that can facilitate or hinder ESD.

In conclusion, self-and action-efficacy, personal attitudes, worries, private engagement, and knowledge, alongside perceived student interest, pressure, and school awareness, are plausible aspects of the nomological net of teachers' ESD integration that we investigated and elaborate on next.

Teachers' Efficacy as Key Motivational Factor

To fulfill their role as change agents, teachers must be adequately prepared and supported. This involves not only acquiring the necessary content knowledge but also developing the pedagogical skills to engage students in critical discussions about sustainability and to inspire them to take action. Efficacy, encompassing both self-efficacy and action-efficacy beliefs, is a critical motivational factor in education, influencing teachers' enthusiasm, commitment, and instructional practices [19-24].

Efficacy refers to the belief in one's ability to execute actions necessary for specific performance attainments. It significantly impacts not only teachers' professional well-being but also their ability to foster student engagement and learning outcomes. Both theory and prior empirical evidence suggest that efficacy beliefs are key for teachers to feel capable of addressing complex and sometimes controversial issues in their classrooms, such as sustainability [25, 26]. Self-efficacy, specifically, is the belief in one's own capabilities to organize and execute the courses of action required to manage prospective situations [19]. Action efficacy, on the other hand, pertains to the belief that certain actions will produce desired outcomes [also termed action-outcome expectancy, 21, 27]. Although empirically distinct, these constructs are often closely related, and it is essential to distinguish between them to understand their individual effects accurately. To this end, multivariate analyses, like network analyses, are necessary.

High self-efficacy in teaching is associated with greater perseverance, openness to new teaching strategies, and inclusion of contextualized, called-for practices [24, 28]. ESD-related self-efficacy, more specifically, has been found to be positively related to self-rated content knowledge of (typically, pre-service) teachers [29-33]. While there is little empirical evidence on teachers' action efficacy beliefs, the theoretical assumptions for their relevance for ESD implementation mirror those of self-efficacy. Highly efficacious teachers are more likely to adopt innovative and student-centered teaching methods conducive to ESD. They should also be more resilient in the face of challenges and more motivated to persist in their efforts to integrate sustainability into their teaching practices. Heightened efficacy enables them to overcome barriers such as limited resources or institutional support and motivates them to incorporate sustainability topics into their curricula [25, 26].

Personal Factors: Attitudes, Eco-Anxiety, Private Engagement, and Knowledge

As pointed out before, the successful implementation of ESD is likely associated not only with efficacy beliefs but also by further personal factors of the teachers [34]. These personal factors include attitudes towards sustainability, worries about environmental issues

(eco-anxiety), personal sustainable behaviors, and the knowledge they possess regarding sustainability topics. Understanding how these personal factors interact and relate to teaching practices can provide deeper insights into the variability in ESD implementation among teachers.

Teachers' attitudes towards sustainability education likely play a relevant role in shaping their teaching practices. Attitudes encompass beliefs, feelings, and behavioral intentions towards teaching sustainability and environmental issues [35]. Teachers who believe in the importance of sustainability and view it as a critical component of education are more likely to incorporate these topics into their lessons [13]. Teachers with strong pro-environmental attitudes have been found to be more likely to adopt teaching practices that promote sustainability and encourage students to engage in sustainable behaviors [34, 36]. Notably, teachers attitudes towards environmental education are intertwined with their knowledge about environmental topics, pointing to a need to investigate both together when examining teachers' implementation of ESD [37].

Eco-anxiety, or environmental worries, refer to the feelings of concern and anxiety that individuals experience regarding environmental degradation and the potential future impacts of climate change [38]. Such worries can have both positive and negative effects on teaching practices. On one hand, teachers who are highly concerned about environmental issues may feel more motivated to incorporate sustainability topics into their lessons to raise awareness and foster proactive behavior among students. On the other hand, excessive worry can lead to feelings of helplessness or eco-paralysis, where the magnitude of environmental problems seems so overwhelming that it inhibits action [38, 39]. First research suggests that teachers who manage to channel their environmental concerns constructively are more likely to engage in ESD [40]. These teachers use their worries as a driving force to educate and inspire students, helping them understand the importance of sustainability and encouraging them to take action.

Teachers' private engagement regarding sustainable behaviors also should be closely connected to their approach to ESD. Sustainable behaviors refer to actions that individuals take to reduce their environmental impact, such as recycling, conserving energy, reducing waste, and using sustainable transportation [41]. Teachers who actively engage in these behaviors are more likely to integrate sustainability principles into their teaching practices, serving as authentic role models for their students. Note that engagement is a multifaceted construct, including behavioral and affective tendencies [42, 43]. Indeed, research indicates that teachers who practice and care about sustainable behaviors in their personal lives are more confident and motivated to teach these behaviors to their students [e.g., 36] Private engagement can enhance the authenticity and effectiveness of sustainability education, making it more relatable and impactful for students.

