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Using Minecraft as an educational tool for supporting collaboration as a 21st century skill

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ABSTRACT

Collaboration is an important 21st century skill, and there is an increasing interest in computer-supported collaborative learning (CSCL) in teaching and learning practices regarding the necessary knowledge and skills for 21st century learners. However, solutions are still lacking concerning how to enable learners to collaborate when working with a specific subject. This study developed and tested a learning design using Minecraft as an educational tool in math classes in higher education over a 2-year period. The research questions are: 1) How can Minecraft be used as an educational tool for learning subject-specific skills, and what are the implications for the development of 21st century skills? 2) How can social network analysis (SNA) and interaction analysis (IA) be used as a research methodology for analyzing the use of Minecraft as an educational tool for learning subject-specific skills? Data was analyzed using a mixed-methods approach, in which both a quantitative perspective through SNA and a qualitative perspective through IA were employed. Findings of the study: 1) suggested that using Minecraft for learning a subject-specific skill triggered collaborative learning processes, 2) facilitated the development of 21st century skills in math classes, and 3) combining SNA and IA as a research methodology for analyzing the use of Minecraft for learning subject-specific skills. These findings serve as a stepping stone for teachers and researchers to create learning designs that use a digital educational tool to facilitate collaborative learning and advance the literature on CSCL and educational practice.

1. Introduction

Education plays an essential role in preparing students for the future, and 21st century skills are a set of abilities critical for students to develop in order to succeed in the information age [1]. Although skills considered as 21st century skills and their definitions vary across different frameworks, collaboration, communication, information and communication technology literacy, creativity, critical thinking, and problem-solving are some of the most important skills [2]. According to several researchers, collaboration is a crucial 21st century skill that all students should have access to and learn before entering the labor market [2–9]. Recent research suggestsed that 21st century skills—particularly for education and the workplace in the current economy—should entail an explicit focus on technological skills [8,10]. In line with this, van Laar et al. [8] raised the dilemma that although the literature on 21st century skills emphasized a broad spectrum of skills, only a few studies explicitly integrate digital aspects. However, several researchers emphasized that using educational technology to develop 21st century skills among students is an emerging area of research that needs further investigation [11–13]. This points to a need for more research exploring the use of educational tools for supporting the development of 21st century skills. This article aims to address this gap by adding to the current literature with a design-based intervention research study where Minecraft has been used as an educational tool for solving math tasks in an educational context within groups of students.

1.1. Computer-supported collaborative learning (CSCL) in education

The present study frames collaborative learning within the research field of CSCL as the study entails both collaborative and technological perspectives, in line with the argument outlined above. There is an increasing interest in teaching and learning practices regarding the role of CSCL in important skill development among students [9]. CSCL is a branch of learning sciences that focuses on how people collaborate using technological tools as mediating artifacts [14]. The widespread use of digital technology has created opportunities for social interactions, both distributed and co-located, and numerous applications have been designed to support collaborative learning. This led to the rise of the

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interdisciplinary research field of CSCL [15]. The central elements in CSCL are the premise that networked computers can bring learners together in new ways and that shared digital environments can foster interactions that develop learners' new understanding in their areas of learning [14]. The central concept in CSCL is meaning-making, a collaborative construction of shared meaning in a joint activity where interactions are mediated by technological artifacts [14]. An emerging trend in the CSCL literature is investigating CSCL in the context of education, more precisely how teaching and learning can be supported using educational technology [16–20]. Limited research exists on how collaboration can be supported using technological tools. Therefore, to address this gap, the study focused on how a specific technological tool can be used in an educational context to facilitate collaborative learning.

1.2. Minecraft as an educational tool

This study explores how student teachers can work in small groups to solve math tasks using Minecraft[1] as an educational tool. Minecraft is a commercial off-the-shelf block-based sandbox game, often compared to digital Lego, which involves constructing different buildings and figures. It is an open-world multiplayer game, suitable to encourage teamwork and non-linear gameplay [21]. It is among the most widely sold games of all time and is particularly popular among children and young adults. Here, we utilized Minecraft Education Edition, an alternative version of the game developed specifically for use in educational settings. This version offers features specially designed for educators, such as easy server setup, students' ease of access, and teacher control with various options for facilitation. Teachers can control what goes on in the game and can make sure that the students are in the same community by, for example, setting up and turning off violence and various characters that can damage the game's avatars, turning off chat, or turning off the possibility that the game's characters may be damaged by falls, fire, and drowning. Minecraft is increasingly being used in educational contexts worldwide. Several studies have explored its use in educational contexts [22–27]. Other studies have scrutinized how Minecraft can be used for students' knowledge creation in maths [28], sciences [29], arts [30], languages [31], and social studies [32]. Previous studies have explored how Minecraft can support the development of spatial abilities in science, technology, engineering, and math education [33] or information literacy [34]. Nonetheless, further research regarding its implications for improving classroom teaching is warranted.

1.3. Studies of social network analysis in CSCL research

A growing body of research in the CSCL context uses social network analysis (SNA) to analyze social relationships. According to Dado and Bodemer [35], SNA is a promising research method for analyzing relational ties in CSCL activities where learners collaborate to achieve a common goal with the help of computers mediating the collaborative processes [35,36]. The concept of SNA has received increasing attention in recent years due to the appealing focus of SNA by visualizing relationships among entities and the patterns and implications of these relationships [37]. Some studies have used SNA to analyze data in an educational context [38–40]. Other studies have explored the use of SNA as part of a mixed-methods approach for analyzing participating networks during collaborative learning processes [32,41]. Furthermore, other studies have used SNA for analyzing data in a CSCL context [32, 42–44]. Roschelle et al. [45] suggested the need for more research regarding the use of CSCL tools in actual educational practice outside the context of research investigations. In this study, SNA was used to study the social interactions and collaborations among student teachers to solve math tasks using Minecraft.

