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A Cultural-Historical Perspective on How Double Stimulation Triggers Expansive Learning

SPECIAL COLLECTION: DESIGN, LEARNING AND INNOVATION: FRAMEWORKS AND USES

RESEARCH

How Teachers and Social Educators Can Use Double Stimulation to Implement Computational Thinking in Mathematics

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ABSTRACT

Computational thinking (CT) has become central to introducing digital artefacts for educational use. However, little is known about implementing CT in the mathematical school curriculum, and many educational staff members have not been introduced to CT in their initial training. Introducing CT in an educational setting calls for interventions that allow educational staff to adopt new concepts and to explore ways of implementing CT and digital artefacts to support students' computational and mathematical understanding. This article focuses on formative interventions applied in the form of *Change Laboratory* to implement digital artefacts with a particular interest with regard to educational staff's expansive learning processes. To foster such expansive learning processes, double stimulation methods were introduced to enable educational staff to analyse and reflect on their work practices collectively. The research was conducted as an ethnographic intervention study in a primary school in Denmark. It began in 2019 and was completed in 2021. Participants were primary school students followed from 2nd grade to 3rd, alongside their math teacher and social educator. The data consisted of five Change Laboratory sessions fully transcribed from video recordings, including classroom activities between sessions. Through a Cultural Historical Activity Theory lens, the article concludes that by mapping educational staff's expansive learning actions, it is possible to identify how the participants collectively change their activities or not. Thus, analysing which phase of double stimulation that triggers a specific learning action provides knowledge about integrating CT and digital artefacts to support mathematical understanding.

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KEYWORDS:

Activity system; Change laboratory; Computational thinking; Digital artefacts; Mathematical understanding

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1 INTRODUCTION

Digital artefacts such as robots and technology-enhanced learning environments have recently aroused educational interest, and computational thinking (CT) has been used as an approach to a new learning paradigm. According to Gadanidis et al., (2017), there is a natural and historical link between CT and the mathematical discipline in logical structures and the ability to model mathematical problems. When students explore mathematical problems using computational problem-solving strategies, such as programming, algorithmic thinking and creating computational abstractions, it can help them gain a deeper understanding of mathematical problems (Pérez, 2018). From these points of view, it is important not only to learn about arithmetic but also to learn to think like a mathematician (Pérez, 2018; Grover and Pea, 2018). Jeanette Wing (2006) described CT as a way of 'solving problems, designing systems, and understanding human behaviour by drawing on concepts fundamental to computer science' (p.33). CT can be seen as a 21st-century skill that can help students to understand and take advantage of computing in many different domains. It also provides a way to learn to think like a computer scientist and to develop a specific set of problem-solving skills to create solutions that can be performed by a computer or an information-processing agent (Grover and Pea, 2018; Cuny et al., 2010). However, using CT to teach school subjects is challenging due to a lack of qualified teachers who can teach CT as a subject (Menekse, 2015). Given this shortcoming, it is important to investigate how educational staff as a part of their professional development, can develop CT practices to be used in their teaching (Lee et al., 2011). Not only should educational staff be offered professional development courses, as stated by Black et al. (2013), but they should also be provided with ongoing support and resources to share teaching designs and experiences with colleagues. According to Virkkunen (2006), such activities must be profoundly and qualitatively transformed when new technology and concepts are introduced.

Thus, introducing new concepts calls for intervention methods that allow participants to adopt new concepts and to identify needs for change in relation to their teaching. This could as posit be related to an activity system, which through its basic structure, consisting of subject, object, and artefact, offers a unit of analysis for understanding human actions (Vygotsky, 1978). This way of defining an activity system has lately been expanded to include the features of rules, community, and division of labour (Engeström, 2016). In the context of activity system, Change Laboratory (CL) is used as an intervention method to help participants breaking away from given frames of action, collectively transforming an activity, and supporting shared transformative agency.

In the present study, the concept of agency is considered as a process where individual actions become sustained through transformed collective activity systems. This is aligned to how agency is applied within the Cultural-Historical Activity Theory (CHAT), where transformative agency typically develops through a stepwise process facilitated by various iterations of double stimulation loops. In this way, agency is tapped and supported by double stimulation, which constitutes a crucial method in CL as it step by step supports participants to take volitional action. Moreover, double stimulation informs the process of how new and potentially unstable concepts can become stable and a part of participants' everyday actions (Sannino, 2015; Portes et al., 1997).

1.1 PURPOSE AND RESEARCH QUESTIONS

This paper focuses on how educational staff utilises double stimulation to trigger expansive learning actions and how they collectively develop an understanding of using CT and digital artefacts in mathematics. By expansive learning, we refer to how educational staff deals with and learn something that is not yet there (Engeström, 2016). Through this, we target a contribution to the discussion of using double stimulation in formative interventions. This led to the following research questions:

- How can the methods of double stimulation support educational staff in their development of an expansive learning process; and
- What phases of double stimulation trigger specific learning action in the implementation of computational thinking in mathematics?

In answering these questions, the paper describes how CL interventions were carried out to operationalise an analysis of the participants' dialogue while implementing CT in mathematics. The analytical focus intends to identify the four phases of double stimulation and expansive learning actions in five sessions of a CL intervention.

In the following section, we present the background to the study and describe the theoretical framework. Next, a summary of the performed CL interventions to provide a context for the analysis. This is followed by a description of the methodology and context of the research. Finally, the outcomes of the study are presented, followed by a conclusive discussion.

2 BACKGROUND AND RELATED WORK

CL is a formative intervention method based on the theory of expansive learning (Engeström, 1987, 2007; Virkkunen and Newnham, 2013) and has been widely used for promoting innovation and organisational learning. Previous studies including the CL method have been applied in different practices, ranging from libraries (Engeström et al., 2013) to hospitals (Skipper et al., 2016), innovation management (Lund and Juujärvi, 2015), social welfare (Edwards et al., 2009), and education (Bligh and Flood, 2015; Morselli, 2019; Morris et al., 2021).

