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Fostering students' systems thinking competence for sustainability by using multiple real-world learning approaches

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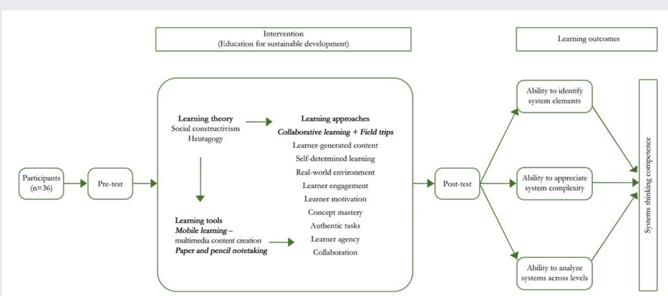
ABSTRACT
For a sustainable future, equipping sustainability change agents with relevant sustainability competencies is crucial. Among these competencies is system thinking competence – the understanding of complex interrelationships among the dimensions of sustainable development and the impacts of the interrelationships. Learning approaches relevant to fostering sustainability competencies have been studied. However, research is rare on fostering systems thinking competence by simultaneously using multiple, real-world, and innovative learning approaches. To address this gap, we conducted a pre-test–post-test exploratory experimental study involving higher education students ($n=36$). The study explored the contributions of field trips and collaborative learning in combination with mobile learning and paper-and-pencil note taking. The study simultaneously implemented a combined set of learning approaches in a real-world environment. The results suggest that the learning approaches and the real-world environment contribute to fostering the systems thinking competence of participants by exposing them to complex real-world systems and enabling the exchanging of diverse ideas among collaborating participants. As such, our study contributes to social constructivist learning discourses in education for sustainable development by indicating specific combinations of learning approaches and environments that facilitate the meaningful engagement and motivation of learners through self-regulated learning.



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1. Introduction

Sustainability challenges including climate change, inequality, and poverty are global challenges. These challenges are problems that need to be dealt with by stakeholders all over the world to move toward a more sustainable future (Leal Filho et al. 2019). The term 'sustainability challenges' is used in this study to emphasize the need for sustainability efforts to focus on tackling certain challenges. These challenges need to be addressed by, among other actions, identifying and fostering relevant competencies that help sustainability change agents to contribute toward a more socially, environmentally, and economically sustainable world. These competencies include – inter alia – systems thinking competence (STC) (Brundiers et al. 2021; Demssie et al. 2019; Heiskanen, Thidell, and Rodhe 2016; Osagie et al. 2014; Redman and Wiek 2021; Wiek, Withycombe, and Redman 2011). In addition to identifying competencies, exploration of what learning approaches foster these competencies is crucial to address sustainability challenges (Hesselbarth and Schaltegger 2014; Segalàs, Mulder, and Ferrer-Balas 2012). In the effort to foster sustainability competencies (SCs), previous studies focused on recommending certain pedagogical approaches. Combinations of innovative learning approaches (i.e. different from traditional, less relevant, but dominant ones, such as lectures) are important to foster SCs. However, the practice of employing such approaches is not common (Lozano et al. 2019). Studies that investigate the practical implementation of combinations of innovative learning approaches in authentic environments to foster STC are lacking. This study addresses this gap by exploring the contribution of implementing a set of learning approaches (i.e. field trips, collaborative learning, and mobile learning) in fostering the STC of students in higher education.

In the context where this study was conducted, Demssie et al. (2019) identified 15 competencies required for sustainability change agents. Among these, STC gained the highest rating from sustainability experts. This competence is elaborated in Section 2.1 below. Systems thinking competence helps sustainability change agents to realize the complexity of social, environmental, and economic environments. Systems thinking competence helps leaders of organizations to realize the impacts of their actions on others (Williams et al. 2017). As such, the competence facilitates the contributions of sustainability professionals and organizational leaders to a more sustainable future. Because of the significance of the competence, several other studies have also identified systems thinking as one of the key SCs (Heiskanen, Thidell, and Rodhe 2016; Lozano et al. 2017; Osagie et al. 2014; Roorda 2013; Sandri 2013; Wiek, Withycombe, and Redman 2011). Accordingly, this competence was selected for the current study.

Various studies indicate the importance and challenge of developing STC for sustainability. Molderez and Ceulemans (2018) describe the competence as "one of the most difficult competencies for students to acquire. Nevertheless, it is one of the key competencies of education for sustainable development" (p.758). Remington-Doucette et al. (2013) note that "unlike other types of cognitive activity, systems thinking is not intuitive or innate. When thinking about a problem, we do not naturally think about all things connected to it and their interrelationships." They also emphasize that "it is necessary to cultivate this skill explicitly" (p.410). Because of its importance, developing students' STC is the key, and because of the difficulties involved in fostering it, the use of a combination of innovative learning approaches in authentic environments is important.

In this study context, Demssie et al. (2020), identified field trips, real-world learning, collaborative learning, and information and communication technologies (ICT) as learning approaches that facilitate learner engagement to enhance SCs. These pedagogies and their relevance are discussed in the conceptual framework. A combination of these learning approaches was utilized in the current exploratory intervention study. This intervention was connected to the authentic case of Addis Ababa's waste management system (WMS).

1.1. A Short introduction to the research context

Addis Ababa is the capital city of Ethiopia. With an average altitude of 2,300 meters above sea level, it is one of the highest capital cities in the world. The area of the city is 540 square kilometers (Melaku and Tiruneh 2020). The population of Addis Ababa city is about 4.8 million (Central Intelligence Agency 2020). The city government is divided into 10 sub-cities. It is the seat of multiple significant international organizations, including the United Nations Economic Commission for Africa and the African Union.

The waste management (WM) activities in Addis Ababa, from the generation of waste to its disposal at the major landfill, called Koshie, have significant social, economic, and environmental implications on residents and workers in the WMS, among others. These include health risks and related expenses, the risk of landslides, and plastic waste that harms animals. Because the complex issues present in the WMS relate to the three dimensions of sustainable development (people, planet, and profit), it was used to contextualize the study.

Utilizing learning approaches that facilitate the active engagement of learners – such as mobile learning, field trips, and collaborative learning – is important (Demssie et al. 2020; Monroe et al. 2019). Moreover, some studies recommend a combination of learning approaches to foster SCs (Lozano et al. 2019). However, we have not come across studies that have investigated the implementation of a combination of the aforementioned learning approaches in authentic environments to foster STC. To address this aspect of the education for sustainable development (ESD) literature, our study explored the contributions of using a combined set of learning approaches in fostering STC.

The participants of this study were 36 final year Bachelor's students in the Department of Geography and Environmental Studies at Addis Ababa University (2022), in Ethiopia. The University website indicates that the focus areas of this Department include "Physical Geography, Human Geography, Remote sensing and various tool courses including Geographical Information Systems, and Photogrammetry and Cartography."

In the remainder of the paper, we present the conceptual framework, methods, results, discussion, limitations of the study, suggestions for future research, and conclusions.

2. Conceptual framework

In this section, we discus STC, ESD, social constructivism, heutagogy, authentic learning, learning approaches for STC, field trips, collaborative learning, mobile learning, and paper-and-pencil note taking.

2.1. Systems thinking competence

The origin of systems thinking is related to several disciplines. Córdoba-Pachón (2011) notes that it is "a body of knowledge that initially emerged in biological investigations has spread to other areas like physics, psychology, cybernetics, information technology, community development, and management" (p.43). The ability to identify the elements of a system, to recognize interconnections among them (i.e. the ability to appreciate the complex nature of systems), and to analyze a system across different levels are the key components of STC (Chiu, Mamlok-Naman, and Apotheker 2019; Plack et al. 2018; Warren, Archambault, and Foley 2014).

