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Adopting educational robotics and coding to open dialogic spaces in lower secondary education

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Abstract

This article explores how the adoption of educational robotics, cloud-based animation software, and simplified visual programming software can provide valuable opportunities for dialogic interaction and learning. The potentialities of this type of activity are often overlooked in dialogic investigations. Based on empirical illustration, we discuss how open-ended educational tasks involving the creation of material-digital artifacts can promote the expression of the students' voices and the emergence of a dialogic space in which both human and non-human Others, as well as chronotropic dynamics and materiality, play a crucial role. To provide a polyphonic account of the dialogical processes detected, we analyzed excerpts from two group interviews with seven lower secondary school students (aged 11-12) and excerpts taken from meetings with their teacher. Our qualitative analysis shows that the technology-mediated activity provided valuable opportunities for opening a dialogic space in which the students could express their own voice in interaction with both human and non-human Others. The material world (including the virtual materiality of computer-generated objects) seems to play a twofold role. First, the resistance of the virtual and material objects can contribute to the opening of a dialogical space between the child and the world; second, the chronotopic relations seem to have an impact on the dialogic learning process. These are valid opportunities for educationally relevant dialogic interaction. They should be cultivated and supported to further advance the pedagogical value of educational robotics and coding.

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time relations and social interaction in technology-mediated learning adopting, an approach based on dialogic and socio-cultural theories.

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Introduction

During the pandemic situation caused by COVID-19, schools were forced to embrace distance education or develop hybrid teaching practices, thus resorting to digital spaces where students and teachers could meet. Since online education disrupts the social conventions and norms of social interaction already established in a classroom (Anagnostopoulus et al., 2019), most of the attention around technology in education focused on its role as a mediator for social interaction. The most used types of technology are meant either to allow social interaction at a distance or to enrich the landscape of educationally relevant social interaction in face-to-face learning situations. For instance, they might empower classroom dialogue through purposely designed software (Mercer, Hennessy & Warwick, 2019), enrich dialogical interaction using interactive whiteboards (Ritella & Sansone, 2020), or enhance the process of knowledge building using asynchronous tools such as the web forums (Tan et al. 2021).

Other types of technology, such as fabrication technology, programming software, and educational robotics kits, have recorded less attention. Nevertheless, these technological tools can become potential objects of dialogue and/or instruments for individual or collaborative educational activities. The spreading and use of this type of technology in education are not grounded in its communication function but in its potential for creating and sharing material-digital artifacts that might have educational significance. This type of technology attracts young students because of the connection to daily life experiences and the

practical hands-on activities involving objects such as sensors, motion detectors, and lights (Papadakis, 2020).

This article explores how adopting the latter class of technological tools can provide valuable opportunities for dialogic interaction and learning. In particular, we use empirical illustrations to discuss how open-ended educational tasks involving the creation and sharing of material-digital artifacts can promote the expression of the students' voices. In addition, we illustrate the emergence of a dialogic space that involves the participation of both human and non-human Others, and discuss the role played in this process by space-time relations and materiality. To provide a polyphonic account of the dialogical processes detected, we will discuss excerpts from two group interviews with lower secondary school students and excerpts taken from some meetings with their teacher. This teacher adopted open-ended knowledge-creation tasks using educational robotics, cloud-based animation software, and simplified visual programming software in his teaching practice. During the meetings, the teacher portrayed his pedagogical approach and perspective on the learning processes emerging when the students use these technological tools during his classes.

In the following section, we provide the rationale and theoretical background of our investigation. Subsequently, we provide details concerning the research aims, the participants, and the research method. Then, we describe the main dialogic features characterizing the approach adopted by the teacher. Finally, we will use the empirical materials to illustrate how the dialogical nature of the students' engagement with the technology involved both human and non-human voices and explore how space-time relations played a role in the learning process.

Theoretical framework

The learning activities involving the design and fabrication of virtual or material artifacts by the students are central in "object-centered" approaches to learning such as "knowledge-creation" (Paavola *et al.,* 2004). In this approach, a key role is played by epistemic mediation, that is, a deliberate process of deepening inquiry by creating external knowledge artifacts that crystallize meanings and provide steppingstones for directing and guiding further personal or collective inquiry efforts. The use of digital fabrication technology and programming software in knowledge-creation activities has been associated with the label "maker-centered learning" (Riikonen et al., 2020), suggesting a connection with the social movement of makers. The maker movement refers to "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" (Halverson & Sheridan, 2014, p. 496). As discussed by Hatch (2014), a crucial feature of the maker movement is its democratizing effect. The evolution of technology (which allows individuals to design, fabricate, and share a wide range of material and virtual objects) combined with a spreading culture of making implies that individuals and local maker communities can easily consider themselves innovators. Thus, makers creatively engage in the invention, design, and production of digital-material objects that, in their perception, potentially could change the world, at least in terms of improving their own and their community's lives. Accordingly, the maker culture "has become a way to express creative and communal drive" (Halverson & Sheridan, 2014, p. 495).