In the context of the present study, the CL method is applied as a resource for supporting educational staff in developing ways of using CT and digital artefacts in their math teaching activities. By means of CL they can analyse their existing work practice and identify critical tensions and contradictions, and collectively develop new ways of working (Engeström, 2001; Engeström and Sannino, 2010). This way of analysing tensions and contradictions to explore and model new forms of working happens in a cyclical manner and forms the basis of Engeström's theory of expansive learning (Engeström, 2001). Here, tensions and contradictions are considered as triggers of expansive learning if the participants can co-create a solution based on new forms of work activity (Engeström, 2011; Virkkunen and Newnham, 2013; Engeström and Pyörälä, 2021). This relates to the conceptualisation of double stimulation (Sannino, 2015; Vygotsky, 1987), which is considered as central to nurturing this kind of expansive learning cycles (Engeström, 2001). As the principle indicates, the stimulus is in two parts, where the first stimulus consists of four phases and relates to mirror data and the second to mediating conceptual tools (Vygotsky, 1987). This is further elaborated in the theoretical framework section.

To elaborate the concept behind double stimulation, Annalisa Sannino (Sannino, 2015) presented a detailed model of double stimulation. This model was backed up with empirical findings from two experiments built on Vygotsky's (1997) 'waiting experiment'; one conducted with individuals (Sannino and Laitinen, 2015) and one with groups (Sannino, 2015). After that, several scholars have tested and further developed the double stimulation methods in various fields of practices (Engeström et al., 2020). Morselli (2019) developed Sannino's model of double stimulation into a CL intervention study with in-service teachers. He concluded that all four phases of the double stimulation model appeared at the workshops, supporting the theory of expansive learning. This intervention was elaborated further in Moselli and Sannino (2020), who concluded that the four phases of double stimulation do not follow the model in strict order and that the four phases were not reduced to a single session. Studies (Engeström et al., 2020; Sannino, 2015) show that the iterative mediation between the phases included in double stimulation processes are essential to connect the method and expansive learning potentials.

Considering the somewhat fuzzy matter of dealing with CT and digital artefacts in teaching and learning of mathematics, it is critical to study how educational staff's learning can be promoted throughout the double stimulation method in their teaching as learning progresses through the different phases of stimulation. Here, the cultural-historical perspective through its interest in the use and development of artefacts that might mediate a change of understanding of a specific problem is useful (Edwards, 2017). The double stimulation method offers opportunities for both facing such challenges and to create tools to break through this kind of situation and expand on new potential solutions (Engeström et al., 2020; Sannino, 2015). Hence, double stimulation facilitates people to apply volitional actions to transform tensions and contradictory situations actively and collectively by designing novel or improved solutions to certain challenging circumstances. This turns the focus to the intervening issue, which Engeström and Sannino (2010) stress does not happen by itself. Rather, expansive learning cycles and intervention must be carefully initiated and sustained.

Augustsson (2021) investigated the longitudinal development of expansive learning from an educational perspective in a small-scale intervention. According to Augustsson (2021), the seven expansive learning actions can function as an analytical tool by mapping the teachers' expansive learning development. The findings indicate a parallel movement between the abstract and the concrete in the teachers' expansive learning actions when designing new curriculum units; this is also evident in the expansive cycle that does not necessarily follow the cyclic learning actions step-by-step. However, there is a connection between double stimulation and expansive learning, but it is still a challenge to integrate it into a coherent conceptual model and use it in a practical intervention design (Engeström et al., 2020). Several studies have focused on double stimulation and transformative agency (Sannino et al., 2016; Engeström et al., 2014), but the querying about in what ways the specific phases of the double stimulation method mediate and potentially trigger expansive learning is less investigated (Engeström et al., 2020). Morselli's study (2019) is an exception as it connects the main trigged expansive learning actions in the CL-session with the four phases in Apparatus 1. Still, the author is not looking at the connection between double stimulation and which exact learning action that was triggered.

3 THEORETICAL FRAMEWORK

The present study and the analysis of the collected data were framed within CHAT. According to CHAT, knowledge creation is considered as a non-linear process that is always embedded in practice and mediated by tools and signs in a social activity of students and educational staff (teachers and social educators). Consistent with the idea of focusing on the educational staff's expansive learning processes, we aimed to use the data to identify how double stimulation can trigger an educational staff's expansive learning process and examine how digital artefacts can be implemented in mathematics to foster CT.

In the following sub-sections, we provide a short account of the key ideas regarding double stimulation and the expansive learning process and elaborate on the combination of these methods, which is part of the analytical focus.

3.1 DOUBLE STIMULATION

To examine processes of the educational staff's work with CT in mathematics, we drew on Vygotsky's (1997) principle of the double stimulation. This principle was used to create new expansive forms of learning and focus on developing their understanding of CT in mathematics (Engeström, 2007). According to Vygotsky (1962), double stimulation is represented by two stimuli: 'Two sets of stimuli are presented to the subject, one set as objects of his activity, the other as signs which can serve to organize that activity' (Vygotsky, 1962: 56). Double stimulation considers development of higher mental functions as a process in which a group faces a *conflict of stimuli* or *a conflict of motive*, which serves as the first stimulus. Double stimulation allows a group to work with conflicts, identify or construct an artefact to be used as a second stimulus, and help educational staff to break out of a challenging situation and offers a fundamental principle for a pedagogy of agentive actions and expanding opportunities (Engeström et al., 2020).

Vygotsky's (1978) original experimental approaches to double stimulation primarily examined the second stimulus and how the subject changes the situation using the second stimuli. In the context of this article, educational staff work with CT in mathematics as a shared object; the question concerns how they use auxiliary artefacts as second stimuli to develop and work with CT through mediated artefacts and collectively expand their learning process against volitional action.

Double stimulation can be used as a basis for formative interventions. By formative, we mean interventions that do not have predetermined end-results but are formative by being generated in the intervention activity (Engeström, 2016). A CL intervention is driven by contradictions and is historically bounded rather than motivated by predefined object and outcomes. According to this approach, the CL acts as a process provided by a researcher, who guides the CL participants in changing their way of working with a conflict. Accordingly, through double stimulation, the researcher can provide participants with concepts or representations of the participants' activity systems. In this way, double stimulation methods work with contradictions in activity systems and link them to the participants' expansive learning (Engeström et al., 2020). In the present study, educational staff deals with the issue of implementing CT and digital artefacts in mathematics through formative interventions focusing on double stimulation. The use of double stimulation will provide this implementation with an insight into which contradictions the educational staff has to take apart and find solutions for by dealing with the object.