Based on several studies (Barile et al. 2018; Chiu, Mamlok-Naman, and Apotheker 2019; Giangrande et al. 2019; Kay and Foster 1999; Nguyen et al. 2012; Osagie et al. 2014; Sipos, Battisti, and Grimm 2008; Wiek, Withycombe, and Redman 2011), we operationalized STC in terms of these three abilities. In the context of SCs, Wiek, Withycombe, and Redman (2011) define STC as "the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global)" (p.207). Based on this definition, we define STC as 'the ability to recognize the elements in and complexity of a system, to understand the interrelationships of the elements, and to appreciate the impacts of the interrelationships at local, national, and global levels.' This definition of STC is based on the cognitive and affective dimensions. As such, it is different from other definitions that conceptualize competence as a performance requirement (Mulder 2014, 2019). The performance-related definition considers competence as an integration of knowledge, skills, and attitudes to perform a task (Miller, 1990; Shavelson, 2013). Furthermore, this conceptualization of competence indicates that competence cannot be directly assessed; it can be inferred from performance (Shavelson, 2013). In our study, STC is not conceptualized in terms of a person's ability to perform a task. Rather, it is operationalized in terms of the three abilities detailed in points A to C of Section 3.6.2. These three abilities relate to the cognitive understandings of systems and subsystems. Additionally, the ability to appreciate complex interrelationships has the potential to affect a person's attitude. For instance, in the context of sustainability, STC entails, among others, the knowledge of the elements of social, environmental, and economic aspects of development. This knowledge acquiring aspect of STC is what we consider as a cognitive dimension. Another important aspect of STC is one's ability to realize the complex interrelationships among different elements of a system and the impacts of the interrelationships. It is expected that gaining this ability encourages a person to be responsible in their decisions and actions. This is because realizing the potential impacts of a person's decisions and actions affects their attitude and values, guiding them in a more sustainable way. This aspect of STC is what we consider as the affective dimension. Shrivastava et al. (2012) indicate that the combination of relevant cognitive understandings and affective experiences is important to encourage sustainability-friendly decisions and actions of a person. The features of STC in the above definition make it relevant to sustainability, as the competence enables understanding the impact of human activities on the different dimensions of sustainable development. These abilities are crucial for progress toward a more sustainable future (Wiek, Withycombe, and Redman 2011; Williams et al. 2017).

Sustainability challenges are described as complex and "wicked" (Ho 2021). Addressing these challenges requires the ability to realize the complex interconnections among different dimensions of a system (for example, among people, planet, and profit) and collaborate with professionals of diverse expertise (Friman et al. 2018). Systems thinking competence helps people to appreciate such complex interrelationships. Molderez and Ceulemans (2018) note that "systems thinking approach stresses the dynamic interconnectedness between humans and non-humans." (p.760) Wesselink et al. 2015 note that STC enables a person to understand such interdependences.

Among the SCs identified by Demssie et al. (2019), a research conducted in the context of this study, STC was sustainability experts' most favored competence. Furthermore, in several other contexts, STC was frequently identified as a crucial competence for sustainability (Heiskanen, Thidell, and Rodhe 2016; Osagie et al. 2014; Redman and Wiek 2021; Roorda 2013; Wiek, Withycombe, and Redman 2011). These factors, in addition to the essence of STC discussed in Section 2.1, were the reasons to focus on STC in this study.

2.2. Education for sustainable development

Education for sustainable development is education intended to enable transitions to sustainable development by balancing social, environmental, and economic aspects of development (Barth 2016). ESD mainly focuses on enhancing the readiness and ability of today's students (i.e. future sustainability change agents) to address sustainability challenges (Mogensen and Schnack 2010).

Several authors interchangeably use the terms education for sustainability, ESD, and sustainability education (Grosseck, Ţîru, and Bran 2019). In our study, ESD is conceptualized as education intended to prepare students to contribute to efforts toward a more sustainable future as individual citizens and professionals in different organizations. The learning approaches and environments in ESD are mainly guided by social constructivism theory. This theory is discussed in the next section.

2.2.1. Social constructivism

Social constructivism entails, among others, the active role of learners, the importance of collaborative and self-regulated learning (Lambrechts and Van Petegem 2016; Preece and Hamed 2020; Wesselink et al. 2007). Woo and Reeves (2007) describe social constructivism as learning "… from rich conversation with other people who have similar or different perspectives based on their own life experiences" (p.18). The authors indicate that the crucial aspects of social constructivism include "the role of peers…, use of relevant and authentic tasks…, appreciation of multiple perspectives…, problem solving in real-world situations, and collaboration in the learning …" (p.19). Noroozi and Kirschner (2018) note that sharing and debating diverse ideas by peers are also among the aspect of the social constructivist learning paradigm. In this study, we use social constructivism to mean a combination of learning approaches and environments that facilitate the meaningful participation and collaboration of learners in real-world contexts.

2.2.2. Heutagogy

Aguayo, Eames, and Cochrane (2020) define heutagogy as "…self-determined and real-life learning, and within user/learner-generated content and contexts…, guided by learners' motivations and needs" (p.2, 11).

Narayan and Herrington (2014) indicate that heutagogical approaches entail learning in authentic contexts, student-centeredness, future-orientation, learner agency, and preparation of learners for the unknown world (p.150).

Meaningful engagement of learners is important in developing STC. In this study, meaningful engagement refers to the significant role and active engagement of learners in the learning process as described above in the discussion of heutagogy.

2.2.3. Authentic learning

Authentic learning is a type of learning that takes place by interacting with, learning from, and within the real-world in different ways. For example, Kearney and Schuck (2006) note that "authentic tasks provide real-world relevance and personal meaning to the learner…" According to the authors, authentic learning should provide "exposure of learners to the real-world, and allow students to generate their own problems to solve…" (p.190).

Herrington and Oliver (2014) note several elements that constitute an authentic learning environment. They indicated that authentic learning environments need "to preserve the complexity of the real-life setting, complex tasks to be investigated by students …, and the opportunity to collaborate" (p.4).

2.3. Learning approaches to foster systems thinking competence

In this study, the concept traditional learning approaches refers to learning approaches where learners are passive recipients of knowledge from teachers and learning is confined to classroom walls. As discussed in several studies, the relevance and effectiveness of such learning approaches in ESD are questioned (Figueiró & Raufflet 2015; Hesselbarth and Schaltegger 2014; Segalàs, Mulder, and Ferrer-Balas 2012). Therefore, this study was conducted within a social constructivist framework and using heutagogical approaches. As discussed by Vare et al. (2019), learner-centered approaches that allow learners to engage in knowledge co-creation, collaboration, and authentic learning environments are relevant in ESD. Accordingly, the contributions such learning approaches were selected to be explored. To enhance learners' SCs, learning approaches such as collaborative learning, mobile learning, and field trips are recommended (Molderez and Ceulemans 2018). The relevance of the selected learning approaches in teaching SCs is discussed below.

2.3.1. Field trips

Field trips are among the learning approaches that are effective in fostering STC (Assaraf and Orion 2005; Keynan, Ben-Zvi Assaraf, and Goldman 2014). This learning approach enhances STC because field trips take learners out of the confinement of the classroom and into the real-world and motivate students (Holgersen, 2021). In real-world contexts, learners get exposed to complex realities and realize that social, environmental, and economic phenomena are not independent of each other (Vare et al. 2019). In addition, Holgersen (2021) notes that "on a field trip, information and sources of knowledge are more often related to seeing, hearing, and experiencing than to reading" (p.361). As such, field trips help learners to appreciate complex interrelationships among different dimensions of systems. The realization of complex interrelationships is a key aspect of STC. Hence, field trips facilitate the enhancement of this aspect of STC.