Finally, *knowledge* of sustainability topics should be essential for teachers to effectively incorporate ESD into their curricula. This includes understanding key concepts related to environmental science, climate change, resource management, and social equity, as well as being aware of current sustainability issues and potential solutions [44]. In part, such knowledge can already be generated by high private engagement regarding sustainability. Teachers who possess a strong knowledge base are better equipped to design and deliver lessons that engage students in meaningful discussions about sustainability. However, from an empirical side, knowledge about sustainability does not necessarily directly lead to acting accordingly [45]: Attitudes towards environmental and sustainability issues and towards the effectiveness of possible solutions (i.e., their action efficacy), negative emotions as potential barriers, and teachers' own, personal approach to dealing with sustainability are arguably relevant factors besides teachers' knowledge regarding their integration of ESD in their teaching.

Student Interest and Pressure and School Awareness

The successful implementation of ESD is likely not only related to efficacy beliefs and personal factors of teachers but also to student- and institution-related factors. As pointed out before, this is a key insight from educational psychology research, supplementing the insights on the more personal competence-related factors of teachers. In particular, students' interest in sustainability topics and perceived pressure to engage with these topics, and school awareness of environmental issues appear as relevant aspects of the nomological net surrounding teachers' ESD implementation.

Student *interest* in sustainability topics is a likely driver of effective ESD. When students are genuinely interested in and curious about environmental issues, they can be expected to engage more deeply with the content and participate actively in learning activities [46]. The relevance of student interest for ESD extends beyond student outcomes; it also plays a crucial role for teachers. High levels of perceived student interest in ESD topics should nudge teachers, in their professional role,

to rather pick up these topics in their lessons. Moreover, perceived student interest can serve as positive feedback for teachers, reinforcing their intention and motivation to teach sustainability topics.

At the same time, perceived *pressure* from students to address sustainability can, following the same rationale as before, act as an additional motivational factor, pushing teachers to integrate these topics more thoroughly into their lessons. In the light of the Fridays for Future movement, which is mainly led by school-aged students, pressure to cover sustainability topics from students might be a prevalent occurrence [47]. When students express a strong desire to learn about sustainability, it can validate and reinforce teachers' efforts, thereby boosting their motivation and confidence.

Finally, to close the circle back to the whole-institution approach [1], school *awareness of environmental issues* is another likely relevant aspect surrounding effective ESD. When a school collectively prioritizes and actively engages in sustainability practices, it creates an environment that values and supports ESD initiatives. Such heightened awareness can be inspiring to integrate such issues into own teaching and lead to a more cohesive approach to ESD, as teachers feel supported and encouraged by their school's commitment to these principles. Schools that engage in sustainability initiatives set a practical example for both teachers and students—this can reinforce teachers' efforts to incorporate sustainability topics into their lessons, as they see the tangible benefits and relevance of these practices within their own school environment [13].

The Present Research

With the present work, we investigate the multifaceted interplay of factors surrouding the incorporation of sustainability into teaching practices among in-service teachers in Germany. Doing so, we address limitations of previous studies, which often focused solely on specific, isolated aspects and primarily considered perspectives of pre-service teachers or teacher education students [rather than in-service teachers; e.g., 34].

More specifically, our research questions were, first, to examine variability in teachers implementation of ESD practices in their lessons, second, to study these for any notable differences regarding participants' demographics, and third, to explore the nomological net of implementation of ESD practices in their lessons with regards to self- and action-efficacy beliefs, personal attitudes, eco-anxiety, private engagement, and knowledge, as well as perceptions of student interest and pressure alongside school awareness.

Regarding the latter, our main research aim, we employed network analyses. Network analyses (NA) are a novel, and increasingly popular statistical approach that allow for a nuanced understanding of the complex interplay between personal and contextual factors in shaping teachers' engagement with sustainability education [48-50]. NA is an approach to understanding the organization of constructs and their interrelations by treating variables (constructs or items) as nodes and their relationships as edges [51, 52]. This approach is variable-centered, representing global relations between indicators using partial correlations, both graphically and numerically [53]. NA is particularly well-suited for examining complex and dense patterns of relationships, such as those in the present research, as it considers all nodes simultaneously while avoiding issues of multicollinearity that often arise with large numbers of related variables in traditional factor-analytic approaches [54, 55]. In NA, nodes form communities characterized by strong edges. Edges in NA, based on partial correlations, represent the unique relationship between two nodes while controlling for their relations with other nodes [56]. The visual and numerical representation of these relationships enables researchers to identify influential nodes with strong, close, and multiple edges to other nodes.

As such, NA offers a nuanced understanding of the complex interplay between personal and contextual factors in shaping teachers' engagement with sustainability education. It complements traditional factor analysis methodologies in three notable ways. First, NA provides a comprehensive view of interconnected variables by analyzing multiple edges and expected influences simultaneously, which is ideal for studying the intricate relationships between factors related to ESD implementation. Second, NA visually represents networks, revealing whether groups of indicators form coherent communities, facilitating the interpretation of relationships and network structure. Third, NA identifies influential nodes which is helpful to better understand points of interest for interventions to support teachers' sustainability practices.