3.2 THE FRAMEWORK OF APPARATUS 1 AND 2

Sannino (2015) describes Vygotsky's definition of double stimulation as a principle for understanding how participants make volitional actions in new and uncertain situations. The author defines those principles as Transformative Agency by Double Stimulation (TADS). TADS refers to how participants intentionally break away from challenging circumstances by transforming them with help from an artefact that changes the participant's internalisation process to externalisation by using a second stimulus.

> Double stimulation comprises conflictual aspects, in particular conflicts of motives. Together with the two types of stimuli, conflicts of motives constitute the core of a strategic setup that human beings establish to intentionally affect their behaviour and the world around them. (Sannino, 2015: 1)

According to Sannino (2015), Vygotsky's method of double stimulation is a key to understanding how individuals and collectives produce volitional action in each given activity. Through a review of Vygotsky's work on double stimulation, Sannino (2015) elaborated the theory further, as illustrated in Figure 1.

Apparatus 1 consists of four phases. In the first phase, the participants are confronted with conflicting stimuli. In the second phase, the conflict between stimuli triggers a conflict of motives. The third phase includes selecting one stimulus and converting it into an auxiliary motive. The fourth phase consists of establishing a connection between the desired reaction and the emergence of the auxiliary stimulus. This starts with what Vygotsky (1997: 215) referred to as the 'the real or actual conflict' of stimuli (phase 4a). Next, phase 4b, is the 'closure of the connection between the given stimulus and the reaction' (p. 215). Apparatus 2 consists of the implementation of the decision formed in Apparatus 1.

Apparatus 1 concerns the design of a new idea, concept, or practice that tackles a problem or a challenge that can only be solved by collective actions and can be traced within a formative intervention (Sannino, 2015; Morselli and Sannino, 2020). Apparatus 2 concerns the implementation of a new concept or model and can be traced between and after the CL sessions (Morselli and Sannino, 2020). In Apparatus 1, participants form a solution to deal with the implementation and object through an auxiliary motive. In Apparatus 2, the participants implement such a solution. In the present

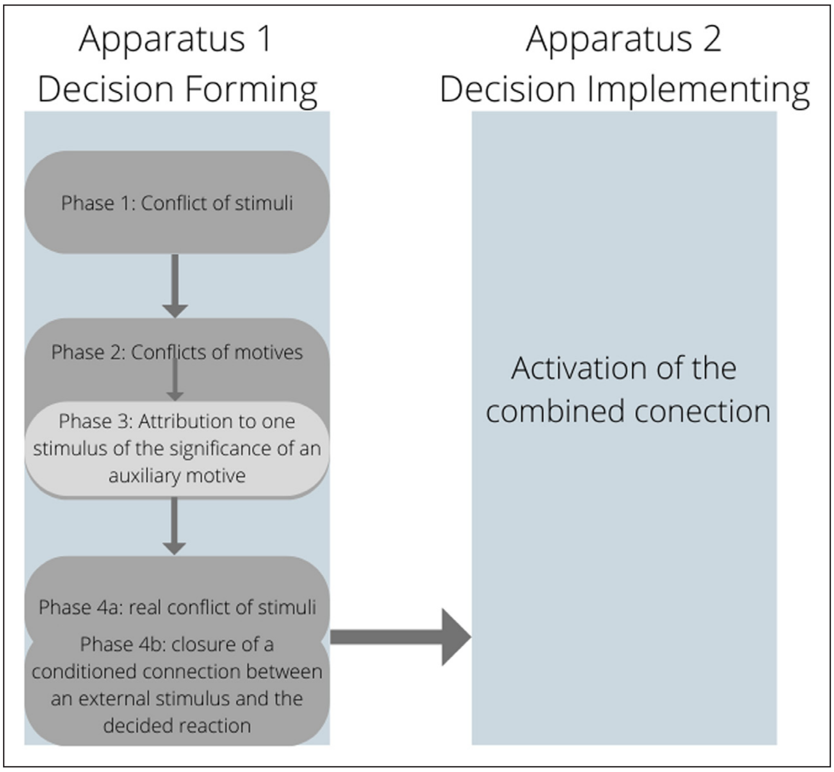

Figure 1 The double stimulation model of the emergence of volitional action (Sannino, 2015), based on Vygotsky's (1997) text on self-control.

study, the educational staff started with forming a solution to how they could implement CT and digital artefacts in mathematics (Apparatus 1). This was followed by an implementation of the solution (Apparatus 2) that emerged in apparatus 1.

3.3 FORMATIVE INTERVENTION

Vygotsky's (1978) principle of double stimulation forms a basis for formative interventions. A formative intervention design is premised on collaboration between participants working in a specific setting. Furthermore, a formative design acknowledges the participants' complexity of practices and the contradictions that could be encountered within the learning process. A formative CL intervention focuses not only on the change of practices but also on building up the participants' collective transformative agency in collaboration with the new understanding of the activity and a further development perspective (Virkkunen and Newnham, 2013).

The context of the present study would be educational staff in a classroom setting. A series of formative interventions were designed to acknowledge the complexity of the educational staff's existing practice and the contradictions that could be encountered within a learning process. A series of formative interventions were designed to support the educational staff's professional development process. Vygotsky's principle of double stimulation was used to unfold the educational staff's expansive learning process (Engeström, 2001). The first stimulus related to the overall problem situation, and the second stimulus acted as a mediating tool to support the new model for the activity under the transition. We used this process of stimuli to foster community understanding and collaboration among the educational staff. The first stimuli also drew on observations and interviews made concerning the educational staff's teaching. The data were used to code and select repeated themes from practical incidents described by the educational staff. These issues were captured as quotes and were shared with the educational staff as the first stimulus. The incidents from the first stimulus are used as mirror data to start a dialogue and collaborative problem-solving among the educational staff (Engeström, 2016).

