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Using Storytelling for Sustainable Development Education in STEM: A Systematized Literature Review

Thi Kim Uyen Nguyen, Utah State University

Uyen Nguyen is a Ph.D. student in Engineering Education at Utah State University. She earned a master's degree in Mechanical Engineering Technology from Ho Chi Minh City University of Technology and Education. Her research interests include exploring innovative teaching methods and addressing challenges to improve the overall quality of education toward sustainable education.

Dr. Angela Minichiello P.E., Utah State University

Angela (Angie) Minichiello, PhD is a military veteran, licensed mechanical engineer, and Associate Professor of Engineering Education at Utah State University.

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Abstract

The pressing global issues of climate change, environmental degradation, social inequity, and economic instability have elevated sustainable development to a top priority in education. At its core, sustainable development is the pathway we can take to a balanced future. That is, a future where we can live in harmony with each other and with the planet, allowing resources to replenish.

In this context, integrating Education for Sustainable Development into STEM is critical. The reason is that STEM skills are essential for developing technological and scientific solutions to tackle complex sustainability challenges. Traditional STEM education, however, often emphasizes technical concepts and rarely focuses on the emotional connection, missing the link between them and sustainability. Because of this disconnect, students are less motivated to learn and address real problems related to sustainable development. Bridging this gap is essential to fostering students to contribute meaningfully to sustainable solutions.

To address this issue, storytelling, with its capability of fostering empathy, emerges as a potential transformative pedagogy. UNESCO also recognized storytelling as an engaging pedagogy that makes abstract ideas come alive. It connects sustainability concepts not only to learners' lived experiences and values but also to indigenous knowledge and cultural heritage. This systematized literature review examines how storytelling has been used to promote awareness, foster social emotions, and encourage sustainability-related behavior in STEM education, which is still not widely and effectively used. Particularly, this study will seek to address the following research questions:

• RQ1: How have storytelling teaching strategies been employed in STEM education for the purpose of sustainable development?
• RQ2: How have storytelling teaching strategies in STEM education fostered changes aligned with sustainable development?

A systematic search was conducted across four databases, including Scopus, PsycInfo, Education Source, and ERIC, using keywords related to four aspects - storytelling, STEM education, sustainable development, and expected outcomes about awareness, attitude, and behavior. With a strict adherence to the Prisma process, in total, 13 peer-reviewed articles were included in the final step for synthesis.

The results show that a story-based approach in STEM education is implemented in diverse forms, such as oral storytelling, digital storytelling, visual/image narratives, and VR 360-degree experiences. The positive impacts, not only in awareness but also in emotional responses and shifts in attitude among participants, were descriptively analyzed. Besides, we also identified the limitations of the studies themselves and the interventions that have been conducted. Involving only English-language papers, there will inevitably be omissions in the final ones included in the synthesis. However, following the PRISMA process strictly strengthens the reliability of the findings in the paper. It can provide educators with comprehensive practical insights to optimize interventions, helping to bring sustainability into the classroom in meaningful and lasting ways.

1. Introduction

Despite increasing efforts over two decades, beginning in 2005 when the United Nations (UN) formally launched the Education for Sustainable Development (ESD) initiative [1], the world continues towards an environmental breaking point. Reports from the Intergovernmental Panel on Climate Change (IPCC) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services showed that damaging changes related to the climate crisis are not only happening but accelerating [2], [3]. In their report, IPCC emphasized that "The pace and scale of what has been done so far, and current plans, are insufficient to tackle climate change." [2, p. 1]. Following, the 2024 UN report stated that progress on sustainable development has stalled and now requires bold moves [4].

Today, the need to integrate ESD into science, technology, engineering, and mathematics (STEM) education is critical, as STEM skills are essential for developing technological and scientific solutions to complex sustainability challenges. However, several studies critique traditional STEM education for its heavy emphasis on technical knowledge and skills and do not support to develop broader skills related to social and environmental contexts or ethical consideration [5], [6]. These systems successfully equip future engineers with knowledge and technical skills, but fail to promote their engagement with broader societal or environmental challenges [7], [8]. Many studies [9], [10] point out a gap between the STEM knowledge students gain and the motivation or sense of responsibility needed to act on sustainability problems.

To bridge this gap, one direction that educators have been exploring is storytelling. In education, weaving knowledge, values, and emotions into narratives helps learners connect personally with complex topics. These connections support emotional engagement, memory, and meaning-making in ways that standard explanations do not always reach [11], [12]. Studies in sustainability education suggest that storytelling can help students imagine consequences, see possibilities, and build the kind of personal mindset that encourages future behavior [13], [14], [15]. Storytelling also makes room for reflection and building meaningful understanding, leading to more sustainable attitudes and behaviors across various populations [16], [17].

2. Purpose

Given the potential of storytelling for ESD, we investigated if and how storytelling has been used as a teaching approach to raise awareness, foster social emotions, and encourage behaviors aligned with sustainable development among STEM students at various educational levels. We conducted a systematized review of the empirical literature to answer two research questions (RQ):

RQ1: How have storytelling teaching strategies been employed in STEM education for the purpose of sustainable development?

RQ2: How have storytelling teaching strategies in STEM education fostered changes aligned with sustainable development?

We systematically searched the empirical, peer-reviewed literature across four databases, including Scopus, PsycInfo, Education Source, and ERIC, using keywords related to four

aspects–storytelling, STEM education, sustainable development, and expected outcomes related to awareness, attitudes, and behaviors. With a strict adherence to the PRISMA process [18], we identified 13 peer-reviewed articles for synthesis.