Method

To answer our research questions, we surveyed 419 teachers from various school types across Germany using established scales and a knowledge test to measure factors related to the implementation of sustainability education. We examined the relationships between teachers' incorporation of sustainability and their self- and action-efficacy, personal attitudes, eco-anxiety,

private engagement, and knowledge, alongside perceived student interest and pressure, and school awareness through network analyses. We provide all data and code underlying this investigation in an open repository:
https://osf.io/dvgqc/?view_only=9416b2d3a0174f6a9da63c6b8aa78e0d

Participants and Procedure

The participating teachers were sampled from various types of schools across Germany, ensuring a diverse representation of educational settings. The participants had an average age of 45 years (*SD* = 10.9) and an average of 16 years of teaching experience (*SD* = 9.9). The sample comprised 68% women, reflecting the gender distribution typical of the teaching profession in Germany [approximately 72% of teachers in Germany are women, with an average age of 44 years; 57]. The teachers came from a range of school types and educational tracks, providing a comprehensive overview of the teaching landscape. Specifically, 38% of the teachers worked at high schools ("Gymnasium"), 17% at intermediate schools ("Realschule"), 9% at primary schools ("Grundschule"), 5% at comprehensive schools ("Gesamtschule"), and 4% at middle schools ("Mittelschule"). Additionally, 20% of the participants were from other school types, such as Waldorf schools and vocational schools ("Berufsschule"). Regarding their professional backgrounds, 79% of the participants were fully certified teachers, 14% were career changers, and 4% were teacher trainees.

The teachers participated in an online survey, recruited through professional networks, educational associations, and social media platforms. Participants were informed about the study's purpose, assured of the confidentiality of their responses, and provided with instructions on how to complete the survey. Informed consent was obtained from all participants before they began the survey, and ethical standards for research involving human subjects by the American Psychology Association (APA) and the German Psychology Society (DGPs) were carefully followed.

Measures

Before administering the survey, a pilot test was conducted with a small group of teachers to ensure clarity and suitability of the items. Based on the feedback, minor adjustments were made to the survey to improve comprehensibility.

ESD Implementation

To assess the extent to which teachers implemented ESD in their classrooms, we captured the frequency to which the teachers addressed sustainability-related themes into their teaching practices. We used the sum score of two items to reflect explicit and implicit consideration in their lessons (e.g., for explicit consideration: "How often in the course of the school year do you explicitly address sustainability and climate protection in your lessons?"), after providing examples of what explicit or implicit consideration entails. Teachers were instructed to refer their responses to the average across all classes and subjects, responses were recorded on a Likert scale ranging from 0 (*never*) to 5 (*almost each lesson*).

Self- and Action-efficacy

Self-efficacy was measured using eight items adapted from Klassen, Bong [58]. This scale assesses teachers' confidence in their ability to effectively teach sustainability and climate protection topics (e.g., "To what extent can you provide alternative explanations in the area of sustainability and climate protection when your students do not understand something?"; internal reliability, McDonalds ω_h= .88) Responses were recorded on a scale ranging from 1 (*not at all confident*) to 9 (*completely confident*).

Action-efficacy was measured with three items adapted from Rieß and Mischo [59]. This scale captures teachers' beliefs on the effects of teaching actions on students' sustainable behaviors (e.g., "Through school-based teaching of sustainability and climate protection, the sustainable behavior of students can be influenced"; ω_h= .62). Responses were recorded on a 4-point Likert scale from 1 (*strongly disagree*) to 4 (*strongly agree*).

Personal Factors: Attitudes, Eco-anxiety, Private Engagement, and Knowledge

Attitudes towards sustainability education were measured with a 5-item scale adapted from Keller, Rinas [60]. This scale captures teachers' beliefs about the necessity and importance of teaching sustainability and climate protection (e.g., "I believe that it is … for teachers to convey sustainability and climate protection to students"; ω_h= .87). Responses were recorded on a semantic differential scale from 1 (e.g., *unnecessary*) to 7 (e.g., *necessary*).

Eco-anxiety was assessed using a scale with 13 items adapted from Hogg, Stanley [39]. This scale measures the frequency with which teachers experience anxiety or nervousness about climate change and other sustainability challenges (e.g., "When you think about climate change or other sustainability challenges, how often do

you feel nervous, anxious, or tense?"; ω_h= .92). Responses were recorded on a scale from 0 (*never*) to 4 (*almost every time*).

Teachers' private engagement in sustainable behaviors was assessed using a 9-item scale from Geiger, Gasper [36]. This scale measures the frequency of personal practices such as recycling, conserving energy, and reducing waste, along with their affective-cognitive evaluation (e.g., "I use my bike, public transport or walk for my everyday journeys"; "It makes me angry when I see how Germany is missing its climate protection targets"; ω_h= .86) Responses were recorded on a 4-point scale from 1 (*strongly disagree*) to 4 (*strongly agree*).

Knowledge of sustainability was assessed using an 8-item single-choice test from Geiger, Gasper [36]. This test evaluates teachers' understanding of key concepts related to sustainability and climate protection. A sample question is, "What does the carbon footprint of a product represent?", with answer options "The typical coloring of the sky caused by high CO_2 concentrations"; "The amount of all greenhouse gas emissions generated during the life cycle of a product" [correct]; "The amount of CO_2 that a product releases when it decomposes", and "The chemical change caused by CO_2 in the atmosphere".

Student Interest and Pressure and School Awareness

Teachers' perceptions of student interest in sustainability topics was measured using a single item adapted from Waltner, Rieß [61]. With a single item, teachers rated their students' interest in sustainability compared to other subjects: "How do you rate your students' interest in sustainability and climate protection compared to other subjects?" Responses were recorded on a scale from 1 (*less than other subjects*) to 4 (*higher than other subjects*).