1.4. Research questions and significance of study

A better understanding of how learners use Minecraft as an educational tool when working in groups to learn a subject-specific skill (math) can help us evaluate the impact of using educational tools as part of a learning design and the implications for developing 21st century skills. This may help us guide future efforts to enhance CSCL environments and interventions, enhance the use of educational tools in education, and enable learners to develop 21st century skills. The present study addresses the following research questions:

1) How can Minecraft be used as an educational tool for learning subject-specific skills and what are the implications for the development of 21st century skills?
2) How can social network analysis (SNA) and interaction analysis (IA) be used as a research methodology for analyzing the use of Minecraft as an educational tool for learning subject-specific skills?

The findings of this study can provide additional knowledge regarding the use of educational tools in education in general, thus enabling collaborations with a positive impact on the development of 21st century skills. The learning design developed and examined in this study can encourage teachers and researchers to use such educational tools as part of their teaching to support students to learn subject-specific skills and simultaneously enhance their collaboration skills and development of 21st century skills.

2. Methods

2.1. Research model and procedure

A series of classroom interventions were developed and tested in which students in their second year of teacher education were given math tasks to solve in groups using Minecraft. Overall, two interventions were tested over 2 years. Approximately 400 students divided into 10 classes participated in the interventions. The students participated in the project for 1 year (1 year represents 1 intervention). The data were derived from the second intervention of the project, i.e., five classes of student teachers. Each class consisted of approximately 40 students, and the class duration was 90 min. Based on the evaluation of and feedback from each intervention, the learning design and intervention were modified and refined. Our approach is in line with a design-based research process, an educational research tradition focused on the development of pedagogical practice and theory [46]. To ensure that the student teachers benefit from the learning design, competence goals from the Norwegian curriculum for elementary school students in mathematics when creating the math task were adopted. We designed the following specific learning goal for our intervention: build a three-dimensional figure in Minecraft and use geometry concepts, such as mirroring and the coordinate system, in practice.

The context of our classroom intervention was that we provided the student teachers (grouped in 2–4) with an empty virtual sculpture park in Minecraft and were tasked to build different pixel art figures in their assigned spot in the park. The students had to mirror the figure across a line of symmetry (reflection), re-creating the figure. When creating the Minecraft map, the center of the park was deliberately placed where the axes of the coordinate system intersect (origin). This enables Minecraft's built-in coordinate system to aid the students in task-solving. The pixel art figure was either chosen from a variety of example figures provided by the teachers or found by the students themselves (by using Google).

2.2. Research context and sample

The students were co-located on campus in the classroom. Each

[1] We used Minecraft Education Edition, which is a version of Minecraft designed for use in educational contexts. We will refer to it as "Minecraft" for the rest of the article to make the text more readable.

student created their own Minecraft avatar and joined a shared server with their group members and classmates. Approximately 40 students per class built their pixel art figures in the same park simultaneously. Two Minecraft servers containing the sculpture park were utilized per class, as each server in Minecraft Education Edition only allows for a maximum of 30 participants. The decision to provide shared servers for the class, instead of one server per group, was taken to encourage cross-group interaction.

The goal of the learning design was two-folded: support the development of pre-service teachers' knowledge in mathematics and in teaching using digital educational tools. Mathematics, precisely geometry, was chosen as the context for the learning design and interventions due to the relevance of the competence goals in the national math curricula. At the time this study was conducted, the specific competence goal in the national math curricula for elementary school students was that students should learn how to mirror a figure and create 2D and 3D figures. While doing this, they should develop digital skills by exploring, visualizing, and using digital tools in problem-solving. In addition to focusing on subject-specific and digital skills, the Norwegian common core curricula highlighted the importance of several generic skills, including collaboration. We believe that these competence goals could be achieved using Minecraft, because the tool offers open-world building, learner control, and is characterized by the ability to create, explore, and collaborate [21]. Our learning design was meant to model how Minecraft might be used in elementary school settings to learn subject-specific skills, digital skills, and collaboration for the student teachers. As these were teacher students, they were expected to reflect on whether and how this experience would be useful in future learning situations with their own future students. Although the mentioned competence goals were aimed at elementary school students and with Minecraft being more popular among children than adults, tasks such as these also proved relevant for student teachers on the path to becoming elementary school teachers. This is because they need to know both subject-specific skills and engaging educational tools. Although the subject-specific task might appear basic for adult students, the task along with the fact that most students were unfamiliar with Minecraft as an educational tool proved to be an adequate challenge for the amount of course time allotted. In addition, the students themselves could regulate the task difficulty by choosing to construct more complex structures in the figure they chose to build. While the primary learning goal for these students was subject-specific tasks, mathematics was not the focus of this study. The role of the math subject in our study was that it provides a context for the learning design and the use of the educational tool. We utilized Minecraft as the primary learning environment and an educational tool in the math class.

Participant selection. The participants in the study are student teachers in their third semester of primary teacher education (a five-year master's degree). The students were explained the purpose of the study and that it was voluntary and they could withdraw from the study at any time. However, the class in which this study was conducted was mandatory for all third semester students. The group mainly consisted of students in their 20 s, and the majority of the students had little to no experience with Minecraft. The students organized themselves into groups of 2–4 students. There were no criteria for grouping; however, each member had to voluntarily provide informed, written consent to participate in the study.

2.3. Instruments used

2.3.1. Collecting data from group conversation

Data were collected using a screen recording software that recorded the in-game actions and conversations among the student teachers when using Minecraft to solve the math task. Virtual ethnography was used to collect the data—a method used for analyzing social interactions in online contexts and collecting data through social interactions—which reflects the participant's approach [47]. Using participant observation meant that we sometimes asked the student teachers to explain what they were doing. Overall, the data consisted of 18 h of screen recordings. This study included 6 h of recorded observation video collected from 11 students who were divided into 4 groups. To ensure data privacy, the research project was reported to and approved by the National Center for Data Services in Norway. All the students' names were anonymized and were given fictitious ones. The screen recordings were transcribed before the analysis.

