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A matter of connection: The 4 Cs of learning in pre-service teacher education for sustainability

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ABSTRACT

Teacher education for sustainability (TEfS) aims to prepare future educators for their role as societal change agents by developing in them specific sustainability competencies. Whereas previous literature has dealt extensively with concepts and empirical work connected to learning objectives in TEfS, this paper links these learning outcomes, or what student teachers learn in individual course offerings, to the learning process—how they learn. In this way, we reveal factors of common teaching and learning formats in TEfS that may either foster learning or hinder it. At Arizona State University (ASU), the TEfS course Sustainability Science for Teachers (SSfT) is a mandatory component of all elementary-education (K–8) programs. As similar requirements appear in more and more teacher-education programs, it is important to understand how learning in course offerings like SSfT should be designed in order to best support student achievement of intended learning outcomes.

More than 100 pre-service teachers and four instructors, all taking or teaching the SSfT course at ASU, participated in this single explanatory case study, which adopted a mixed-methods approach. To richly portray students' learning processes, as well as the outcomes of their learning in the course, this study involved non-participatory observations, a pre/post-course survey, end-of-semester focus groups, and semi-structured interviews. Its findings suggest that four forms of connection (the 4 Cs) namely personal, professional, social, and structural, are particularly impactful on students' learning in the SSfT course. Finally, these insights are accompanied by a set of recommendations as to what to consider when planning and designing similar TEfS course offerings. Future research should focus on the K–12 students of educators trained in education for sustainability (EfS) to understand the extent to which educators can use their new skills and knowledge to empower and motivate K–12 students to persistently engage in real-world projects that contribute to systemic change.

1. Introduction

As educational professionals take on the goal of fostering education for sustainability (EfS) and equipping learners with the "knowledge and skills needed to promote sustainable development" (DESA, 2015), the spotlight is becoming increasingly focused on the capacity of teachers and educators to act as "learning facilitators" (UNESCO, 2014) and effective change agents in the realm of education. The Global Action Programme (GAP) on EfS, an undertaking of the United Nations Educational, Scientific and Cultural Organization (UNESCO), dedicates an entire key action area to educators in the field (Ibid.). Consideration of teacher education for sustainability (TEfS) is not limited to political agendas; in academia, there are currently growing numbers of both publications addressing TEfS (Evans et al., 2017) and efforts to integrate sustainability in higher-education programs and teacher curricula (Barth, 2015). Several universities in countries like Australia, Germany, Spain, and Sweden have designed and implemented sustainability courses or modules in their teacher-education programs (Andersson, 2017; Brandt et al., 2019; Jorge et al., 2015; Tomas et al., 2015). However, sustainability coursework in K–12 (pre-service) teacher education is much rarer in other countries, such as the United States (McKeown & USTESD Nolet, 2009).

In accordance with the identified need to educate sustainability-

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literate teachers (Nolet, 2009), much of the recent research has focused on the actual achievement of intended learning outcomes and the development of required competencies (Evans et al., 2017). Although attempts have been made to link pedagogical approaches to the delivery of competencies (Dlouhá and Burandt, 2015; Lozano et al., 2017), "impartial research where students' individual experiences … are studied in depth … [to investigate] the multitude of influences on their learning" is still missing (Backman et al., 2019, p. 149). Barth (2015) further emphasizes that the focus of research must shift to the question of how "learning takes place and how it can best be supported" (p. 86). Correspondingly, based on an in-depth explanatory case study approach (Yin, 1984), this paper aims to link learning outcomes, or *what* students learn, with the learning processes, or *how* they learn, in order to reveal concrete mechanisms of specific teaching and learning formats that foster—or hinder—learning in a hybrid course environment. Our analysis of these learning outcomes is based on the concept of an EfS-specific professional action competence, as introduced by Bertschy et al. (2013). According to their distinction between the three competence aspects of content knowledge (CK), pedagogical content knowledge (PCK), and attitude, we here consider students' sustainability-related knowledge, pedagogical skill, and their motivation to implement EfS at the school level in their future teaching careers.

2. Theory

While much research elaborates competencies for sustainable development and discusses various pedagogical approaches, too little has thus far investigated the links between common teaching and learning formats in TEfS, factors of student learning processes that hinder or support learning, and the real achievement of intended learning outcomes (Svanström et al., 2008).

According to Shephard (2008), sustainability initiatives in higher education are extremely diverse. Still, many refer to the idea that learners should develop a certain set of competencies, along with the related knowledge, skills, and attitudes (e.g., Azeiteiro et al., 2015; Lambrechts et al., 2013; Pappas et al., 2015). In teacher education, this is reflected in the overall aim of developing student teachers' "capacity and (in some cases) commitment to embed SE [sustainability education] into their own teaching practices" (Evans et al., 2017, p. 411). A decade ago, Nolet (2009) coined the term of "sustainability-literacy" in the teaching context, emphasizing the "ability and disposition to engage in thinking, problem solving, decision making, and actions associated with achieving sustainability" (p. 421). Since then, several approaches to teachers' EfS competencies have been introduced and discussed (e.g., UNECE, 2013; Sleurs, 2008; Timm and Barth, in press; Vare, 2018). Translating the general key sustainability competencies laid out by Wiek et al. (2011) into specific ways of thinking (WOT), Warren et al. (2014), for instance, introduced a Sustainability Education Framework for Teachers (SEFT) that functions as "a conceptual framework for analyzing and considering sustainability problems and solutions through a networked approach" (p. 5). Building on Shulman's (1987) categories of what constitutes a competent teacher, Baumert and Kunter (2013) designed a model of teachers' professional action competence; that model was contextualized for EfS by Bertschy et al. (2013). Their concept of an "ESD-specific professional action competency" for teachers considers sustainability-related content knowledge (CK), pedagogical content knowledge (PCK) and the drive to implement EfS at the school level (attitude) to be key learning objectives. Accordingly, Brandt et al. (2019) operationalized this construct by measuring changes in students' understanding of the term *sustainability* (CK) and their ability to apply EfS-specific didactic principles (PCK) (Künzli and Bertschy, 2008), as well as their EfS-related self-efficacy (Tomas et al., 2015), perceived relevance of ESD (Ibid.) and pro-ecological worldviews (Dunlap et al., 2000) (attitude).

