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The Complexity of Learning: Exploring the Interplay of Different Mediation Means in Group Learning with Digital Tools

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ABSTRACT

The relationship between the different mediational means for supporting students’ learning with digital tools in science group work in a Norwegian lower-secondary school is examined. Analyses of teacher-student and student-student interactions are located in cultural-historical theory and draw on Galperin’s conceptualisation of learning processes. Findings show that digital tools, task design, peer collaboration, and teacher’s interventions dialectically interplay to shape how learners use mediational means: (1) digital tools are the resources that enable students to explicate their (mis)understandings; (2) compare-and-contrast tasks promote analytical thinking; (3) peers present themselves as resources who promote development of conceptual understanding; (4) the teacher guides learners’ attention towards the potential of the mediational resources, elicits, organises, and structures students’ knowledge. The dialectical interplay of these mediational means creates a system that supports and guides students’ learning.

1. Introduction

The aim of this study is to examine the interplay of different mediational means, including digital tools, in supporting student learning in a classroom setting. Over the last few decades, studies have provided valuable insight into how students’ understanding of science concepts is enhanced in learning with digital tools. Many of these studies have emphasised various forms of digital learning environments and tools that can promote students’ learning. Examples include resources aimed at assisting conceptual reflection and scientific argumentation, such as simulations and transactive scripts (Linn & Eylon, 2011; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2013; Quintana et al., 2004). Some studies have shown the benefits of efficient structural support in task design for students’ learning (Lund & Rasmussen, 2010; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2012), others have explored the role of peer interaction in computer-based learning settings (Noroozi, Busstra et al., 2012; Schellens & Valcke, 2006; Stahl, 2006; Stahl, Koschmann, & Suthers, 2006; Wegerif, 1996). However, despite general agreement on the importance of teachers in group learning with digital tools (Urhahne, Schanje, Bell, Mansfield, & Holmes, 2010; Webb et al., 2009), surprisingly few studies scrutinise their pedagogic role (Strømme & Furberg, 2015).

While important to know, concepts in genetics are challenging for students (Brown, 1990; Lewis & Kattmann, 2004; Lewis, Leach, & Wood-Robinson, 2000; Mertens & Walker, 1992; Moll & Allen, 1987;
Slack & Stewart, 1990; Tsui & Treagust, 2003) and the subcellular processes of mitosis and meiosis are considered to be central to the development of understanding of biology (Kindfield, 1994). This study examines students’ development of conceptual understanding of mitosis and meiosis in group work with digital tools and the teacher’s facilitating of their learning. It was set in a lower-secondary school in Norway, where students aged 15–16 were undertaking classroom tasks on mitosis and meiosis as part of the genetics curriculum. The analyses to be presented reveal the complexity involved in students’ group learning with technology by drawing on cultural-historical theory (Edwards, 2005; Galperin, 1969; Hedegaard & Fleer, 2008; Vygotsky, 1981). In particular, the study introduces Galperin’s (1969) conceptual foundations and employs them as a tool for the analysis of student learning processes.

1.1. Research on Support Components of Students’ Learning

The field of computer supported collaborated learning (CSCL) is closely related to the present study. It is concerned with how information and communication technologies might support learning in groups (located and distributed) (Ludvigsen & Mørch, 2010; Noroozi, Biemans, Busstra, Mulder, & Chizari, 2011; Noroozi, Busstra, et al., 2012). A large number of studies have demonstrated that, in order to improve students’ learning outcomes in CSCL, attention should be paid to the nature of the learning processes. Concepts employed in these discussions include relevance, correctness, width and depth of discussion, justification, and reasoning (Noroozi et al., 2011), and external support in the form of scripts that scaffold learning in CSCL environments (Azevedo & Hadwin, 2005; Noroozi et al., 2011), where collaboration, epistemic, and argumentative scripts in digital environments are seen to scaffold students’ learning.

Collaboration scripts, for example, provide guidelines for how group members should collaborate to accomplish learning tasks (Weinberger, Stegmann, Fischer, & Mandl, 2007). They can be used to specify and sequence learners’ interaction strategies such as eliciting (asking critical questions) and transactivity (responding critically to their partners’ contributions) (Weinberger, Ertl, Fischer, & Mandl, 2005).

Epistemic scripts structure and sequence discourse activities with respect to content and task strategies (Weinberger, Ertl, et al., 2005; Weinberger & Fischer, 2006; Weinberger et al., 2007), which may help learners to construct arguments and contribute to solving problems (Noroozi et al., 2011). It has been shown that epistemic and collaborative scripts can reduce off-task activities and help students to discuss relevant ideas (Weinberger, Ertl, et al., 2005; Weinberger et al., 2007).

Argumentative scripts can be used to structure and formulate the construction of broad, deep, and justified arguments in CSCL environments (Stegmann, Weinberger, & Fischer, 2007; Weinberger et al., 2007). Studies have shown that argumentative scripts can lead to more elaborated, justified, deeper, and broader arguments, which in turn can effectively facilitate the discourse processes of knowledge construction when it comes to warranting and qualifying claims (Stegmann et al., 2007; Weinberger et al., 2007).

Collaboration, epistemic, and argumentative scripts have provided valuable structuring support for students’ learning, the present study therefore builds on this work by taking a cultural-historical perspective, which allows a wider focus on the tools that are used when working on tasks. The approach directs attention to the relationships between and the roles of both social and material support components in students’ learning in groups. The study reported here examined the relationships between and the role of the material digital animations and task design and social peer collaboration and teacher’s guidance in students’ learning.