Likewise, perceived pressure from students to include sustainability topics in the curriculum was measured with the following item: "How do you rate the pressure from your students to address sustainability and climate protection in your teaching?" Responses were recorded on a scale from 1 (*less than other subjects*) to 4 (*higher than other subjects*).

Finally, awareness of sustainability in the school environment was measured using a 4-item scale by Waltner, Rieß [61]. This scale captures the extent to which sustainability and climate protection are prioritized and discussed within the school (e.g., "Sustainability and climate protection topics are important at our school"; ω_h= .74). Responses were recorded on a 4-point Likert scale from 1 (*strongly disagree*) to 4 (*strongly agree*).

Analyses

All analyses were conducted in R, version 4.4.1 [62]. Regarding the first two research questions, we investigated descriptive statistics, including value distributions in violin plots, and multiple one-factorial analyses of variance to test for potential differences in ESD implementation between different subgroups of teachers.

As main analyses, we conducted network analyses to explore the relationships between the various constructs and identify key factors influencing the implementation of ESD in classrooms [63]. Specifically, the network analysis was performed using the "network tools" package version 1.5.0 [64]. The graphical network was estimated using the Fruchterman–Reingold algorithm, which provides a layout for network visualization by treating edges as springs that can stretch and nodes as repulsive objects [65]. This algorithm helps in clearly displaying the structure of the network by minimizing edge crossings and evenly distributing nodes. To address potential issues with representing all edges, which can obscure the meaningful connections, we applied the least absolute shrinkage and selection operator (LASSO) to the Gaussian graphical model. LASSO regularizes the partial correlations, shrinking smaller edges to zero, resulting in a sparser but more interpretable network. This method ensures that the remaining edges are significant and meaningful [66].

Given the recommendations by Isvoranu and Epskamp [67](low sample size; and primary interest to discover a structure that resembles a true network and to discover the strongest edges) we used the Least Absolute Shrinkage and Selection Operator (LASSO) using the EBICglasso function that was applied to the Gaussian

Table 1

Descriptive Statistics and Bivariate Correlations

	Descriptive statistics							Bivariate correlations								
	M	*SD*	Min	Max	Range	Skew	Kurtosis	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
ESD implementation	5.70	2.21	0.00	10.00	0-10	–0.27	–0.21	.45	.22	.12	.09	.33	.14	.14	.17	.23
[1] Self-efficacy	5.14	1.50	1.00	9.00	1-9	–0.29	0.32		.35	.25	–.09	.24	.02	.36	.35	.31
[2] Action-efficacy	2.65	0.68	1.00	4.00	1-4	–0.22	–0.66			.13	.05	.25	–.09	.38	.26	.18
[3] Attitudes	6.19	1.07	1.00	7.00	1-7	–1.84	3.61				.19	.52	.28	.27	.26	.14
[4] Eco-anxiety	1.88	0.57	1.00	4.00	1-4	0.64	0.24					.39	.04	–.02	.01	–.18
[5] Private engagement	5.72	1.08	1.67	7.00	1-7	–1.60	2.78						.35	.24	.16	.10
[6] Knowledge	0.88	0.16	0.00	1.00	0-1	–2.06	5.91							.04	.06	–.02
[7] Student interest	2.32	0.73	1.00	4.00	1-4	–0.03	–0.42								.56	.19
[8] Student pressure	2.11	0.90	1.00	4.00	1-4	0.60	–0.31									.24
[9] School awareness	4.81	0.85	2.75	6.50	1-7	–0.34	–0.79									

Note. $N = 419$. $|r| > .10$: $p < .05$, $|r| > .12$: $p < .01$, $|r| > .16$: $p < .001$.

model in order to regularize partial correlations [68]. LASSO shrinks small correlations to zero, thereby eliminating potentially spurious relations and resulting in a network that contains fewer, but potentially more meaningful, edges. The LASSO graphical network exhibited multiple small edges, running the danger of potentially false positive edges (dense network with $\lambda < .1 * \lambda_{max}$). Accordingly, we applied a threshold to enforce higher specificity at the cost of sensitivity [see Janková and van de Geer, 69]. Edges meeting the minimum threshold were retained and those that did not were set to zero. The resultant network therefore contains fewer, but more genuine, edges. This reasoning was also reflected in our choice of hyperparameter values. Values closer to 0 accept models with a greater number of potentially false edges, and values closer to 0.5 accept models with fewer, but authentic, edges [51, 53]. We chose $\gamma = 0.5$ to estimate a conservative model that contained the most meaningful edges. A non-parametric boostrapping procedure using 1000 draws was used to estimate the edge weights. To draw the edges, we used the default fading rule of the qgraph package [51]; as recommended by Isvoranu and Epskamp [67], considering our research questions. In the graphical networks, positive edges are represented as green lines and negative edges as red lines, with thicker lines indicating stronger connections.