Keynan, Ben-Zvi Assaraf, and Goldman (2014) remark that outdoor learning helps "contextualizing learning in real, complex, world environments, engaging students in particular environments that are meaningful and relevant to them, and triggering learners' phases of processing and reflection, from which new conceptualizations may evolve" (p.103). Dale et al. (2020) note that field trips "can inspire curiosity, learning, and collaborative and collective action" (p.616).

Systems thinking competence entails the ability to zoom in to identify specific elements of a system. It also requires zooming out to see interrelationships among different elements of a system (Chiu, Mamlok-Naman, and Apotheker 2019; Plack et al. 2018; Roxas, Rivera, and Gutierrez 2020; Warren, Archambault, and Foley 2014). Hence, when participants learn by means of field trips, the real-world environment allows them to appreciate the elements of a system and how the different elements interact with each other. As this appreciation of complex interrelationships is the essence of STC, field trips facilitate the enhancement of this aspect of STC.

Field trip learning is among the learning approaches that facilitate self-determined learning. Aguayo, Eames, and Cochrane (2020) indicated that for heutagogy/self-directed learning approaches, among others, "the placement of the outside-the-classroom visit within a teaching unit is pedagogically important" (p.11). The field trip learning used in this study is one of what Aguayo, Eames and Cochrane (2020) call "free-choice educational contexts". According to the authors, these contexts "bring about positive and lasting outcomes that can potentially be life-changing, by promoting reflection and meaning-making processes around socio-ecological issues" (p.9). Holgersen (2021) indicates that one advantage of field trips is their quality of causing motivation among learners.

2.3.2. Collaborative learning

Evans (2019) describes collaborative learning as "learning that involves active collaboration with classmates, community members, and/or others to generate/explore/analyze/interpret/apply ideas/practices" (p.15). Because of these features, collaborative learning has the potential to meaningfully engage learners. It facilitates the construction of knowledge by learners (Moore 2005). Demssie et al. (2020) identified the lack of opportunities to engage learners as a limitation of lecture-based, traditional learning approaches and recommended sustainability-oriented learning approaches, including collaborative learning, to foster SCs.

The use of collaborative learning is recognized as being appropriate in ESD because it facilitates the meaningful engagement of learners (Cotton and Winter 2010; Crofton 2000; Evans 2019; Mintz and Tal 2018). Moore (2005) supports this: "collaborative approaches encourage a shared construction of knowledge by a group of learners" (p.80). Learning approaches aimed at fostering STC should help students to get an overview of all elements involved and appreciate interconnections among different elements or systems. This, according to Warren, Archambault, and Foley (2014), helps the learners to "realize how these systems often directly impact one another." The authors note that, when learning to foster systems thinking, "students should actively share findings with their peers" (p.9). Collaboration facilitates the exchanging of different ideas among students and helps them to identify the elements of a system and their interrelationships. This allows learners to explore and appreciate the complex nature of systems (Scheer and Plattner 2012). In other words, when collaborating students generate and share diverse ideas, their ability in the main features of systems thinking – i.e. recognizing elements of a system and interrelationships among them – is enhanced.

2.3.3. Mobile learning

Mobile learning has been defined in several ways. Mcconatha, Praul, and Lynch (2008) define mobile learning as "learning accomplished with the use of small, portable computing devices. These computing devices may include smartphones, personal digital assistants (PDAs) and similar handheld devices" (p.15). Mobile learning is used for different types of learning activities, including the creation of learning content in the forms of multimedia (Wing and Khe 2009). Furthermore, mobile learning is appealing to learners (Gikas and Grant 2013; Heflin, Shewmaker, and Nguyen 2017; Pimmer, Mateescu, and Gröhbiel 2016; Sung, Chang, and Liu 2016, Sung et al. 2019; Vázquez-Cano 2014). Pimmer, Mateescu, and Gröhbiel (2016) indicate that the camera function of mobile learning "supported information collection and knowledge construction" (p.496). Molnar (2017) explains that "video based learning is increasing in popularity" and that it "is considered to be the most effective way of delivering the educational content to mobile devices" (p.21614).

Mobile learning can take different forms and has various benefits. These include content creation (e.g. recording audio and taking pictures) and sharing (Wing and Khe 2009). It also facilitates the active contribution of learners through their meaningful engagement in the learning process, collaboration, and field trips for real-world learning (Gikas and Grant 2013; Heflin, Shewmaker, and Nguyen 2017; Pimmer, Mateescu, and Gröhbiel 2016; Sung, Chang, and Liu 2016, Sung et al. 2019; Vázquez-Cano 2014). As such, mobile learning has the potential to address the limitations of learning approaches confined in classrooms and to connect learning to the outside world (Ekanayake and Wishart 2014).

Depending on the purpose and type of activities, mobile learning can be related to different theoretical underpinnings. For instance, Pimmer, Mateescu, and Gröhbiel (2016) describe the use of mobile phones "to test vocabulary" as an "instructionist sense of learning", while describing their use "to create video materials", as a "constructionist approach" (p.491). A study by Zahn et al. (2014) shows that the use of learner-generated videos helped learners to gain "new and more complex knowledge" (p.618). This is relevant to STC because understanding complexity is a key component of the competence.

Parsons et al. (2016) note that in their current technological advancement, mobile devices facilitate learning through several activities including "taking photos, making videos, sound recording, using QR codes, using augmented reality, using virtual reality, using sensors, using location sensing and collaborative messaging" (p.46). Isaacs et al. (2019) discuss several ways in which mobile technologies enhance learning. These include facilitating "access to…, reference materials, experts/mentors, other learners…, on-demand learning, real-time communication and data sharing, situated learning…, promotion of active learning and a more personalised experience…, data capture, multimedia…., large and complex data sets collected from user information…, delivering content appropriate to the learner's goals, situation, and resources…" (p.2). One of the key features of mobile learning or other hand-held devices is that they are ubiquitous. Hence, mobile learning could take place anytime and anywhere. This feature facilitates self-determined learning, as discussed by Aguayo, Eames, and Cochrane (2020).

The merits of mobile learning discussed above are the key reasons for using this approach in our study. The other reason is the existence of 60 million mobile users in the context under study: Ethiopia (Ethio Telecom 2022). Despite the large number of mobile users in the country, so far mobile learning approach is not taken advantage of. The typical learning approach is based on paper-and-pencil note taking. This approach is discussed below.

2.3.4. Paper-and-pencil note taking

The paper-and-pencil approach is the standard approach in the Ethiopian higher education. Because of its wide application, exploring the relevance of paper-and-pencil approach in relation to pedagogies suggested for SCs has important implications. Additionally, this note taking method does have advantages in the learning process. According to Mueller and Oppenheimer (2016), studies that compared the conceptual understanding of students who took notes using laptops with those who used paper-and-pencil found out that the latter performed better. The authors state that the explanation for the better performance was that "handwriting is slower, pen and paper note-takers are not able to transcribe the content verbatim and are forced to selectively rephrase the material; doing so helps them process and understand the material more deeply and gain better conceptual mastery" (p.141). Stephens (2016) strengthens this argument that handwritten note taking involves the notetaker's purposeful selection, paraphrasing, and interpretation of the points they record as notes. The author further notes that paper-and-pencil note taking does not distract notetakers while indicating that digital note taking causes distraction. Another difference between the two note taking approaches relates to the ease of drawing diagrams and illustrations. In this regard, the paper-and-pencil approach is found to be more convenient (Luo et al. 2018; Stephens 2016). When it comes to searching specific parts of notes taken, the digital approach has an advantage over handwritten note taking (Stephens 2016).