Studies in this area have tended to examine the role of one support component, such as digital tools, peer collaboration, task, or teacher intervention. Several studies have reported a positive effect of using digital interactive animations, models, and simulations on students’ conceptual development (Rutten, van Joolingen, & van der Veen, 2012; Smetana & Bell, 2012; Williams, Montgomery, & Manokore, 2012). In particular, it has been argued that multiple external representations can provide unique benefits for learning complex new ideas (Ainsworth, 2006) and virtual labs can add valuable experimentation and visualisation components (Baltzis & Koukias, 2009; Kozma, 2003).
Peer collaboration is also identified as beneficial to the process of knowledge construction (Linn & Eylon, 2011; Scardamalia & Bereiter, 2006; Schellens & Valcke, 2006; Schellens, van Keer, Valcke, & de Wever, 2007). Again, a major focus is the learning process. While some researchers argue that student collaboration assists in developing inquiry learning skills (Van Joolingen et al., 2007), others point to the role of collaboration in the development of students’ ability to construct arguments (Linn & Eylon, 2011; Littleton & Howe, 2010; Noroozi, Biemans, Weinberger, Mulder, & Chizari, 2013; Noroozi, Teasley, Biemans, Weinberger, & Mulder, 2013; Noroozi, Weinberger, et al., 2012, 2013). Others, however, emphasise that this collaboration cannot be taken for granted and that students’ collaboration skills have to be developed, and certain rules of conducting a discourse have to be introduced to frame and make peer interaction productive (Howe et al., 2007; Mercer, 2010). Such effort appears worthwhile, as several studies indicate that peer collaboration can improve students’ conceptual understanding (Bell et al., 2007; Howe et al., 2007; Noroozi, Weinberger, et al., 2013; Rummel & Spada, 2005).

There has also been a long-term interest in task design. Cohen (1994) observed that challenging but clear tasks can stimulate learners’ collaborative skills; however, a strong structuring of the task might hamper the student collaboration. Other studies have suggested, nonetheless, that a clear task structure is needed to foster cognitive processing and academic performance (Dillenbourg, 2002; Roschelle & Pea, 1999; Weinberger, Reiserer, Ertl, Fischer, & Mandl, 2005).

The role of a teacher intervention in the technology-driven learning process, however, remains an area requiring more exploration (Greiffenhagen, 2012; Urhahne et al., 2010; Webb et al., 2009). Research suggests that teachers tend to work with individual students or small groups rather than do whole-class teaching (Chin & Hortin, 1993; David, 1991). Technology-rich classrooms are therefore often regarded as student-centred (Collins, 2001; Hancock & Betts, 1994) and the teacher’s role has shifted from being the source of information to being a coach (Sheingold & Tucker, 1990), facilitator (Chin & Hortin, 1993), and guide on the side (Cifuentes, 1997). In technology-driven classrooms, teachers may become concerned about creating a balance between answering requests for information and supporting students in utilising each other’s knowledge and understanding; balancing support at individual or group level; and directing students’ attention to coexisting conceptual perspectives (Strømme & Furberg, 2015). However, although the observations indicate a major change in how teachers may be able to work with students, studies tend to lack detail on what teachers actually do when interacting with students in these new conditions.

Attempts to shed light on the complexity of learning in technology-rich environments have been made by several researchers (Lund, 2009; Lund & Hauge, 2011). We have examined this complexity by placing the lens of cultural-historical theory, and in particular Galperin’s pedagogical phases (Galperin, 1969), on students’ group learning with digital tools. Analysis of student–student and student–teacher interactions from these perspectives allows an exploration of the relationship between and the role of material digital animations, task design, peer collaboration, and teacher interventions in an example of secondary school science learning.

### 1.2. Cultural-Historical Perspective on Learning

In examining the relationship between and the role of digital tools, task design, peer collaboration, and teacher interventions we have drawn on cultural-historical theory, which is based in the work of Vygotsky (1980) and those who picked up his legacy (Cole, 1988; Daniels, 2004; Edwards, 2005; Wertsch, 1986). In particular, it allows an examination of how tools, which may be social and linguistic as well as material artefacts, operate as meditational means that carry the meanings that are of value in a culture. There are some key premises to this approach. First, all deliberate actions are tool-mediated. Second, how tools are used will depend, at least in part, on how well the actor understands their potential. Third, learning involves increasingly informed use of these meditational means as learners make sense of and act in and on tasks. This approach therefore recognises that learning involves a continuous process of connecting individual sense-making with the public meanings that are valued in cultures. These cultures include curricula such as genetics.
There is considerable pedagogic potential in these basic Vygotskian ideas, some of which were taken forward by Galperin. In an attempt to resolve the dualistic dichotomies – individual versus social and external versus internal – Galperin suggested seeing learning as the gradual transformation of socially constructed mental activities (Arievitch, 2003) by identifying dialectically evolving phases of socially meaningful activity. In elaborating this transformation, Galperin suggested six dialectically linked phases of the pedagogic, teaching-learning, process: (1) motivation [motivacionnaya osnova deistviya], (2) orientation [orientirovochnaya osnova deistviya], (3) materialised action [deistviye v materialnoj forme], (4) communicated thinking [gromkaya socializirovannaya rech], (5) dialogical thinking [deistviye vo vneshnej rechi], and (6) acting mentally [skrytaya rech] (Galperin, 2002).