2.3.2. Social network analysis

Social network analysis (SNA) uses terminology and procedures from mathematical graph theory to study networks, where the basic entities are nodes and ties [48]. SNA is useful for analyzing relationships between different units of analysis (nodes and ties) in a network, where individuals are represented as nodes or groups and ties as relationships [48]. To perform SNA, we used Gephi and Discourse Network Analyzer (DNA). DNA is a software that transforms text-based conversational data into a formal network and prepares the data for SNA analysis [49]. DNA was used to thematically code all the social interactions from the student groups, creating thematic codes: building, removing and rebuilding, collaborating, discovering issues, math concept 1–mirroring, and math concept 2–coordinates. The names of the nodes are shown in Fig. 1. Hence, the data were categorized into different thematic groupings. As such, the different thematic codes contain different social interactions. The qualitative data were analyzed in collaboration; however, they were initially reviewed by both researchers individually based on the predefined themes, before later comparing notes and deciding upon which excerpts to use. The original list of themes contained more than 20 different entries, before the researchers jointly agreed to reduce the list to the themes applied in this study. This means that we thematically coded all the transcribed video data before exporting it to Excel sheets and into Gephi for SNA analysis. SNA provides a set of techniques and operations for analyzing the relational aspects of social structures [50]. Networks are composed of nodes and ties, wherein nodes are a set of objects representing entities in the dataset, and ties are the connections between the nodes and provide visual cues as to the degree of connectedness of the graph [51]. In SNA, ties refer to the relation between the participants and their activities. However, the word "edge" is also sometimes used to describe the same phenomenon.

To conduct SNA, we computed the weighted degree centrality and created sociograms using Gephi, an SNA tool. Gephi is an open-source software for network visualization and analysis that helps data analysts intuitively reveal patterns and trends [52]. Using Gephi, we calculated the participants' weighted degree centrality and the activities they participated in. Weighted degree centrality is a term used to analyze the most active and influential actors. Participants with more ties to other actors may be in advantaged positions because they have alternative ways to satisfy needs and are therefore less dependent on other individuals; with more ties, they gain access to more network resources overall [53]. Fig. 1 shows the results of the SNA analysis presented as sociograms representing persons and activities as nodes (in a two-mode network) in a visual display. Gephi was used to create sociograms (Fig. 1). A sociogram is a graphic display consisting of points (or nodes) representing actors and lines (or edges) to indicate ties or relations [53].

2.4. Data analysis

2.4.1. A mixed-methods approach

The application of CSCL techniques to authentic learning scenarios demands new theoretical and practical tools to analyze and assess learning processes [41]. We used a mixed-methods approach to capture the complex phenomena and emerging processes in the use of Minecraft in math classes. This approach flexibly applies diverse methods to embrace the multiple perspectives that behavioral, social, and professional complexities demand [54]. Furthermore, Bazeley [54] underlined

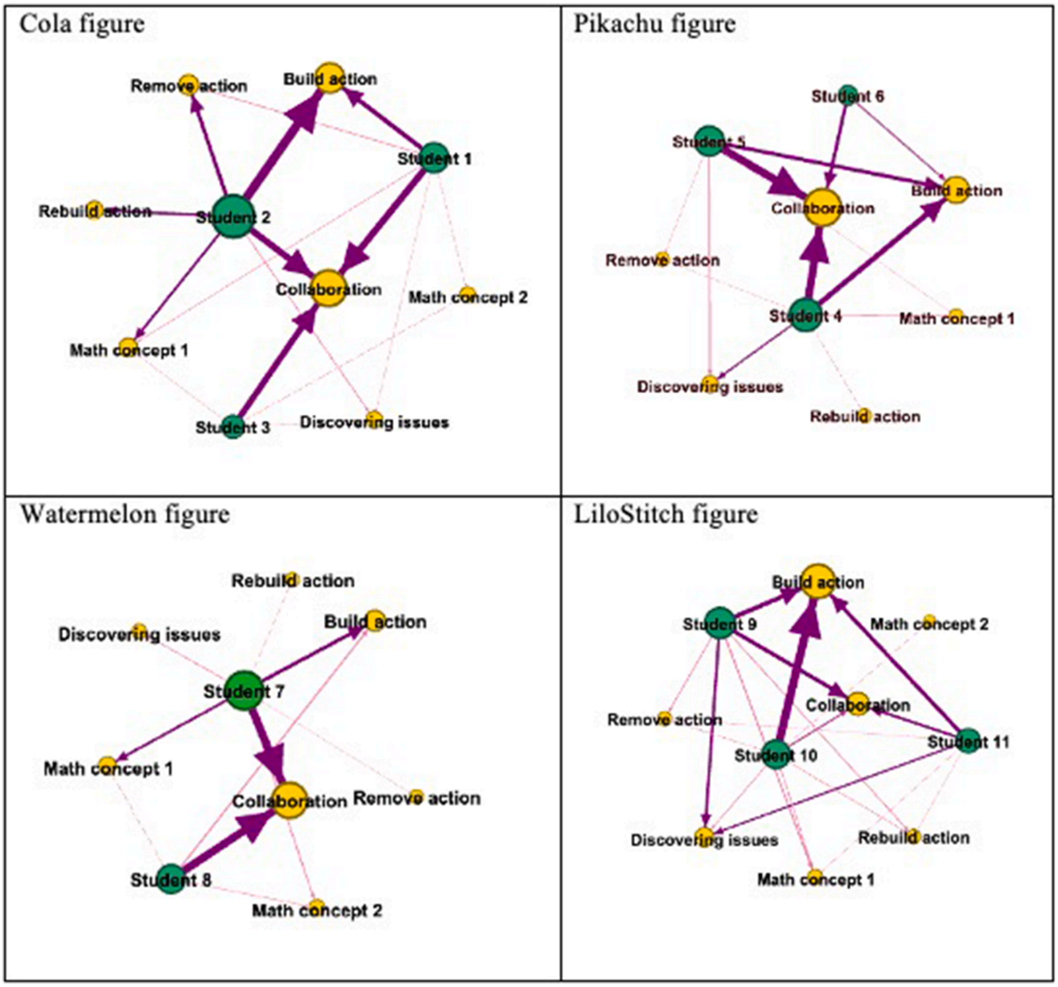

Fig. 1. Sociograms of the interaction patterns in the student teacher groups while solving a math task in Minecraft. Student teachers are represented with green nodes and the activities in which they participated are visualized with yellow nodes. The size of the node reflects the weighted degree centrality, meaning larger size of the nodes reflects higher weighted degree of activity. A thicker tie means a higher weighted degree. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

that when using this approach, researchers ask complex questions and engage with real-world environments in a socially responsible and responsive way.