The paper-and-pencil learning approach is dominant in the study context. Hence, this was considered an additional reason to explore whether and how this note taking approach can contribute to ESD.

Using multiple learning approaches is important as students learn in different ways. As discussed above, Lozano et al. (2019) and Segalàs, Mulder, and Ferrer-Balas (2012) suggest different learning approaches and recommend a combination of learning approaches to foster SCs. However, we have not come across any studies that implemented a combination of collaborative learning, mobile learning, paper-and-pencil note taking, and field trips in an authentic context to foster STC. Hence, this gap motivated us to explore the contributions of the combined use of the above learning approaches to fostering students' STC.

The following research questions guided our study:

1. To what extent does the use of a combined set of learning approaches, (i.e., collaborative learning, field trips, mobile learning/paper-and-pencil approach) enable fostering systems thinking competence?
2. How does the use of collaborative learning and field trips together with mobile phones compare to the use of these learning approaches with paper-and-pencil approaches in effectiveness in fostering systems thinking competence?

3. Methods

3.1. Design of the study

In this study, we used a pre-test–post-test exploratory experimental design guided by the interpretivist paradigm. Hence, our focus is not on each research variable, but on the interdependence among the variables and interpreting the findings in the specific context.

3.2. Participants

The participants were 36 graduating class Bachelor's students in the Department of Geography and Environmental Studies at Addis Ababa University, Ethiopia, enrolled for the course Environmental Studies and Sustainable Development. Of these, 16 were female and 20 were male. Their average age was 22 (Figure 1).

3.3. Ethics

We informed participants that participation was optional. They were informed that no grades or credits were attached to participation or non-participation. Also, no consequences were attached to participation in the mobile phone group or in the paper-and-pencil group. Participants were also informed that the participation would involve visiting a landfill, making street observations, interviewing people, collaborating with students, preparing a report, and attending a closing session. The participants were assured that the data they generated for this study would be kept anonymous and used only for a study intended for publication. The students who expressed interest were recruited and randomly assigned to the mobile group and paper-and-pencil group.They signed a consent form and provided their contact details. Also, we kept the anonymity of the people contacted by the participants of this study (workers in the WM and the household interviewees).

Permission to visit the Koshie landfill was secured from Addis Ababa City Solid Waste Management Agency. There are dangerous objects among the waste items, the landfill is not protected, and two years before the participants' visit, there was a landslide accident that claimed lives. Therefore, the safety of the participants was taken seriously. To understand the kinds of preparation required to protect the wellbeing of participants, the first author visited all the places that would be visited by the participants.

3.4. The experiential learning experience

The final product that participants had to deliver was a report on the strengths and weaknesses of the WMS (i.e. creation, collection, transportation, storage, recycling, or disposal) of Addis Ababa, and to suggest possible improvements to this system. This had to be done in relation to the environmental, social, and economic components of sustainable development. Participants were also instructed to identify interrelationships among the three components of sustainable development and relevant stakeholders in the WMS.

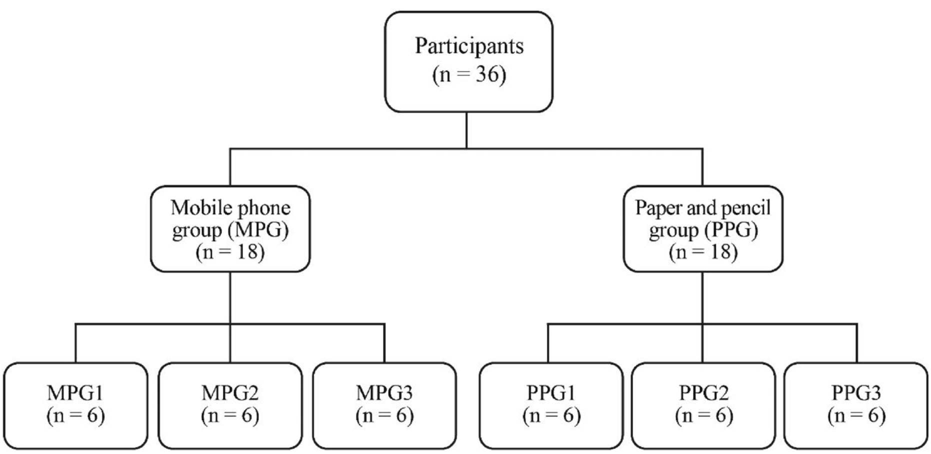


Figure 1. Groups and subgroups of participants.

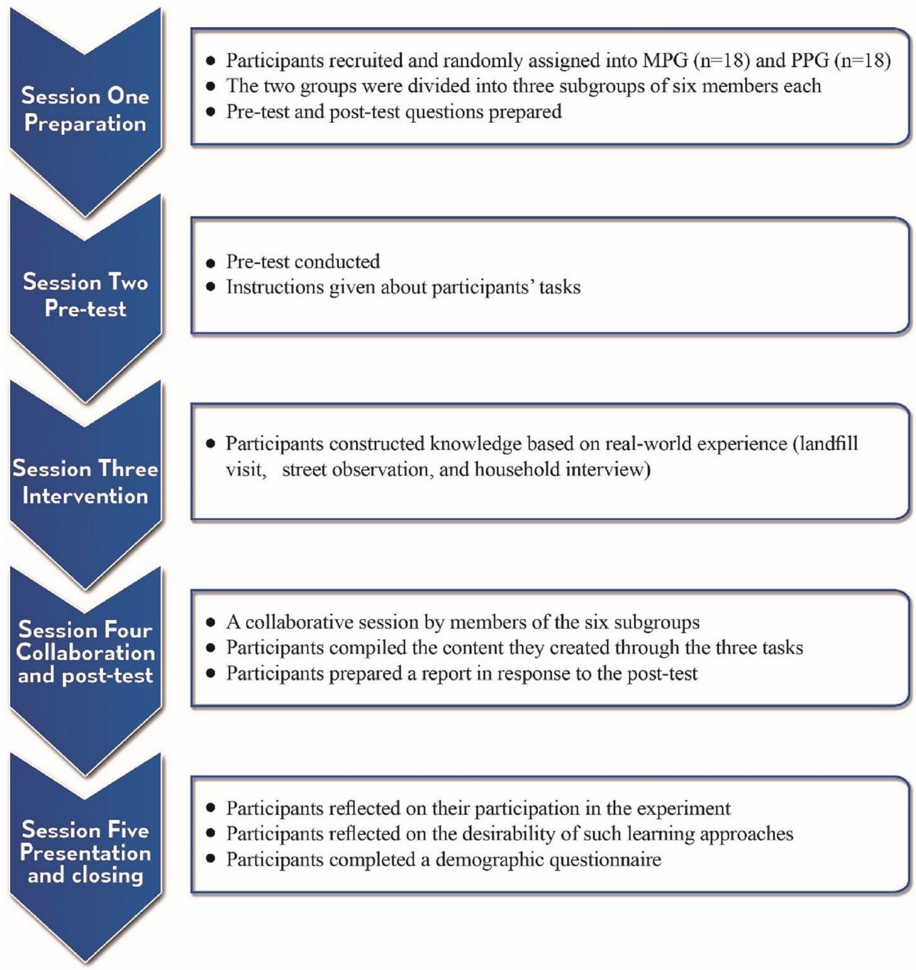


Figure 2. Procedural steps in the intervention.

Before the participants went to the field, they were given an orientation on how to safely and ethically undertake their tasks. Tips for recording videos and taking pictures with mobile phones were given to members of the MPG in order to prevent common technical issues. The procedural steps followed in the intervention are presented in (Figure 2).