Among the most common pedagogical approaches in TEfS are place-based experiential methods and inquiry methods, as well as modeling strategies for EfS that student teachers can apply in the future (Evans et al., 2017). Further prominent teaching and learning formats, as modes of instruction, include discussion and reflection techniques (e.g., Corney and Reid, 2007), concept mapping (e.g., Åhlberg et al., 2005), role-plays (e.g., Aleixandre and Gayoso, 1996), problem-based inquiries (e.g., Bore, 2006), problem-solving activities (e.g., Jenkins, 1999), future-scenarios exercises (e.g., Paige et al., 2008), and lecture-style delivery of information (e.g., Firth and Winter, 2007). Acknowledging the lack of research on the link between competence development and individual teaching and learning formats, Lozano et al. (2017) undertook to close this gap. While the researchers do show that case studies, project- and problem-based learning, community-service learning, jigsaw teamwork, participatory action research, place-based environmental education, and life-cycle analyses are all generally promising approaches, they note that covering all competencies requires, in fact, a diversity of methods (Lozano et al., 2017). In the field of teacher education, research regarding the effectiveness of pedagogical strategies is rather scarce (Evans et al., 2017). Kalsoom and Khanam (2017) showed that inquiry-based learning may yield positive changes in student teachers' knowledge and attitudes regarding sustainability issues. In the context of a hybrid sustainability course, Shelton et al. (2017) suggest that interactive digital storytelling videos may outperform conventional videos insofar as their potential to increase students' engagement and learning in the area of content knowledge (CK). Referring to the development of ESD-specific professional action competence, Bürgener and Barth (2018) describe the promising approach of transdisciplinary living laboratories that incorporate the idea of scaffolding (Hannafin et al., 1999) and include project work with practice partners. Brandt et al. (2019) elaborate on the additional potential of a blended learning course with lectures (flipped classroom), tutorials, and project-based seminar sessions in which students cooperate with partnered schools. Considering the link between learning processes and related outcomes, this paper seeks to open the much-cited 'black box' of learning in an attempt to reveal what actually supports or hinders students' learning on their paths to become change agents equipped with the knowledge (CK), skills (PCK) and motivation (attitude) required to implement EfS in K–8 schools.

Focusing on learning in higher education at large, Biggs and Tang (2011) present a list of factors supportive of students' learning. Among other items, they highlight the importance of motivation, claiming that learners must understand the *value* of engaging in the learning process. Indeed, they emphasize the role that instructors and teaching staff play in increasing students' motivation, supporting learning activities that allow for deep learning, and providing powerful feedback during the learning process. This is in line with Biggs and Tang's idea of social learning, in which students learn both with and from one another through pedagogical approaches like peer tutoring and discussion groups. Also seen to improve learning are building on existing knowledge and drawing structural interconnections between topics. Anxiety, on the other hand, which may be caused by the perceived threat of failure, is identified as a major barrier to learning.

In EfS, we have seen long-lasting paradigms shift from teacher-centered pedagogies to learner-centered ones, from input-to output-orientation, and from content-to problem-and-solution-orientation (Barth, 2015). Considering the oft-cited theory–practice gap in general teacher education (Shulman, 1998), Frisk and Larson (2011) emphasize the importance of

creating real-life learning opportunities in TEfS, through which the relevant competencies can be developed, tested, and reflected. The value of such opportunities is supported by the idea that engaging in early collaboration with schools and forming links to educational practice enhance student teachers' learning (Bürgener and Barth, 2018). In connection with the online delivery of sustainability courses in teacher education, Whitehouse (2008) describes the lack of "synchronous contact" and of the clarifying exchange of ideas as a hindering factor. Varga et al. (2007) and Bore (2006) further report that not all pre-service teachers are accustomed to student-centered and constructivist approaches to learning and may therefore experience difficulties with such approaches, perhaps even manifesting a tendency to resist them. Yet Littledyke and Manolas (2011), who introduced ideological and epistemological drivers and barriers for EfS, argue that constructivist pedagogy "is particularly relevant" (p. 93). Epistemologically, we here refer to ideas of constructivism, conceiving of teaching and learning not as matters of transmitting information but rather of engaging students and centering them—and their learning processes—as the focus (von Glasersfeld, 1995).

3. Methodology

To address the research gap identified and shed light on the link between individual teaching and learning formats (or instructional strategies) in TEfS, related factors that support or hinder students' learning processes, and the achievement of specific learning objectives, this paper seeks to answer the following research question:

What supporting and hindering factors impact pre-service teachers' learning processes in teacher education for sustainability (TEfS), and how do their effects on the achievement of intended learning outcomes at the course level vary according to the applied teaching and learning formats?

This research is a single explanatory in-depth case study (Yin, 1984) focusing on the course Sustainability Science for Teachers (SSfT) taught at Arizona State University (ASU). In this context, we focus on three closely interrelated sub-questions:

(i) To what extent are the intended learning outcomes of the course actually achieved?
(ii) What are the primary supporting and hindering factors impacting the learning processes of pre-service teachers in connection with different teaching and learning formats?
(iii) What individual key moments of learning provide concrete insights into learning processes that impact students' achievement of curricular learning objectives?

3.1. The case

The SSfT course—designed by an interdisciplinary team of scientists, educators, and design experts—launched at ASU in the fall of 2012. It is a three-credit, fifteen-week course, and it is mandatory across all elementary-education (K–8) programs at ASU. The course has been further refined and developed into various iterations since its inception in 2012. It is geared towards preparing pre-service teachers to be sustainable citizens and educators who implement EfS with their future students (Merritt et al., 2019). Its primary objective is to develop sustainability literacy among pre-service teachers by (a) providing EfS-related content knowledge and fostering students' understanding of sustainability concepts and their applications (CK); and (b) providing pedagogical content knowledge for EfS and developing students' ability to apply ways of thinking (WOT) to explain sustainability concepts (PCK). The four WOT—strategic, futures, values, and systems thinking—are connected to the key competencies in sustainability (Wiek et al., 2011) and provide an overarching "sustainability education framework" (Warren et al., 2014), engaging students with the course content. These WOT help the students to think deeply about the content from different perspectives, imagine various scenarios for the future, and analyze systems in order to strategize how best to initiate change in society (Merritt et al., 2018). The course uses a flipped-learning approach in which content is shared in the course's online component through "digital storytelling" (Robin, 2008). Students watch videos related to the weekly topics, take quizzes to assess their understanding of content, and work on reflective assignments. As a second component of the course, students come to class for 75 min each week to discuss concepts and learn pedagogical strategies to integrate course content into their future teaching practices (see Fig. 1). While the class is divided into several cohorts, all instructors teach the same online content, are provided with weekly lesson plans, and meet monthly to discuss pedagogical strategies. By exploring sustainability-related topics (see Figure A), pre-service teachers learn about sustainability concepts, develop EfS competencies, and engage with various pedagogical approaches with the goal of fostering their ability to effectively teach EfS in K–8 settings. The in-class lessons, which vary each week, include specific activities such as the 'Hot Dog' activity—a systems-thinking endeavor in which students map all of the inputs, outputs, and components of the food system needed to produce a hot dog (see Appendix A). The final project and overarching assignment of the course consists of a student-designed digital artifact that outlines a five-day learning unit on a sustainability topic of the student's choice. A broader case description provides greater detail about the contextual conditions, as well as individual learning activities, of the SSfT course (Brandt and Barth, 2020).