3.4 EXPANSIVE LEARNING PROCESS

The expansive learning process treats historical and cultural development as an essential part of the activity and starts with considerations by an individual person questioning existing practices. These individual considerations are gradually unfolded into a collective movement towards new activities. The expansive learning process consists of learning actions that are formed as a cycle in a dialectical structure. CL is a way to trigger and support successful expansive learning processes, and new possibilities are discovered for activity (Engeström, 2015).

The expansive learning action will be elaborated and operationalised under the section of analysis, where the expansive learning process acts as a framework for analysing and developing educational staff's collective professional development process.

4 RESEARCH CONTEXT AND METHODOLOGY

The following section describes the background and context for the CL intervention and contextualises the analysis of double stimulation and learning action conducted in this article.

One of the basics in a CL intervention is understanding organisations as activity systems that develop and learn through expansive learning cycles. The object of an activity system is directed and eventually shaped into outcomes through expansive learning actions. A CL intervention draws on historical and ethnographic data from the participant's activity context. Conflicts, difficulties, problems, and new possibilities from the participant's activity are brought into CL sessions as first stimuli. The second stimulus to addresses collective engagement and make analysis and design new models (Sannino and Engeström, 2017).

In the present study, this specific CL intervention was performed to respond to the challenges of implementing CT in mathematics. The researcher introduced a CL intervention, and the educational staff accepted it to address issues and opportunities by working with CT and digital artefacts in mathematics. The development of new learning activities took place in a design process, where the researcher, the educational staff and their students designed and tested new curriculum materials. Design processes are not a traditional starting point for the CL interventions; typically, a CL intervention is used as a pilot study in an organisation before a more extensive transformation (Augustsson 2021; Engeström et al., 2013). This CL was set up as an iterative design process. Each CL session was planned as a single session to evaluate an iteration and deal with the problems (contradictions) and the activity's possibilities and, finally, process it into new activities.

This study involved three teachers and three social educators, educational staff, from the same school, with 66 students followed from 2^{nd} to 3^{rd} grad. Through this, the one-and-a-half-year professional learning project acknowledged the complexity of the educational staff's existing practice and the contradictions that would be encountered within the learning process. The participants had no previous knowledge of introducing digital artefacts such as robots in mathematics, so before the CL-sessions began, the educational staff participated in a workshop focusing on integrating CT in their maths teaching, where they could test different kinds of educational technology. Before the school year 2020/2021, they took part in another workshop to get some new insights into implementing digital artefacts in the 3^{rd} grade mathematical curriculum. A summary of the sessions and their purposes can be found in Table 1.

In Session 1, the researcher introduced the expansive learning action cycle and presented the CHAT-methodology to the participating educational staff. The use of digital artefacts and CT as a part of teaching math was new to the participants. To catalyse the process, the participants were asked to look after elements of

DATE	PURPOSE OF THE SESSION	FIRST STIMULI	SECOND STIMULI
3.9.2019	Workshop 1 Introduction to CT in mathematics at K-2 level.		
25.9.2019	Session 1 • Presentation of CHAT as a method. • Historical analysis of structures related to CT in mathematics. • Modelling new solutions.	The educational staff's digital competence.	Expansive learning cycle.
13.11.2019	Session 2 • Presentation of field observations. • Barrier and potentials of using digital artefacts. • Modelling new solutions.	Analog artefact. Preparation of teaching. Technology as a supporting artefact.	Activity theory triangle, 1st generation.
29.1.2020	Session 3 • CT concepts and the use in mathematics. • Analysis of the new model. • Modelling new solutions.	New ways of teaching. Problem-solving in Scratch Jr.	CT-concepts. Activity theory triangle, 2^{nd} generation.
1.9.2020	Workshop 2 Introduction to CT in mathematics a K-3 level.		
21.10.2020	Session 4 • Presentation of the educational staff's expansive learning cycle. • Analysis of the new model through a didactical perspective.	Students' development of mathematical learning in Scratch Jr. CT development in traditional math teaching.	Expansive learning cycle. Didactical cycle.
2.12.2020	Session 5 • Presentation of how CT emerges in the new model. • Examining the new model and modelling new solutions.	How CT emerges in the new model.	Didactical cycle. Activity theory triangle. 2^{nd} generation

Table 1 Summary of the Change Laboratory sessions.

CT in their current practices. This stimulus made the use of CT structures visible for the educational staff in their everyday practices.

In Session 2, the participants were presented to the first-generation activity theory model (Vygotsky, 1978). This model was chosen so that the participants could focus only on the subject, the mediating artefact, and the object of an activity. This stimulus made the contradictions noticeable and tangible. It appeared that the digital artefact could serve as a visual artefact that can help students develop mathematical understanding. But it also appeared that if the task is not on the right level for the students, the artefact can serve as an intricate element.

In Session 3, the participants were introduced to the second-generation activity theory model to look for tensions and contradictions in the whole activity system. It became clear that it means a lot for the educational staff to have shared preparation time, but it appeared that it was not always possible. This kind of shared preparations was important as the educational staff wishes to start from scratch by developing new teaching material when integrating CT into mathematics. Because of the Covid-19 community lockdown in Denmark, there was a break between the intervention sessions 3 and 4. This also implied that the educational staff was only sporadically working on the project during this time span (see Table 1).

As can be seen in Table 1, sessions 4 and 5, the model of integration CT into mathematics was examined and remodelled. Because of the need to prepare their own teaching material, the researcher introduced the educational staff to a model of a didactical cycle (see Bartolini Bussi and Mariotti, 2008 for further information). Through the didactical cycle, the educational staff first analysed a teaching sequence from their practices. From that analysis, several new ideas for tasks involving digital artefacts emerged.

The didactical cycle allowed the educational staff to recognise the barriers and potentials of the digital artefact. It however became clear that it was important to designate a good amount of time for the educational staff to transform barriers and potentials into mathematical teaching material fitting the curriculum. The second-generation activity theory model was again introduced to the participants to map new tensions and contradictions within the activity; the most important were the contradictions between the object of introducing CT into mathematics, collaborative preparation of teaching material and the curricular requirement on specific learning outcomes in mathematics.