This review is part of a larger research effort to examine how narrative-based pedagogies can advance ESD within the context of undergraduate engineering education. It serves two purposes. First, this work provides a comprehensive review of the empirical research on the use of storytelling in STEM education for ESD purposes. Second, it informs the design of a forthcoming intervention study situated in engineering education, where technical narratives are integrated with socio-environmental challenges. By mapping current approaches and gaps, this review establishes a foundation for the development and design of teaching interventions to promote engagement in sustainable development through storytelling.

3. Background

This background section situates the study within the urgent context of ESD and the emerging use of storytelling as a pedagogical approach in STEM education. This establishes the theoretical and contextual foundation that motivates the examination of storytelling as a mechanism for fostering sustainability awareness, social emotions, and sustainable behaviors in STEM learners.

3.1. Sustainable Development as an Educational Goal

The pressing global issues of climate change, environmental degradation, social inequity, and economic instability have elevated sustainable development to a top priority in education [19], [20]. The 1987 Brundtland Report officially defined "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [21, p. 42]. At its core, sustainable development is the pathway and the actions we take to reach an end goal - a sustainable future [22] wherein we can live in harmony with each other and with the planet and allow resources to naturally replenish. That idea is now wrapped into policy frameworks and school plans in many countries through UNESCO's ESD roadmap [20]. However, policy alone does not make change happen. Moreover, these problems do not stop at national borders, as environmental, social, and economic systems all around the world are deeply interconnected. Addressing them requires international collaboration across all sectors, the combination of different scientific disciplines, and the active engagement of stakeholders, whether academic or non-academic [23], [24].

The 2030 roadmap from UNESCO points to one simple reality: students need more than just facts; they need experiences that connect knowledge to real life [20]. Accordingly, ESD researchers are growing attention to emotions and values. Research in environmental education has shown that narratives can be used to shift pro-environmental beliefs [25]. Similarly, many studies found that when learning invites reflection about feelings and community, students are more likely to engage in sustained learning and consider behavior changes later [26], [27], [28]. Several empirical classroom studies likewise report that students who are given space to discuss values show deeper attention to complex sustainability problems [14], [29]. These findings show that sustainable development is not just technical, but the affective side matters.

3.2. Storytelling as a Teaching Strategy

Storytelling has long been a means of communication among humans. With capabilities such as engaging the audience, simplifying complex ideas, highlighting relevance, and fostering emotional connection [30], it has a crucial role in preserving and transmitting knowledge, values, and traditions across generations. Along with that, storytelling also served as an effective pedagogy in official education. Clandinin et al. [31] introduced narrative inquiry as a methodology to understand teachers' and learners' experiences in education. Storytelling can help students to experience learning in new ways and, often, encourages better understanding and comprehension [11], [32]. A reasonable explanation is that, when educational content is more integral to the plotline of the narrative, storytelling as a teaching strategy seems to require fewer cognitive competencies for understanding and lead to enhanced learning, especially in children's education [33]. In higher education, Alterio and McDrury [34] demonstrated how storytelling nurtures empathy, emotional intelligence, and social learning. Within a narrower scope in STEM education, this approach can enhance students' grasp of difficult chemistry concepts [35]. It also made high school students more engaged when their personal stories were integrated into curriculum tasks [36]. For instance, story-driven learning, developed at Georgia Tech, integrates personal narratives into problem-based learning units, which have enhanced engineering students' self-awareness, empathy, and engagement [37]. From an emotional perspective, workshops based on storytelling methods can foster empathy and connection among STEM graduate students [38], [39]. These findings demonstrated storytelling's pedagogical value across multiple levels and aspects.

As sustainability education has grown in urgency, educators have adopted storytelling to bridge the gap between abstract global challenges and students' lived experiences. There is growing interest in how storytelling builds the emotional ground for sustainability learning. Veland et al. [40] framed narratives as foundation structures for sense-making during ecological crises. Similarly, Talgorn & Ullerup [17] found that creating shared stories about ecosystems helped participants feel more connected to non-human life and even express ecological empathy. Empirical studies of narrative-based interventions in environmental and sustainability contexts consistently show increased issue involvement, attitude change, and behavioral intention [11], [41], [42]. This shows a promising potential for integrating storytelling into teaching about sustainability issues in engineering contexts.

3.3. The Role of STEM Education in the Global Context

STEM education has now taken on a critical role in the sustainability context, as STEM skills are essential for developing technological and scientific solutions to complex challenges. Integrated STEM practices become important because they push students to notice patterns, test ideas, and make sense of data [43]. Those habits seem to help them understand sustainability more deeply. Accordingly, students start to link scientific ideas with everyday choices, and this connection is often tied to later shifts in attitudes or behavior toward the environment [17].

However, researches show that while STEM programs excel at building professional knowledge and skills, they often provide limited opportunities for students to explore the ethical, civic, and emotional dimensions of sustainability [44], [45]. As a result, students struggle to connect technical knowledge and procedures to social futures or moral questions [7]. This narrow framing contributes to what scholars describe as the knowing–doing gap. Shephard [46]

discussed this gap as education often focused on cognitive knowledge while affective outcomes, such as values, feelings, and action, were ignored. In agreement, Leal Filho et al. [47] also pointed out that students may understand sustainability issues intellectually but feel little personal agency or emotional investment to act. Therefore, to contribute to this common global task, STEM education must move beyond simply delivering technical content. It should also foster emotional engagement, cultivate core ethical values, critical reflection, and practical action toward sustainability.