While the label of *making* is principally associated with the fabrication of material objects, for example, using 3D printers, laser cutters, and other digital fabrication technology, makerspaces are equipped with a range of digital fabrication technological sets. In particular, they might also include educational robotics kits or software enabling the creation of virtual objects such as video animations or videogames (Lock et al., 2020). It is argued that the educational usage of such technological tools involving the creation and sharing of material or virtual objects could support the development of several key skills

and competencies. These may include creativity, critical thinking, social and collaborative skills, etc. Potentially, this may also contribute to connecting pedagogical activities with the students' passions and their lives out of school (Peppler, Halverson & Kafai, 2016). We argue that the latter aspect is crucial for the emergence of genuine dialogical interactions as the students collaborate at activities including one or more of the digital technologies mentioned above. In this sense, the approach to learning and education discussed in this article is not connected only to academic achievements but "takes into account the person as a whole" (Kangas, 2010) with their own unique and creative voice. A few authors have emphasized the importance of the connections between educational activities and the students' interests and passions (Akkerman & Bakker, 2019), which might promote the expression of the students' voices.

Several authors maintain that the efficacy of makerspaces does not depend only on the material features of the space but also on cultural and social aspects: "the role of culture is profound and crucial in shaping who participates (and benefits from) makerspaces and how they benefit from participation, the learning mindsets they develop, and how they connect with others, both within and out of the space" (Kim et al., 2018, as cited in Culpepper & Gauntlett, 2020). This argument shows a potential convergence between dialogic approaches to education and making-based pedagogies. Nevertheless, research in this field has overlooked specifically examining the potential of these technologies for dialogic learning. Indeed, the discourse around making-based pedagogies is often grounded in constructionism, and there is a limited number of studies explicitly addressing the pedagogical use of this type of technology from a dialogic standpoint (e.g., Kumpulainen & Kajama, 2020; Mercer, Wegerif & Major, 2019; Jung & Lee, 2021). This gap might be related to the fact that the first generation of making-based pedagogy focused on technical aspects, while the cultural and social dimensions have been overlooked. As Culpepper and Gauntlett (2020) noted, makerspaces often hold rhetoric of social inclusion but soon turn into "exclusive places," where people unfamiliar with the technology might not feel at ease (see also Vossoughi et al., 2016). The dialogical processes associated with these types of educational activities have not yet been comprehensively examined.

In particular, in this article, we emphasize the importance of an analytic focus on the dialogic interaction with the material world, which is often overlooked in dialogic investigations. In this sense, we agree with Hetherington and Wegerif (2018), who claimed that previously dialogic theory in education had focused mainly on the interaction between human voices. This can include real people participating in a conversation as well as absent individuals or abstract social entities voiced by the real participants (Grossen & Orvig, 2011). Such abstract entities have been theorized in terms of 'generalized voices' (Linell, 2009) or 'cultural voices' (Wegerif, 2012). These are not necessarily human beings but can be institutions, professions, social categories, etc., voiced by participants who hold socially recognized views on the topic under discussion (Ritella & Ligorio, 2016). However, the role of non-human voices and the material world has been overlooked.

When examining specifically research on the dialogical use of technology, scholars have mainly focused on how a range of communication technology tools might support online and/or offline dialogue and how such tools might contribute to the opening of a "dialogic space" (e.g., Cook et al., 2019; Pifarré, 2019). Instead, the role of technology in the creation and sharing of material or virtual artifacts has not yet been central in the dialogic research agenda. Only recently, a growing number of investigations have supported the claim that materiality plays a substantial role in dialogical processes (see, for example, Ritella & Loperfido, 2021; Hetherington & Wegerif, 2018; Kumpulainen & Kajama, 2020) and a few investigations on knowledge creation and making-based pedagogical activities have discussed the socio-material dimension of the learning processes taking place when learners use these technologies (Mehto et al., 2020). The material world has been partially examined in the dialogical literature by adopting the Bakhtinian concept of chronotope (Ritella, Ligorio & Hakkarainen, 2016a). Chronotope has been defined in terms of

socially emergent configurations of space-time, where space and time are considered interdependent social constructions (see Bakhtin, 1981). This concept has been used to investigate the role of spatial and temporal relations in different types of educational activities, considering both discursive and material aspects of space-time relations (e.g., Ritella, Ligorio & Hakkarainen, 2016b; Brown & Renhsaw, 2006).

In sum, we will address a current gap in the existing literature by discussing how a specific focus on both non-human voices and chronotopic relations can improve our understanding of the role that the material world can play during the unfolding of the open-ended making-like tasks.