In the initial motivational phase, a learner’s attitude and relation to the learning outcomes that have to be achieved is formed. In the second orientation phase, Galperin identified three types of orientation: (1) incomplete, where mediational means are identified by learners through multiple trial and errors; (2) complete, where learners are informed about all the mediational means necessary to solve a particular problem; and (3) complete, but being constructed by learners themselves following a general approach. In the third phase of a materialised action, learners interact with material objects, and over time become less dependent on the material support they give and more aware of the meanings they carry. Speech becomes the main guiding tool in the fourth phase of communicated thinking. The fifth phase, dialogical thinking, establishes a dialogue of a learner with him or herself so that the action is being transformed mentally. In the final phase of acting mentally, an action has become a pure mental act, with the focus on the outcome of the action. The action is performed by means of mental images and concepts, which help a learner to deal with similar or differing situations on the basis of previous experience. Galperin was concerned with how mental activity, which originates in material activity, evolves through formal and informal instruction by adults (Haenen, 1996; Rambusch, 2006).

The importance placed on culturally-valued knowledge within cultural-historical theory is also relevant to the present study. Neither Vygotsky nor Galperin paid significant attention to curriculum, consequently we have turned to Schwab (1982) to clarify how curricular knowledge is defined in ways that are compatible with cultural historical approaches to pedagogy. Focusing on science education, Schwab pointed to the need to acquire both the substantive knowledge of a subject, made up of concepts and relations to each other, and syntactic knowledge, which is best seen as the ways of thinking and representing that are expected of experts in the subject (Edwards, 2014).

We suggest that these two types of knowledge help reveal the complexity of students’ progress as learners and the demands made on them as learners of curriculum subjects. The cultural historical view of conceptual development, which Galperin’s work exemplifies, is that a child’s psychological structure is always reflecting a relation to the social and the material (Chaiklin, 2003), where the learner is an active agent in that relationship. From this starting point we attempt to address the following research questions:

RQ1: What characterises the relationship between the digital tools, task design, peer collaboration, and teacher interventions in students’ learning?
RQ2: How do these mediational means support students’ development of conceptual understanding in Science?

2. Methods

2.1. Participants and Setting

A total of 76 year 10 students from two classes, a teacher, and three researchers participated in the project in spring 2014. The school was selected based on its previous successful participation in research projects. The two classes were taught by the same Science teacher, who followed similar teaching plans. The students studied the topic Genes and Inheritance for the period of 12 school hours over the course of four weeks. The teacher divided the classes into groups of four students that worked together during the whole project. Every Science lesson contained a combination of whole-class activities, individual work, and group activities. The teaching sequence over the four weeks is presented in Table 1.
A group task was designed by the researchers together with the teacher and integrated in the teaching flow on 12.03 (see Table 1). It followed a 60-minute teacher’s whole-class explanation session on mitosis and meiosis, supported by animations from Viten.no projected on the whiteboard. The task itself focused on building students’ conceptual understanding of normal and sex cells division (mitosis and meiosis, respectively) in group discussions using digital animations and a compare-and-contrast exercise. At the start of the group work the teacher handed out a task sheet to each of the students, who were sitting in groups of four. The students were asked to read the assignment carefully and, using the recommended digital resources, the textbook, and the diagrams provided in the task sheet, to describe in the course of group discussions the stages of mitosis and meiosis, compare them, and identify similarities and differences between these processes. The groups had 60 minutes to complete the task. Each group had a PC available and each student had to produce responses to the assignment by writing on the task sheet. The assignment contained two distinctive steps:

Step 1: The students were to give detailed descriptions of each of the stages of mitosis and meiosis. The diagrams of both of the processes were provided in the task sheet. The students were advised to use various digital resources located at: Viten.no,1 Tellus,2 Forskning.no,3 Biotechnologinemda.4 In addition, they could also use their Science textbook, Eureka! (Hannisdal & Haugan, 2008).

Step 2: The students were to compare and contrast the stages of mitosis and meiosis and outline the main differences and similarities of these two processes.

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1See: http://www.viten.no/vitenprogram/vsi.html?prgid=uuid%3A42241581-B892-15A9-626C-00000A2341CD&tid=1717509&grp=
2See: http://lokus123.lokus.no/static/flashEmbedder.jsp?contentitemid=37702931&selectedLanguageId=1&title=Celledeling
3See: http://intern.forskning.no/armfinn/kromozoomflash/kromozoom_nonpop.html
4See: http://www.bion.no/temaer/arv-og-genetikk/for-skoler/
The teacher, in his late-30s, had taught Science for 11 years and had a Master’s degree. During group activities the teacher circulated among the groups providing various types of support. Students’ answers in the task sheet were presented and summarised in the following lesson (on 17.03) during a whole-class discussion led by the teacher. The researchers did not intervene in the teaching. Ethnographic notes described the class observations were taken by the researchers.

2.2. Viten.no Environment

Despite of the variety of digital resources that were offered the students, Viten.no occupied the central place in this study. It is an Internet-based digital resource developed at the Science Centre at the University of Oslo (Jorde, 2003), containing sequences of programmes on topics included in the Norwegian secondary Science curriculum. The programmes contain textual information, illustrations, interactive tasks, and animations/simulations. In the present study, students were expected to use the programme “Cells.” The programme contains animations that progressively show the stages of mitosis and meiosis. Each stage is supplied with the textual information on the screen. Figure 1 shows the interface of the animation representing the first stage of meiosis.

2.3. Data and Analysis

Five mixed (gender and abilities) target groups of four students from different classes, selected by the teacher because they were verbally active, were videotaped at different times during the project. Another camera followed the teacher for the whole time. Twenty-three hours of transcribed video recordings constitute the data material of this study. Fieldnotes taken during class observations were used to contextualise the data collected (Derry et al., 2010).