3.2. Data collection

Data was collected during the fall semester (August–November) of 2017, adopting a mixed-methods approach in order to capture a rich image of the students' learning processes and outcomes (see Table 2). Data collection was approved by the Institutional Review Board. The 2017 fall cohort 2017 consisted of 122 students—grouped into 6 sub-cohorts (SSfT-1–6)—of which 104 consented to participate in the research (see Table 1).

A survey was administered both before and after the course to identify the learning outcomes associated with students' sustainability-related content knowledge (CK) and their motivation to implement EfS (attitude). Non-participatory classroom observations helped to better understand the course context and to account for differences between sub-cohorts. Data on learning processes, as well as on perceived learning outcomes with regard to pedagogical skills in EfS (PCK), were collected through student focus groups of 4–7 participants each and semi-structured interviews with instructors. All instruments, including the detailed survey items, interview and focus-group guides, and all related code books, are available on ResearchGate (Brandt et al., 2020).

3.3. Data analysis

The analysis of quantitative survey data was conducted using simple descriptive statistics (frequencies) for the demographics and paired-sample t-tests for a pre/post comparison of attitude scales and changes in students' understanding of the term *sustainability* over time. To make quantitative analysis of the latter phenomenon viable, students' definitions were coded by two independent researchers against a coding scheme considering both intergenerational and intragenerational perspectives as well as the multidimensional understanding of the concept, resulting in a

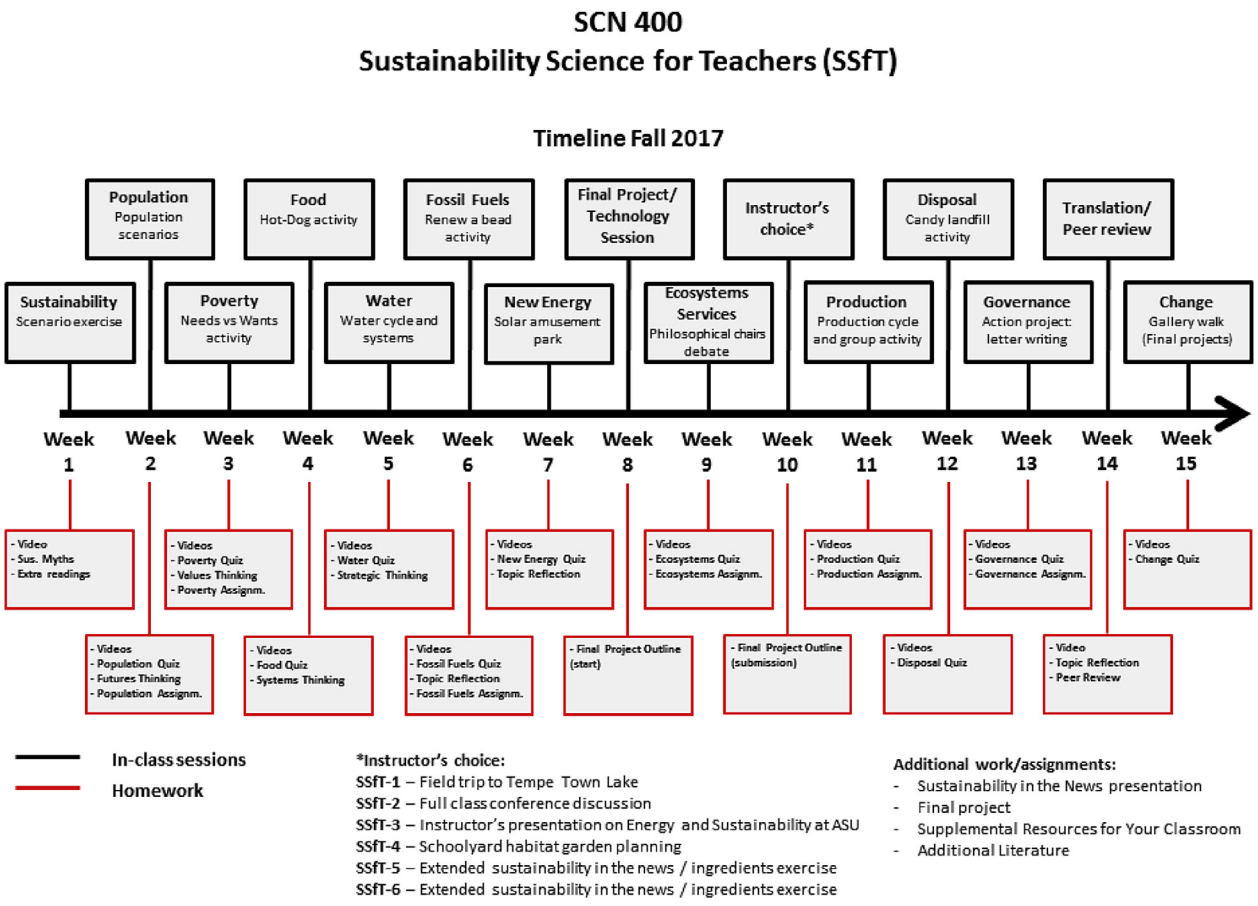

Fig. 1. SSfT course outline (fall 2017).

Table 1
SSfT cohort (fall 2017).

NUMBER OF STUDENTS (NUMBER CONSENTED) STUDENT IDS: s1_300–s1_421	122 (104)	
GENDER	Female: 91.9% (72)	Male: 8.9% (7) (No reply: 25)
AGE	20 years or younger	27.6% (21)
	21–25 years	59.2% (45)
	26 years or older	13.2% (10) (No reply: 31)
NUMBER OF INSTRUCTORS (NUMBER CONSENTED) INSTRUCTOR IDS: t_008–t_011	4 (4)	

score from 0 to 5 (see Appendix B). Intercoder reliability (ICR) was tested, and differences were resolved communicatively.

The qualitative analysis of focus-group and interview transcripts was oriented towards understanding and reconstructing the learning processes and outcomes, following the coding paradigm of grounded theory and applying the method of constant comparison (Strauss and Corbin, 1990). To create a robust coding scheme and ensure ICR, three researchers applied open coding to four of the eighteen focus-group transcripts (>20%), resulting in a code book encompassing both deductive and inductive (in vivo) codes. In search of significant factors impacting students' learning, initially emerging categories such as "course structure," "practical application," "exchange with others," "personal interest," and "preconceptions about science and sustainability" were discussed with the broader research team to allow for different perspectives and interpretations. Through several iterations of axial coding, "connection" was identified as a core category spanning the other phenomena found in the data.