We used a two-step approach to analyze the data by combining social network analysis (SNA) and interaction analysis (IA). This mixed-methods approach was selected to increase reliability and obtain a richer perspective on the data by focusing on two different perspectives within the same dataset: 1) SNA provides a macro overview of the data, and 2) IA provides a detailed micro perspective. SNA is used for analyzing social structures in networks using graph theory to calculate various algorithms and examine the social relationships in the data [48]. Using SNA to analyze the network data and interaction patterns contributes information regarding the participants' relationships that go beyond a purely qualitative perspective. It is an effective method for analyzing social relationships in a network, where it conceptualizes individuals or groups as nodes and their relationships as ties, exploring these relationships mathematically or visually as patterns [50]. However, SNA does not provide information regarding the content of student teachers' conversations; therefore, another method is needed to accomplish this. For analyzing the social interactions, we needed a method that could capture the content of the collaborative processes. Therefore, we chose to use IA of the videorecorded data to go into detail about the content in the social interactions and analyze these processes. We used IA to assess the details of the content in the group conversations among the student teachers. IA is an empirical study of social interactions between humans and the objects in their environments, allowing for the exploration of talk, nonverbal communication, and artifact mediation [55].

2.4.2. *Analytical framework*

Using concepts derived from the literature presented in Section 1, we created an analytical framework used for analyzing the empirical data (see Section 3, Results, below). The analytical framework draws on concepts from the research fields of CSCL and SNA. Combining these concepts enabled a richer analysis of the dataset, including both macro (SNA) and micro (IA) perspectives of the data. Table 1 shows the analytical concepts comprising our framework.

To analyze the collaboration aspects of the social interactions in the different student teachers' groups, we adopted three concepts from the research field of CSCL: breakdown, negotiation, and meaning-making. According to Stahl [19], *breakdown* is when a group encounters a situation where they do not know what to do. A breakdown is usually the

Table 1
Analytic concepts used as part of the analytical framework.

CSCL concepts [19,14]	SNA concepts [58]
Breakdown	Weighted degree centrality
Negotiation	Sociogram
Meaning-making	

driving force in collaborative small-group interaction, because when it becomes apparent to participants that they do not know what to do, someone makes a proposal for action. This is followed by a *negotiation* process, when group members question, refine, or amend the original proposal through a secondary proposal [14]. *Meaning-making* refers to collaborative learning processes where participants align individual interpretations to a gradually shared meaning that is itself co-constructed in the processes [14]. According to Stahl et al. [14], meaning-making, or group cognition, refers to the processes through which participants interact in collaborative settings and the gradual establishment of the group discourse that emerges.

To analyze the social networks from an SNA perspective, we applied the concept of *weighted degree centrality*, which is a degree centrality measure, but a variant, in which the weight of the nodes is also considered [56]. In weighted degree centrality, also known as weighted network, ties are not only present or absent but have some form of weight attached to them [57]. This means that to understand the notion of weighted degree, the notion of degree centrality needs to be understood because weighted degree builds on the notion of degree centrality. Degree centrality is the number of ties connected to a node and is a centrality measure focused on analyzing the nodes' relationships to each other [48,58]. To visualize the weighted degree centrality calculated for the networks, we created a sociogram. A sociogram or graph diagram [48] aims to represent and visualize each row and column in an incidence matrix.

3. Results

In this section, we present and analyze our data. First, we present SNA of the network data as an overview of the dataset of the sociograms of the group interactions. Second, our main findings are presented as a combination of SNA and interaction data. The interaction data is presented as a set of excerpts, numbered 1–4 and derived from screen recordings of the student teachers group work, providing a more detailed analysis.

3.1. Social network analysis of the data

The sociogram presented in Fig. 1 was created based on a two-mode network with two types of sets of actors: student teachers and the activities they participate in, in our case. A two-mode network, or dual-mode network in SNA analysis, consists of two different sets of data [58]. Fig. 1 presents a two-mode network where the student teachers represent one dataset and the activities they participated in represent another dataset. The relationships between the nodes are ties between the students and the activities they participated (building, removing and rebuilding, collaborating, discovering issues, math concept 1–mirroring, and math concept 2–coordinates). This means that in our two-mode network, there were no ties directly between the student teachers or their activities, but only connected the students and the activities in which they participated.

Networks may be directed or undirected. In a directed graph, the ties are arrows (i.e., they have direction). In undirected networks, ties/nodes are unordered pairs [58]. As seen in Fig. 1 (sociogram), the ties in the network have arrows, giving them direction. Directed networks are used to represent relational phenomena that logically have a sense of direction, for example, "gives advice to" [58]. The relational phenomena in our networks included "interacts with." In the networks presented in Fig. 1, the ties represent interactions between the participants and the activities they participate in. The size of the ties reflects the weighted degree centrality. A thicker tie indicates a higher weighted degree centrality. The directions of the arrows provide information about the activities the students participate in. Below, four sociograms representing four different student teachers' groups and their interaction patterns while working on solving the math task are presented.

Fig. 1 represents the four different sociograms of the different student groups. The name of the sociogram is a cue for hinting at the type of pixel art figure the groups build in Minecraft. A node with a high weighted degree centrality indicates a lot of activity connected to that node. The sociograms in Fig. 1 symbolize student teachers, and the activities they participated in are shown as circle-shaped nodes. The nodes reflect the two-mode network: 1) the students (Students 1–9); and 2) the activities they participated in (building, removing, rebuilding, collaborating, discovering issues, math concept 1–mirroring, and math concept 2–coordinates). The size and color of the nodes indicate the weighted degree centrality, which in this case means the number of times a student teacher engaged in one of the activities represented. The data obtained from Fig. 1 helped us address our research questions and inform our IA by identifying the most central activities (yellow nodes) and the most active student teachers (green nodes).