Research aim and questions

Our aim with the present investigation is to explore pedagogical activities involving educational robotics, cloud-based animation software, and simplified visual programming software. In particular, the analytic focus is on exploring the interaction between human and non-human voices and the role of chronotopes in dialogic pedagogy involving this type of technology. In addition, we examine the relationship between the pedagogical activities and the students' interests and passions and how such a relationship might contribute to the expression of the students' own voices.

The research questions guiding the analysis are:

1. Which human and non-human voices are discursively represented by the students when they narrate their experience with open-ended knowledge-creation tasks involving educational robotics, cloud-based animation software, and simplified visual programming software?
2. What was the significance of the material world during the activities, as perceived by the students?
3. How do the students represent the chronotopes associated with such educational activities?
4. How do the carried-out activities align with the interests and passions of the students

Methods and participants

The present investigation involved a technology teacher from a lower secondary school in southern Italy and seven of his sixth-grade students (aged 11-12) who volunteered to participate in the research. The main source of data consists of two online semi-structured group interviews conducted in May 2020, during the first national lockdown. The first group involved three male students who carried out several projects using educational robotics kits. The second group involved three male students and one female student, mainly using cloud-based animation software and simplified visual programming software. Each interview lasted about 45 minutes. The interviewer asked the students open questions concerning: i) the activities they had engaged in during the last few months; ii) what they liked or disliked; iii) the task-related social interaction; iv) the digital and material resources they used; v) the difficulties they encountered; vi) the creative process activated to design their own original artifacts.

The interviews were analyzed through qualitative content analysis (Hsiah & Shannon, 2005) involving the following steps:

1. Transcription of the interviews, which were anonymized using pseudonyms.
2. Iterative coding of the utterances relevant to the research questions by two independent coders, focusing on: a) the human and non-human voices that were represented as significant resources for the ongoing activity, b) chronotopic relations implicitly represented in the students' speech, and b) the interests and passions of the students that were connected with the activity.
3. Discussion within the research group concerning the utterances coded differently by the two coders until

complete agreement was reached (See table 1 for an overview of the final categories emerged).

4. Construction of summary tables and visual representations of the categories emerging from the coding.
5. Interpretation of the data and in-depth qualitative analysis of a selection of relevant excerpts.

Table 1: the categories emerged from the analysis

Categories	Sub-categories
Human / Non-human voices	Videos: references to videos that were considered by the students significant for the activity
	Software programs: references to software programs that the students considered to be significant for the activity
	Books: references to books that were considered by the students significant for the activity
	School context: references to the school context, represented as a resource by the students
	Family context: reference to the family context, represented as a resource by the students
	Peers: reference to social interaction with peers, represented as a resource by the students
Interests and passions	Interests and passions: references to the students' interests or passions

The technology teacher collaborated with the researchers in all phases of the research. In particular, he assisted with the data collection, including the recruitment of the students and the collection of the informed consent of the students' parents. He also participated in several research meetings with the researchers providing further information about the educational activities described by the students during the interview. He contributed to the interpretation of the findings. We considered the teacher's point of view to be important because it allowed us to uncover some dialogic features of the design and implementation of the educational activities, which are important for the interpretation of the interviews. Therefore, in the following section, we will report on the teacher's description of the pedagogical design of the activities mentioned by the students during the group interviews. In addition, since the teacher's voice contributed to reaching a polyphonic understanding of the dialogic processes examined in this article, when relevant for the interpretation, the teacher's perspective has been integrated into the discussion of the findings.

The teacher's perspective

The first important aspect concerning the design of the activities that the teacher emphasized is the open-ended nature of the tasks assigned to the students. Although he sometimes defined a theme or a general description of the virtual or material object that the students should create using the technology, the students were usually free to self-organize their own activity and autonomously decide what kind of object to create. The teacher did not impose a right path, but he put "the technology in the students' hands," and he let them explore and discover what they could do with it. Most of the time, he asked the students to

engage with the technology in small groups, gradually guiding each group in developing their projects using the available technological tools. While the students engaged in the activity, he provided help and support when needed. Some students became very enthusiastic, and every day they greeted the teacher by showing a "shoe box with inside a new robot, their last creation." Although the teacher was proud of the commitment shown by some students, he also admitted that, at times, it was challenging to interact equally with all the students since a few were pressing for continuous feedback. Sometimes, he had to ask some students (described as "rivers in flood") to hold on because he needed to involve the other students.

To emphasize the freedom left to the students during the activities, the teacher narrated how some of the students engaged with educational robotics according to their own interests rather than according to a specific task:

Excerpt 1

> **Teacher:** They started bringing me things that were not connected at all with the tasks I might assign, I mean they came and brought something, saying, "this is my last creation," when they brought something, I said, "but why don't you? you could also do this to improve it" and since then I started assigning some tasks, but at the beginning, it was just their own creations.