This study adopted a similar method as Augustsson (2021), who examined episodes of expansive learning action with in-service teachers in a high school in Sweden focusing on introducing digital literacy and video creation as a part of the curriculum. The methods about expansive learning actions are combined with Morselli (2019) and Morselli and Sannino (2020), which operationalised and tested the model of double stimulation in an educational context with in-service teachers in an Italian vocational school.

The present study considered these relationships by examining connections between double stimulation and expansive learning action to understand how double

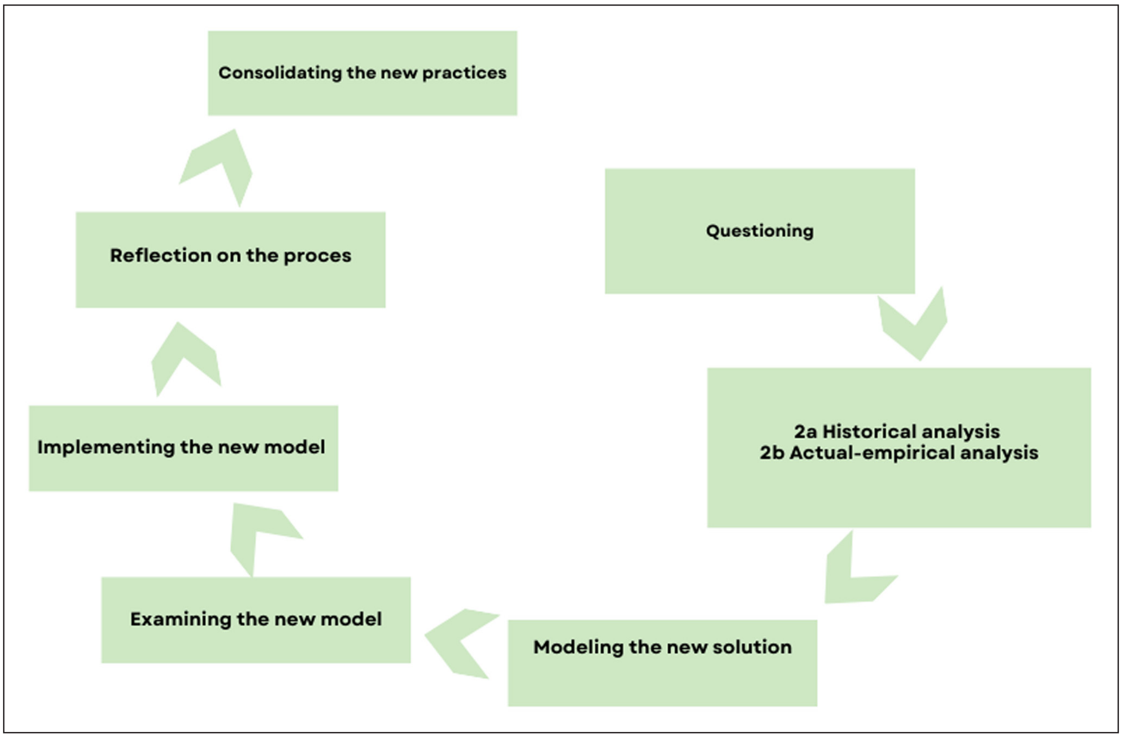

Figure 2 The ideal-typical cycle of expansive learning (Engeström, 2015).

stimulation can be used to support educational staff working with digital artefacts in new learning situations. Like the research mentioned previously, this study used mixed methods to combine quantitative and qualitative approaches using sequential phases by first analysing the qualitative data and then the quantitative data (Creswell and Creswell, 2018).

The next section will first operationalise Sannino's (2015) model of double stimulation (Figure 1) and Engström's (2016) model of expansive learning (Figure 2). We elaborated on these two models using a specific CL intervention to identify double stimulation incidents and their connections to learning actions at the conversational level between the researcher and the educational staff as well between the educational staff. The CL intervention consisted of five sessions, which were recorded and fully transcribed. The length of each session varied between 53 and 87 min. The total length of the five sessions was 354 minutes. There were altogether 1641 speaking turns during the five sessions. The first author facilitated the intervention through five sessions. The video recordings from the classroom observations were recorded with the educational staff's permission and the students' parents. We then treated the data confidentially and anonymized the participants in line with the Danish Code of Conduct guidelines. The study is still ongoing, and there will be one more CL session, and one follow-up session. Accordingly, data from these two final sessions are not included in the present study.

4.1 ANALYSIS

Following the method devised by Engeström et al. (2013) and further developed by Augustsson (2021), the first step of the analysis identified learning actions and their frequencies in the CL processes. To identify learning actions, the data material was first divided into episodes based on their substantive content. Each episode was analysed and deductively coded using the expansive learning cycle framework, and each episode was given a specific learning action and a preliminary description (Creswell and Creswell, 2018). The criteria for identifying the seven different learning actions included the following:

1. Questioning: criticising or rejecting already accepted practices and existing knowledge.
2. Analysing: any action taken to explore the systematic and historical causes of a situation.
3. Modelling: the ideation and construction of an explicit new idea that explains and comes with a new resolution to the problematic situation.
4. Examining: running, operating, and experimenting with the new model to understand its dynamics, potentials, and limitations.
5. Implementing: applying the model and enhancing it during utilisation.
6. Reflecting: evaluating the new model and reflecting on the process of expansive learning.
7. Consolidating: the generalisation of the outcome and consolidating it into a new stable form of practice (Engeström et al., 2013).

As a second step, we identified non-expansive learning actions across the data. We examined the contents of the actions that were not identified as expansive (Engeström et al., 2013). Third, we returned to the transcript and identified possible phases from Apparatus 1 according to the following criteria:

Phase 1	a problem related to the object of the activity, or the unit of analysis observed by the researcher or the participant
Phase 2	a conflict of motives articulated by the researcher or the participant and dealing with the object of the activity
Phase 3	a possible auxiliary motive that helps to overcome the problem in Phases 1 or 2 such as an idea or a concept, etc.
Phase 4	a plan for implementation of the model, which could be coordination of the process or who should complete certain tasks related to the object of the activity.