3.1.1. Analyzing and comparing the sociograms

The rationale for presenting the sociograms of the four different student groups is that we wanted to compare the interaction patterns between groups. When comparing the four sociograms (Fig. 1), the largest nodes with the highest weighted degree centrality can be interpreted as the "collaboration" activity nodes. This means that among the different activities connected to using Minecraft for solving math tasks, "collaboration" is the most central activity, with the highest weighted degree of centrality measure of all four sociograms (see Table 2). In Tables 2 and 3, we applied a node weighted degree centrality in which the weights of the nodes are considered and the definition of degree centrality is slightly modified to accommodate the node weights [56]. This means that weighted degree is a degree centrality measure not normalized to percent, as the data is more meaningful and true to present the SNA data as it was originally derived from Gephi, where it was calculated when the weighted degree centrality was computed.

When analyzing the sociograms, we noticed that the "collaboration" nodes were situated near the center of the network in all four sociograms, indicating that this activity was a central element in the student teachers' groups while they were solving the math tasks. Determining how the node was situated in connection to the other nodes also indicated the weighted degree centrality (center position indicates a high weighted degree centrality and periphery indicates a low weighted degree). Some nodes sit at the *periphery of their networks*, whereas others are firmly at the center, reflecting their position in the network [59]. Collaboration is an interaction pattern that comes across as a shared trait in all sociograms, while the node "remove action" is at the periphery of all sociograms, reflecting that this activity was not a central part of the students' activities. Another interaction pattern shared in the four sociograms was node "Math concept 1" (mirroring), which stands firmly at the center of the networks (see Table 3).

In summary, two interaction patterns emerged from the data from an SNA perspective: 1) collaboration is a central activity, and 2) mirroring is a central activity.

3.2. Analyzing the qualitative data

In the previous section, we used SNA to identify interaction patterns, revealing that the "collaboration" and "math concept 1–mirroring" nodes were the two central activities in the groups. The labels of the nodes emerged as intermediate terms while screening and classifying the data. Therefore, we present empirical data focusing on the thematic

Table 2
Weighted degree centrality of node "collaboration".

Name of figure	Weighted degree centrality
Cola	69
Watermelon	60
Pikachu	179
LiloStitch	49

Table 3
Weighted degree centrality of node "math concept 1–mirroring".

Name of figure	Weighted degree centrality
Cola	12
Watermelon	12
Pikachu	6
LiloStitch	13

concepts of "collaboration" and "math concept 1–mirroring." Four empirical data extracts were presented—one from each sociogram presented in Fig. 1. Two data extracts focused on the mirroring process of the figures, and two focused on collaboration aspects. We used a qualitative perspective to analyze the dataset using IA [55] to bring the meaning of collaboration processes in the student groups to the foreground.

3.2.1. *Extract 1: planning the mirroring of the watermelon figure*

Contextualizing the extract. The extract was derived from a screen recording of two students building and mirroring the Watermelon figure in Minecraft (Fig. 2). The interaction occurred at around the 3 min mark in the group work, at the beginning of the process of building the figure. The extract focused on how the students discuss and plan on mirroring the figure.

Turn	Participant	Empirical data	Analytic concept
1	Olivia	"Have you found out how far away?" … "Hi? Do you make it that way?"	Breakdown
2	Sophia	"Yes, we'll make it that way upwards. We have to make it stand."	
3	Olivia	"Yes, so it must be … ."	
4	Sophia	"And those are the bottom ones."	
5	Olivia	"But you must not make it over [across] like that. We are going to mirror it. It must be across the road there." [Points out that Sophia has made the foundation wall along the road and believes it should be turned so that it can be mirrored across the road—otherwise there will only be two identical figures]	Negotiation, mirroring (weighted degree centrality 12)
6	Sophia	"Oh yes, I thought the left was mirrored. Because if that's the way it is here, then it will be in a way … . Yes, maybe … ." [Realizes that Olivia is right]	Mirroring (weighted degree centrality 12)
7	Olivia	"I thought one like that on the side, and then one like that on the other side."	Meaning-making
8	Sophia	"That makes sense. Yes, I agree with you."	Meaning-making
9	Olivia	"Good" [laughs]	
10	Sophia	"Let's see. So, then we have to … since it is … should we have it mirrored there or there?"	Mirroring (weighted degree centrality 12)
11	Olivia	"Here. So then there must be six [blocks], it seems."	Meaning-making
12	Sophia	"Yes, there are five [blocks], but we can have six [blocks], and there will be one without."	
13	Olivia	"Is it five (blocks)? Yes, that there will be one in between?"	
14	Sophia	"So that there will be one [block] there, and then we kind of start. But then it becomes 1, 2, 3, 5, and 6." [Sophia and Olivia count together]	

(*continued on next column*)

Fig. 2. Screenshot of the Watermelon figure the student teachers co-created and mirrored.

Theoretical analysis. To ensure that the students understood the concept of mirroring, the teacher asked the students to build a pixel art figure and mirror it. Fig. 2 shows a screenshot of the Watermelon figure co-created by one of the student groups and mirrored in Minecraft. In turn 1, Olivia reacted to how Sophia created the Watermelon figure and questioned the direction in which it was created. Here, Turn 1 represents a breakdown that involved discovering an error and discussing how to address it [19]. This triggered a negotiation process [14] in turns 5–7, where Sophia and Olivia presented their different understandings of how the figure should be built. In turns 7–8, the student teachers gradually built on each other's statements and attempted to create a shared understanding and common ground of how to build the figure. In turns 6–14, the student teachers established a group discourse and *shared meaning-making process* [14]. In turns 5–8, the students discussed how to mirror the figure, and it is interesting to notice how they reflected on subject-specific knowledge, the math concept of mirroring, as part of their meaning-making process. This is an example of how Minecraft, as a tool, enables students to discuss math concepts and use the knowledge of such concepts in practice by actually building a mirrored figure. In turns 11–14, Olivia stated that they needed to build five blocks; however, after discussing with Sophia, they finally agreed to build six blocks. This is similar to the collaborative construction of shared knowledge, which is a premise in meaning-making processes [14].