In excerpt 1, it is possible to notice that the teacher let the students' voices emerge, welcoming their creations and building on the students' own creative engagement. He saw his role as being that of an advisor, suggesting ways in which they could improve the objects they created. In this way, the teacher seemed to attempt to build a connection between the student's voice and the voice of the school curriculum.

While before the pandemic, the teacher proposed this type of task as a collaborative activity to be carried out in groups; during the pandemic, the activities were re-designed to comply with the imposed restrictions. The teacher assigned a series of open-ended tasks inviting the students to create digital or material objects at home using a range of technological tools. For example, the students were invited to design a robot that would help in dealing with the pandemic. The students were guided by the teacher throughout the process of creation. Students sent to the teacher videos, emails, and messages to show him what they created and received feedback from him.

A further aspect emphasized by the teacher was the importance of social interaction among students and the characterization of the learning process as a creative endeavor. The teacher considers social interaction as necessary to develop student's skills and competencies:

Excerpt 2

> **Teacher:** I see educational robotics in this sense, as a tool for collaborating with each other. You see, these students have created their own WhatsApp group, and they exchange suggestions, advice… I mean, it is a constant flow. […] with the digital classrooms with the Ipads they reach levels of knowledge of the tablet in a short time. They do a great part of the job by themselves, I mean the one who discovered something explains to the other and then, afterwards… the spiral of creative learning… one says something, and they grow up together, also with robotics they do the same thing in practice. And then for me, this is… these are cornerstones, I mean the most important thing for me is just this, it is not the final product, the product is ok. You created it, and it works, but that is more a satisfaction for the students themselves… what I like the most is the process; I mean, it's what they tell me.

Finally, of great importance for the teacher was the reflective activity he prompted by asking the students to narrate their learning experience, to explain what they built with the technology and how they

built it. He attempts to offer a learning environment in which students do not feel the pressure of the assessment. The teacher claimed that when the students are not worried about their grades, they seem more relaxed and engaged in the activity. Consequently, the teacher did not consider what the students showed as strictly connected to the grade, and students did not ask what grade would be assigned to them. This attitude allowed for enjoyment of the activity, with students acting in a relaxed way even when showing some objects that did not work properly. In the teacher's account, this was related to the fact that he tended to provide only formative feedback aimed at helping them to find solutions to the problems they encountered during the activity or suggest revisions to the artifacts that, in his opinion, could potentially have a pedagogical value.

Findings

Voices emerging during the interviews

Table 2 provides an overview of the frequencies of each category and subcategory. The analysis allows us to identify seven main voices represented by the students as they narrated the activity. According to the researchers' interpretation, the students considered each of these voices to be a significant resource for the ongoing educational activity. The most frequent human voice represented during the interviews, especially during the second one, was the voice of peers (which occurred 19 times in total). The analysis of the excerpts reveals that the social interaction among peers was very intensive in some cases. This is the case of the three students from interview #1 that created a WhatsApp group where they exchanged ideas and helped each other when they were not physically together.

Table 2: frequencies of categories and subcategories.

Categories	**Subcategories**	Interview #1		Interview #2		TOT	
Non-Human Others	Videos	5	17,86%	2	4,55%	7	9,72%
	Books	0	0,00%	3	6,82%	3	4,17%
	Software programs	1	3,57%	6	13,64%	7	9,72%
	School context	4	14,29%	7	15,91%	11	15,28%
Human Others	Teacher	2	7,14%	4	9,09%	6	8,33%
	Family	1	3,57%	2	4,55%	3	4,17%
	Peers	5	17,86%	14	31,82%	19	26,39%
Interest and passions	Interest and passions	10	35,71%	6	13,64%	16	22,22%
	TOT	28	100,00%	44	100,00%	72	100,00%

For some students, peer interaction was an occasion to learn how to use the technologies even before the teacher introduced them at school (Excerpt 3). The teacher emphasized that he observed instances of peer tutoring during which the students taught each other what they knew. Some students, who initially were not at all familiar with the technology, became passionate about it because of the interaction with friends enthusiastic about it.

Excerpt 3

> **Larry:** Roland and I had a friend who was very good with computers and with programming, so he taught us how to use the robots.

Second, the teacher was mentioned four times by three students, who emphasized the help provided by the teacher for the development of their project, also noting that he provided additional technological tools that allowed them to improve their creation according to their own desires. For example, Roland mentioned that the teacher loaned him some building blocks that were essential for creating the robotic arm that he was keen to construct. Three students also mentioned the family as a significant resource for their projects, especially in terms of support received by some family members.