The number and strength of edges a node shares with others in the network were assessed through common centrality indices: (1) *betweenness*: measures the extent to which a node lies on the shortest path between other nodes, indicating its role as an intermediary or bridge within the network, (2) *closeness*: reflects the average distance from a node to all other nodes, highlighting how quickly information can spread from that node throughout the network, (3) *strength*: represents the sum of the absolute values of all edges connected to a node, indicating its overall level of connectedness. Further, and accounting for the mix of positive and negative edges, we used one- and two-step expected influence (EI1 and EI2) values. These metrics provide accurate estimates of node influence in networks with both positive and negative connections [70]. Note that the term "influence" is not intended to imply directionality or causality here, rather it is used to describe relations between nodes in terms of their number, strength, and distance. Specifically, *EI1* represents the direct influence of a node, calculated as the sum of its connections, and *EI2* represents the indirect influence of a node, capturing its impact on other nodes through intermediate connections. Similarly, we calculated bridge centrality and expected influence values to understand the role of nodes in connecting different communities within the network.

The robustness of the estimated network was verified through several methods. Following Epskamp, Borsboom [71], we used the bootnet package (version 1.5.5) to investigate the stability and accuracy of the network with 2,500 nonparametric bootstrapped samples. The accuracy of the estimated network was checked following Epskamp, Borsboom [71] threefold recommendations. First, bootstrapped Confidence Intervals (CIs)

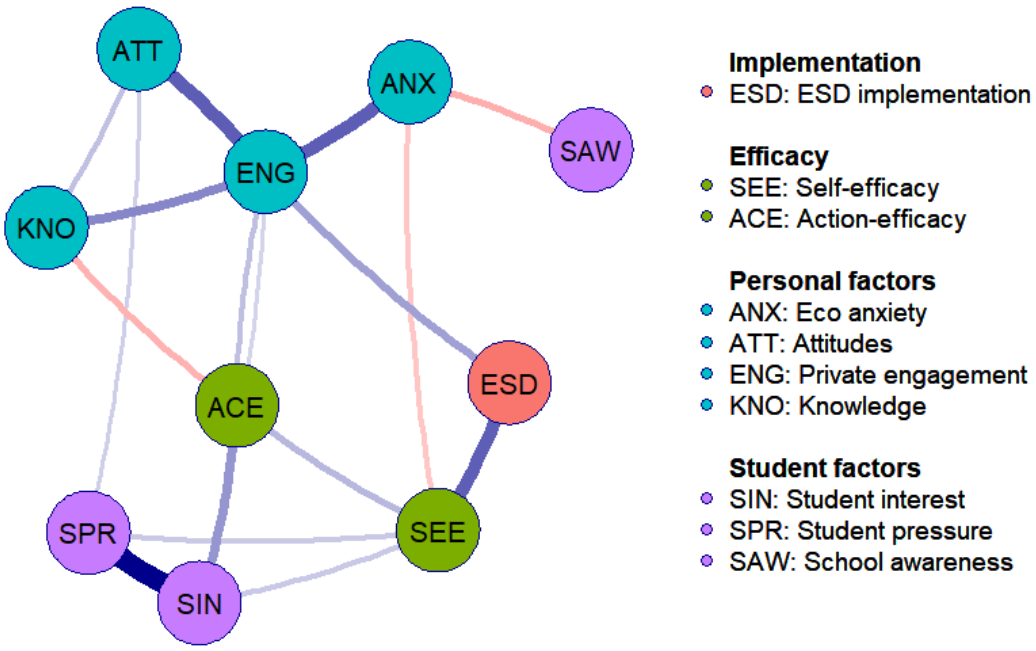

Figure 1. ***Graphical Network of ESD Implementation and its Nomological Net Based on Regularized Partial Correlations Between Nodes.*** *Note: Blue and red edges represent positive and negative partial correlations, respectively. Edge weights ranged from –0.12 (ANX–SAW) to 0.41 (SIN–SPR).*

were used to assess the stability of the edge weights and centrality indices, ensuring that the results are not unduly influenced by specific data points (see Figure S2). Second, we conducted stability checks across data subsets of edge weights and expected influence indices on subsets of the data (see Figure S3). Third, bootstrapped difference tests were performed between pairs of nodes to evaluate the reliability of the centrality measures (see Figure S4).

Results

Variability Between Teachers in ESD Implementation in Their Teaching

Regarding ESD implementation and our first research question, we observed almost the full theoretical range ranging from participants reporting to never explicitly and never implicitly implementing ESD in their lessons, to do so both explicitly and implicitly almost every single lesson, across all their taught subjects and classes (see Table 1). The distribution of responses approximated a normal distribution, with most participants scoring in the mid-range. This is also illustrated by the dense clustering of scores around the central values (see violin plot, in Figure S1), indicating that many participants incorporated ESD topics on a monthly or weekly basis, while fewer participants were at the low or high ends of ESD integration. The central tendency towards moderate frequency highlights that most participants integrated ESD moderately, with room for more frequent inclusion of sustainability topics in education.