The weighted degree centrality of the mirroring activity reflected in this figure was 12, a relatively high number (compared to the other figures in Table 3). This means that when working with building and mirroring the Watermelon figure, the students spent a significant amount of their time on the mirroring processes. This is interesting because it underlines that the students certainly "did" math—they talked about the math concept they were learning (mirroring), and they used their knowledge about mirroring in practice while building a mirrored figure of the watermelon. Thus, SNA provided interesting data about the mirroring process, which would not be so easily accessible with simply detailed IA of small/selected parts of the data.

3.2.2. *Extract 2: building and mirroring the LiloStitch figure*

Contextualizing the extract. The following extract was derived from the screen recording of a group of three students interacting and collaborating to build and mirror the LiloStitch figure in Minecraft (Fig. 3). The interaction occurred around the 27-min mark of the group work, toward the end of the building process. The extract focuses on how

Fig. 3. Screenshot of the LiloStitch figure the students co-created and mirrored.

the students discussed the mirroring of the figure.

Turn	Participant	Empirical data/utterance	Analytic concept
1	Isabella	"They should be mirrored. And then the ears are wrong."	Breakdown, mirroring (weighted degree centrality 13)
2	James	"Because?"	Negotiation
3	Isabella	"Because the ears are different from one side to the other." [The ears in the figure should be slightly different on each side. It is the only thing different in the figures.]	Mirroring (weighted degree centrality 13)
4	James	"But it is not very difficult to fix."	Negotiation
5	Isabella	"No, it is not … ."	
6	James	"But then we just fix it. We just do that." [Flying to fix the ears]	Meaning-making
7	Isabella	"Now we have mirrored the figure."	Mirroring (weighted degree centrality 13)

Theoretical analysis. Fig. 3 shows a screenshot of the LiloStitch figure (left) cocreated by one of the student groups in Minecraft and the mirrored version of the figure (right). This extract began with Isabella pointing out (turn 1) that the figure should be mirrored and that the ears are not mirrored. This reflected a breakdown [19] when they discovered a mistake and did not know what to do, prompting a negotiation process [14]. When James asked what was wrong (turn 2), Isabella responded by explaining why the ears were not mirrored (turn 3), and the negation continued until turn 6. In turn 6, the students reached an agreement about how to mirror the ears and fix them, resembling a meaning-making process. It is also interesting to observe how the students discussed the notion of mirroring and how to approach this when building the figure (turns 1, 3, and 7).

This extract was chosen because it had the highest weighted degree centrality of the mirroring activity (i.e., the general amount of time and focus spent mirroring the figure), being 13. This indicated that the students focused more on mirroring the figure than on building the original version and discussing it, as compared to the other groups of students. One possible interpretation of and explanation for this may be that this is a large and complicated figure to mirror, therefore requiring more discussion on how to accomplish it. This aligns with what we see in the extract—namely that the students have some breakdowns and difficulties with mirroring the figure, especially the ears (turn 3). It is interesting to observe that this breakdown, from how to mirror the figure, led to a subject-specific discussion of the math concept they were focusing on (mirroring).

3.2.3. *Extract 3: collaboration processes when building the Pikachu figure*

Contextualizing the extract. This extract was taken from the screen recording of a group of three students interacting when they were collaborating on building the Pikachu figure in Minecraft (Fig. 4). The interaction below occurred around 15 min into the group work, in the middle of the building process. The extract focuses on how the students discussed, planned, and started building the Pikachu figure.

Turn	Participant	Empirical extract	Analytical concept
1	Leo	"Tony, now something has gone wrong here."	Breakdown
2	Tony	"What's up there then?"	
3	Jacob	"Now something's wrong here, boys."	Breakdown

(*continued on next page*)

Fig. 4. Screenshot of the Pikachu figure the students co-created.

(*continued*)

Turn	Participant	Empirical extract	Analytical concept
4	Leo	"No, it is not."	Negotiation
5	Jacob	"Yes."	
6	Leo	"Yes, it has shifted one [block]."	Negotiation
7	Jacob	"We are one [block] too far to the left. Do not destroy." [Talking to Leo who is removing one block from the figure]	
8	Leo	"I just removed it."	
9	Jacob	"It must be there." [Goes next to the figure to rebuild the block]	
10	Leo	"Should I build the tail again then?"	
11	Jacob	"I promise, the middle of the top is right, sort of. You see it's the outline."	Meaning-making, collaboration activity (weighted degree centrality 179)
12	Leo	"Hmm?"	
13	Jacob	"Yes, because it's going to the right—do you see that? But it is not a crisis."	

Theoretical analysis. Fig. 4 shows a screenshot of the Pikachu figure co-created by one the student groups in Minecraft. This extract began with Leo exclaiming he had discovered something incorrect while constructing the figure (turn 1), reflecting a breakdown [19]. Following this, a negotiation process began (turns 4–11) and the students presented their differing opinions regarding the building process. In turn 11, Jacob tried to build a shared understanding with Leo, similar to the meaning-making process [14]. In extract 3, there was no focus on mirroring. Fig. 4 revealed that Pikachu was not mirrored because the students ran out of time. Hence, the Pikachu figure had the lowest weighted degree centrality (6) on mirroring of all the student groups (Table 3). However, the Pikachu figure had a relatively high weighted degree centrality on the collaboration activity of 179, which was the highest of all the student groups (Table 2). Building a large figure as Pikachu requires a higher weighted degree of collaboration, as it becomes more complex and the students need to interact more. Contrarily, when students are building a small figure, there is less need to collaborate on solutions to problems that arise. This indicated that the more complex a given task, the more the students need to collaborate to solve the task.

3.2.4. Extract 4: collaboration—cola figure

Contextualizing the extract. The following extract was derived from the screen recording of a group of three students interacting while collaborating on building and mirroring the Cola figure in Minecraft (Fig. 5). The interaction occurred approximately 3 min into the group work, at the start of planning the building process. The extract focuses on how the students discussed, planned, and began to build the Cola figure.