Third, concerning the non-human voices, several students mentioned that they used YouTube videos as inspiration for their creations or as a resource for solving problems encountered during the process. Only two students mentioned the use of books as a resource for their activity. Instead, the school context seemed to be an important non-human voice in the account of five students, which seemed to be strictly related to the chronotopic constraints of the activity. In the following sections, we will report specifically on the analysis of non-human voices and discuss how in our interpretation, the chronotope of physical co-presence at school provided an invisible ground for social interaction with peers.

The voice of the material world

In this section, we will discuss two excerpts as empirical illustrations of how the dialogically minded use of technology in educational activities can contribute to the opening of a dialogic space including non-human voices, thus emphasizing the role played by materiality during the learning process.

In Excerpt 4, Roland describes the process through which he ideated and constructed one of his creations, which is a robotic arm including a robotic hand. Roland's idea was that by means of sensors, the robotic arm would detect the movement of a human hand and activate some electric motors, which would then continue the movement initiated by the person "wearing" the robotic arm until the sensors detected a different movement.

Excerpt 4

> **Roland:** Ok, I first watched this glove in a video. Then I started from the fingers. I built a kind of very thin panel, this much, more or less [gesture showing how thin the panel was]. And I thought this could be a finger, but I thought it will never work. Then one day, I tried and I engaged in building the hand. I said, "but it is a beautiful idea, I guess that a nice thing could come out from this." Then I improved the fingers, I improved stability. And then there was a problem. I was not able to sustain it, I needed to keep the mechanical arm attached to my own arm, right? And so, I was not able to keep it stable, I needed to put some joints that would be able to keep it stable. And after a few tries, I succeeded. Then I moved to the programming, but it was also not easy, but I made it. […] and at the end, I decided to decorate it a little bit to make it more beautiful. And then, since I did not have three touch sensors, I had asked the teacher to lend me two of them, so I had to disassemble the arm [in order to return the borrowed parts].

The idea of the robotic arm was first taken from a video he had previously watched online. Roland was at the same time enthusiastic about the project ("it is a beautiful idea") but also skeptical about its realization ("it will never work").In addition to the dialogical interaction between two inner voices, Roland's account includes non-human voices that allow for discussion of the role of the material world connoted by constraints and practical problems. As Roland had "a few tries," the material world provided a feedback

loop and iteratively pushed him to figure out complex solutions to emerging problems (e.g., "I was not able to sustain it") until he eventually succeeded.

A similar process to the one described by Roland during the interview was insightfully discussed by Pickering (1993) as he presented his concept of the "mangle of practice." For Pickering, the material world tends to resist human action so that an iterative process is activated. First, the person (or group of people) acts on materials. Second, the materials might resist the action by raising "obstacles" to the realization of the intended actions. Third, the (individual or collective) actant acknowledges the resistance of the material world that reacts to their intention and responds through what Pickering (1993) labels as *accommodations*, that is, actions meant to circumvent the emerging obstacles.

Within the educational context, Biesta (2012) framed such interaction between learners and the materials in terms of a dialogue between the child and the world. Biesta's contribution conceptualizes the existence of several ways in which a person can respond to the resistance of the material world, distinguishing between the monological and dialogical responses. On the one hand, there are two (monological) ways of addressing such resistance. The first is when a person attempts to simply impose their will upon the world, which, at its extreme, may lead to the destruction of the object of resistance. According to Biesta, the second monologic possibility is to withdraw oneself from the resisting world, not engaging with it, and not connecting with it. Both these options are characterized as monologic since they imply either the destruction of the voice of the resisting external world or the self-silencing of the students' voice, thus closing the potential dialogical space residing in the interaction between these voices. On the other hand, the third option that Biesta suggests is to inhabit the educational – dialogical – space that emerges in the "frustrating middle ground between the two extremes of world-destruction and self-destruction" (Biesta, 2012, p.95).

Excerpt 4 illustrates how the creative processes that emerged during Roland's engagement with the educational robotics kit were dialogic in nature and included non-human voices. The teacher's design of the activity might have contributed to enhancing the dialogicality of the process. Indeed, he did not attempt to dictate procedures for using the technological tools (which would tend to silence the student's voice). Instead, he allowed students' own voices to emerge in a dialogue with the material world that resisted and was iteratively addressed through dialogical "accommodations," which at times might have been developed in interaction with peers or with the teacher, or both.

In Roland's account of his own activity, the middle ground theorized by Biesta was found as the student did not give up his desire to build a robotic arm when encountering difficulties or when he expected that it might not work properly. Roland accepted and addressed the emerging "voice" of the resisting materials, iteratively revising the initial design to make it work. The open-ended nature of the task might have supported the emergence of such a dialogical space, as Roland was allowed to engage with the world with his own creative voice (autonomously conceiving the object to be created based on his own interest). He was also encouraged and supported by the teacher (and by his peers, as reported several times during the interview) in the dialogical interaction with the resisting materials. Finally, at the end of the excerpt, Roland also expressed his creativity and aesthetic sensitivity by decorating his robotic hand to "make it more beautiful."