Pedagogically, a central reason for this disconnection is that traditional STEM teaching methods seldom focus on the emotional connection and value orientation. Therefore, they often fail to develop the key competencies required for ESD, such as systems thinking, anticipatory thinking, civic agency, and socio-emotional engagement [48], [49]. Storytelling might be a pathway to address this gap. A well-structured story, when placed within STEM instruction, can show how sustainability problems unfold across many settings. This approach feels necessary because sustainability challenges rarely follow a neat framework [50], [51]. It could be a valuable complement to traditional STEM pedagogy. Thus, a clear understanding of the storytelling intervention design and associated impacts will be useful for developing and implementing future interventions.

4. Methodology

This study employs a systematized literature review, which follows a structured and transparent process for identifying, selecting, and synthesizing relevant literature. The primary strength of this approach lies in its rigor and replicability. However, it is not fully exhaustive, as the review is limited to four academic databases.

4.1. Search Strategy

We limited the search to peer-reviewed journal articles published in English between 2005 and 2025 (September). Because we did not know the specific date that storytelling was first used as a teaching method in ESD, we set a wide publication time frame starting in 2005, when ESD entered formal UN implementation through the initiative of the Decade of Education for Sustainable Development [1].

To identify relevant literature, we conducted a systematic search using four robust academic databases available at our university: Scopus, APA PsycInfo, ERIC, and Web of Science (via EBSCOhost). We focused our search strategy on retrieving empirical studies that used storytelling as an intervention in STEM education toward changes aligned with sustainable development. We developed search terms that included combinations of keywords related to four aspects–storytelling, STEM education, sustainable development, and expected outcomes about awareness, attitude, and behavior. We then used Boolean operators to construct search strings.

After testing multiple search strings that produced widely varying numbers of records, we refined the final search string for each database (see TABLE I) to best match our inclusion criteria and research focus. Using these search strings, the final searches yielded 183 articles across four databases (Scopus, APA PsycInfo, Education Source, and ERIC).

TABLE I
DATABASES FOR THE LITERATURE SEARCH STRING

Database	Syntax	Results
Scopus	(TITLE-ABS-KEY((storytelling OR story-based OR narrative* OR "narrative pedagogy") AND (STEM OR "science education" OR "engineering education" OR "STEM education" OR "STEM students") AND ("sustainable development" OR *sustainability OR "sustainable future" OR "education for sustainable development" OR "sustainable development goals" OR SDGs OR "environmental education" OR "climate education") AND (awareness OR understanding OR perception OR attitude OR behavior OR behaviour))) AND PUBYEAR > 2004 AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"cp")) AND (LIMIT-TO (LANGUAGE,"English"))	61
APA PsycInfo	(story OR *storytelling OR story-based OR narrative OR narrative-based) AND ("engineering education" OR "science education" OR "STEM education" OR STEM students) AND ("sustainable development" OR "sustainable education" OR "education for sustainable development" OR ESD OR *sustainability OR "environmental education" OR "climate education") AND (awareness OR understanding OR perception OR attitude OR behavior OR behaviour OR action)	16
Education Source	(story OR *storytelling OR story-based OR narrative OR narrative-based) AND ("engineering education" OR "science education" OR "STEM education" OR STEM students) AND ("sustainable development" OR "sustainable education" OR "education for sustainable development" OR ESD OR *sustainability OR "environmental education" OR "climate education") AND (awareness OR understanding OR perception OR attitude OR behavior OR behaviour OR action)	50
ERIC	(story OR storytelling OR story-based OR narrative OR narrative-based) AND ("science education" OR "STEM education" OR STEM students) AND ("sustainable development" OR "sustainable education" OR "education for sustainable development" OR ESD OR "environmental education" OR "climate education" OR *sustainability) AND (awareness OR perception OR attitude OR behavior OR behaviour)	56

4.2. Inclusion and Exclusion Criteria

Inclusion criteria. Articles must meet all criteria to be included: (1) empirical study (qualitative, quantitative, or mixed methods), (2) conducted in a STEM educational setting (formal or informal educational contexts, e.g., schools, universities, workshops, online programs), (3) participants included STEM students (of any level), (4) used Storytelling or Story-based teaching methods or interventions, (5) outcomes addressed sustainable development (e.g., awareness, attitudes, or behaviors on any aspects), (6) published in English after 2004, and (7) document types are peer-reviewed journal articles, conference papers.

Exclusion criteria. Articles meeting any criterion are excluded: (1) non-empirical studies, (2) non-STEM educational settings, (3) non-STEM participants, (4) no Storytelling or Story-based teaching methods/interventions, (5) not related to Sustainable Development, (6) non-English or pre-2005 articles, and (7) inappropriate document type (i.e., book, thesis, or report).

4.3. Screening and Selection Process

The initial search yielded a total of 185 records, including 183 retrieved from four databases through the search string, one identified by the first author through Google Scholar, and one suggested by the second author. After removing 37 duplicates, 148 unique records remained, which we screened using titles and abstracts against the inclusion/exclusion criteria. Then, the remaining 40 full-text articles were retrieved and assessed for eligibility. A final total of 13 studies met all criteria and were included in the synthesis. We also documented the reasons for the exclusions. The screening process was reported using the PRISMA flow diagram, as illustrated in Fig. 1.