3.5. Procedure

The study involved the following five sessions. The sessions, excluding preparations, took place from May to July 2019.

3.5.1. Session One – Preparation

Participants were randomly assigned into MPG ($n = 18$) and PPG ($n = 18$). Next, both groups were randomly subdivided into three subgroups of six members each. This was done to facilitate the collaboration of the group members and the three tasks. That is, from each subgroup of six members, two members visited a landfill, two engaged in street observation, and two in household interviews. In the preparation phase, we prepared questions for pre-test and post-test. See Section 3.6.1 for an explanation of the contents and instructions of the pre-test and post-test.

3.5.2. Session Two – Pre-test

All participants ($n = 36$) were given a pre-test. The participants did the test in their separate subgroups. In this session, we also gave participants specific instructions regarding each of the tasks (i.e. landfill visit, household interview, and street observation). The pre- and post-test required participants to write down their answers to the questions. During the pre-test and post-test, there was no word or time limit. The longest a group took during the pre-test was 40 min.

3.5.3. Session Three – Intervention

All the activities in the learning sessions were intended to enhance the STC of participants. The landfill visits, household interviews, and street observations were used as different types of field trips. These activities were intended to expose participants to the real-world and help them to identify elements of the WMS; appreciate complex interrelationships and the stakeholders in the WM context; and realize the impacts of the interrelationships. For example, in the household interviews, these interrelationships were intended to be understood from real-world WM processes as experienced and described by residents.

The collaborative session was intended to facilitate learning by bringing together the content participants created in the different activities and share each other's different perspectives about the content. The collaboration was intended for participants to make sense of the information and the different spatial levels to which the identified interrelationships are relevant. As such, the combined learning activities were intended to facilitate fostering the STC of participants.

Each participant had to engage in one of the three tasks, in a collaborative session, and the closing session. The decision regarding who would participate in one of the three tasks (i.e. landfill visit, household interview, and street observation) was made by the subgroup members themselves.

Following the instructions they were given, the members of the MPG used mobile phones while the members of the PPG used paper-and-pencil to create content based on their participation in the three tasks described below. The members of the MPG took pictures and recorded videos, and the member of the PPG took notes of activities related to the social, environmental, and economic aspects of the WMS. Furthermore, the participants discussed these issues with different stakeholders they met.

The intervention, including the mobile learning, was entirely offline. This was intended to make participants responsible for their learning and help them develop systems thinking, by constructing knowledge themselves based on their first-hand experience in the real-world. Offline approaches prevented the possibility of depending too much on others' works available on the Internet.

As the intervention in this study was conducted to facilitate self-determined learning, the participants were informed that they were free to decide what content would be relevant to WM practices that have implications on the three dimensions of sustainable development. Participants were not instructed to take notes or create multimedia content in any specific way. For instance, the members of the PPG were free to take notes in any way they considered was appropriate. All members of the PPG took notes in a form of text. In addition to text notes, some groups used tables to organize their notes.

Members of the MPG created multimedia content in form of pictures and videos of any activity, stakeholder, or place they believed was relevant to their tasks.

Landfill visit

The participants who visited the Koshie landfill observed (informal) garbage pickers, the waste disposal process, nearby residents, relationships among the garbage pickers, types of waste on the landfill, talked to the garbage pickers, and created content.

Street observation

The participants went to selected streets in Addis Ababa to observe different WM activities related to their tasks to create content based on the instructions.

Participants visiting Koshie landfill, Addis Ababa

Household interview

The participants went to six neighborhoods of Addis Ababa and interviewed 24 households. The neighborhoods were purposely selected to include residents of diverse economic statuses. The specific households were selected by participants based on their availability. Participants were provided only with general instructions. They were free to decided what questions to ask, and what topics to discuss. The interviews focused on the WM process, from creation to disposal, and the implications of these on the three dimensions of sustainability.

3.5.4. *Session Four – A collaborative session and post-test*

The members of the six subgroups came together and repeatedly watched the videos they made, viewed the pictures, and read the notes they took. In this collaborative session, participants were instructed to compile and make sense of the content they had created throughout the three tasks. They did the same and prepared a report, the final product of their participation, in a form of responses to the post-test. The longest a group took to complete the post-test was nearly two hours.

A truck loaded with waste. Picture taken by a street observation group.

3.5.5. Session Five – Presentation and closing

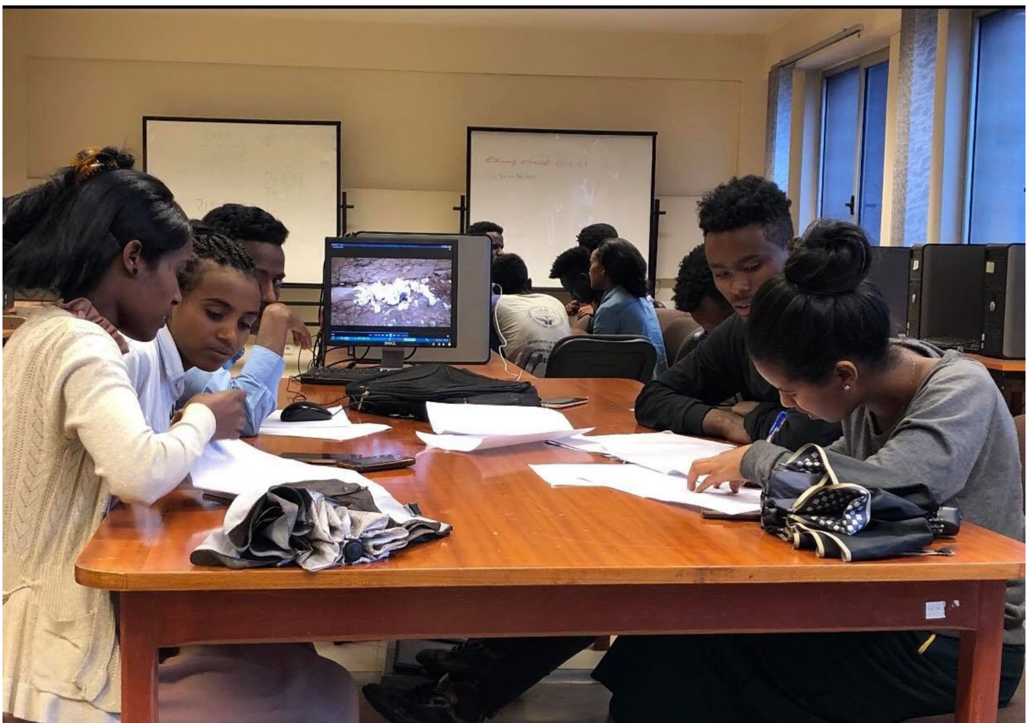
During the closing session, each group shared their opinion regarding how they found the experience and what they learned from participating in the study. In this session, participants discussed the desirability of such learning approaches in their Bachelor's program (Geography and Environmental Studies) and completed a demographic questionnaire.

3.6. Pre-test, post-test, and analysis of participants' reports

3.6.1. Pre-test and post-test questions

We used the following two questions for the pre-test and post-test.

1. Identify strengths and weaknesses in the waste management system and suggest possible solutions to improve the system.
2. Identify interrelationships among the dimensions of sustainable development and stakeholders in the waste management system.
3. Do both questions 1 and 2 from the point of view of the three dimensions of sustainable development.


Members of a group in a collaborative session.