The resistance of the external world concerns not only the material objects used during the activity but also the features of programming software and virtual objects. In this sense, recent research introduced the concept of "virtual materiality" (Paavola & Miettinen, 2019), emphasizing how some virtual objects provide tangible means for interaction and collaboration. Accordingly, the resistance posed by virtual objects can also trigger dialogic processes, as we will discuss using Excerpt 5 as an empirical illustration.

In this excerpt, Jack and Matthew describe how they worked with a programming software – Scratch – to generate geometrical figures. The teacher did not provide a correct procedure, letting the students figure out what kind of instructions were needed to draw the figure chosen by each student.

Excerpt 5

> **Jack:** I used the formula. I mean basically you take 360 degrees and divide them by the number of sides, and you get the degrees that you needed to generate the figure.
> **Matthew:** well, not only this. It was not only like this because also sometimes, when I did as… using Jack's method, I obtained [a figure] with couple of degrees more than the others.
> **Jack:** but not for the odd ones ((meaning figure with odd numbers of sides)), for the odd ones, you understand? You cannot make 360 degrees divided by 7.
> **Teacher:** no, what Jack says is right but actually there are some approximations and then it might not work out
> **Jack:** if you want to make a heptagon, 360 divided by 7 you cannot make it…

The strategy that Jack describes in order to draw the figure using the programming software was to use mathematical formulas to calculate the size of the angles between the sides of the figure. In Excerpt 5, we notice that the resistance the students encountered in the virtual environment also provided opportunities for reflection on relevant disciplinary problems. Jack explains that he used a formula, "simply," dividing 360 degrees by the number of sides of the figure. However, Matthew claimed that the formula does not always work properly, as sometimes he had not been able to generate exactly the figure he intended to draw. For some of the geometrical figures, the formula worked well, while for others, it did not. The problem encountered was familiar to Jack, who responded that the formula does not work with figures having an odd number of sides, giving the example of the heptagon. From a dialogic perspective, these occasions of sensemaking have high learning potential. They might provide grounds for opening a dialogical space for collective knowledge building in a struggle with the virtual objects' resistance. The open-ended nature of problems encountered by the students encourages them to engage in further collective dialogue. It leads them to seek explanations and solutions as they creatively engage with the technology. These opportunities for educationally relevant dialogic interaction might deliberately be cultivated and supported to advance the pedagogical value of the implemented pedagogical activities.

In this section, we used two empirical illustrations to show how the interaction with both the material and the virtual objects provided occasions for opening a dialogical space. Therefore, we claim that this type of learning activity can: i) provide a high potential for learning; ii) support the process that Biesta (2012) labeled as the dialogue between the child and the world, and iii) offer an optimal site for investigating the role played by non-human voices in learning processes.

Social interaction and chronotopes of distance education

In this section, we will discuss how the chronotopes implicitly represented in the students' narration functioned as gateways for dialogical interaction. In our interpretation, the students described a chronotope associated with the technology-supported activity in the classroom before the pandemic, which was radically transformed when they were forced to embrace distance education. We will analyze a few excerpts from the group interview to discuss the chronotopic relations we identified in the data and their significance for the ongoing dialogical processes.

On several occasions, the students mentioned interactions at school they had with peers around the technology before the pandemic. They reported that when they were at school, they were keen to complete their making projects, and sometimes they even used their free time during the breaks to work on them. Several students in their narration mentioned the physical environment of the school, especially

referring to the proximity with their classmates. In some excerpts, students contrasted the activities at school before the pandemic with the ones that they carried out from home during the lockdown. The following excerpt (Excerpt 6) provides a good illustration of this theme. In Excerpt 6, Anne joins a discussion about the help-seeking and collaborative interaction they experienced while engaging with the technology.

Excerpt 6

> **Anne:** I did not ask my parents for help because they are not good with these things. When I was in school, I asked the teacher for help, especially for programming and these things, instead concerning the drawings [she refers to the drawing of geometrical figures by providing instructions to the software program] … I think that at that time Max was my desk mate… and so if we did not understand something, he used to help me, and by the end we always succeeded. Instead, in this period [during the lockdown due to the pandemic], I asked for help only from my friends.

Anne's contribution clearly shows that sitting next to a peer at school provided grounds for a flow of social interaction with her classmate, which was interrupted during the lockdown. The spatial proximity with Max encouraged her to ask for and receive help from him before. Instead, since the distance learning started, she no longer asked for help from Max, addressing only some other peers that she considers to be her "friends" when needing help on this kind of activity. Through the analysis of Anne's words, we infer that the space-time of the classroom (characterized by physical proximity) facilitated interaction with peers that she would not address at a distance. This excerpt shows how the material conditions of interaction (being desk mates in the classroom vs. being at home) in Anne's perception had an impact on her social interaction with peers.