4. Results

4.1. Learning outcomes

We examined the extent to which the intended learning outcomes—increased motivation to implement EfS (attitude and beliefs), sustainability-related content knowledge (CK), and pedagogical content knowledge (PCK)—were actually achieved. Students' attitudes and beliefs were measured against the revised NEP scale developed by Dunlap et al. (2000) to trace ecological worldviews, the perceived relevance of EfS, and EfS-related self-efficacy (SE) (Tomas et al., 2015), with acceptable-to-good Cronbach's Alpha (α) values falling between 0.61 and 0.74. A pre/post comparison using paired t-tests revealed that students' ecological worldviews, the perceived relevance of EfS, and EfS-related SE increased significantly during the course (see Table 3).

Content knowledge (CK) was measured by the changes in students' definitions and understanding of the term *sustainability*.

Table 2
Overview of instruments.

SURVEY TO IDENTIFY STUDENTS' LEARNING OUTCOMES (CK & ATTITUDE)	Pre- & Post-course survey (online/LimeSurvey) ($n_{pre} = 90$, $n_{post} = 79$, $n_{pre\&post} = 66$) • New Ecological Paradigm Scale (15 five-level Likert items) (Dunlap et al., 2000) • EfS-related self-efficacy scale (7 four-level Likert items) (Tomas et al., 2015) • Perceived-relevance-of-EfS scale (6 four-level Likert items) (Tomas et al., 2015) • Self-reported definition of sustainability (open item) Pre-course survey • Previous work experience (closed item with 8 checkboxes) • Extracurricular activities (closed item with 10 checkboxes) • Motivation to become a teacher (open item) Post-course survey • Demographic information (items on age and gender)
FOCUS GROUPS TO IDENTIFY STUDENTS' PERCEPTIONS OF THEIR LEARNING PROCESSES AND LEARNING OUTCOMES (PCK)	**18 end-of-semester focus groups (approx. 35 min.) (n = 95)** encompassing open questions about: • How students would describe their learning process, particularly concerning perceived drivers of and barriers to their learning • The extent to which they felt they achieved the explicit learning objectives of the course and what the key moments of learning were in this regard • What was particularly helpful to their personal learning process and what they would change about the course if they could
INSTRUCTOR INTERVIEWS TO IDENTIFY INSTRUCTORS' PERCEPTIONS OF STUDENTS' LEARNING PROCESSES AND OUTCOMES, AS WELL AS THE SPECIFICS OF THE TEACHING AND LEARNING ENVIRONMENT	**4 end-of-semester interviews (approx. 35 min.)** encompassing open questions about: • The instructors' career paths • Their individual approaches to teaching and learning both in general and in this particular course • Their perception of learning processes and achievement of the course-specific learning objectives among their cohort of the fall 2017 semester
NON-PARTICIPATORY OBSERVATIONS TO IDENTIFY THE SPECIFICS OF THE TEACHING AND LEARNING ENVIRONMENT	**Observation notes (52 sessions)** encompassing notes about: • The teaching and learning environment • The materials and teaching approaches used • In-class activities and learning processes

Table 3
Attitude scales.

	Pre-test			Post-test					
	N	*M*	*SD*	*N*	*M*	*SD*	*df*	Cohen's *d*	Sig.
Revised NEP scale (15 items; 1–5 Likert scale)									
SSfTf all 2017	62	**3.71**	.42	62	**3.92**	.39	61	**.60**	.00**
Perceived relevance of EfS (6 items; 1–4 Likert scale)									
SSfTf all 2017	63	**3.54**	.43	63	**3.77**	.31	62	**.59**	.00**
EfS-related self-efficacy (7 items; 1–4 Likert scale)									
SSfTf all 2017	64	**2.61**	.50	64	**3.26**	.31	63	**1.34**	.00**

** Significant at the 0.01 level (2-tailed).

Table 4
Understanding of sustainability (CK).

	Pre-test			Post-test					
	N	*M*	*SD*	*N*	*M*	*SD*	*df*	Cohen's *d*	Sig.
(overall) Sustainability definitions (0–5) time perspective + dimension orientation									
SSfTf all 2017	64	**1.38**	1.03	64	**2.20**	1.15	63	**.62**	.00**
Time perspective (0–3) 0 = no time perspective, 1 = future perspective, 2 = intergenerational perspective, 3 = intergenerational and intragenerational perspective									
SSfTf all 2017	64	**.78**	.63	64	**1.11**	.86	63	**.38**	.00**
Dimension orientation (0–2) 0 = no dimensions mentioned, 1 = one-dimensional perspective, 2 = multidimensional perspective									
SSfTf all 2017	64	**0.59**	.66	64	**1.09**	.79	63	**.55**	.00**

** Significant at the 0.01 level (2-tailed).

Table 4 depicts the results of the coded answers given before and after the course, showing a significant increase in the complexity of students' understanding of the concept of sustainability.

Students' self-reported change in their pedagogical content knowledge (PCK) is assessed through a variety of statements about developing the ability to later implement EfS at the school level. "Teaching sustainability and combining it with other curricula" (S1_325), for instance, was explicitly facilitated by this course. However, while some students highlighted that the course prepared them to implement EfS at various grade levels, others reported difficulties in breaking down the complexity of sustainability topics in fashions appropriate to different age groups:

> If I wanted to do sixth grade, I feel like even breaking it down to that, without completely like breaking them down, would be difficult. (S1_341)

Students generally seemed to have gained a certain theoretical understanding of how to implement EfS at the school level, yet they pointed to a lack of practical experience:

> I got at least an idea of the topics, to be like, okay, well, I can create a lesson plan …, but it is more just like a basis thing, like it wasn't anything like that I'm able to like go out and teach it right away. (S1_336)

Referring to the lesson plans from the final project, another student added:

It's preparing me for how I'm going to create my lessons in the future and kind of giving me ideas on what that's like in a real classroom, and of course like maybe now it's not going to work, and I can adjust later on when I gain more experience as a teacher. (S1_333)

A similar picture emerged with regard to students' ability to apply the four ways of thinking (WOT) to explain sustainability concepts. While some students reported that they "found it really easy to implement [the WOT] in [their] final project [s]" (S1_337), others continued to encounter difficulties distinguishing between the WOT: "they kind of blend together in my mind" (S1_354). The majority of students, however, seemed to have had an approximate understanding of the WOT.

This appearance is confirmed by the assessment made by the course instructors, who reported that students "seem to grasp that idea" of the WOT and sustainability issues per se, whereas it remained unclear whether students had become capable of implementing them in their future teaching careers.

We don't perform as well on the learning objectives related to the ways of thinking than we would do on ones related to understanding, you know, sustainability problems across the variety of domains. (T_008)

4.2. Learning process

Utilizing the analytical paradigm of grounded theory (Strauss and Corbin, 1990), we analyzed learning according to six key elements: (1) the teaching and learning environment (context), (2) the participants and their backgrounds (causal conditions), (3) the learning process (phenomenon), (4) factors supporting or hindering the learning process (intervening conditions), (5) ways of dealing with those intervening factors (strategies), and (6) the different learning outcomes (consequences). In the context of this study, we specifically set out to investigate the phenomenon of learning processes (element 3) and how the pedagogical approaches (element 1), reported supporting or hindering factors (element 4), and related strategies (element 5) impacted the learning outcomes (element 6). Students' individual backgrounds as causal conditions (element 2) were not part of this study's focus.