Turn	Participant	Empirical extract	Analytical concept
1	Liam	"But how does this go then, Hugo? What are you thinking now? What are your plans?"	Breakdown
2	Hugo	"Eh, I have to have room for the cola … . I do not think I write 'Coca Cola' … . There will only be room for 'cola.'"	
3	Liam	"Yes, but why did you build it like that then?"	Negotiation
4	Emma	"C O L [A]—okay, we have to start here. If it starts here … A … then three blocks per [letter]."	
5	Liam	"Yes! It must be."	Negotiation
6	Emma	"Eh, L O … so … C."	
7	Liam	"Now it would have been fine with notes that could sketch out how to do it."	
8	Emma	"Mmm"	
9	Liam	"Can you go back, Emma?"	
10	Emma	"Hmm?"	
11	Liam	"Oh yes! Oh! Ah!"	
12	Julie	"Ooh!"	
13	Emma	"Mm C O L … col … . This is crashing in … ."	
14	Julie	"Then you just have to move everything a notch away then … ."	Meaning-making, Collaboration activity, (weighted degree centrality 69)
15	Emma	"Mmm!!!"	Meaning-making
16	Liam	"But take away a block of the cola then we can—eh, no it will be too short … ."	
17	Emma	"But maybe we can have it this way instead? Because then we can mirror this … ."	Mirroring (weighted degree centrality 12), meaning-making

Theoretical analysis. Fig. 5 shows a screenshot of the Cola figure built

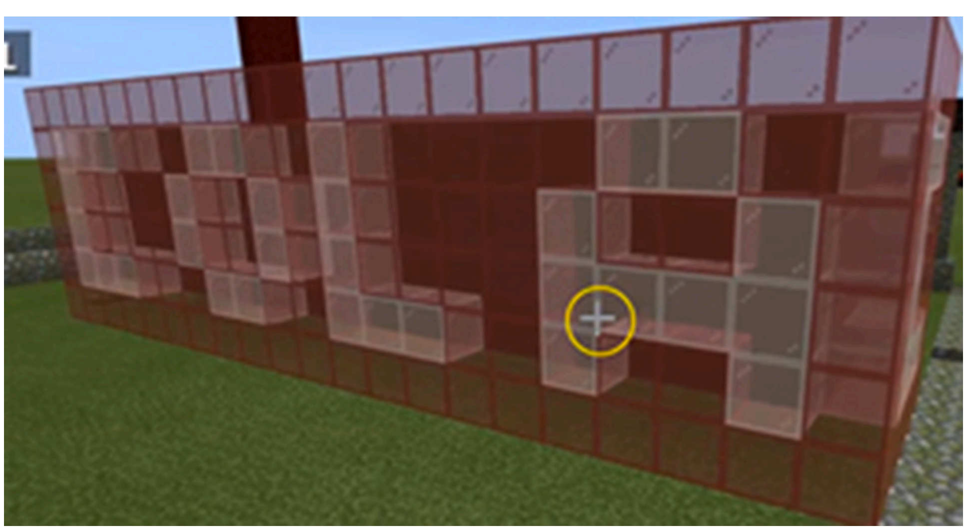

Fig. 5. Screenshot of the Cola figure the students cocreated and mirrored.

by the students in Minecraft. This extract began with Liam discovering a mistake with the Cola figure they were building in turn 1. This has similarities to the notion of breakdown. Stahl [19] underlined that breakdowns are usually a driving force in small group interactions because others will respond with proposals for fixing the said breakdown. Accordingly, the breakdown was followed up by a discussion of how to fix the lettering problem and what blocks to use (turns 3–13). In turn 14, they reached a common understanding of how they could fix the problem, similar with the meaning-making process [14]. This finding is supported by the weighted degree of the collaboration activity derived from the SNA analysis, which has a weighted degree of 69, suggesting that this group is one of the most collaborative groups (Table 2). In turn 17, the activity of mirroring had a weighted degree centrality of 12, indicating that this is a relatively central activity that emerged between the students in the co-creation process. In summary, one can conclude that the participants when building the Cola figure in Minecraft were both active in collaborating and mirroring.

SNA provides us with an interesting analysis regarding the common interaction and collaboration patterns in the student groups, which we could not have obtained from a purely qualitative analysis. Using SNA helped us identify the nodes "collaboration" and "math concept 1–mirroring" as essential activities in all four student groups.

4. Discussion

4.1. How can Minecraft be used as an educational tool for learning subject-specific skills and what are the implications for the development of 21st century skills?

4.1.1. Using Minecraft as an educational tool for learning a subject-specific skill facilitates collaborative learning processes

IA of the data extracts revealed the detailed collaborative learning processes that emerged as a result of using educational tool in a math class. Three different phases of collaborative learning were identified: a) breakdown, b) meaning-making, and c) group cognition. In extract 1–4, the initial phase of the collaboration process resembled a problem or breakdown phase, triggering further discussion and collaboration. As these phases emerged from IA of the data extracts, it suggests that they are empirically founded terms and are different from the theoretical terms in the conceptual framework. These data are supported by SNA, which showed an overview of the collaboration patterns, and the results revealed "collaboration" and "mirroring" as interaction patterns. An underlying premise of CSCL is that networked computers bring learners together in new ways and that shared digital environments can foster interactions that produce new understandings for groups [14]. In the extracts, we noticed that the groups collaboratively created a shared understanding of how to fix the problems. This follows the work of Stahl et al. [14], viewing meaning as shared and embodied in the artifacts in the world, underlining how groups can think and have cognitive agency. Valtonen et al. [20] analyzed different journals within the field of educational technology to develop an understanding of technology-related learning processes. Our study extends this research by offering an empirical intervention study exploring the use of educational tools and their impact and implications on the development of 21st century skills. Schulz et al. [18] studied how to use an educational tool as part of learning a subject-specific skill, and as such their work has some parallels to our findings. However, our findings took this research one step further because we also captured and analyzed two interaction patterns during group work. When using Minecraft as an educational tool for learning subject-specific skills, two patterns of interaction were identified through using SNA: collaboration and mirroring. The collaboration pattern revealed the extent the student teachers collaborated and worked together when co-creating and building the figures (Figs. 2–5) in Minecraft. Likewise, the mirroring pattern revealed the extent the student teachers participated in the activity of mirroring a figure in Minecraft.