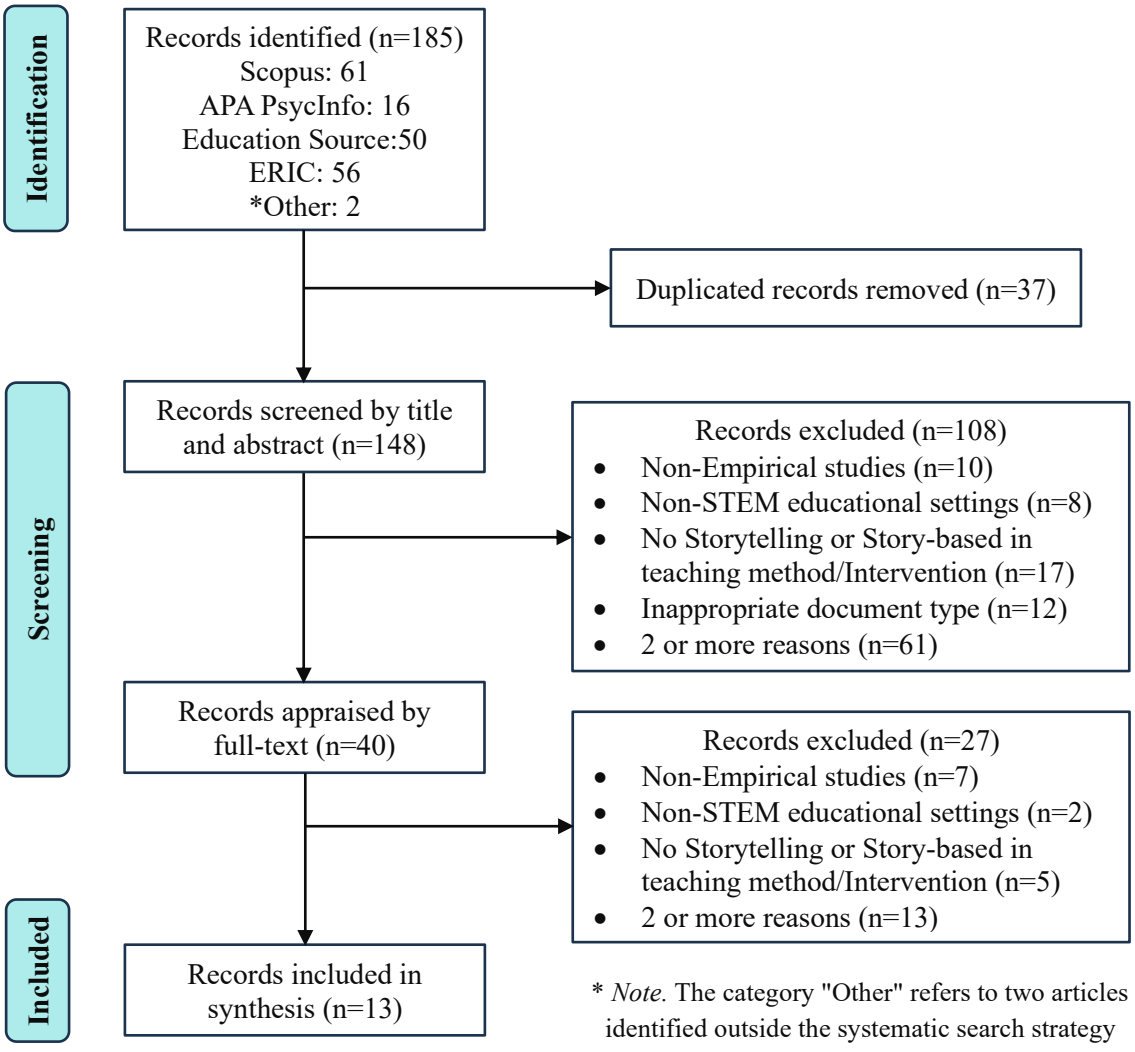

Fig. 1. The process of the selection for the literature review according to the PRISMA guidelines.

4.4. Data Extraction and Analysis

A narrative synthesis approach [52] was used to analyze the data. For each final included study, we coded study characteristics and intervention features. We built two Excel forms to extract data from each study. We used the Study Characteristics form to collect key information about the study itself, including: study design, participants, setting, study goals, and study limitations.

The Intervention Characteristics form collected key information about the intervention that has been implemented, including: intervention description, delivery method, participant activities, measurement method, outcomes, and Intervention limits. Relationship between characteristics of individual studies, their findings, and the link between study results were analyzed and reported.

5. Results

The results section presents the synthesized findings from the systematized literature review. This section focuses on intervention models and related outcomes. Together, the findings provide a holistic understanding of how storytelling has been applied within sustainability education research in STEM education.

5.1. Overview of the Sample

Our final dataset included 13 studies. Included studies spanned diverse geographical and cultural contexts and were grouped into three main regions: Europe, North America, and Asia. One study was conducted in both Europe (Denmark) and North America (the USA) [41], so we counted 14 regional data points in total, as shown in Fig. 2. Overall, this worldwide distribution displayed the growing attention of scholars across the globe in integrating storytelling in the STEM field to tackle related sustainability challenges. Although we set a wide publication time frame from 2005, there were no papers published before 2014 that met all our inclusive criteria. A possible explanation is that while storytelling and narrative-based pedagogies have a long history and broad acceptance in general education [53], especially in social sciences and humanities education [54], they are less common in STEM education at the same time. This approach seems to spark more interest among STEM educators and researchers when sustainability becomes more urgent, and STEM education can not stand outside global common tasks.