Regarding our second research question, we did not observe notable differences in this data distribution across different types of teachers (see Figure S1). Likewise, ANOVA results indicated no statistically significant differences in ESD implementation across different types of schools, with $F(5, 321) = 0.69$ and $p = .63$; gender, with $F(1, 273) = 0.01$ and $p = .93$; or professional status, with $F(1, 274) = 2.14$ and $p = .15$. We did observe that ESD implementation slightly covaried with teacher age ($r = .15$, $p = .01$). Further, there were small to medium correlations with the assessed efficacy beliefs, personal, and student-related factors (see Table 1), strengthening the assumption that these were relevant aspects to be considered regarding the nomological net. The bivariate correlations among these factors also spoke to their intertwinement, paving the grounds for the subsequent network analysis.

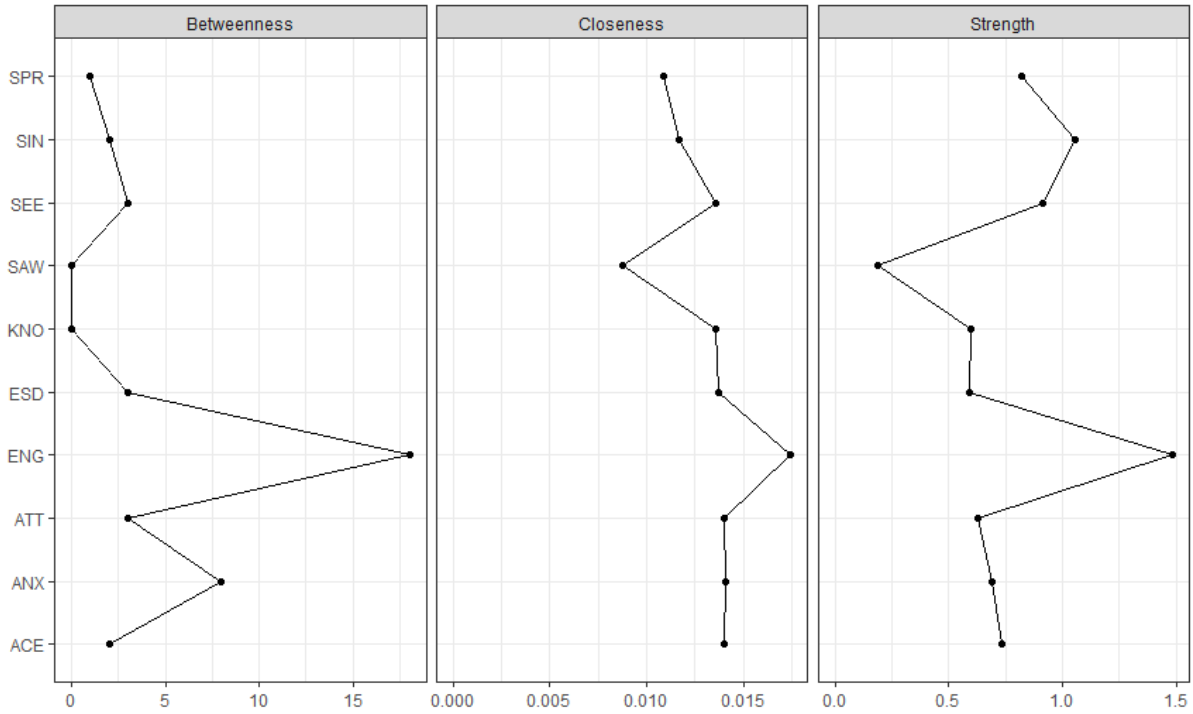

Figure 2. ***Centrality Indices.*** *Note: ACE = Action-Efficacy, ANX = Eco-anxiety, ATT = Attitudes, ENG = Private Engagement, ESD = ESD Implementation, KNO = Knowledge, SAW = School Awareness, SEE = Self-Efficacy, SIN = Student Interest, SPR = Student Pressure*

Network Analysis on the Nomological Net of ESD Implementation

The purpose of the NA was to examine the nomological network along with centrality and influence statistics. In Figure 1, the measured constructs are presented as differently colored circles. Positive and negative edges are depicted as green and red lines, respectively. Following Epskamp, Borsboom [71], bootstrapped CIs showed that estimated edge weights were accurate, and the EI indices were relatively stable with a stability coefficient of 0.52 (i.e., 52% of the data could be dropped to retain with 95% certainty a correlation of .70 with the original dataset). Additional details on the network stability and accuracy are provided in the Supporting Information.

The LASSO graphical network is shown in Figure 1 [see 67]. ESD implementation was located at the right of the network. In terms of statistically significant relations with the considered factors, ESD implementation was positively associated with self-efficacy (edge weight = .30) and private engagement (edge weight = .16). This suggests that teachers who felt more confident in their abilities and those who personally engaged in sustainable behaviors were more likely to integrate ESD into their lessons, considering all other factors.

Private engagement emerged as a central node that scored highly on all centrality and bridge indices (see Figure 1, and supporting information). Notably, private engagement served as a key bridge for the other three personal factors, attitudes, eco-anxiety, and knowledge, that clustered together in the upper part of the model. Knowledge was placed on the left of the model, and shared, beside the edge with private engagement, a negative edge with action-efficacy; implying that teachers who have less knowledge on sustainability are more easily convinced on how efficacious ESD actions can be.