3.6.2. Analysis

The analysis of participants' reports started with operationalizing STC in terms of its three key components. Next, participants' performance in these components was evaluated following the steps explained in points A–C below.

a. Ability to identify the dimensions of a system – the ability to identify social, environmental, and economic dimensions of sustainable development was evaluated by using indicators for each of the three dimensions (see supplementary material/Appendix A). Before the intervention, we prepared these indicators from sources in the literature (Ajmal et al. 2018; Dempsey et al. 2011; Kates, Parris, and Leiserowitz 2005; Mahdei et al. 2015; UN DESA 2007). To accept a point by participants as a social dimension of sustainable development, it had to be related to one of the indicators of the social dimension mentioned in Appendix A and to the WMS. The same was considered for the environmental and economic dimensions. For instance, a group identified a 'lack of sense of belongingness' as an environmental issue. According to the guidelines, this point is a social dimension issue. Therefore, the point was not considered valid.

b. Ability to appreciate the complex nature of a system – this was assessed as the ability to identify interrelationships among the dimensions and the ability to recognize relevant stakeholders in the WMS. Here, the identified interrelationships were also analyzed on whether they were between two dimensions or among all three dimensions of sustainable development. We considered interrelationships that involved the three dimensions to be higher-level interrelationships, as they show a better understanding of system complexity. Quotes from participants' reports exemplifying different levels of interrelationships are given in Section 4.2.1.
c. Ability to analyze a system across different levels/spatial scales (local, national, and global). This was evaluated based on the levels the participants' reports addressed. That is, whether the identified points concerned only sub-cities in Addis Ababa, Addis Ababa as a whole, Ethiopia, or a global scale. To determine which spatial scale a point by a group concerns, we focused on relevant clues. For instance, if a group made a point regarding the need for a government policy with a national significance, we considered this to be on the national/Ethiopian scale. If a group suggested that '…waste containers in a sub city should be collected timely…" we considered this point as sub city level issue.

To make the evaluation of the participants' reports as transparent and objective as possible, the indicators explained above were prepared by the first author and used after being reviewed and improved by two of the co-authors. Furthermore, after the first author graded all the reports of the two groups, two of the co-authors reviewed the analysis against the aforementioned indicators.

4. Results

In this section, the findings of the study regarding the three defining components of STC are presented. These components are the ability to identify dimensions of a system, the ability to appreciate the complexity of a system, and the ability to analyze elements of a system across spatial scales. In this study, these abilities are contextualized in the WMS and related to the social, environmental, and economic dimensions of sustainable development.

4.1. Ability to identify elements of a system

In their pre-intervention test, members of both the PPG and the MPG were able to identify elements of the WMS that related to the social, environmental, and economic dimensions of sustainable development. This could be because of their background in Geography and Environmental Studies. The number of elements identified before and after the intervention by both groups for each of the three dimensions is almost comparable. Details of the findings are presented in Table 1.

Both groups were able to identify more points related to the three dimensions of sustainable development after the intervention. Below are three examples of the points identified by the members of the MPG and the PPG for the three dimensions of sustainable development.

Table 1. Number of social, environmental, and economic elements of the WMS identified by the two groups before and after the intervention.

Sustainable development dimension	Mobile phone group pre-intervention	Mobile phone group post-intervention	Paper-and-pencil group pre-intervention	Paper-and-pencil group post-intervention
Economic	9	17	11	15
Social	9	21	7	20
Environmental	13	18	10	16
Total dimensions	31	56	28	51

Table 2. Number of stakeholders and interrelationships among the social, environmental, and economic dimensions of the WMS identified by the two groups before and after the intervention.

	Mobile phone group Pre-intervention	Mobile phone group Post-intervention	Paper-and-pencil group Pre-intervention	Paper-and-pencil group Post-intervention
Interrelationships	0	9	0	7
Stakeholders	5	13	5	5

1. *Social: Poorly managed landfill pollutes the air and people are forced to leave their residences.*
2. *Economic: Waste is being used as a source of energy.*
3. *Environmental: Biodiversity can be negatively affected because of river contamination.*

4.2. Ability to appreciate the complex nature of a system

This aspect of systems thinking consists of the two components presented in Sections 4.2.1 and 4.2.2. One is the ability to identify interrelationships among the dimensions of sustainable development (as specified in Appendix A). The other is the ability to recognize relevant stakeholders that affect and are affected by the system. Here, participants' reports were assessed to see whether they identified interrelationships. The interrelationships were also examined further to check whether they addressed two or all the three dimensions.

4.2.1. Ability to identify interrelationships and stakeholders

Participants identified strengths, weaknesses, and suggested solutions regarding the WMS in Addis Ababa about the three dimensions of sustainable development.

Table 2 shows that in the pre-intervention test, neither of the two groups were able to identify any interrelationships between the elements of sustainable development. In the post-intervention, however, both groups were able to identify interrelationships. Regarding the number and complexity of the identified interrelationships, members of the MPG performed better than their PPG counterparts. A detailed explanation of this is given in the discussion section. Below is an example of an identified interrelationship from each group.

4.2.1.1. Example by the MPG.

The waste management system creates jobs (Economic). The people who get the jobs manage the waste and contribute to a clean environment (Environmental). A clean environment enhances motivation to work (Social).

4.2.1.2. Example by the PPG.

Poor waste management causes pollution-related problems (Environmental). This displaces people (Social). Displaced people move to new locations. This increases pressure on the environment (Environmental).

4.2.2. Identification of stakeholders

Table 2 shows that before and after the intervention, the MPG and PPG identified stakeholders (i.e. people and organizations whose actions affect others and are affected by others' actions) in the WMS. Members of the MPG identified more stakeholders after the intervention. Examples of the stakeholders identified by both groups include WM workers, residents, and the government. The additional stakeholders identified by members of the MPG include future generations, factory representatives, and garbage collectors' associations.

The findings related to stakeholder identification are interpreted in the discussion section.

4.3. Ability to analyze a system across different scales

The participants' reports were also examined to see the spatial scales (i.e. sub-cities in Addis Ababa, the whole Addis Ababa city, Ethiopia, or global) addressed by the points they identified as social, environmental, and economic elements of the WMS. Accordingly, with the increase in the number of the three elements identified by both groups, the variety of spatial scales also increased after the intervention (Table 3).

Below are examples of quotes, one from each group about the points they made concerning Ethiopian and global scales.

- *Ethiopia – The WMS facilitates for different government agencies to work together. (PPG)*
- *Global – Proper waste management contributes to the prevention of climate change. (MPG)*

5. Discussion

In this section, we discuss the main findings regarding participants' ability to identify elements of a system, ability to appreciate the complex nature of a system, and ability to see implications of interrelationships among the elements on different spatial scales.

5.1. Ability to identify elements of a system

Participants' STC was assessed in terms of the core components of the competence. The first of these is the ability to identify elements of a system. In this regard, before the intervention, members of both the MPG the PPG were able to identify elements of the WMS regarding the social, environmental, and economic dimensions of sustainable development. This could be because of their background as final year bachelor students of the Geography and Environmental Studies program. In addition, it is important to note that all participants were motivated as they got voluntarily involved in this study. Demssie et al. (2020) indicated that the higher

Table 3. Dimensions of sustainable development identified by participants categorized by spatial scale.

	Social, environmental, and economic elements of the waste management system		
	Level (local to global)	Pre-intervention	Post-intervention
Mobile phone group	Sub city	13	15
	Addis Ababa city	15	35
	Ethiopian	0	2
	Global	3	4
	Total	31	56
Paper-pencil group	Sub city	5	12
	Addis Ababa city	21	38
	Ethiopian	1	0
	Global	1	1
	Total	28	51

education system in Ethiopia is dominated by knowledge-oriented approaches. Such approaches might be adequate in enabling participants to identify the dimensions of sustainable development. The results in this study suggest that the intervention enabled both groups to identify more elements of the WMS than they did in the pre-intervention test. Compared to the PPG, the MPG performed better in identifying elements of the WMS.