During the interview, several times, the students mentioned constraints or technical problems that hampered their social interaction with peers during distance education activities, which contributed to reduced collaboration and reciprocal help-seeking. For the students, the chronotope of distance education seems to be characterized as a space where collaboration and social interactions encounter more obstacles than in the classroom. Nevertheless, since the students seem to have established a habit of collaboration across several school projects, at times, they include the voice of their peers in their individual activities even when collaboration seemed impossible to them. A good illustration of this process is described by Matthew (see Excerpt 7). Before the excerpt, Max described a project developed in collaboration with Matthew using a cloud-based animation software named Powtoon (the label being a portmanteau of "PowerPoint" and "Cartoon"). At this point, the researcher asked if this was the only idea they developed collaboratively.

Excerpt 7

> **Matthew:** there were other two ideas we realized [together], also in Powtoon when we were doing a task on the characteristics of glass. I phoned him [referring to Max] and asked if he wanted to do it [the digital creation] with me. Since we were not able to make an arrangement… it was a bit difficult… since it seemed that he was not able to access [the online software] from the iPad… in the meantime I was asking him if he wanted to do it or not. We got to the point that each of us made it by himself but both of us made it including the character of the other.

In Excerpt 5, Matthew describes some of the challenges he encountered when trying to engage in a collaborative activity with his peer at a distance. Despite the apparently insuperable difficulties, the two students did not give up. As they were forced to work individually due to technical problems, they decided to reciprocally embed the voice of the other in their creations by using each other's characters when creating their individual online animated presentation. In this way, the students could develop a highly dialogic artifact even when working individually. This was not required by the teacher; it was an autonomous

decision taken by the students. This may be an effect of the culture of dialogue and collaboration already promoted by the teacher.

In conclusion, the analysis of the excerpts discussed in this section shows how the different space-time configurations emerging in students' perceptions during classroom teaching and distance education impacted their social interaction with classmates and peers. Nevertheless, they sometimes found creative solutions to include each other's voices in their activity despite the challenges encountered.

Meeting students' interests and passions

In this section, we provide some empirical illustrations of how the dialogically minded design of educational activities involving educational robotics, cloud-based animation software, and simplified visual programming software aligned with the interests and passions of several of the interviewed students.

During the interviews, several students reported that they particularly liked robotics kits based on building blocks as they liked to see their ideas "come alive" (e.g., Nando: *"I like to unleash my fantasy with the Lego model, and afterward I program it,*" Roland: "*for me, it is easier to build [the robot], it's more beautiful because I am able to represent my ideas*"). The open-ended task provided by the teacher (discussed above), together with the features of the technological tool, seems to provide a learning environment where the students feel free to creatively engage with the technology by expressing their own voice. The teacher confirmed that students' enthusiasm tends to "*go sky-high*" when he provides this type of robotics kits rather than with pre-assembled robots to be programmed. The students seem to appreciate the possibility of building robots according to their own inspiration rather than programming pre-assembled robots.

Cloud-based animation software also seems to align well with the interests and passions of some students. When Nando discovered this type of software program (introduced by the teacher), he decided to use it to create a comic strip on Charlemagne and the history of the Holy Roman Empire. In Nando's view, this particular use of the technology at school was connected to his own passions and interests: "*when I was younger, I already had this passion for ancient comic books, and then I saw the virtual ones, and I developed a passion for them.*" In this sense, these tools have supported playful learning processes, able to stimulate creativity and knowledge co-creation (Kangas, 2010).

One of the students, Max, clarified that expressing his own creativity through these technological tools was not immediate. Indeed, in Excerpt 8, while providing an example of peer support when he was helping a friend with educational robotics, he reflected on his own learning trajectory of using the technology.

Excerpt 8

> **Max:** for example, Matthew wanted to start building and since I had two different platforms for building, I loaned him one and he did some practice with it. For example, for building the first programmable small cars, an easy thing, it can be done with some instructions, at least when I learned it, I always followed the instructions. Then when you became more expert, then you can start building what you want, following your own fantasy…

In Excerpt 8, Max reflected on how he himself learned how to use the technology, which initially required some practice based on the instructions provided by the companies selling the robotics kits. Subsequently, he was able to follow his own fantasy creating the objects that he liked, but only after acquiring a good knowledge of the technology. In this sense, Max portrays his current creative engagement with educational robotics as an outcome of such a learning process.