A summary of the length of the video recordings is presented in Table 2. Groups 1–3 belong to one class, which was filmed during the whole project, while Groups 4 and 5 belong to another class which was filmed only when the students were working on the group tasks on 12.03 and 17.03. These learning situations were particularly interesting for us as the students engaged in the group task solving with digital tools supported by the teacher’s interventions.

Detailed analysis of interactions in Groups 3 and 5 (40.8 and 51 minutes, respectively) working on the task on mitosis and meiosis on 12.03 (see Table 1) were undertaken, along with the analysis of teacher’s interventions in these groups. Four interaction extracts are presented: two extracts of students’ interactions in Groups 3 and 5 and two extracts of the teacher’s interventions in these groups. These extracts represent typical students-student and student-teacher interactions that happened in groups and the exchanges represent different points in students’ understandings of the science concepts. The analysis explored the relationship between and the role of the social and material mediatio nal tools as students engaged with them.

<table>
<thead>
<tr>
<th>Group /teacher</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>174</td>
</tr>
<tr>
<td>Group 2</td>
<td>180</td>
</tr>
<tr>
<td>Group 3</td>
<td>174</td>
</tr>
<tr>
<td>Group 4</td>
<td>84</td>
</tr>
<tr>
<td>Group 5</td>
<td>84</td>
</tr>
<tr>
<td>Teacher (whole-class teaching and group interventions)</td>
<td>678</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1374</strong></td>
</tr>
</tbody>
</table>

The initial analytical procedure was inspired by interaction analysis, where interactions between interlocutors are analysed sequentially (Jordan & Henderson, 1995). Each utterance was analysed in relation to the previous one in the ongoing interaction. The primary unit of analysis was sequences and turns within sequences rather than isolated utterances (Linell, 2009). Therefore, analytical descriptions are oriented toward the interactional achievements of the participants. This approach implies that the focus is not on the meaning of single utterances but instead on how meaning is created within the exchange of utterances (Mercer, 2010). The description of the setting precedes each interaction sequence (Geertz, 1973), which provides situational meaning for the chosen extracts. The analysis was performed in two steps (Linell, 1998; Roschelle, 1992): in the first step we described what happened in the interaction sequences by referring to the distinctive lines of interactions and in the second step we analysed the interactions from the perspective of co-construction of understanding and the relationships between and the role of material and social mediational means in students’ learning. Once the interaction analysis was completed, the interactions were examined through the analytic lens offered by Galperin’s dialectically linked pedagogic phases to begin to unpack how the meditational means supported students at different times of the learning process. Such use of Galperin’s theory was innovative and we were interested to explore whether the lens of the dialectically linked pedagogic phases would help in our analysis of the complexity of students’ group learning in Science with digital tools. The video recordings were transcribed according to the Jeffersonian transcription notations (Atkinson & Heritage, 1984) (Appendix, Table A1). The discourse was conducted in Norwegian and the material presented in the study was translated by the wider research team.

3. Results

In the extracts presented, the students are studying the topic Genes and Inheritance. They have already been introduced to the scientific concepts of DNA, genes, chromosomes, bases, amino
acids, proteins, phenotype, and genotype. The teacher has just finished his whole-class explanation of the processes of mitosis and meiosis. The students are sitting around the tables in the groups of four and working on the task (see section 2.1) assigned by the teacher.

3.1. Analysis of Students’ Interactions of Group 5 and the Teacher’s Interventions in this Group

Extract 1a presents the teacher’s intervention right at the beginning of the group work. The students have just read the text of the assignment – according to Galperin’s phases the students are in the orientation phase. We start when the teacher approaches the group while circulating in the class.

Extract 1a:

1. Teacher: Use the task sheet, please!
2. Danny: I am just drawing the diagrams.
3. Teacher: Do you understand what happens at the beginning?
4. Kelly: Yes, how the chromosomes – the difference between normal cells and sex cells. The number of the chromosomes that divide: there will be just 46 and 46 chromosomes ((points at the mother and daughter cells in mitosis)), but here there will be 23 from 46 ((points at the daughter and mother cells in meiosis)).
5. Teacher: OK, right. So you are on the differences. Do you know what happens at the very stages of these processes?
6. Felix: It was difficult to see what happens when you showed Viten during your explanation. I was sitting at the back and saw only black dots, so I did not get anything. But here we can see everything very clearly ((looks at the diagrams in the task sheet)).
7. Teacher: Yes.

Right at the start of their work, the teacher encourages the students to write their answers in their task sheets (line 1), although Danny chooses to draw the diagrams in his exercise book (line 2). In response to the teacher’s attempt to check students’ understanding of his explanation during the whole-class session (line 3), Kelly summarises one of the differences between mitosis and meiosis (line 4). The teacher draws students’ attention to the actual stages of mitosis and meiosis (line 5). Felix complains that he had some difficulties seeing the animation during the whole-class session, but looking at the diagrams in the task sheet, he confirms that he can distinguish the stages of the processes (line 6).

What makes the teacher’s intervention important right at the beginning of students’ learning in the so-called orientation phase (Galperin, 2002)? One way of interpreting this is that the teacher’s intention is to ensure that the students understand the task and follow the steps of the assignment consecutively. Doing so may bring the students to the same starting point and build common grounds for further productive peer collaboration. Danny prefers to draw his own diagrams in his exercise book, which eliminates him from the group discussion. He joins the conversation when he has finished drawing and only then is he able to participate and contribute. The teacher performs a guiding role, and this function is of particular importance in the orientation phase as it creates a basis for the establishment and presence of the support tools to assist students’ learning. Moreover, by encouraging the students to use their task sheets, the teacher emphasises the potential of the task as a mediatational resource.