5.2. Ability to appreciate the complexity of a system

The other key component of systems thinking – i.e. the ability to appreciate the complexity of a system – was operationalized as the ability to identify interrelationships among elements of a system and the ability to recognize stakeholders in the WMS. Interrelationships and interdependence could be among different systems/dimensions, or "between humans and non-humans" (Molderez and Ceulemans 2018). According to Nguyen, Graham, Ross, Maani, and Bosch (2012), "systems thinking skills are important in helping younger students understand many complex relationships that exist in the natural and social world" (p.15). Therefore, students developing STC are equipping themselves with a crucial competence to contribute to a more sustainable future. This is so because they understand interrelationships, the potential impacts of an action on another system, the environment, or people. This understanding could lead to informed and responsible decisions, and actions related to sustainability (Demssie et al. 2019). In the context of the environment, Kollmuss and Agyeman (2002) argue that a lack of understanding of the complex nature of systems "prevents us from a deeper understanding of the consequences of natural destruction." (p.254)

The ability to appreciate complex interrelationships of system elements is a key aspect of STC. For instance, York et al. (2019) note that "systems thinking is a holistic approach for examining complex, real-world systems, in which the focus is not on the individual components of the system but on the dynamic interrelationships between the components" (p.2,742).

In this study, none of the participants could identify any interrelationship before the intervention. As observed from these results, among the three key components of STC, the ability to appreciate the complexity of a system seems to be the most difficult to foster. Remington-Doucette et al. (2013) support this observation as they note that "… systems thinking is not intuitive or innate. When thinking about a problem, we do not naturally think about all things connected to it and their interrelationships." Hence, the authors emphasize the need to focus on the ability to appreciate interrelationships. (p.410)

Unlike in the identification of elements of a system, it does not seem that the previous knowledge of our participants gained from knowledge-oriented approaches helped them in the appreciation of interrelationships among the dimensions they identified. Before the intervention, the participants considered the dimensions as isolated elements. Neither of the two groups could recognize any interrelationship during the pre-intervention test. They were, however, able to identify a few stakeholders in the WMS.

Could less effectiveness in revealing interconnections be one of the limitations of knowledge-oriented and classroom-bound learning approaches? Future studies may be interested in exploring this.

After the intervention that facilitated meaningful engagement through collaboration in authentic contexts, both groups' STC was enhanced, in particular, their ability to appreciate system complexity. This could be because the field trips, collaboration, and content creation helped participants to appreciate the complex interrelationships in the WMS. For instance, if we take one of the components of the intervention – i.e. collaboration among participants – it was among a small group of six people that consisted of participants who created content from a landfill visit, household interviews, and street observations. Hence, the intervention allowed participants to learn about the WMS from the different perspectives of their group members. These collaborative activities facilitate understanding of a system's complexity through exchanging diverse observations and ideas. As Scheer and Plattner (2012) noted, team-based learning approaches facilitate learning complex topics as team members contribute diverse ideas or solutions to a problem.

As the data and examples in Section 4.2.1 indicate, after the intervention, members of both the MPG and the PPG identified interrelationships and more stakeholders than they did before the intervention. As such, participants were able to identify possible ways in which decisions or actions in one of the dimensions of sustainable development could affect other dimensions.

Our results about participants' appreciation of system complexity agree with the findings of previous studies that when learners collaborate and get exposed to the real-world, they appreciate complexity of systems. Sherman and Burns (2015) noted that when learning using collaborative approaches, "… students not only acquire information about specific sustainability-related content, but they also develop or enhance their systems-thinking skills as they explore interconnections between topics…" (p.232). Kay and Foster (1999) support this claim by indicating that utilizing real-world contexts and issues allows learners "… to experience irreducible complexity first-hand." (p.4)

Demssie et al. (2020) conducted a study in the same context as that of the current one. The authors indicated that meaningfully relating education to the real-world is crucial if SCs are to be fostered.

Cotton and Winter (2010) note that for sustainability education, in general, focusing on "real issues" instead of "knowledge and a content orientation" is crucial (p.5). The relevance of collaborative and real-world learning experiences as explained above suggest that the use of these learning approaches could be among reasons for the improvement of the STS of all our participants.

5.2.1. Difference between the MPG and PPG in appreciating the complexity of systems

The major difference in the performance of the two groups was the ability to appreciate the complexity of a system. In this regard, it seems that the MPG got more out of the intervention. This difference was twofold: first, in the number of identified interrelationships and stakeholders, and second, in the number of the high-level interrelationships they identified. We considered interrelationships that involve all the three (i.e. environmental, social, and economic) dimensions of sustainable development to be high-level interrelationships.

After the intervention, members of the MPG identified more interrelationships than their PPG counterparts. The MPG was also able to identify twice the number of high-level interrelationships the PPG identified. The better learning result of participants using mobile phones to create multimedia content in understanding complexity is consistent with findings of earlier studies. For instance, Zahn et al. (2014) conducted a quasi-experimental study into the effect of learner-generated videos on causes of obesity and stigmatization. They had an experimental group that created YouTube videos and a "control group that read a newspaper article on the topic". They found that, unlike the participants who read a newspaper article, the students who created videos gained "new and more complex knowledge" (p.618). Another reason for the better performance of the MPG could be because students are usually interested in using mobile phones (Pimmer, Mateescu, and Gröhbiel 2016).

Compared to information kept on paper by the PPG, using video was an opportunity for the MPG to keep the authenticity of what participants observed in the field. The participants in the PPG had to remember the reality (i.e. in the landfill, the streets, and households), based on the notes they took, and interpret that based on their understanding of those notes. This may leave room for different interpretations. On the other hand, the members of the MPG watched the videos they recorded and viewed the pictures they took. This could give them an advantage in readily relating to the authentic context. The application of mobile learning, as used in our study – i.e. through learner-generated videos and pictures – enables authentic learning (Gikas and Grant 2013). Kearney and Schuck (2006) conclude that "student generated digital video projects can be used to develop authentic learning" (p.206). They also note that opportunities for collaboration contribute to learners' motivation and authentic learning. The benefit of the camera function of learning with mobile phones related to learners' motivation has been indicated by several studies (Ekanayake and Wishart 2014; Molnar 2017; Pimmer, Mateescu, and Gröhbiel 2016).

The combination of learning approaches used in our study facilitated for learners to play an active role in deciding what content is important and what deserves to be captured as multimedia content or notes on paper, to discuss it in groups, and to organize the content into a report. Mobile learning used to make a learner-generated videos enables constructivist learning through the meaningful engagement of learners (Pimmer, Mateescu, and Gröhbiel 2016). Mayer (2003) explains how learning happens when learners are actively engaged as follows.

> … learning occurs when learners engage in active cognitive processing including paying attention to relevant incoming words and pictures, mentally organizing them into coherent verbal and pictorial representations, and mentally integrating verbal and pictorial representations with each other and with prior knowledge (p.129).

5.3. Ability to analyze a system across different scales

The other feature of STC we looked at in the reports of participants was their ability to recognize different scales (from local to global) of the elements of a system. Accordingly, the results of the analysis showed that participants identified different issues with implications for sub-cities in Addis Ababa, the whole city, Ethiopia, and global scales. It seems that the intervention enabled the participants to recognize more elements of sustainable development. With this increase in the number of elements identified by participants of both groups, there was an overall increase in the number of issues that concern different levels. While most of the issues identified after the intervention by both groups concern Addis Ababa city, there were also differences between the two groups. For instance, members of the MPG identified more sub city, Ethiopian, and global issues than their PPG counterparts. On the other hand, members of the PPG identified more Addis Ababa city issues than the MPG members. This ability to see elements of a system concerning different scales could help a person to appreciate the possible impacts of an action somewhere on people or the environment somewhere else.