The meetings with the teacher allowed us to uncover additional aspects related to the students' interests and passions. In particular, he claimed that while providing assistance and feedback to the students, he was also able to recognize their interests and passions and engage in a dialogic relationship with each student, even with some who are usually silent in class:

Excerpt 9

> **Teacher:** the first days when I observe them, a student like Max, he would be one who … well a professor at the beginning would not even give him a six ((out of 10)) because he is a reserved person, silent, he stays hidden in the back of the classroom, he does not say anything, he speaks only if he is summoned… and then there are instead those students that… you see them… that they are all show, while he is substance, he does not make a show, but you have to observe, otherwise… I don't really know how to explain […] Max… Since the first day of school, he brought me one small thing after the other… well, let's call them small things. He made himself known… […] when they [referring to Max and Roland] realized that they could bring me… that we could talk… that maybe we could make some things together, then they started arriving with these shoeboxes full of robots …

Excerpt 9 shows that the teacher perceives this approach to teaching as promoting the free expression of the students' interests and passions, even those normally silent. This allows the generation of a dialogical space where the students "bring" their creations to the teacher as tools that mediate a truly engaging dialogic relationship with him. This dialogic interaction allows the teacher to recognize the specific passions of each student, as shown in Excerpt 10:

Excerpt 10

> **Teacher:** every one of them has his own [passion]… there is the one who… the one of the mechanical art, he is obsessed with the transmission of motion, he likes to put cogwheels everywhere, … the other one is obsessed with arts, with legs, he wants to create a man and in the end he will do it… while Max likes different types of things, he goes from tracked vehicles to the car that can climb, he builds a bit of everything… the photovoltaic system…

The teacher often had the impression that when the students engaged with the open-ended collaborative activities, he was able to observe "their own selves" (Excerpt 11):

Excerpt 11

> Teacher: I like very much to observe them. I stay there with them. I observe them while… also while they are fighting inside the group … because then some leaderships emerge that you would not normally expect in a classroom. The student always shy, who is always silent, now is coordinating the whole group. Here [at school], they do not usually do a task like this; so, when I talk about this to their parents, they say 'yes, at home they are like that,' so maybe at school, they wear a mask, in the classroom, they tend to hide.… Instead, when we do an activity with robotics, their own self comes out, they are themselves. This is the thing that I like the most, in this way I get to know them better…

Excerpt 11 shows that the teacher considers tensions and conflicts emerging during the group work as a venue for the authentic self of each student to emerge. Such conflicts can be considered valuable from a dialogic pedagogy perspective. Indeed, it is exactly the tension and even conflict emerging in dialogical interaction that "fuels students' understanding and learning" (Kim & Wilkinson, 2019, p. 74). Interestingly, in this excerpt, the teacher becoming capable of seeing the authentic self of the students can also be considered an outcome of this dialogic tension.

Through these excerpts, we understand how the activities based on educational robotics, cloud-based animation software, and simplified visual programming software seem to build on the students'

genuine interest and are able to promote both the students' authentic expression as well as the dialogic interaction with the teacher and with peers.

Conclusions

In this article, we have discussed how a dialogic approach to the adoption of educational robotics, cloud-based animation software, and simplified visual programming software can provide valuable opportunities for opening a dialogic space where the students can express their own voices in interaction with both human and non-human Others. It appears that the open-ended nature of the task facilitated the connection of the educational activity with the students' interests and passions, thus promoting the expression of their own voices.

We also illuminated how chronotopes were particularly relevant since the educational activities were initially carried out in the classroom and suddenly were moved online during the lockdown caused by the pandemic. Therefore, the material world (including the virtual materiality of computer-generated objects) seems to play a twofold role in the educational activities we have examined. First, the resistance of the materials can contribute to the opening of a dialogical space "between the child and the world" (Biesta, 2012); second, a crucial aspect of the role of the material world resides in the chronotopic relations that function as a ground for learning and that through an "invisible mediation" (Authors, 2016) can have an impact on several aspects of the learning process.

We believe that this article addresses a research gap in the literature. Indeed, as discussed above, the early scholarship on making mainly focused on technical aspects and overlooked the social and cultural dimensions of mediated learning making activities, while the dialogical scholarship on the pedagogical use of technology did not pay enough attention to the material aspects of learning.

The analysis shows that fertile learning processes can emerge when the adoption of digital fabrication and programming technology is framed in the context of open-ended making-like activities where the students are free to express their own creative voices in dialogical interaction with both the material and the social world. It appears that the open-ended nature of the task facilitated the connection of the educational activity with the students' interests and passions, thus promoting the expression of their own voices. More research is needed to discuss the details of the teaching strategies that will demonstrate to promote dialogic learning when designing and implementing making-based educational activities. In particular, the collection and analysis of observational data, including video records of the participants' activity, would be valuable for enriching the polyphonic understanding of the processes examined in this article.

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