Following these steps, the analysis was theory-driven coded, and the occurrences of expansive learning and the four phases in Apparatus 1 were calculated (Kaup, 2022). Table 2. shows two examples of each phase in Apparatus 1 and the connection to a learning action, translated from Danish into English.

5 RESULTS

This section begins with an overview (Table 3), which summarises the occurrences of expansive learning action and the four phases of Apparatus 1 across the five CL-sessions. This is followed by a presentation of the results of, first, the learning action in the five CL sessions and then, an overview of the four phases in Apparatus 1 through the five sessions. After that, the learning action and the four phases are compared to see which phase triggered a specific learning action.

The first column in Table 2, shows the learning action and Apparatus 1, and the first row illustrates the five sessions. We elaborate on this data in Figures 3 to 5. As shown in the row for the learning action of consolidation, there was no sign of consolidation and generalisation through the five sessions; this indicates that the educational staff has not yet established a stable practice

PHASE	QUOTE	LEARNING ACTION	CL SESSION	SPEAKING TURN
1	It was troublesome. I agree that the student should program the robot, but it should not be challenging to add two numbers together.	Questioning	1	128
	It's just when we have no more hours left for preparation; then we have to stop the project. It's no longer than that if he (the headmaster) has chosen that we should do it.	Questioning	2	156
Phase 2	For some, there is a lack between the two robots (Beebot and Ozobot) to the mathematical content.	Analysing	2	50
	At least I wish we had more collective preparation hours and more math lessons together (*the educational staff becomes aware that it becomes easier to create meaningful tasks together*).	Analysing	3	271
Phase 3	Should we try to look at what it might look like if you were to work with these BeeBots, for example?	Modelling	1	163
	Can we use a diary?	Reflection	3	300
Phase 4	I'm writing straight away to her (*the teacher had to write to a mom to get some material for a task*).	Modelling	1	212
	We promise. Or so I promise.	Analysing	5	237

Table 2 Quotes that capture Apparatus 1 and the expansive learning action.

LEARNING ACTIONS	SESSION 1	SESSION 2	SESSION 3	SESSION 4	SESSION 5	TOTAL	TOTAL OCCURRENCES IN %
Question	5	4	3	2	0	14	6,2
Analysis	25	19	20	17	17	98	43,4
Modelling	14	5	6	6	9	40	17,7
Examining	1	7	4	7	7	26	11,5
Implementation	0	4	4	11	11	31	13,7
Reflection	1	3	7	2	5	18	8,0
Consolidation	0	0	0	0	0	0	0
Learning action total	46	42	44	45	49	226	
Non learning action	2	2	1	2	1	8	
Apparatus 1							
Phase 1	11	14	21	11	15	72	33,6
Phase 2	9	9	17	6	11	52	24,8
Phase 3	12	10	15	11	18	66	30,8
Phase 4	4	3	5	2	9	23	10,7

Table 3 Summary of the result of expansive learning action and the four phases of Apparatus 1.

and are still at the beginning of the development of CT in mathematics.

The diagram in Figure 3 illustrates how the analysis action dominated the expansive learning cycle: it peaked in Session 1 and then faded out as the process went on. The action of modelling follows the curve of the analysis. When the act of analysis is frequent, so is the act of modelling, which implies that when the educational staff conduct an analysis, they also model new solutions. The learning actions that dominated the first session included questioning, analysis, and modelling. In the second session, the educational staff began to examine and reflect on the process. In the fourth and fifth sessions, the learning action within the implementation increased. However, the diagram demonstrates that the educational staff began to adopt the model and examined and reflected on the process to support the implementation. The fifth session also revealed that new ideas for the model were developed when the educational staff began to analyse the implementation process. Generally, the learning action sequence is in line with the theoretical model for the expansive cycle (Engeström et al., 2013).

Figure 4 describes the phases of double stimulation and their expansions through the CL-sessions. The fourth phase is stable from session 1 to 4, with a peak in session 5. Figure 4 also illustrates a connection between the first, second and third phases. Phase 1 and 2 represents the conflict of stimuli and conflict of motives, which consists of problems, challenges, or dilemmas the educational staff want to solve. The third phase concerns possible auxiliary stimuli that work with ideas and solutions. When the first stimuli occur in phase 1 and 2, the second stimuli are used through an auxiliary stimulus to deal with the problematic situation.

Figure 5 compares expansive learning actions and the occurrences of the four phases of double stimulation; it appears that the act of analysis dominated Phases 1 through 3. However, Phase 3 also experienced a change since modelling, examination, and implementation were highly represented. The fourth phase is characterised by modelling, reflection, and examination.

As illustrated in Figure 5, the learning action of questioning emerged in Phases 1 and 2 but not in Phases 3 and 4. The learning action of analysis also dominated Phases 1 and 2.

As it can be seen from Figure 5, the learning action of analysis dominated the first phase, but questioning and examination were still well represented. It seems that when a conflict of stimuli occurred, it triggered