The events in Extract 1b chronologically follow the events in Extract 1a. The students of Group 5 are attempting to turn the laptop on; however, this takes long time. While waiting for the laptop to load, they start discussing the task based on the teacher’s explanation, the notes they have taken, and the Viten.no animation they saw on the screen during the whole-class explanation session. Being involved in the group discussion, the students are in the phase of communicative thinking (Galperin, 2002).

Extract 1b:

1. Adam: The first thing in meiosis is that it reduces the number by half, right? I mean the number of the chromosomes.
2. Kelly: Yes, meiosis is reduction division.
3. Adam: The first stage –
4. Felix: The first stage is exactly the same as in normal cell division.
5. Adam: DNA is copied –
6. Felix: Each chromosome makes a copy of itself and the membrane of the nucleus of the cell dissolves. Then they come together –
7. Adam: DNA is copied and it torques into chromosomes again afterwards.
8. Felix: Yes, here each of the chromosomes makes a copy of itself and they get closely together for recombination. The chromosomes exchange small parts of the DNA and they divide first into two new cells and then into four cells. This is exactly the same as in the picture. What did he [teacher] say about this at the beginning?
9. Adam: (writing) The chromosomes exchange genes, can we say so?
10. Felix: Yes, we can say so in the process of recombination. But you see here, in a normal cell division, two new cells are formed that are completely finished (points at the daughter cells in mitosis in the task sheet) and here two cells are formed that are pulled from each other at once (points at the daughter cells in meiosis). They repeat the process again straight away.
11. Adam: Here there won’t be copies, but four new cells, versus two identical cells here.
12. Felix: Here they divide at once, so they aren’t copies of the original cell, but four new cells. If they did it one more time again, there would have been two completely identical cells produced, exactly the same as those two (points at the daughter cells in meiosis). But in this case four different cells are produced.

Adam points out that the process of meiosis leads to the reduction of the number of chromosomes by half (line 1), which Kelly summarises as a reduction division (line 2). By eliciting each other’s reasoning (lines 3–11), Adam and Felix give an account of the stages of meiosis, comparing them with mitosis, and Felix concludes that four completely different cells form, versus mitosis where two identical daughter cells are produced (line 12).

The interacting learners are moving between the phases of a materialised action and communicated thinking (Galperin, 2002) and the impact of the compare-and-contrast task is reflected in the way the students conduct their discourse by drawing parallels between the processes. In lines 10, 11, and 12, Felix and Adam compare the daughter cells form in mitosis and meiosis and emphasise the differences in these cells. With this, the compare-and-contrast task promotes scientific thinking. The boys take leading roles in the discourse and there are numerous examples of how these students extend each other’s accounts: lines 3 and 4, 5 and 6, 7 and 8, 9 and 10, 11 and 12. By eliciting their ideas, the peers present themselves as a resource that promotes development of their conceptual understanding. Hence, the task design, requiring compare-and-contrast, affects students’ discourse and is linked with the peer collaboration.

In the phases of a materialised action and communicated thinking (Galperin, 2002) the students rely on the diagrams provided in the task sheet to support their explanations. Felix identifies the process of recombination with its representation in the diagram in the task sheet (line 10), and he refers to the diagrams to compare the daughter cells produced in mitosis and meiosis and outline the differences between them. By using the diagrams, Felix makes his thinking visible for other students, supported with the pictures, his ideas transform into concepts accessible by his peers. Diagrams assist and shape students’ discourse and hence, peer collaboration.

Summing up, Extract 1a highlights the role of the teacher as a facilitator of students’ learning in the orientation phase that establishes grounds for the use of mediational tools and reveals their potential as support components. Extract 1b reveals the dialectical interplay of the task design, and peer collaboration in the phases of a materialised action and communicated thinking. Digital tools are present indirectly in this extract as a source of scientific knowledge, which students acquired during the whole-class teaching session and which they elicit through interactions with the diagrams provided in the task sheet. This intertwines the diagrams as mediational tools into the interplay of peer collaboration and task design in the support of students’ acquisition of substantive and syntactic knowledge (Schwab, 1982).

3.2. Analysis of Students’ Interactions in Group 3 and the Teacher’s Interventions in this Group

In Extract 2a, the students are in the middle of their discussion of the process of meiosis using the animation from Viten.no. In the phase of a materialised action (Galperin, 2002) the girls Mira and
Helena have already looked through the stages of the animation of meiosis, however, they struggle to understand why chromosomes produced in meiosis are different. At this point Chris joins the conversation. We enter when Chris turns to the textbook and supports his explanation by pointing at the picture showing 23 pairs of chromosomes present in a human cell.