Members of the MPG identified more elements related to the three dimensions of sustainable development. Similarly, they were able to identify more issues related to three of the four scales. As such, it seems that mobile learning facilitated authentic learning (Gikas and Grant 2013; Kearney and Schuck 2006) for this group.

As indicated earlier, the camera function of mobile phones was used in this study to facilitate the learning of participants following their field visits in the real-world. The offline nature of the interventions facilitated constructivist learning by providing the participants with the opportunity to meaningfully engage in collaboration and knowledge construction. While the lack of opportunities to learn from online resources can be considered a limitation of offline mobile learning, this same feature can be seen as strength. That is, unlike learning involving connection to the Internet, offline learning does not allow learners to copy from or depend too much on others' works. Additionally, no internet-related costs are involved. The advantages of the offline approach could be especially relevant to resource-constrained environments, such as the context under study. Furthermore, telecom services are a government monopoly in Ethiopia. Additionally, the government in Ethiopia – and some other countries – limit or shut down the Internet whenever there is a political problem (Rydzak et al., 2020).

Scheer and Plattner (2012) stated that the design of competence-based constructivist learning needs “to be constructed, situated in context, self-regulated by the learner and collaborative” (p.10). All these conditions were fulfilled by the combination of learning approaches used in this study. The interventions in this study were conducted in a complex real-world context of WMS. The participants were active in knowledge co-construction through collaboration and other learning approaches. Among others, these features of the interventions enabled the use of authentic learning environments, as discussed by Herrington and Oliver (2014). As Narayan and Herrington (2014) indicated the key features of heutagogical learning approaches include freedom to create content and collaborate with peers and teachers. Guided by these features of heutagogy, the interventions in this study facilitated collaboration of participants to create and make sense of relevant content.

The different learning approaches in the intervention complemented each other. As Mintz and Tal (2018) and Pimmer, Mateescu, and Gröhbiel (2016) indicated, collaboration, mobile learning, and field trips promote learner engagement and motivation. The field trips facilitate collaboration among the participants. The collaborative session in our study allowed participants to learn from the combination of the three activities (landfill visit, street observation, and household interviews). Mobile learning facilitates field trips for real-world learning (Heflin, Shewmaker, and Nguyen 2017; Pimmer, Mateescu, and Gröhbiel 2016; Sung, Chang, and Liu 2016, Sung et al. 2019). Dale et al. (2020) note that novel environments and experiences, such as the ones provided by field trips, promote curiosity and collaboration. The authors explain that learners benefit from such environments by “getting away from the familiar…” and as they appreciate the “contrast between what a learner thinks they know and what they are experiencing.” (p.615)

Our findings suggest that the interventions helped participants to understand the processes, stakeholders, limitations, strengths, and weaknesses of the WMS. Furthermore, some of the experiences seem to have affected the attitudes of participants. This is seen from participants’ descriptions of their conversations with informal garbage pickers, understanding the informal workers’ socioeconomic challenges and needs. For example, the members of a sub-group wrote in their report

> it is really sad to see that the informal garbage collectors are working in difficult and risky environments. Their health is compromised but the government is not supporting them. This needs to be addressed by the contributions of concerned stakeholders.

The combination of relevant knowledge and positive attitude the participants demonstrated in their reports seems promising to encourage them to take sustainability-friendly decisions and actions as individual citizens or professionals. This observation agrees with previous studies. For instance, Shrivastava et al. (2012) note that in the context of sustainability, “it is passion and emotion (and not cognitive understanding alone) that lies at the core of behavioural changes” (p.27).

From the findings of this study, it appears that the interventions intended to enhance the STC of participants helped them to appreciate the need to take actions to move toward a more sustainable future. Accordingly, the participants were able to identify specific actions required to improve the WMS. The actions suggested by participants involve several stakeholders and are the results of holistic thinking. Below are some of the actions they recommended.

> Establish a new landfill facility in a different location than the current (and only) one in the city
>
> Put in place mechanisms to prevent river contamination
>
> Implement human population planning to balance the number of people and WM services

Among others, the participants’ ability to come up with the recommendation of concrete actions suggests the possible contributions of STC to sustainability-oriented actions.

5.4. Limitations of the study and possible lines of future research

The objective of this study was to explore the contributions of a combination of learning approaches in an authentic context in fostering STC, which is one of the key SCs. The results indicate that the intervention, a combination of learning approaches and learning environments, helped participants of both groups to enhance their STC. However, the results did not show which specific learning approach contributed more (or less) than others. Also, because of the nature of the study, it is not clear which specific outcomes (e.g. identifying elements of a system, appreciation of complex interrelationships, or analyzing a system across spatial scales) were the results of which specific intervention. Given the study design, we can only say that the intervention as a combined package shows a promising result in fostering the STC of participants.

The other limitation of the study relates to the specific types of mobile learning activities we used. In this study, mobile learning activities were limited to multimedia content creation. Though these learning activities have important contributions in learning STC, students' learning experiences could be further enhanced if more functions of mobile technologies were used. In other words, the exclusion of more recent affordances of mobile learning (such as virtual reality and augmented reality) may have limited the experiences of participants. All learning activities used in the intervention in this study were used offline. Despite the advantages of the offline nature of mobile learning, the use of this approach may have limited, among others, the real-time collaboration of participants.

Future studies should ideally explore the relative importance of learning approaches used in a combined fashion. Further exploring the underlying mechanisms that make the interventions effective is also recommended. To complement one of the limitations of our study, we suggest future studies that combine multiple learning approaches with advanced affordances of mobile learning. This could include the use of internet-connected mobile learning activities with proper planning to limit the possibility of depending too much on online content.

6. Conclusion

To enhance learners' STC, the study simultaneously used a combination of multiple learning approaches. Usually, in theory, studies recommend certain pedagogies to foster SCs without implementing multiple pedagogies. This study took the sustainability pedagogies-related discourse a step further by practically using a set of learning approaches in a real-world environment. The results suggest that the combined use of field trips and collaborative learning helped in fostering the STC of both the mobile phone group and the paper-and-pencil group. The most notable difference between the two groups was the better performance of the mobile group in appreciating system complexity. Mobile learning facilitates the enhancement of STC by allowing learners to actively engage in the learning process and exchange ideas among collaborating participants. In this study, the opportunity for a meaningful engagement was taken to a level where participants were free to decide what learning content to create. This facilitated the use of social constructivism and related heutagogical learning approaches that promote meaningful engagement of learners in knowledge co-construction.

Theoretically, the findings suggest that ESD discourses should focus on combinations of multiple learning approaches and real-world environments to enhance STC.

Hence, designing courses involving SCs, particularly STC could benefit from meaningfully engaging learners in the learning process. This may include providing them with only overall guidance and allowing them to decide the content of knowledge they are supposed to create, facilitating their collaboration with peers, and contextualizing learning in authentic/real-world cases that involve complex interrelationships. This allows learners to see interrelationships among social, environmental, and economic systems, and appreciate the complexity of sustainability-related issues.

Our study contributes to the social constructivist learning literature in the context of sustainability competence development. The findings indicate that the STC of learners is enhanced when learner-generated content is created by allowing students to meaningfully engage, freely decide the content they want to create, collaboratively make sense of the content, organize it, and present it. The major contribution of this study is related to the real-world context and the combined use of multiple learning approaches to foster one of the SCs, systems thinking.

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