Self-efficacy, while closely related to ESD implementation, did not stand out as a key bridge like private engagement. Instead, we observed only weak edges, with student interest and pressure, that closely clustered together in the bottom left of the model. While primarily operating as bridge towards student interest and pressure, self-efficacy shared one statistically significant edge with the personal factors, namely a negative edge with personal anxiety. This implies that highly self-efficacious teachers also tended to feel less eco-anxiety than other teachers, all other factors considered. Action-efficacy was placed to the left of self-efficacy,

bridging it towards private engagement with which the latter shared no direct edge. This emphasizes different roles of private engagement and self-efficacy in the model.

Notably, while student pressure and interest were closely grouped, school awareness was not part of this community, but placed on the other end of the model. Also, this proved the least relevant node in the model, in terms of observed influence (see Figure S6).

Discussion

Given its global significance, particularly highlighted in the United Nations' Sustainable Development Goals (SDGs), understanding how teachers implement ESD in their classrooms is crucial to address our society's challenges towards sustainable futures. In this study with a large and broad sample of practicing teachers from Germany, we discovered large differences in ESD implementation. Demographic variables like age, gender, and school type were not significant predictors. Instead, psychological and malleable aspects emerged as explanatory and shaped the nomological net surrounding ESD implementation which we investigated through network analyses—a novel statistical approach that proved suitable to investigate the complex interplay of personal and institutional factors surrounding ESD. Taken together, these findings suggest actionable pathways for enhancing ESD implementation, focusing on bolstering teachers' self-efficacy and considering their private engagement in sustainable practices.

More specifically, our findings for Research Question 1 revealed significant variability in how frequently teachers incorporate ESD into their lessons. The central tendency towards moderate frequency highlights a balanced approach to ESD in teaching practices, with most teachers incorporating sustainability topics on a monthly or weekly basis. This suggests that while teachers are somewhat engaged with sustainability topics, there is still a substantial opportunity to deepen their engagement, thus strengthening the frequently articulated necessity of initiatives aimed at encouraging more frequent inclusion of sustainability topics in education [e.g., 72, 73], while generally supporting the need for better understanding this variability that we followed up on in the present work.

To this end, and addressing Research Question 2, our study found no significant differences in the implementation of ESD based on demographic factors such as age, gender, or school type. This conclusion was supported by both visual inspection of value distributions and explicit statistical tests. These findings challenge commonly held ideas that older teachers are less capable of integrating ESD into their lessons or that only younger teachers, who might have received more recent training in sustainability education, are likely to implement ESD effectively. This aligns with findings from previous research that suggest the personal factors that we considered in our network analysis, rather than immutable demographic characteristics, are more relevant in influencing ESD practices [6, 7].

For Research Question 3, our findings highlight self-efficacy and private engagement as the primary factors relevant to ESD implementation. Interestingly, these two constructs emerged as quite distinct, with no direct relationships between them and belonging to different communities within the network analysis. Private engagement, in particular, functioned as a key bridge among other personal factors, in line with its broader theoretical influence encompassing cognitive and affective-behavioral aspects [42, 43]. Reflecting both personal commitment and practical actions toward sustainability makes private engagement a valuable proxy for identifying teachers who might benefit most from targeted support. For instance, teachers who are already engaged in sustainable behaviors in their private lives may be more receptive to engaging in practical initiatives focused on ESD and could serve as starting points to get the ball rolling by initiating sustainability practices in their schools. Conversely, teachers with low private engagement might especially benefit from participating in professional development about ESD. On a more general note, the identified relevance of private engagement aligns with the mission identified in our introduction, suggesting that an isolated approach may not be effective as a whole-school approach that integrates personal, professional, and institutional support [1, 5]. For ESD, teachers are not merely conveyors of knowledge but also role models and catalysts for change within their school communities.

Self-efficacy, while critical for ESD implementation, was not related to these personal factors, but rather to perceived student interest and pressure and, negatively, to eco-anxiety. This suggests that, as expected, students' positive feedback concerning sustainability topics makes teachers feel more efficacious about teaching these topics. As our results are cross-sectional, however, this might also suggest that teachers who are confident about teaching ESD in the first place rather spark students' interest. This phenomenon has been observed in mathematics education before [74], suggesting that fostering teachers' self-efficacy to teach ESD might trickle through, here additionally fostering students' in-

terest in sustainability topics. At the same time, the negative link between self-efficacy and eco-anxiety reinforces the notion that high self-efficacy can protect against the anxiety-inducing uncertainty of environmental issues [38].

Moreover, the overall sparse relations between self-efficacy and other aspects considered in our model suggest that additional factors beyond our current scope may play a significant role in fostering self-efficacy. One such aspect is collective self-efficacy, the shared belief in the group's capabilities to achieve goals, which has been shown to impact individual self-efficacy and instruction [75]. Another, related factor is principals' leadership [e.g., 76]. While the present research focused on individual teachers' perspectives, an inclusion of such broader institutional factors could help to better understand and enhance teacher self-efficacy in the context of ESD.

The negative edge between action-efficacy and knowledge (i.e., teachers holding less knowledge on sustainability being more easily convinced of the efficacy of ESD actions) highlights another noteworthy area for intervention. This phenomenon can be partially explained by the Dunning-Kruger effect, which suggests that individuals with lower levels of knowledge may overestimate their competence [77]. Our findings imply that these linkages are bridged by increased action efficacy beliefs, i.e., teachers with little knowledge are more convinced how easily efficacious ESD actions can be. While this is an intriguing theoretical perspective to follow up on in future research, this also implies that considering action efficacy as a potential intermediary belief might offer additional room for practical interventions seeking to emphasize action efficacy beliefs of teachers with little knowledge.