Fig. 2 shows the axial coding scheme that emerged from the overall analysis. While non-participatory observations informed us about the teaching and learning formats used in the course (context), the survey provided information about students' CK and attitudes as learning outcomes (consequences). Last, but not least, the focus groups shed light on the supporting and hindering factors (intervening conditions) that impacted students' learning processes, the related strategies, and the extent to which students believed that they developed PCK as a result of taking the course (consequences).

The key theme of "connection" emerged from the analysis of the focus group data as the phenomenon that best describes the learning process. *Connection* generally refers to "the relationship of a person, thing, or behavior to someone or something else" (Cambridge Dictionary). In the context of learning in the SSfT course, four forms of connection became evident as influencing factors, each having its own characteristics as well as unique consequences associated with its presence or absence: social connection, structural connection, personal connection, and professional connection. The latter two manifestations, personal and professional connection, are both underlain by a fifth form: real-world connection (see Fig. 3).

Below, we elaborate on these forms of connection, which we term the 4 Cs, by revealing their impacts on intended learning outcomes in the context of relevant teaching and learning formats. Fig. 4 portrays the relevance of the 4 Cs to achieving the stated learning objectives through the different teaching and learning formats of the SSfT course, highlighting the most dominant links with thicker arrows. We also introduce strategies applied in cases of *dis*connection, and finally, we present individual key moments of learning that best represent the each form of connection.

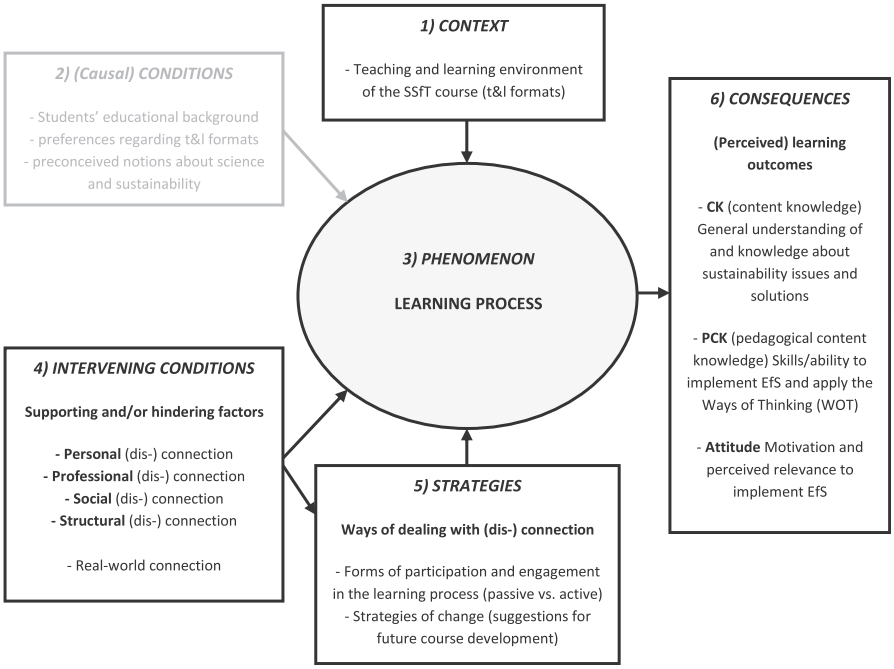

Fig. 2. Axial coding scheme of learning in the SSfT course.

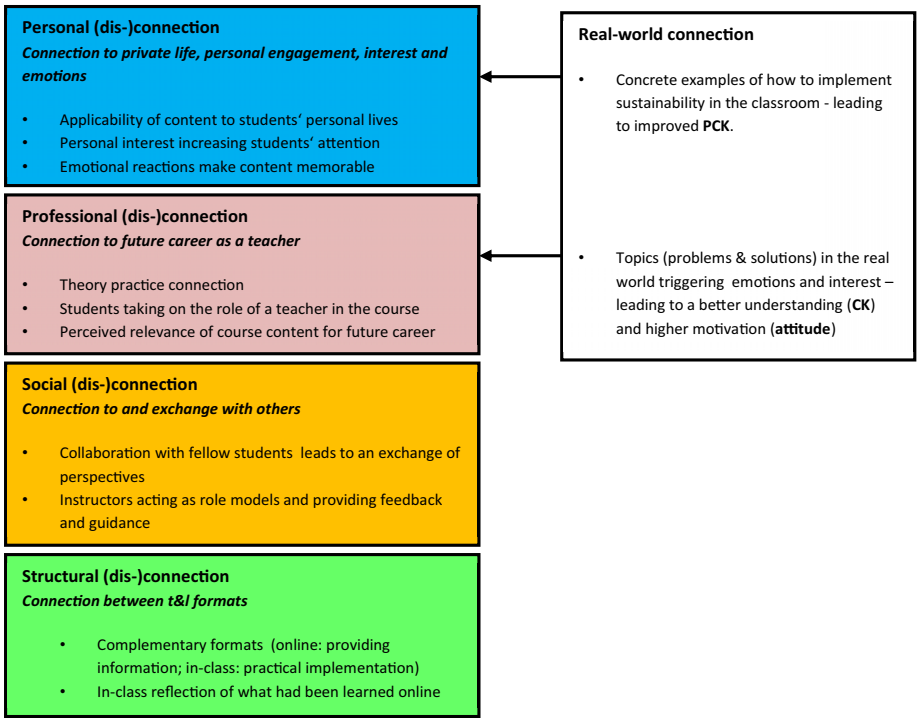

Fig. 3. Forms of connection.

4.2.1. Personal connection

The phenomenon of personal connection involves the individual engagement, interest, and emotions sparked in students by the learning process. Further, it implies their agency in the learning process and the applicability of course content to their private lives (personal relationship). Eventually, students' hands-on engagement and emotional reactions to the content, activities, and structure of the course appear to both increase their interest in the course topics and improve their memory of what has been learned (see Appendix C1).

Teaching and learning formats, intervening conditions, and outcomes.

Several students appreciated opportunities to learn at their own pace (online learning) and emphasized the importance of relevant and relatable videos, which appeared particularly helpful in closing knowledge gaps (CK). The real-world connection elucidated by videos sparked students' emotions, increased their interest, and caused the information to be more deeply absorbed. Additionally, some videos were perceived as particularly engaging and had positive impacts on students' motivation (attitude):

> There were some [videos] where I was like, okay, I'm ready, let's go change the world (S1_365).