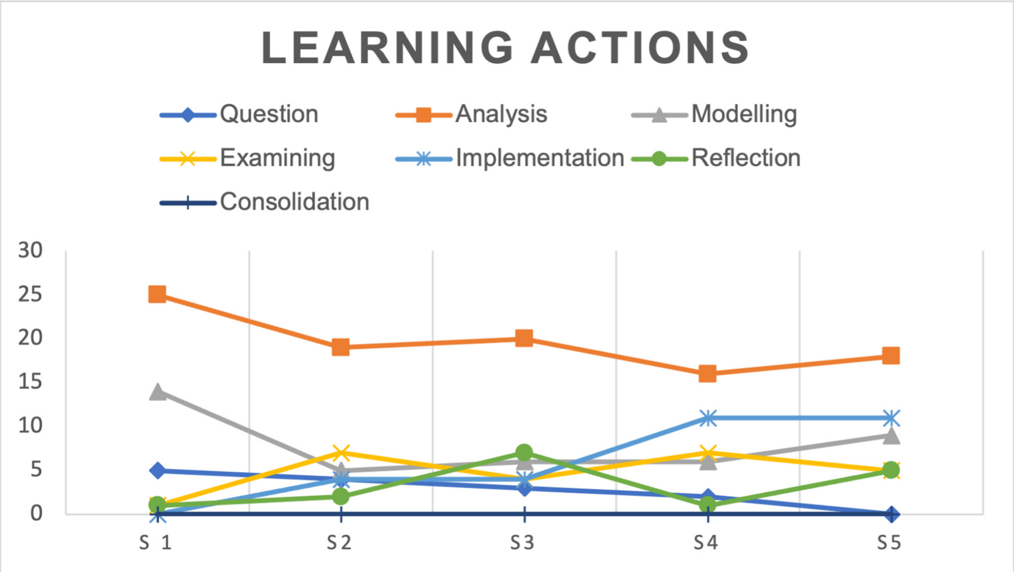

Figure 3 Learning action through the five CL-sessions.

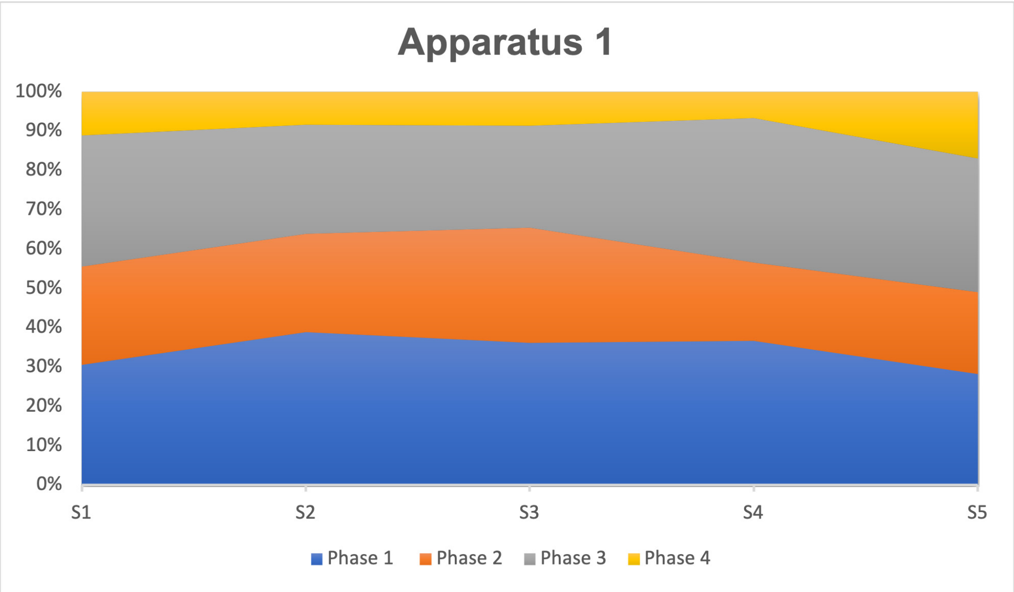

Figure 4 The four phases in Apparatus 1 through the five CL-sessions.

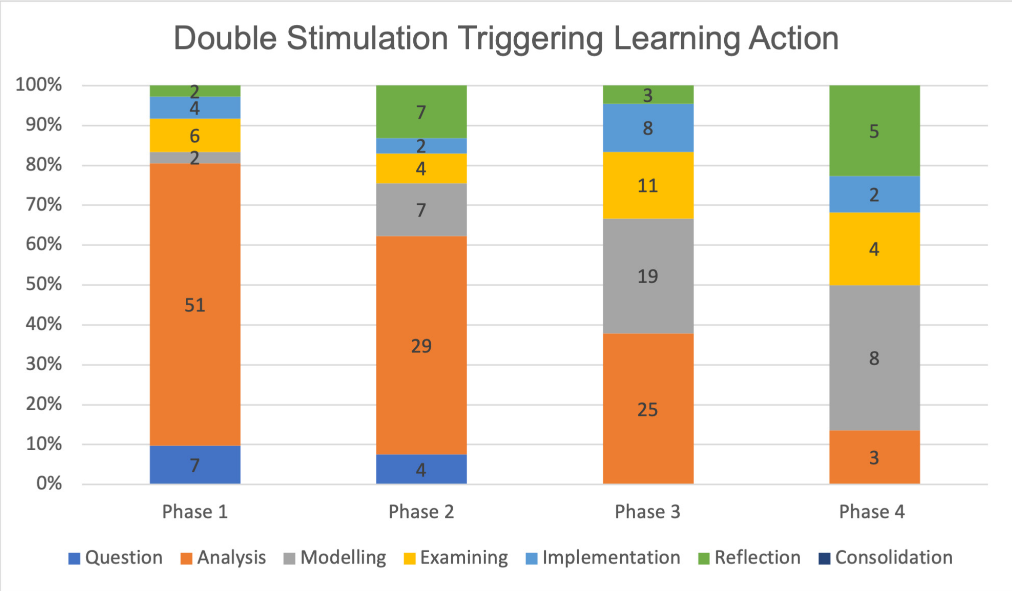

Figure 5 The connection between the Apparatus 1 and expansive learning action.

the learning action of analysis by questioning and examination.

The learning actions of questioning, analysing, examining, and reflecting characterise the first and second phases of double stimulation. The educational staff pointed out the problem and the conflict of motives related to the object of the activity. The learning action of analysis was notably triggered during the first and second phases. In the third phase, during which the educational staff and the researcher developed a solution or a model to deal with the conflict of stimuli or motives, the learning actions of analysis, modelling, examining, and reflection were triggered. The learning action of implementation will occur in Apparatus 2. However, the learning action of implementation can start a new phase in Apparatus 1, when the educational staff begins to question the implemented activity and begin to analyse it to identify recent conflicts of stimuli and conflicts of motives in Apparatus 1. So, there is a movement from Apparatus 1 to 2, but there will also be a movement from Apparatus 2 to 1. The Apparatus 1 and 2 shall not be seen as a linear model but as a model in constant motion of a cyclical dialectic process (Sannino, 2015).