4.1.2. Using Minecraft in math classes facilitates the development of 21st century skills

Data analysis indicated that the emerging social interactions between student teachers when using Minecraft as a mediating artifact in math classes facilitated the development of 21st century skills. Callaghan [25] explored how Minecraft could be used for teaching secondary students and described how it permitted the enhancement of engagement, collaboration, and creation of authentic learning activities. Furthermore, Karsenti and Bugmann [26] created a Minecraft challenge for 118 students and found that Minecraft increased motivation, development of collaboration skills, and programming skills, in line with our study. Sari et al. [6] emphasized how student collaboration skills are an important component that can support 21st century skills and how students can develop them. However, they did not emphasize the technological aspects of collaborative learning, which was a limitation. Our study thus extends their research by including a technological component, Minecraft, to mediate social interactions. Samsudin et al. [5] analyzed the implications of using Minecraft as a means of learning 21st century skills among primary school students, and the findings were similar to our study. We added to this research by exploring the use of Minecraft in a student teacher's context. Yilmaz and Yilmaz [9] investigated the impact of metacognitive support for increasing task and group awareness in CSCL through a pedagogic agent and found that it had a significant impact on students' motivation, metacognitive awareness, and group processes. Similar to our findings, the authors observed a positive influence using a technological tool to mediate social interactions. However, there are limited studies explicitly focusing on educational tools and emphasizing how technology can trigger development of these skills. The present study builds and extends on the study by Andersen et al. [22] because they explored the use of Minecraft in a social science class, whereas our study focuses on math class. Our results showed that using Minecraft as an educational tool enhanced the students' skills. This suggests that future teachers may be inspired to use Minecraft as an educational tool and design group work for the students to enable them to collaborate and work on subject-specific tasks in an engaging matter, which may improve the students' skills.

4.2. How can SNA and IA be used as a research methodology for analyzing the use of Minecraft as an educational tool for learning subject-specific skills?

SNA is a useful method for obtaining an overview of how the participants talked, collaborated, and interacted with each other, including connection to the activities. Gaining this network overview of the data would not have been possible by selecting only some empirical data extracts to analyze in detail.

Bokhove [38] argued that SNA is a useful method for exploring classroom interactions, underlining how it is important in capturing classroom interactions and analyzing the resulting data. We have extended this research by also exploring how SNA is useful for capturing collaborative learning in an educational context mediated by an educational tool. De Laat et al. [39] presented how SNA used in combination with content analysis could be used for studying CSCL activities. Similar to our study, the authors combined SNA and IA to explore CSCL activities in a math class using an educational tool for solving math tasks. However, we took the research by De Laat et al. [39] one step further by situating the context of our research in a specific empirical case exploring a real-life situation instead of discussing the benefits of combining the methods from a theoretical perspective. Marcos-Garcia et al. [43] used SNA as a rationale for implementing a method for supporting collaborative learning among actors and their emerging roles. Our study is an extension of the previous study and differs from it as we do not focus on analyzing the participants' roles. We revealed two different collaboration patterns among the participants during their group work, suggesting that our study puts greater emphasis on the collaboration patterns. As such, our study extends the previous research using IA and SNA to explore the mutual development of mass collaboration in online communities [32] ndersen & Mørch.

Martínez-Monés et al. [41] explored how a mixed-methods approach (SNA combined with qualitative analysis) was used for studying participatory aspects of learning in CSCL contexts over three different case studies. Our study differs from this, as we conducted an intervention study by collecting and analyzing empirical data in a CSCL context, combining SNA and IA, to reveal collaboration patterns and aspects of collaborative learning. Wu and Nian [36] studied the dynamics of an online community using SNA to explore interaction-based and association-based relational ties among participants and artifacts under their pedagogical design. On a more general level, our study adds to this research by also exploring the social dynamics in an educational context, although our study places greater emphasis on the implications for collaborative learning and development of 21st century skills. In summary, there are limited studies using mixed-methods approach to analyze collaborative learning in a CSCL context mediated by an educational tool.

5. Conclusions, limitations, and future research

The present study contributes unique insights to the growing research on the use of technology in education to facilitate collaborative learning. By identifying aspects of collaborative learning emerging in group discussions mediated by Minecraft, this study acknowledges the potential that educational tools have for developing 21st century skills in education. As such, this study extends the current literature on the use of educational tools in CSCL. The processes we studied are examples of how teachers can utilize educational technology to facilitate active and engaged learning of subject-specific skills. In addition, these findings show how collaborative learning, viewed as the process of breakdown, negotiation, and meaning-making, emerges when using Minecraft to solve math tasks. Overall, the present findings imply a valuable starting point for creating learning designs that enable the development of 21st century skills through collaborative learning.

This study is a methodological contribution to the field of CSCL as it describes how to analyze and capture collaborative learning processes. The article goes beyond the traditional IA of qualitative data by integrating SNA into IA. When SNA (a network macro perspective on the data) and IA (a detailed micro perspective on the content of the data) are combined, the findings offer a rich understanding of collaborative learning when using an educational tool as a mediating artifact in learning a subject-specific skill. Such a combination of analyses of the same dataset increases data reliability. Using Minecraft as an educational tool for learning subject-specific skills, two patterns of collaborative interaction were identified using SNA: collaboration and mirroring.

These findings have implications for educational practice and researchers, especially when considering how to create learning designs for facilitating collaborative learning as part of developing 21st century skills. Our analysis illustrated that Minecraft can be used not only as an educational tool for subject-specific skill development but also enables collaboration, which is a key activity that students engage in when using Minecraft. In conclusion, the present study sets an innovative agenda in CSCL research for examining collaborative learning as a 21st century skill. However, this study has some limitations. First, it focused only on collaborative learning, which is only one of several important 21st century skills. In future studies, it would be interesting to explore whether other aspects of 21st century skills can be triggered using educational tools for learning subject-specific skills. Second, although this study indicates students' engagement, collaboration, on-task engagement, and activity towards the learning objectives, it does not assess whether the learning objectives were fully achieved. Future research evaluating subject-specific skill learning through group learning in Minecraft and testing Minecraft in other contexts or domain-specific subjects and observe what collaborative learning processes emerge are warranted.

Declaration of Competing Interests

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.

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