Explicitly linking personal engagement to an improved understanding of content (CK), students emphasized the importance of hands-on activities. Demonstrating a connection between hands-on activities and students' motivation (attitude), some students traced their excitement about the course back to feeling engaged within the classroom. In-class activities, having established a personal relationship to the course content, the were also linked to students' PCK:

> The activities we did in-class made it more, I don't know, relatable, even further than the videos, because you could see, like, how we could use it in future classrooms. (S1_319).

The quizzes, on the other hand, were partly perceived as "lower-level-thinking assignments … [that] didn't resonate as deeply" (S1_305). The impact of quizzes on overall course grades put pressure on some students, and consequently, they suggested replacing the quizzes with reflective tasks.

Even though several students enjoyed watching the videos, many struggled with the quantity of material. Some even indicated that dealing with too much information caused them to feel anxious. One strategy that students applied in such cases was to stop watching the videos and start "guessing the answers to the quiz" (S1_369), which led to information being lost (CK). Occasionally, students went so far as to state that some of the videos were boring. Some of these students also tended to decrease engagement and cease watching the videos, while others forced themselves to complete their work. Hence, while personal interest seems improve the learning process by enhancing the degree of attention paid, personal disconnection leads to just the opposite:

> You know we're learning about something, but when you're just sitting there like 'when is this going to be over,' like that's all you're thinking about, you're not even paying attention to the video at that point. (S1_378)

4.3. Exemplary key moments

Some videos seem to have resonated especially strongly with students and stuck with them after watching. A video dealing with

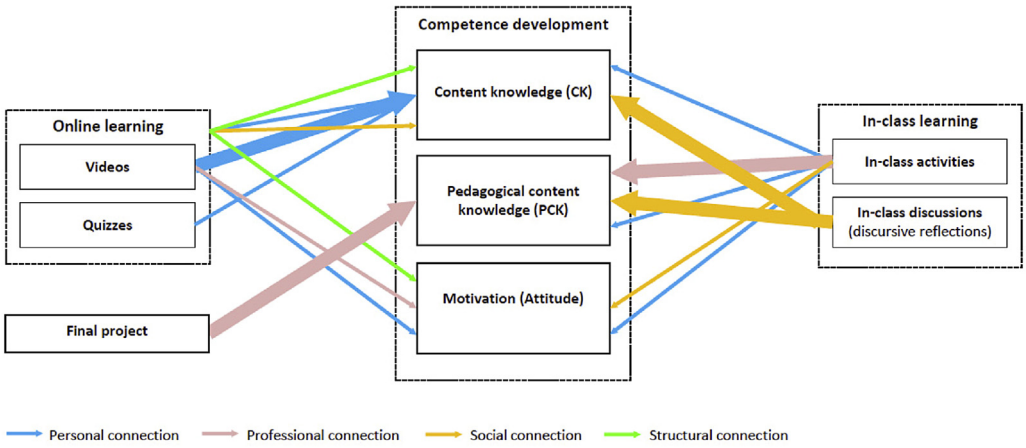

Fig. 4. The impacts of the 4 Cs on learning outcomes in different teaching and learning formats *Note*. More dominant links are denoted by thicker arrows.

the production of attire, for instance, was particularly relatable: "we all want the jeans to look a certain way" (S1_345). Students reported enjoying a variety of in-class sessions, but hands-on activities like the solar-amusement-park exercise, for which students were asked to build their own miniature park rides, induced unique levels of excitement. Discussing personal engagement, students indicated that this activity helped them to dig deeper into the topic of renewable energy:

> I really liked that one, kind of like, because some content, I covered the understanding through the video, and like in class, through the activity, I kind of [really] get into it. (S1_327)

Even though the homework assignments were rarely mentioned in conjunction with personal connection, the fossil-fuels assignment, in which students calculated their own carbon footprint, was perceived as a key moment:

> That's when we thought about things that we could, like, implement into our lives, like in a year, in a month … I thought that was really impactful. (S1_305)

The governance assignment, in contrast, elicited different feelings in students. That assignment, in which students wrote letters making political demands to policymakers and politicians, created feelings of agency in students as they were put in a position to express their opinions. It also ensured a personal connection, as students were able to select an issue of personal interest.

4.3.1. Professional connection

The phenomenon of professional connection corresponds to the link between theory and practice. Here, the key aspects are students' role in the learning process, opportunities to practically implement EfS, and expected learning outcomes with respect to applicability in future classrooms (see Appendix C2).

> One of the biggest parts of this class is like, how can we do this in the future? (S1_385)

Teaching and learning formats, intervening conditions, and outcomes.

Students described it as helpful to take the perspective of—and be treated as—an actual teacher during the course, and they appreciated the applicability of course content to their future classrooms. Concerning in-class activities, students indicated that by the end of the semester, they appreciated having a portfolio of activities they would be able use:

> I think the greatest learning came from the in-class activities that we did, that were interactive and hands-on and also gave us an example, a strong example, of what we can do in our future classrooms to integrate sustainability. (S1_358)

Continuing to link these activities to a broadened pedagogical repertoire, students reported an improved ability to apply the different WOT (PCK):

> Because [of] the activities that were aligned with [them] … we know how to actually use those ways of thinking. (S1_375)

The videos, which introduced each topic, were generally considered to help develop an understanding of sustainability concepts (CK). Yet in terms of professional connection, some of the videos not only enhanced students' factual knowledge but also provided examples of how to implement EfS (PCK). In the same context, the videos' real-world relevance, and "visually seeing it" (S1_353), made the information more memorable. Some, however, raised the critique that there could have been greater emphasis on implementation strategies, especially for different age groups:

> Alternative activities for different grade levels, I think, would be helpful. So, more of, like, the teaching in class. (S1_335)

Accordingly, some students proposed spending a second day in class each week to focus on implementation. And while many students claimed that the final project did entail professional connection—as the project was "all about how we would teach it" (S1_315)—others emphasized the lack of opportunities for practical implementation. Students suggested that future renditions of the course would be improved by engaging in practice simulations of the final projects with the seminar group.

4.4. Exemplary key moments

The SSfT alumni video, in which former students of the course reported on their current EfS practices, represents an exemplary key moment of learning in the area of professional connection. Students appreciated seeing "teachers who have taken this course and how they've applied it to [the] classroom now" (S1_333), and they asked for additional practical examples of EfS implementation:

> I want to see more teachers being like, 'okay,' like, 'hi, I'm a third-grade teacher, I incorporate sustainability through this [method].' (S1_343)

Watching this particular video led to a genuine increase in students' self-efficacy, as well as an attitude best expressed by "we can do that" (S1_367). Furthermore, students perceived several in-class activities as applicable in their future classroom. An activity on the water cycle and human water systems, for instance, was seen as helpful in comprehending the different WOT and recognizing "diverse preferences of students regarding learning formats" (S1_353). The hot-dog activity and its systems-thinking approach towards food production also seemed applicable to students' future careers:

> Even younger students … can make those connections … [and] really understand the systems thinking. (S1_330)

4.4.1. Social connection

Social connection refers to the feedback and guidance conveyed by the instructor by modeling sustainable behavior and engaging approaches towards teaching and learning, as well to as the exchange of thoughts and perspectives (sharing knowledge) with fellow students—through interactive activities and in-class discussions, for instance (see Appendix C3).