Extract 2a:

1. Chris: Let me show you. I’ve got a diagram. Here is a picture of all the chromosomes ([shows in the textbook Eureka]). In a normal cell division [mitosis], for example, they make only two, they copy themselves. In the next stage, they copy themselves up to four – two of each. So, each of these chromosomes goes to one of the cells. At the end both of the cells have both of those two. But here [in meiosis] they make copies of themselves, so they double, two of them go here, to one cell and two of them go there, to another cell.
2. Helene: And they divide again.
3. Chris: And they divide again, so some of the cells get one of these and some of the cells get one of these. So, one cell gets 23 chromosomes that come randomly, they can be one of these and one of these and one of these ([points at the diagram in Eureka]). They are randomly important here. So for each pair of chromosomes, you get one of these chromosomes.
5. Mira: ([looks at the screen – animation stage E]) Do you get one of these? Are you thinking of these? ([points at the screen on the single chromosomes that appear in each of the daughter cells]). And they don’t divide any more. I still do not understand is it just me, or–
6. Chris: Go back to C. What is important here: think about this as one chromosome ([points at the screen at the copied chromosomes]). This is only a copy, so this is one chromosome and this is one chromosome. And these two is a pair of chromosomes – go to the start.
7. Mira: Is this, for example, a copy of this? ([points at the blue and the red chromosomes on the screen])
8. Chris: No! These two blue are just one chromosome with two identical – This is a copy of that one ([points at the blue chromosomes]).
9. Mira: Yes, this is a copy of that one ([points at the blue chromosomes]).
10. Chris: Yes, in fact, it’s just one blue and one red that make a pair of chromosomes.
11. Helene: In a normal process of mitosis.
12. Chris: Yes. So, now in E – If this was a normal process of cell division, this part would have replaced that part and this part would have replaced that part ([points at the red and blue stripes on the chromosomes]), so you would have had two similar chromosomes.
14. Chris: So, now you have one pair of chromosomes and another pair of chromosomes, they are not similar. And they divide again, so each half turns into a full chromosome, but they are a bit different now, they have mixed with each other.
15. Mira: Yes, there are red and blue lines here and there.

Using a diagram in the textbook that shows a photo of 23 pairs of chromosomes, Chris describes the stages of mitosis and points out that in meiosis, an extra division occurs (line 3). He turns to the animation to explain the difference between the copied chromosomes and the homologue pairs (line 6). Helene adds that these chromosomes would have been of the same colour in the process of mitosis (line 11) and Chris emphasises the different structure of the chromosomes in mitosis and meiosis (line 12). Mira provides more details that show her understanding – she mentions the red and blue lines on the chromosomes that reflect these differences (line 15).

According to Galperin’s phases of a teaching-learning process, the students interacting with material resources supported by group discussions are making the transition from the phase of a materialised action to the phase of communicated thinking (Galperin, 2002). A more knowledgeable student, Chris, joins the conversation and emphasises that at the first stage the chromosomes copy, whereas recombination happens at the second stage of meiosis (lines 12, 14). He explains that this makes one of the fundamental differences between meiosis and mitosis and gives an answer to the problem stated in the assignment.

The steps of the task are important components that allow students to form their understanding of mitosis and meiosis. The compare-and-contrast task draws students’ attention to identifying the differences between the scientific phenomena, which enhances students’ attention to detail and promotes development of their conceptual understanding. The way the students conduct their discourse is of particular interest: Chris builds his explanation of the stages of meiosis, comparing them with the stages of mitosis (lines 1, 12). In this way he helps other students to shape their understanding of meiosis and at the same time solve the task. Chris explains the differences between the processes and the structure of the chromosomes (lines 1, 6, 8, 10, 12, and 14), Mira poses critical questions (lines 5, 7), Helene follows
Chris’s explanation attentively and appears to echo his thoughts on various occasions, as in lines 2 and 11. In this way the compare-and-contrast task does not only promote analytical thinking, but it affects the whole discourse among the students and, hence, peer collaboration.

In the phases of a materialised action and communicated thinking (Galperin, 2002), Chris draws on the digital animations presenting the stages of meiosis to compare them with mitosis, which allows other members of the group to visualise the processes and follow the explanation he gives. Chris refers to stage E of the animation to emphasise when the differences between the processes start to occur (line 13). Supported by the animations, the words of Chris offer a particular meaning and there is evidence of conceptual grasp on the part of Mira and Helene. This grasp is expressed in words as Mira confirms her understanding in line 15.

Chris, Helene, and Mira contribute to solving the task, their conversation is shaped by the assignment, and the digital animations help the students to elicit any (mis)understandings. The compare-and-contrast task shapes the way the digital tools are used, while peer collaboration in the phases of a materialised action and communicated thinking (Galperin, 2002) establishes a connection between the digital tools and the task design. This interplay of the digital animations, task, and peer collaboration promotes the development of students’ substantive and syntactic knowledge (Schwab, 1982).

In Extract 2b, the students of group 3 are in the middle of writing the differences between mitosis and meiosis in their answer sheets, they are in the transfer from communicative to dialogical thinking (Galperin, 2002). The teacher approaches the group and intervenes in their work:

**Extract 2b:**

1. Teacher: Are you in the middle of describing the differences?
2. Helene: Yes, this is a difficult phenomenon.
3. Teacher: Yes, and if you compare these two processes – what happens with the chromosomes? What is the result?
4. Helene: Well, I think the main point is that they divide one extra time comparing to the previous process.
5. Teacher: Yes.
6. Helene: And DNA–
7. Chris: It makes DNA to copy the same number of times as in mitosis, but the cell divides four times. There will be 46 chromosomes in two cells as they divide an extra time. So, each chromosome doubles, copies itself once, but divides twice, therefore there will be 23 chromosomes in each cell.
8. Teacher: Yes, it looks quite easy, what happens here ([points at the diagram of mitosis])? How many chromosomes are there?
10. Teacher: 23 (?) pairs?
11. Helene: Yes.
12. Teacher: Are these daughter cells similar to those ([points at the mother cells])? Are there 23 pairs too ([points at the diagram of meiosis])?
13. Helene: Here, we’ve got 23 pairs, right ([points at the mother cell])? And here we’ve got 23 pairs divided by 2, haven’t we?
14. Teacher: Here are 46 single chromosomes.
15. Mira: And there will be 23 single chromosomes.
16. Helene: 23 in each of them, right ([points at the diagram])?
17. Teacher: Half of the number that was at the beginning.
18. Mira: Because they divide an extra time.
19. Teacher: So, this is the difference. And this is an important difference. The number of the chromosomes reduces twice. Here the daughter cells are identical to their mother cell ([points at the diagram of mitosis]), but what about those cells comparing to this one ([points at the daughter cells and the mother cell in meiosis])? [...]
20. Mira: Are they different sex cells’ chromosomes?
21. Teacher: This too. They are also different. This is an important difference between these two processes of cell division. Look at these two processes, what about the number of cells produced?
22. Mira: Can you repeat it?
23. Teacher: OK, how many cells have you got here ([points at the daughter cells in mitosis])? One cell divides up to two. Here ([points at meiosis]) one cell divides up to–
24. Helene: Four.
25. Teacher: Right! Do you see the difference?
27. Helene: Yes.
28. Teacher: What about the similarities? ([goes away from the group])