The results show that there is a shift in the fourth phase, where modelling became the dominant learning action, followed by reflection. The fourth phase was also about planning a new date for the educational staff meeting between the CL sessions to prepare their teaching and teaching material. It was mainly in the fourth phase that the educational staff showed learning actions to break away from the given activities and the possibilities to create time for meetings between the CL sessions. The educational staff used those meetings to transform the object and design options for CT in mathematics.

6 DISCUSSION AND CONCLUSION

This study attempted to combine the model of double stimulation (Sannino, 2015) and the expansion of learning action (Engeström et al., 2013) at the level of interactions that occurred within a specific CL intervention. We found that the learning action of analysis was the dominant learning action during all the CL-sessions. We also found that the learning action of analysis dominated the first three phases of Apparatus 1. The first and second phase appeared to trigger the learning action of analysis, indicating that Phase 4 in Apparatus 1 triggered a warranty of learning actions. This support of learning actions could help the educational staff overcome problems and conflicts of motives, especially related to modelling, examination, and reflection.

The results of this study indicate that the four phases of Apparatus 1 in the CL did not follow the double stimulation model in a stringent order, but all four phases did occur in all five CL-sessions. Like Morselli and Sannino (2020), who studied double stimulation in educational settings, we found that the four phases of Apparatus 1 were spread across the CL-sessions. As outlined by Morselli and Sannino (2020), a potential explanation for this could be that double stimulation operates from the level of conversation. The level of conversation can lead to the development of higher-order thinking (Vygotsky, 1978), while educational staff begin to collaborate and build a collective perception about the first stimulus. The levels of conversation can also be explained by the combination of double stimulation and expansive learning action. The analysis shows that the first stimulus mainly triggered questioning and analysis and that the second stimulus triggered analysis, modelling, and examination. The expansive learning process and the four phases of double stimulation are fruitful methods for understanding the transformation of the educational staff's practices. It opens for an analytic and reflective practice where educational staff can implement and model their practices. A focus on double stimulation and expansive learning also helps educational staff solving conflicts of motives with the help of auxiliary artefacts. Through commitment, they can overcome conflicts of motives and explore possibilities of new practices for implemented CT into mathematics.

The connection between the four phases of double stimulation and expansive learning action helped the researcher and the educational staff to get insights into the activity. The researcher used this understanding to facilitate the five CL sessions and made a pre-planned script to support the desired learning actions. But as Augustsson (2021) also emphasises, there must be space in the CL for deviations from the cycle of expansive learning and the pre-planned script; those deviations can be defined as signs of voluntary agency to break away from a giving action. The researcher used the pre-planned script to select auxiliary tools that help the educational staff analyse and understand the activity to foster the activity system changes. The auxiliary tools are used expansively to create new understandings and new possibility for action. Over time, this makes it possible for the educational staff to deal with conflict situations, break away from given frames of action, and create new ones. In this article, the focus was on Apparatus 1, but it is also important to take Apparatus 2 into account. There is a progression and a complexity between Apparatus 1 and 2; it is essential to have the process of iteration in mind when creating a CL intervention. When a solution appeared in Apparatus 1 and implemented in Apparatus 2, the new activity could promote a new conflict to deal with in Apparatus 1. The process is not linear but dialectic, as it moves back and forth between Apparatus 1 and 2. It is also essential to consider that the entry point for this CL interventions was a design process for implementing CT and digital artefacts into mathematics; this can explain why all four phases of double stimulation emerged in the five CL sessions. The educational staff was already modelling a new solution in the first session, so they had something to test and implement between session one and two, which allowed them quickly to get some insights about what will work in their specific working context. The design process supports the educational staff to work in small iterations within and between each CL session and thus step-by-step gained insights that could feed into proposed solutions. The collection of ethnographic data between each session helped in the creating of mirror data and to push forward the expansive learning action with the use of the four phases of double stimulation.

When it comes to implementing CT in a school's curriculum, the educational staff's professional development seems important. As pointed out by Bocconi et al. (2016), many educational staff have not learned about CT in their initial training, and CT may require new pedagogical approaches. Therefore, it is essential to develop methods that can be used to examine what educational staff learn about CT from professional development and how they translate that knowledge into their classroom practices. Double stimulation methods can help explore CT's development by examining how Apparatus 1 is developed. This study focused on the growth of the four phases in Apparatus 1 and the combination of expansive learning. However, more research on this topic needs to be undertaken to fully investigate what is happening between Apparatus 1 and Apparatus 2 to fully establish knowledge about CT's implementation in mathematics. According to Augustsson (2021), there is a need to spread the intervention over a more extended period with the final sessions after the implementation to achieve all seven learning actions, otherwise it can be difficult to capture them all. In this CL intervention, there was no sign of the seventh learning action, i.e., consolidation and generalisation of the new practices, even though the CL intervention was spread out over one-and-a-half-year to capture all the seven learning action. The main reason that the seventh learning action did not occur was that the educational staff were still at the beginning of implementing CT and digital artefacts in mathematics. Even though the educational staff had a long time reflecting on the process between sessions, there were two long periods of lockdowns because of Covid-19 in the research period where the educational staff did not work with the implementation, which implies the consolidation of the new practices.

Concluding this section, we can say that a formative CL intervention design helps the educational staff overcome conflicts of motives and contradictions when implementing CT in the mathematical curriculum. The methods of double stimulation make the conflicts of motives and contradictions visible for the educational staff to overcome and make new collective solutions with the help of the cycle of expansive learning actions. To implementing CT into the mathematical curriculum, the educational staff must have enough time to work with their understanding of CT and how these fits into mathematics supported by the researcher and mirror data from the educational staff's practises.

The theoretical contribution of this study lies in the use of Cultural-Historical Activity Theory and the dialectical connection between expansive learning actions and double stimulation. It shows promise for collectively implementing new content and creating more sustainable changes in a school subject.

COMPETING INTERESTS

The authors have no competing interests to declare.

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