4.4.1.1. Instructor. Many students highlighted the motivational influence of a passionate instructor who modeled sustainable behavior. The outcomes associated with such admirable instructors are a keener interest in the topics discussed and an increase in those topics' perceived relevance:

> She [the instructor] was so passionate that you're like, 'okay, this is important,' like 'I really need to focus.' (S1_318)

Another supporting factor was the course's unbiased approach to teaching, which considered both the benefits and drawbacks of sustainability. Students also appreciated guidance and feedback, particularly during in-class reflections on online material, and claimed that the instructor explicitly helped them to close their knowledge gaps (CK):

> The driving factor for learning was just that our teacher was so knowledgeable in sustainability … he was like our sustainability Google that we could just ask any question. (S1_354)

4.4.1.2. Teaching and learning formats, intervening conditions, and outcomes. A learning format frequently mentioned as allowing for social connection to play out was in-class discussions and discursively reflections upon the online material. These exchanges with others supported students' learning. Underscoring the benefits of in-class discussions, students highlighted the value of "connecting together how [sustainability] really influences our day-to-day life" (S1_371). In other words, in-class discussions created a personal connection. The prevalence of discursive exchanges of thoughts and reflections on the online material appeared to lead to a better understanding of the topics (CK):

> When we sat in our groups, talking about it, it helped me understand better, like, what we're doing, and like, why we all feel that way [that] we do about the topic. (S1_300)

Moreover, respectful debates and hearing out the opinions of all students in class were explicitly linked to practicing values thinking and improving students' PCK. With respect to the online class component, on the other hand, several students stated that they missed receiving immediate feedback from the instructor and interacting with fellow students. Students reported that these losses negatively impacted their understanding of the material (CK):

> I feel like when it's just online, I don't really get that interaction with people, and … I don't [understand] the content as much as I should. (S1_306)

4.4.1.3. Exemplary key moments. Students appreciated the opportunity to give one another peer feedback as part of the final project, exchanging ideas about their individual teaching and learning units, which added to their PCK:

> … to be able to see other people's topics as well, and I feel like, 'hey, that is something else we can talk about in our classroom.' (S1_308)

The in-class debate (known in class as *philosophical chairs*) over the social, ecological, and economic implications of building the Dakota Access Pipeline helped students practice their values thinking (CK):

> I thought that was a really good activity to kind of get us to, like, use the different thinking, and values thinking particularly; I feel like we were able to argue, like see a lot of people's opinions come out and, like, what values they had. (S1_375)

In the comparable 'needs vs. wants' activity (a component of the poverty unit), students jointly decided what is wanted, as opposed to needed, in life:

> It was like different values, you know, it's 'you prefer this over this.' … So, that was kind of like, your own values thinking, and it was really cool to see like, you know, you resonate with someone else. (S1_344)

4.4.2. Structural connection

The structural dimension of connection entails a consistent course structure and the explicit link between individual teaching and learning formats. The key focus here is on the relationship between individual components of online learning—such as videos, quizzes, and assignments—and in-class activities, as well as discursive learning scenarios in face-to-face sessions (see Appendix C4).

4.4.2.1. Teaching and learning formats, intervening conditions, and outcomes. Within the focus groups, the different teaching and learning formats were mainly discussed against the backdrop of their perceived roles and respective (dis)advantages. Broadly, students reported that the online portion had provided relevant information, while the in-class sessions had been useful in clarifying and implementing the material that had been learned online. While a few students claimed to dislike dealing with two different learning environments that "need to be conjoined" (S1_326), the majority appreciated that the two components of the hybrid course format complemented each other. Several students highlighted

that the online portion laid a foundation by introducing the different topics, thereby preparing the students for in-class sessions, which expanded upon the videos in turn:

> It was impactful, watching the videos about the different types of thinking, that's like when I originally learned from the video. And so then, in the class, I like, actually implemented it, but I learned from the videos what the difference is between each. (S1_376)

As mentioned above (section 4.2.3), reflecting (discursively) in class upon the online material was perceived a major driver of learning. However, hindering elements were also present with respect to structural connection. Students repeatedly referred to the link between videos and quizzes and the actual order of online tasks. Grade-oriented students appreciated that quiz questions could be used to contextualize the videos because the questions were already available prior to watching; others, however, emphasized that this resulted in limited learning outcomes and a loss of relevant information (CK):

> I felt like I was watching the videos more to answer the quiz than for my own understanding. (S1_314)

Discussing the strategies they applied when encountering this sort of structural disconnection, which caused partial decreases in personal engagement with the learning process (attitude), some students reported that they had found ways to score highly on the quizzes without even watching the videos—although doing so (e.g., by Googling the answers to the quiz) meant renouncing true learning:

> As soon as I found out you can get a good score without watching the video, it kind of took away from learning, because it just made it easier to get around actually learning (S1_354)

4.4.2.2. Key moments of learning. Individual in-class activities such as the hot-dog activity (from the food unit) and the renew-a-bead activity (fossil-fuels unit) were directly incorporated into the final project. Consequently, students understood the final project as drawing a structural connection and linking the different teaching and learning formats:

> Our signature assignment in this class is like, we're taking what we learn from one of the lessons and building off of that. (S1_336)

5. Discussion and outlook

The academic discussion surrounding teacher education for sustainability (TEfS) has yet to come to a consensus as to the most relevant elements of EfS-specific competences and how they should be addressed in pre-service teacher education. According to the competence model developed by Bertschy et al. (2013), TEfS is expected to develop student teachers' sustainability-related content knowledge (CK), their skillset (PCK), and their willingness and motivation (attitude) to implement EfS at the school level.

Examining students' learning outcomes from the SSfT course (see RQ sub-question **i**), the results of this study indicate that the participating students have developed both a more positive attitude towards EfS and an improved array of CK, in the sense of a better understanding of sustainability. While the perceived relevance of EfS was relatively high among the SSfT students, their pro-environmental worldviews (measured via the NEP scale) were quite similar to those of German pre-service teachers. However, as the SSfT course constituted, for the majority of ASU students, a first encounter with sustainability, their understanding of the term and concept was notably less complex (Brandt et al., 2019).