Having received an account of students’ progress and a summary of the reduction division, the teacher asks about the number of chromosomes in mitosis (line 8). He draws students’ attention to the
number of chromosomes in the daughter and mother cell in mitosis and meiosis (line 12) and summarises students’ ideas in the statement about 46 single chromosomes at the beginning (line 14). Mira and Helene extend the teacher’s thought by reporting on the number of chromosomes in the daughter cells (lines 15, 16). The teacher concludes that the number of chromosomes in meiosis reduces by half (line 17), which is different in mitosis. In conclusion, he emphasises that the chromosomes are not similar in the daughter cells, which constitutes another difference in meiosis (line 21).

The teacher joins in when the students are in the middle of working on their task, they have employed the digital tools in the phase of a materialised action and have established collaboration within the group in the phase of communicated thinking (Galperin, 2002). Having received a detailed description of the stages of meiosis from Chris, he poses the question that requires comparing, by pinpointing the stages of the processes where the differences occur and, hence, promotes scientific thinking in the group. The teacher relies on various mediational tools, he refers to the diagrams in the task sheet to support his questions and make them visual, and he creates a pattern in his sentence by pointing at the number of chromosomes in the cells in mitosis (line 12) that prompts the students with the right answer (lines 13–18). In the phase of communicated thinking (Galperin, 2002), the students imitate their teacher, they use the pattern created and come up with the right answer. The pattern makes the teacher’s thinking accessible to the learners.

Summing up, the analysis of interactions in Group 3 suggests that the teacher intervention in the phase of communicated thinking establishes a dialectical link with the peer collaboration, task design, and digital tools, which in turn interplay and determine each other. In this interplay, the teacher has a guiding function, helping the students to structure their knowledge and complete the task. Extracts 2a and 2b therefore demonstrate the dialectical interplay of social and material mediational tools supporting students’ acquisition of substantive and syntactic knowledge (Schwab, 1982) in the phases of a materialised action and communicated thinking (Galperin, 2002).

4. Discussion

This study has attempted to conceptualise the interplay of mediational means in supporting students’ learning in a group setting in Science. Taking a cultural-historical perspective and employing Galperin’s pedagogic phases, it has examined student involvement in classroom interactions in order to identify whether and how students engage in and with an array of mediational tools comprising digital tools, task design, peer collaborations, and teacher interventions. The analysis of the interactions revealed a dialectical interplay between these mediational tools to the extent that they shape how each is used to support student learning. In this section, the findings are discussed in relation to previous research. The practical implications for teachers’ design of learning situations with digital tools are then outlined.

First, the analyses discussed above have shown that the compare-and-contrast task in the phases of a materialised action and communicated thinking (Galperin, 2002) was not simply a matter of improving student collaboration (Cohen, 1994). Rather, the compare-and-contrast design drew students’ attention to the details between the scientific phenomena and promoted development of conceptual understanding. The compare-and-contrast design shaped the discourse in both of the groups, where peer collaboration was directed at solving the task. The task design presupposed the development of students’ discussions in the phase of communicated thinking, establishing a dialectical link between the task design and the peer collaboration.

Second, the task design offered possibilities for the way the digital tools were utilised. Extract 2a served as a good example of this process. In the phase of a materialised action (Galperin, 2002) the students turned to the programme Viten.no, as advised in the task sheet, to build their understanding of mitosis and meiosis. Digital tools assisted Chris, Helene, and Mira in eliciting their misunderstandings in the phase of communicated thinking, the tools helped them to visualise abstract scientific phenomena, identify the differences between the processes, and, hence, build their conceptual
understanding. In Extract 2b, digital tools were present indirectly as a source of information for the students during the whole-class teaching session. The learners relied on this information when solving the task and making sense of the diagrams presented in the task sheet. Indeed, in the phase of communicated thinking (Galperin, 2002), the students of Group 5 used the diagrams to co-construct their knowledge.

With this, the task design dialectically contributed to the way the digital tools were utilised by Group 3 and the diagrams were used in Group 5. While the task design was interacting with the use of visual displays, peer discourse in the phase of communicated thinking was evidenced as an arena to discuss these visualisations, display ideas, make thinking visible, and contribute to the joint construction of knowledge (Linn & Eylon, 2011; Mercer, 2010; Mercer & Wegerif, 1999; Scardamalia & Bereiter, 2006). The use of digital tools and the pictorial diagrams in the phase of a materialised action stimulated peer discourse in the phase of communicated thinking. Hence, peer collaboration was shaped by the digital tools, the diagrams in the task sheet, and the task design, allowing us to trace a dialectical link between these mediational means.