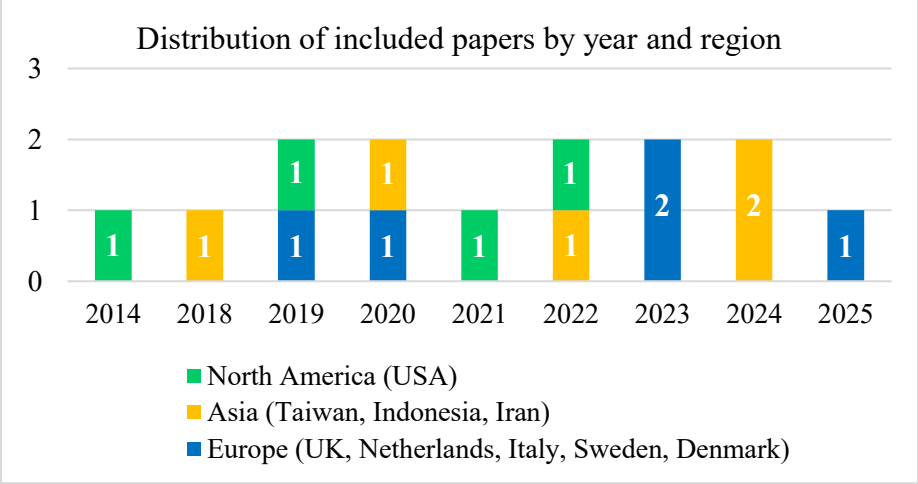

Fig. 2. Distribution of included papers by year and region.

Note. One study was conducted in both Denmark and the USA, resulting in 14 regional counts from 13 studies.

5.2. Diverse Methodological Approaches and Intervention Models

In this section, we present a description of the studies and their key characteristics, as shown in Appendix A. Across the reviewed studies, participants were predominantly undergraduate students enrolled in STEM-related courses, including engineering, environmental science, chemistry, textile and clothing studies, and interdisciplinary sustainability programs. A smaller

number of studies involved secondary or middle school students, within formal science or STEAM classrooms. Only a few interventions extended into informal learning contexts like workshops, involving stakeholders.

TABLE II describes the methodological approaches and intervention models used in the studies. Methodological approaches are how data were collected and analyzed (qualitative, quantitative, or mixed methods), whereas intervention models were categorized based on differences in instructional design, including how stories function within learning environments and learner engagement.

TABLE II
Relationship between methodological approaches and storytelling intervention models

Methodological Approach	**Intervention Model**		
	Ethical dilemma-based	Immersive / Digital narratives	Participatory futures-oriented storytelling
Qualitative	✓	✓	✓
Quantitative	✓	✓	
Mixed methods	✓	✓	✓

Research designs vary, with a key pattern being that most lean toward interpretive or design-based research (e.g., [17], [55], [56]). Six of the thirteen studies rely on case study methodology, utilizing data from interviews, journals, or similar materials, which foster deep insights into participant experiences. That same qualitative bent showed up in participatory storytelling (e.g., [57]) and in studies looking at shifts in attitudes toward animals [58]. Whereas experimental designs often combine quantitative data [59], [60] to quantify impacts, and provide statistical evidence, or highlight differences in comparison with conventional teaching [58], [61]. Only two studies [40], [58] employed solely quantitative methods. This is understandable, as the objectives in this field often include emotional aspects. Combining quantitative data with other methods can help researchers gain a deeper understanding of experience and emotional nuances.

Most studies emphasized participatory and interactive approaches that actively involved learners in the storytelling process. Across the 13 studies included in the final synthesis, storytelling interventions were grouped into three overarching models: ethical dilemma-based storytelling (e.g., [58], [60], [61]), immersive and digital narratives (e.g., [59], [63]), and participatory futures-oriented storytelling [15], [56], [62], [64]. Ethical dilemma-based approaches typically embed sustainability issues within moral conflicts or decision-making scenarios, encouraging critical reflection and values-based reasoning within STEM contexts. Immersive and digital narratives relied on media such as video or virtual environments to foster emotional and embodied engagement with sustainability themes. Participatory futures-oriented storytelling foregrounded learner authorship, inviting participants to co-create narratives that imagine alternative or future scenarios related to environmental and social change, emphasizing learner agency. In several cases, studies integrated elements from more than one model (e.g., [17], [41]), illustrating the flexible and layered nature of storytelling interventions in sustainability education.

5.3. Similarities and Differences in Measures and Outcomes

We described the intervention types and their characteristics in detail in Appendix B. It also illustrates a general perspective on the main outcomes from these intervention approaches. A focused version on measurement instruments and associated outcomes is shown in TABLE III. The included studies employed a wide range of instruments to assess storytelling outcomes. Most studies leaned on self-reported surveys and reflective writing. Only a few used behavioral or physiological data. This diversity reflects the multidimensional goals of storytelling interventions but also highlights the lack of a shared measurement framework across studies. Across the 13 studies, the most common outcomes reported were higher student engagement and increased awareness of sustainability. Eight studies showed increased engagement, often described as emotional or cognitive engagement. About half of the studies recorded awareness and understanding of sustainability issues.