In summary, both self-efficacy (work-related) and private engagement (largely outside work) are necessary for effective ESD implementation. Our findings emphasize the importance of considering both constructs for practical consideration; while private engagement might be particularly relevant for fitting interventions to teachers, self-efficacy is more feasible to be addressed through direct and broad intervention (also justified by the strongest relationship identified with ESD integration for self-efficacy). We outline ideas for practical implications based on these insights later on.

Generally, while highlighting these two aspects within the nomological network surrounding teachers' ESD integration, our study also emphasizes the importance of a multivariate approach to explore the complex landscape of the nomological net of ESD implementation. By employing a novel type of analysis, network analysis, we were able to capture the intricate interrelations among various factors, demonstrating the merits of not only focusing on single constructs but also broadly involving cognitive, behavioral, and emotional-affective aspects. Further, our approach underscores the significance of educational psychology in contributing to this line of research, as it provides a comprehensive understanding of how different personal and contextual factors interplay to influence ESD practices. By integrating insights from educational psychology, environmental education, and sustainability studies, we can develop more holistic strategies to support teachers in incorporating sustainability into their teaching. This aligns with the recommendations of Didham, Fujii [78], who advocate for interdisciplinary approach to teaching and research ESD—another encouraging takeaway from the present research.

Limitations

Despite the strengths, this study also has several limitations that need to be borne in mind when interpreting the results. First, while our broad sample from various types of schools across Germany and the inclusion of practicing teachers that match well with the general population of teachers in Germany is a notable strength, the findings' international generalizability may be limited to similar contexts. Given that Germany's formal incorporation of ESD into curricula is moderate by international standards, our results may be generally applicable to other contexts. However, one must consider that Germany, being part of the WEIRD (Western, Educated, Industrialized, Rich, and Democratic) countries, differs significantly from many other countries, underscoring the need for more international studies [79].

Second, while having an actual knowledge test is an important asset, all other constructs are based on self-reports. Most of the considered constructs such as anxiety, engagement, and efficacy beliefs are inherently cognitive and affective, and cannot be readily assessed through other means. However, it would be insightful to supplement these self-reports with additional data, such as actual behavior, which could be approximated using a diary approach [80].

Third, the cross-sectional nature of the data limits our ability to draw causal interpretations. While our research helped identify two focal leverage points of interest (self-efficacy and private engagement), future

studies using longitudinal designs are necessary to follow up on the underlying mechanisms and validate these findings over time.

Fourth, while we conducted multiple robustness tests to ensure the reliability of our findings, the insights and particularly the network structure generated through this study require further confirmation. Future research should replicate and extend these findings to ensure their stability and applicability in different contexts and with diverse populations.

Practical Implications

Paralleling empirical results for higher education teachers [10], our findings can provide first ideas on how to enrich practical implications on how to foster school teachers ESD integration into their teaching. Courses in sustainable development within pre-service teacher training have been found to be capable of effectively modifying students' beliefs, attitudes, and norms [81]. As noted before, our results imply the need to also focus on enhancing teachers' self-efficacy and to consider their private engagement. While content-specific courses are often advocated [37] and might be warranted for teachers teaching in certain subjects or school types [e.g., in primary schools, see 82], it is equally important to specifically target self-efficacy. Given that subject knowledge continuously evolves, teachers must develop the confidence and skills to independently acquire and update this knowledge.

To this end, teacher training programs could incorporate strategies that build teachers' confidence in their abilities to teach sustainability. This can be achieved through practical workshops, collaborative projects, and opportunities for reflective practice. For instance, integrating self-efficacy building activities into content-specific professional development can create a dual focus on both knowledge acquisition and personal confidence. Practical examples include role-playing exercises, peer teaching sessions, and scenario-based learning, which allow teachers to practice and refine their skills in a supportive environment.

Moreover, a strong sense of efficacy can help mitigate the negative effects of eco-anxiety [38], a challenge that was also evident in our sample. Training programs could additionally bolster self-efficacy beliefs (that were negatively associated with eco-anxiety in the present research) by addressing eco-anxiety directly by providing coping strategies and fostering a sense of empowerment among teachers. This can include discussions on managing environmental concerns, resilience-building activities, and creating a community of practice where teachers can share experiences and support each other.

Conclusion

In the quest to better understand differences in teachers' integration of ESD in their teaching, we observed large variability between teachers that was not attributable to demographic factors. Our network analysis illuminated the intricate web of the nomological net surrounding ESD implementation, highlighting self-efficacy and private engagement as two key aspects with functionally different roles. Our findings imply that by understanding and addressing these factors, educators can create more engaging and supportive learning environments that foster a deeper commitment to sustainability among students. This, in turn, will contribute to the broader goal of developing informed and proactive global citizens capable of addressing the complex challenges of climate change and sustainable development, where seeds of today's educational efforts blossom into the thriving ecosystems of tomorrow.

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