Third, the analysis performed in this study indicates the contributions of the teacher’s interventions (Chin & Hortin, 1993; Collins, 2001; David, 1991; Hancock & Betts, 1994), where the teacher, as a mediational mean, fulfils a range of different functions at different points in students’ sense-making. Extract 1a showed how the teacher worked at building a common recognition of the mediational support tools available to the students, exemplifying the orientation phase of the teaching and learning process (Galperin, 2002). By clarifying the details of the task design and emphasising the digital tools, the teacher ensured the presence of these mediational means in students’ learning. In doing so, he helped to promote peer collaboration within the group and students’ engagement with the available mediational means.

Extract 2b demonstrated the role of the teacher’s intervention in the phase of communicated thinking (Galperin, 2002). The teacher created a pattern for analysis that students followed when outlining the differences between the processes of mitosis and meiosis. In doing so, the teacher helped the students to organise and structure their knowledge and complete the task. The teacher’s intervention was shaped by the task design and hence, dialectically linked with it. At the same time, the teacher’s intervention influenced the student discourse, affecting peer collaboration. The teacher supported his explanations with the diagrams in the task sheet and relied on the understandings the students gained in the phase of a materialised action when working with digital animations. In this way, the teacher’s intervention was integrated into the interplay of the task design, digital tools, and peer collaboration, and established a dialectical link with them. However, the analysis has shown that the teacher’s interventions appeared to be important for different reasons at different stages in students’ sense-making. It therefore suggests the need for further research scrutinising the role of the teacher at different phases of students’ learning with digital tools.

5. Conclusion and Implications

Our attempt to conceptualise the complexity of group learning with digital tools offers an account of the dialectical interplay of the mediational means of task design, peer collaboration, teacher interventions, and digital tools to create a structure that supports and guides students’ engagement with the curriculum. The analysis has shown that the dialectical interplay of the mediational means allows for students acquiring the relevant substantive knowledge of the concepts of mitosis and meiosis and their relations to each other, together with the syntactic knowledge (Schwab, 1982) of scientific thinking in the form of analytical comparing and contrasting.

There are several implications arising from the study for how we approach classroom pedagogy. First, understanding the dialectic nature of learning alerts one to some of the challenges of teaching in digital environments. The analysis performed in this study revealed the structure created by the interplay of the material digital tools and task design and social peer collaboration and teacher’s intervention that supported and guided students’ learning. This structure appeared to be sensitive
to the learners’ needs. For example, other mediational tools may enter the system and replace some of the components permanently or stay in the system for a period of time, providing temporary support. This happened in Extract 1b, where students used diagrams in the task sheet to build their understanding of mitosis and meiosis.

The second, and perhaps more profound, implication of the dialectical link between material and social mediational tools in supporting and guiding students’ learning is the emphasis the analysis places on the system created through the dialectical interplay of the different meditational means. These dialectical links give rise to how each of the mediational tools assists learning: (1) the digital tools were used as depictive resources that enabled students to explicate their (mis)understandings; (2) the compare-and-contrast task guided students’ attention towards the similarities and differences in mitosis and meiosis and promoted learners’ scientific thinking; (3) peers elicited mutual ideas and understandings and presented themselves as resources, which promoted development of students’ conceptual understanding; (4) the teacher guided learners’ attention towards the potential of the mediational resources, elicited, organized, and structured students’ knowledge.

The recognition of the dialectical relationships in the system of interplaying meditational means both draws on and gives support to Galperin’s detailed attention to the dialectically linked phases involved in learning in formal settings. In particular, the analysis here has shown that in the phases of orientation, materialised action, and communicative thinking, the dialectical interplay of material and social mediational tools shapes how each of them is used by learners.

The third implication, which is only tentatively indicated in the present study, is the role of the teacher at different points in the teaching-learning process: in guiding the students towards the potential offered by the material resources and enabling peer collaboration in the orientation phase, in and organising students’ conceptual understanding in the phase of communicated thinking (Galperin, 2002).

The fourth implication arises from the employment of Galperin’s theory in this study. It appeared to be useful as a tool for the analysis of students’ learning processes. Galperin’s dialectically linked pedagogical phases were a helpful addition to the method inspired by interaction analysis to understand what students did at different times as they progressed in their learning. We suggest that this approach may offer new pathways for the use of Galperin’s conceptual contribution in further research exploring teaching-learning process and designing of learning activities.

These findings therefore have implications for learning designs with digital tools, suggesting the importance of accommodating material and social support components. They also suggest that further research is needed to examine the role of the teacher at different phases of learning with digital tools.

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References


## Appendix

### Table A1. Transcript conventions

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ ]</td>
<td>Text in square brackets represents clarifying information</td>
</tr>
<tr>
<td>=</td>
<td>Indicates the break and subsequent continuation of a single utterance</td>
</tr>
<tr>
<td>?</td>
<td>Rising intonation</td>
</tr>
<tr>
<td>:</td>
<td>Indicates prolongation of a sound</td>
</tr>
<tr>
<td>()</td>
<td>Short pause in the speech</td>
</tr>
<tr>
<td>[...]</td>
<td>Utterances removed from the original dialog</td>
</tr>
<tr>
<td>-</td>
<td>Single dash in the middle of a word denotes that the speaker interrupts herself</td>
</tr>
<tr>
<td>–</td>
<td>Double dash at the end of an utterance indicates that the speaker's utterance is incomplete</td>
</tr>
<tr>
<td>(italic)</td>
<td>Annotation of non-verbal activity</td>
</tr>
</tbody>
</table>