TABLE III
MEASUREMENT INSTRUMENTS AND ASSOCIATED OUTCOMES

Data source	Examples from included studies	Primary outcomes assessed
Surveys / Scales	Attitude scales, environmental knowledge tests, empowerment questionnaires, and narrative transportation scales	Knowledge gain and attitudes toward sustainability; values and sense of agency; limited change among already highly engaged students
Reflective writing	Student journals and reflection	Ethical reasoning, identity development, and emotional engagement; uneven depth of reflection and lack of initiative
Interviews & Focus groups	Semi-structured interviews, group discussions	Perceptions of learning, meaning-making, sense of agency; reports of disengagement or reduced motivation in post-COVID
Behavioral measures	Donation choices, recycling actions, and time volunteered	Pro-environmental behavior and intentions
Physiological measures	Activity (EDA), Autonomic Nervous System (ANS)	Emotional arousal and engagement
Performance products	Stories, STEAM projects, service-learning outputs	Creativity, futures thinking, applied understanding

Interpretive studies consistently reported enhanced empathy, primarily based on reflection analysis or interviews (e.g., [60], [61]). Experimental setups, however, revealed measurable differences, such as stories producing higher arousal or greater willingness to donate than fact-based messages [41]. Mixed-methods (e.g., [15], [17]) bridged this, using hybrid tools, suggesting that combining qualitative depth with quantitative metrics yields more comprehensive outcomes. Especially, some studies used add-on physiological measures, such as EDA and ANS, to track arousal peaks and meaning shifts as stories unfold [41], [63].

Many interpretive case studies or mixed methods reported consistent results such as increased empathy, environmental awareness, and participation. For example, in Hendersson & Wamsler's workshops [64], where participants identified emotional barriers like shame, leading to co-authorship in climate stories. Similarly, Talgorn's ecological stories [17] were used in participatory workshops, where participants built personas and postcards. These were analyzed

to find empathy mechanisms. The results pointed to projection-based empathy and stronger group bonds, echoing the emotion-focused “rumbling” described by Hendersson [64]. Unlike structured classrooms, this approach allowed creative freedom, leading to deeper discussions, such as Jordan's solar futures [56], where narratives balanced decline and growth themes. Although the workshop model was dominant, lectures based on narrative conducted in a classroom context were also found promote collaboration, yielding similar attitudinal changes.

Overall, common outcomes across 13 studies were the records of increases in engagement, awareness, and especially attitudes. Others also documented limitations or unintended outcomes, such as a lack of initiative [64], post-COVID disengagement [57], and limited impact on already active students [17]. Behavior-related outcomes, such as action competency and pro-environmental actions, appeared to result in limited or partial success. Notably, only one study covered instant behaviors that were observed in the intervention process, for example, donations, recycling, time volunteered, and newsletter sign-ups [41]. Moreover, they are just short-term actions. This is probably due to the research question or research direction, because evaluating behavior is always more difficult than examining cognition and attitude [28]. Even so, this finding highlights a gap or limit in most of the intervention designs of the studies included in the final synthesis.

6. Discussion and Implications

The findings highlight the potential of storytelling in providing sustainability education, tying into wider ideas on narratives [54], where stories help people sort experiences and make sense of the world rather than memorize facts. Participatory approaches, such as those described by Talgorn and Ullerup [17] and Hendersson and Wamsler [64], were found to strengthen empathy and a sense of agency, though the effects seem tied closely to how the stories are built and shared. Some newer works used immersive Virtual Reality (VR) [15], [63] to add embodied dimensions and support affective learning over rote knowledge. Ethical situations from Rahmawati et al. [60], [61] blended STEM with core ethical values, building skills across aspects that matter for the Sustainable Development Goals. Findings across studies suggest that storytelling can attract students, spark empathy, and get students in STEM thinking about sustainability. Still, changing actual behavior and keeping those changes going over time was not yet clarified. All this shows the flexibility of storytelling approach, yet highlights the role of design in shaping outcomes.

The findings show that storytelling works best when learners are active contributors. As such, instead of just being learners exposed to narrative, storytelling in ESD should be designed as an active learning process that integrates ethical reflection or futures-oriented imagination. All these different functions should be combined deliberately to support sustainability learning outcomes. To optimize, future designs should blend the appropriate and varied assessment modalities. Hybrid measures (e.g., EDA & reflections), as in Palmieri et al. [63], could mitigate subjectivity. Scaling up pilots, as attempted by Chen et al. [55], could ease concerns about sample size, though it brings its own challenges. Ideas point to customizing with visuals for youth engagement, while ethical dilemmas seem to invite deeper thinking about responsibility. In particular, behavior shifts, especially long-term changes over time, should be given more attention to drive actual action and solutions.

The synthesis provided in this review offers several practical and scholarly uses. For educators, the findings could point the way for designing storytelling-driven teaching strategies via design features, measurement tools, and related outcomes, to weave ESD storytelling into STEM courses. For researchers, the review identifies gaps in outcome measures that can guide future research.

7. Limitations

The most frequent limitation in the included papers was small and homogeneous samples. As such, the results may not apply well to other groups with different backgrounds and distinct needs. Cultural and contextual limits are notable because stories are often tied to culture or local circumstances. For example, work rooted in Indonesian classrooms emphasizes shared values like mutual respect, which may not translate to Western individualism. This variability constrained generalizability, with novelty biases in other contexts. Another time-related limitation was the short duration of interventions, and the intervention effects were measured right after the activity ended, leaving open the question of long-term impacts. This underscores the need for long-term studies.