Insights regarding PCK development, on the other hand, remain rather ambiguous. Although the students developed a certain theoretical understanding of how to implement EfS at the school level, they still lacked practical experience, and they reported uncertainty about how to apply the WOT and break down sustainability concepts for different grade levels. Furthermore, students' self-reported learning outcomes, with respect to PCK and their ability to implement EfS, are sometimes difficult to distinguish from EfS-related self-efficacy items that cover students' trust in their own capabilities. What is missing is an adequate instrument for measuring PCK development in a performance-oriented approach, which would allow researchers to move away from contestable self-assessments. It is further important to consider that teachers generally play two roles, each related to a specific set of intended learning outcomes: the role of the professional (instilling CK, PCK, and attitude) and that of the global citizen (raising awareness and inducing behavior change). This latter role, however, was not the focus of this study.

With respect to learning from the different teaching and learning formats of the SSfT course (see sub-questions **ii** and **iii**), four forms of connection (the 4 Cs) manifested as key factors impacting students' learning processes. As described above, a personal connection to the course content sparked students' interest, increased their attention, and improved their memory. Being engaged by hands-on activities or emotionally touched by documentary videos with real-world relevance increased students' motivation to engage with EfS (attitude) and helped them develop an understanding of the course content (CK) and how to use it in their future teaching careers (PCK). Personal *dis*connection, on the other hand—such as feelings of anxiety that result from the scope of the video material—sometimes prevented students from absorbing and retaining information. This finding accords with recent insights from a study by Ojala (2013), and it substantiates findings in the interdisciplinary field of neuroscience and education that pointing to a role of emotions in affecting students' performance and learning (Immordino-Yang and Damasio, 2007). However, while negative emotions can be difficult to handle and may cause students to stop what they are doing, they also have the potential—when treated with constructive regulation strategies—to incite critical thinking and reflection (Ojala, 2013).

Second, professional connection—referring to explicit links to (future) implementation of EfS at the school level—supported students' learning processes. Whether it was through a video featuring successful SSfT alumni, working on the final project, or being engaged in activities that equipped students with a portfolio of EfS lessons, professional connection—supported by a layer of real-world connection—strengthened students' pedagogical skills (PCK), as well as their motivation to act as future change agents (attitude). Only the lack of practical experience and the missed opportunity to implement the teaching and learning units used in students' final projects were seen as hindering factors. The importance of the perceived value and practical relevance of learned material has already been emphasized in previous work concerning higher education at large (Biggs and Tang, 2011). With particular regard to TEfS, Bürgener and Barth (2018) showed how open learning environments and cooperation with partnered schools could enhance students' learning by incorporating a practical component and strengthening the professional connection. Future research should focus on K–12 students in the classrooms of

EfS-trained educators. It is crucial to understand the extent to which educators can use the ways of thinking and knowledge they have learned to empower and motivate K–12 students to persistently engage in real-world projects that contribute to systemic change.

In the context of social connection, the role of instructors was particularly highlighted. Instructors' passion for the course content was passed on to students and increased their motivation to engage with sustainability topics, their perception of the relevance of EfS, and the attention they paid to the course content. As also described by Biggs and Tang (2011), instructors' feedback was another key factor guiding students' learning processes in this study. Furthermore, students' ability to exchange thoughts and ideas with their classmates in group discussions and discursive reflections helped them to close knowledge gaps and develop their CK. Respectfully debating the social, ecological, and economic implications of major projects like the Dakota Access Pipeline with the entire class, as guided by an unbiased instructor, gave students further practice in values thinking and improved their pedagogical skillset (PCK). These results confirm the importance of social interaction and opportunities to exchange ideas, not only in TEfS (Whitehouse, 2008) but also in pluralistic approaches and deliberative communication in EfS at large (Ojala, 2013). While So and Brush (2008) have already showed that collaborative learning in health education is more *satisfying* to students, the SSfT cohort indicated that face-to-face interaction is not merely satisfying but *fundamental* when learning about sustainability. Students identified the need to understand one another's values and perspectives through respectful discussion.

Finally, a structural connection and deliberate links between different learning formats have proven to be important, particularly in affecting the development of students' content knowledge (CK). In the context of this study, structural connection was only mentioned in cases of hindering links, or *dis*connection. While the order of tasks associated with the online course component had a limited impact on students' motivation to engage with the material, the direct application of individual in-class activities to the final project and the in-class reflections upon the online material was perceived as helpful to the overall learning process. This too corresponds to the findings of Biggs and Tang (2011), who claim that building on existing knowledge and establishing structural interconnections between topics directly improve learning.

Above all, the 4 Cs are not separate entities—rather, they are interlinked elements that not only impact students' learning processes but also have the potential to foster, or hinder, one another. While most findings presented here appear generalizable to learning in higher education at large, rather than specific to the field of TEfS, it is clear that passionate yet un-biased instructors and learning formats that allow for the discursive exchange of thoughts and ideas are crucial to supporting learning in connection with the complex, value-laden concepts of sustainability and EfS.

It is worth mentioning that the course we investigated was characterized by special conditions that do not necessarily apply to other courses around the globe. Not only is the course mandatory for all elementary-education majors, but the financial resources it has amassed since its launch in 2012 make this case particularly unique. With Nobel laureate Leland H. Hartwell and other external stakeholders on board, funding was available to produce high-quality digital storytelling videos and ensure consistent in-class activities. On the other hand, the SSfT course serves as an exemplar of hybrid TEfS courses as it includes a variety of teaching and learning formats applied worldwide.

Although our results are to a certain extent 'bounded' to this case study and cannot be simply generalized, we take the final step of providing a list of recommendations based on student feedback about their learning processes.

- As the SSfT students have repeatedly highlighted appreciation for instructors that serve as role models, thereby facilitating the learning process, we recommend seeking out instructors who are passionate about sustainability and capable of presenting and discussing sustainability issues and solutions in an unbiased manner.
- Since structural connection facilitates engagement with and understanding of the course content, we highly recommend that those in the position to do so make considerate decisions about course structure and the order of tasks, particularly in online learning environments.
- Students' personal connections to the course content enhance their motivation and understanding. We advise that content is made relevant to students and that the relationship between emotion and cognition is recognized.
- To account for the significance of social connection and face-to-face interaction, which was particularly emphasized when dealing with sustainability topics, we advise that opportunities be guaranteed for discursive reflected and group discussions of sustainability issues and sustainability solutions.
- To finally do justice to the professional connection and improve students' pedagogical repertoire as well as their willingness to actually implement EfS at the school level, we recommend that tasks be integrated to design and implement—or at least simulate—exemplary EfS lesson plans, e.g., through cooperation with partnered schools.

Many of these elements were present in the observed course, and they may be useful design elements to consider for other EfS courses.

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CRediT authorship contribution statement

Jan-Ole Brandt: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Visualization, Project administration. **Matthias Barth:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Funding acquisition, Project administration. **Eileen Merritt:** Conceptualization, Methodology, Writing - review & editing, Resources, Project administration. **Annie Hale:** Conceptualization, Methodology, Writing - review & editing, Resources, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Supplementary data

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