However, we admit the limitations of this review. Our search may have missed non-English or gray literature. This can lead to publication bias toward positive outcomes when negative results are underrepresented. The 13-paper sample lacks geographic diversity (e.g., South America, Africa). The lack of work from these regions, where the perspective on sustainable development may be influenced by the living and economic context, might narrow the global picture. Despite these limitations, the review provides a comprehensive understanding for optimizing narrative-based intervention and helps educators to bring sustainability into the classroom in meaningful and lasting ways.

8. Conclusion

Set against a background of the growing role of STEM in sustainability education, this systematized review shows storytelling as a flexible and often powerful tool. This approach can foster empathy, knowledge, and agency across diverse contexts. By synthesizing 13 studies, we found consistent benefits in attitude shifts and engagement, with models like ethical dilemmas and immersive narratives proving adaptable. These interventions not only enhance learning but also empower learners as agents for sustainable futures. However, differences in designs create ups and downs, and diversity in measurement designs complicates direct comparisons. As such, by laying out what the setups involved and what they led to, this paper gives a full picture for designing future efforts.

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Appendix A: Included Study Characteristics

Papers	Study Design	Participant	Setting	Study Goals
Ross et al., 2023	Qualitative case study	60 students (year 8) and teachers in the You and CO2 program	UK secondary schools (online/remote due to COVID-19); climate change education program	Model student engagement and teacher delivery in a climate change education program; understand impacts of COVID-19 on implementation and outcomes
Chen et al., 2023	Project-based learning (PBL) pilot study, mixed method	25 students (most from STEM backgrounds) + 2 community college interns (non-STEM)	Introductory data science course in collaboration with digital storytelling interns from a community college	Explore digital data storytelling in PBL design to raise sustainability awareness from domain, disciplinary, and educational perspectives
Liu, 2024	Mixed-methods intervention study with 360° VR storytelling	140 students for narratives; 37 for surveys (from second-year to final-year students, a wide range of disciplines)	Undergraduate climate change course for all majors	Evaluate impact of the intervention guiding students to explore/narrate climate change futures on understanding and perceived contribution ability
Palmieri et al., 2025	Mixed-methods hybrid	60 participants (students in product design and interaction design, and entrepreneurs)	Part of the EMOTIONAL project, exploring a first-person narrative from a ceramic object	Assess the potential of 360◦ VR storytelling to enhance learning through embodied knowledge, attitudinal change, and emotional awareness
Talgorn & Ullerup, 2023	Qualitative design-based research	Workshop 1: 31 first-year design students; Workshop 2: 10 professionals/senior students; Workshops 3–4: 25 stakeholders each (marketing, business, design, innovation)	Workshop 1: online course; Workshop 2: in-person at an international design conference; Workshops 3–4: at a multinational company	Investigate participatory storytelling's role in building empathy for nonhuman stakeholders and including them in sustainable design, drive sustainability engagement
Hendersson & Wamsler, 2020	Qualitative case study using the "Rising Strong" approach	14 students from different sustainability-oriented Master's Programs	5 workshops focused on climate change narratives	Examine how storytelling on climate change fosters empathy, systems thinking, co-authorship, and identifies barriers and opportunities for agency
Lin & Li, 2018	Qualitative method	31 undergraduate students (science, engineering, and social sciences)	A course at a University in Taiwan collaborates with two museums	Examine the effect of storytelling on improving students' attitudes toward animals
Morris et al., 2019	Experimental study across three experiments	158 participants (in study 1), 315 US residents (in study 2), 87 participants (in study 3)	Lab in a Danish University (study 1), online experiment (study 2), lab in a US University (study 3)	Compare stories vs. factual information in climate change communication in triggering emotions, arousal, and pro-environmental actions

Rahmawati et al., 2020	Mixed-methods using ethical dilemma story pedagogy (EDSP)	462 middle school students (across 6 schools)	14 Chemistry classes in 6 middle schools	Investigate impact of ethical dilemma story pedagogy in chemistry classes on student empowerment, chemistry knowledge, ethical values, and sustainability awareness
Rahmawati et al., 2022	Interpretive case study	155 secondary students across 4 high-school classes	Chemistry classes integrated with sustainability	Investigate potential of EDSP to empower students with chemistry knowledge and transdisciplinary capabilities to solve environmental problems
Afkar et al., 2024	Case study of a one-year teaching course; mixed method	48 students in a renewable energy course (4 classes of 12), classes I&II used conventional teaching, classes III&IV used storytelling approach	One-year course at a University, Iran in collaboration with international partners	Test a storytelling-based teaching method to improve creativity, knowledge retention, engagement, and attractiveness vs conventional teaching in renewable energy topics
Jordan et al., 2021	Design-based research; qualitative analysis	19 participants (3 middle school students, 6 high school students, 4 teachers, and 6 university engineering students)	A team-based summer research program focused on solar cell projects at a national engineering research center	Test conjectures on how futures thinking via speculative fiction supports learner agency, sustainability activism, and environmental justice
Baytar & Ashdown, 2014	Experimental study; quantitative analysis	160 undergraduate students (fashion and textile-related majors); 78 in the control group, and 82 in the intervention group	All activities and surveys are online	Examine whether video-based storytelling can improve environmental knowledge, attitudes, and behavioral intentions in textile and clothing students

Appendix B: Storytelling Intervention Characteristics

Papers	Intervention description	Delivery methods	Participant activities	Measure methods	Outcomes
Ross et al., 2023	Three workshops: carbon footprint exploration, interactive narrative reading, and student-created digital stories using the Twine platform	In-class workshops delivered by teachers	Explore carbon footprints, discuss how to reduce, engage with IDNs, and write climate change interactive digital narratives	Analysis of student interactive digital narratives, teacher interview	Challenges in re-igniting engagement post-COVID, need for place-based adaptations, and partial success in personalization
Chen et al., 2023	A semester-long PBL using digital data storytelling to create sustainability-themed stories (slides, scripts, or video)	Video on human flourishing published by the Templeton Foundation	Explore sustainability topics, create and present data stories, and join two Zoom cross-training workshops	Survey at the beginning of the project discussions, students' work products, reflections, and interviews	Raised awareness of sustainability issues, increased confidence in cross-disciplinary communication, build skills in analytic data
Liu, 2024	Innovative teaching module with phases: climate science learning, exploring futures via interactive tools, narrating carbon-neutral visions	Instructed by scientists and educators using an online platform with adjustable parameters	Examine current situations of climate scenarios, discuss possible future scenarios, form and write visions of sustainable futures	Content analysis of narratives; the pre- and post-instruction survey data were evaluated using the Wilcoxon signed rank test and an effect size measure	Students understood sustainable future facets; intervention significantly improved action competency, especially confidence
Palmieri et al., 2025	360° VR storytelling narrative from a ceramic object's perspective on cultural heritage, facilitating meaningful, affective learning	Workshops with a story delivered by 360° VR experience	Experience immersive narrative, complete subjective assessments, EDA tracking (n=26)	Subjective (attitudinal scales, semantics, engagement); objective (EDA)	Enhance emotional and cognitive engagement, semantic shifts toward sustainability, arousal peaks at key narrative moments
Talgorn & Ullerup, 2023	Participatory workshops for creating eco-stories with human/ nonhuman personas to build empathy for the planet	4 workshops (1.5–3 hours) with an intro delivered by a presentation and video	Persona and story creation in small groups and open discussion	Analysis personal stories (n=28) and feedback from questionaire (n=51)	Foster empathy, creativity, collaboration, communication skills (limited impact on activists)

Hendersson & Wamsler, 2020	Workshops using "Rising Strong" approach to frame climate change as a story, fostering authorship and emotional awareness	Facilitated workshops with creative writing, focus group discussions on emotions	Write personal climate stories, list and discuss emotions in group, and co-write an ending to the story	Notes from workshops, portraiture analysis for summarizing patterns	Lack of initiative, disconnection; common emotions like shame/guilt; catalysts: empathy, co-creation; barriers: complexity, rationality
Lin & Li, 2018	Integrate museum on-site learning for a storytelling module and a service learning session	Lectures, group work, and oral performances of stories	Create animal stories, personal meaning maps, perform for peers and children, and join interviews	Personal meaningful map content analysis (pre/post), online group interviews	Positive changes in attitudes toward animals, increased empathy and ethical reflection
Morris et al., 2019	Narratives structured as stories vs. factual info on climate change across 3 studies	Story format vs fact information in study 1, video format in studies 2 and 3	Study 1: Reading + tasks Study 2: Videos + tasks + physiological monitoring Study 3: Videos + questionnaires + tasks + physiological monitoring	Self-reports, physiological responses (ANS), and observed pro-environmental behaviors	Stories increased engagement, transportation, and some pro-environmental actions
Rahmawati et al., 2020	EDSP in constructivist chemistry classes over 8 weeks	Teacher facilitated storytelling of ethical dilemmas	Reading and discussing dilemma stories, collaborative decision-making, and reflective journaling	Survey, reflective journals, classroom observations, student interviews	Students engaged in learning, empathic communication, collaborative decision-making, awareness of personal and environmental health
Rahmawati et al., 2022	Ethical Dilemma Teaching Model with stories on environmental issues ties four topics in chemistry	Teacher facilitated at classroom across five stages	Discuss dilemmas, conduct experiments, reflect in journals, and participate in interviews	Interview, reflective journaling, and extensive classroom observations	Students engaged in chemistry, critical reflection, collaborative decision-making, and local environmental awareness
Afkar et al., 2024	Storytelling method with nature theme for renewable energy topics, compared with conventional teaching	Instructor uses a narrative plot with real photos, slides, and audio	Connect slides to scientific concepts, build frameworks, summarise/ improve stories, and group tasks	Participation metrics, feedback questionnaire, and final grades (comparative classes)	Improved engagement, attractiveness, retention, and cognitive/ affective gains

Jordan et al., 2021	5 workshops: speaker series, field trips, hands-on activities, write solar futures narratives	Lectures and field trip activities	Assess socio-technical conditions, prototype solar-powered art, co-create future scenarios, share	Content analysis of 18 narratives	Writing practices foster hopeful future thinking and some sociotechnical awareness
Baytar & Ashdown, 2014	Video on the apparel industry's environmental impact, students completed online pre/post surveys	Video and online survey	Intervention: video viewing; control: text and images; online pre/post surveys	Pre/post scales (knowledge, attitudes)	Raise awareness and encourage sustainable consumption