Characterizing Learning Mediated by Mobile Technologies: A Cultural-Historical Activity Theoretical Analysis

Jalal Nouri and Teresa Cerratto-Pargman

Abstract—Mobile technologies have not yet triggered the knowledge revolution in schools anticipated, in particular, by the telecommunications industry. On the contrary, mobile technologies remain extensively used outside the frontiers of formal education. The reasons for this are many and varied. In this paper, we concentrate on those associated with the prevalent methodological weakness in the study of innovative educational interventions with mobile technologies. In this context, the paper investigates the following question: what is the potential of second-generation cultural-historical activity theory (CHAT) for characterizing learning activities mediated by mobile technologies? To this end, an empirical study was designed with the goal of examining five small groups of students (fifth grade, age 12) who were using mobile devices in authentic educational settings, within a natural science inquiry-based learning activity outdoors. Second-generation CHAT was operationalized as an analytical and dialectic methodological framework for understanding learning activities mediated by mobile devices. The study contributes a characterization of mobile learning and identification of constraints and transformations introduced by mobile technology into students' tasks.

Index Terms—Mobile learning, evaluation, analysis, methodology, cultural-historical activity theory, inquiry-based learning

1 Introduction

Since the 1990s extensive and various research studies have populated the field of mobile learning making proof of a great interest in investigating the potential role of mobile technologies in education [1]. However, mobile technologies have not yet kick-started the knowledge revolution that has been widely anticipated, primarily by the telecommunications industry, in the educational sector. Indeed, recent studies in the field of literacy theory and media education have shown most of the innovations related to the use of information and communication technologies in schools have not yet impacted on pedagogical or school development [2], [3], [4]. These results interrogate researchers, teachers and educational policy-makers who see that mobile technologies are a familiar part of the lives of most teachers and students in Europe and abroad. The deep penetration of mobile devices into children's and adults' everyday lives along with the frequent exclusion of these devices at schools creates a tension in society that we believe is worthy of analysis from a critical research perspective [5], [6]. For instance, Naismith et al. [1] ably synthesize the disparity between a discourse underscoring the potential of mobile devices in schools and the reality of their quasi non-use for educational purposes. They contend that "The challenge for educators and designers, however, is one of understanding and exploring how best we might use these resources to support learning." (p. 1).

- *The authors are with the Department of Computer and Systems Sciences, Stockholms University, Stockholm, Sweden.*
E-mail: {jalal, tessy}@dsv.su.se.

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The reasons behind the disconnection of mobile devices from education are often associated with political, educational, institutional, technical and social factors. Although we acknowledge that it is essential to understand how these aspects are interrelated and form ecologies wherein students' learning is nurtured, here we only concentrate on educational research aspects. In particular, we reflect on the role that methodological tools play in the conceptualization of learning with mobile technologies. Unfortunately, methodological and analytical issues related to the study of learning activities mediated by mobile technologies have been overlooked [7], [8]. Few studies have looked in depth at the multiple relations that unfold in learning contexts mediated by mobile devices.

From these observations, we here argue that research efforts in the field of mobile learning will benefit much from descriptive, analytical and dialectical accounts of the activity systems which the use of mobile devices promotes, constrains or/and transforms in established school practices. This argument is supported by an empirical study conducted with the goal of investigating inquiry-based field trips including the use of mobile devices in natural sciences. The study has been analysed from a second-generation theory of cultural-historical activity put forward by [6]. More specifically, we have analysed the learning situations observed in terms of an activity system characterized by students' interactions among them (i.e. community, rules, division of labour) as well as with nature, the mediating artefacts (i.e. mobile phones and tablets), and tasks consisting of students' exploration of tree species and biotopes in the woods.

The article contributes to a better understanding of learning in the context of inquiry-based learning facilitated by mobile devices, and it underscores the potential of using

Engeström's activity theory model for understanding learning activities that can be constrained and/or facilitated by mobile devices.

2 Background

When mobile learning emerged as an educational research field in the mid-1990s, early approaches attempting to define mobile learning were strongly anchored on the use of mobile technology rather than on the pedagogical outdoor practice that mobile technology was intended to support. For a time, techno-centric conceptualizations of mobile learning, and the equating of the term mobile with mobile technology, were accompanied by a number of technology-driven projects with weak pedagogical underpinnings [9]. The aim of these projects was mainly to exploit a new generation of pen tablet and personal digital assistant devices for learning [9]. Techno-centric perspectives on mobile learning still prevail, although they do not remain unchallenged. In the last few years elaborate views of mobile learning have been articulated, based, for instance, on classifications of supported pedagogical paradigms [1]. This has been a significant step forward in the evolution of mobile learning and in particular toward an understanding of social and collaborative aspects of outdoor practices mediated by mobile technologies.

According to Naismith et al. [1] and Pachler et al. [10], the number of case studies within the mobile learning field, documenting pilots and trials is large and is rapidly increasing, encompassing a spectrum of different target groups, subjects, pedagogical models, and contexts of learning. Among mobile learning projects conducted within natural science classrooms, we distinguish the following studies:

The *Ambient Wood project* [11] was one of the first notable mobile learning projects. The aim of this project was to explore how playful learning experiences can be created where children investigate and reflect upon biological processes in a physical environment augmented with digital abstractions. The planned learning activities in the project were designed to prompt children to learn when interacting with aspects of the physical environment supported by a variety of devices and multi-modal displays. The physical space that formed the basis of the experience was a real wood, inhabited by a rich collection of living and dead forms that the children identified, explored and probed.

The *Bird and Butterfly Watching and Identification* project [12] was another early innovative study of how mobile technologies can be used to support students learning how to identify and characterize birds and butterflies. In this project, learners used mobile devices to photograph the birds and butterflies that they observed in a natural environment and to access a knowledge database containing pictures and information about them.

The *MPLS* or the *Plant Identification* project [13] is a more recent project. MPLS was designed to improve the development and learning of a plant curriculum. In the MPLS project primary school students used mobile technologies to explore plants in a natural environment. The mobile technologies used supported identification of plants through offering a manual search in a database with pictures of the plants or by image recognition applied to pictures taken by the students.

Studies conducted within these methodological orientations have contributed to a refined conceptualization of learning with mobile technologies in field trips and have presented innovative ideas about how technology might work as a socio-cognitive tool in schools. However, these research efforts have in their endeavours overlooked methodological questions related to the study of affordances and constraints (i.e. transformations) that the use of mobile technology introduces into teachers' practices and students' learning. Moreover, there are few articles that discuss or demonstrate the use of cultural-historical activity theory (CHAT) in the analysis of transformations introduced by mobile technologies. Among these we find Sharples et al. [14], who introduced an activity theoretical framework for the analysis of mobile learning as well as Zurita and Nussbaum [15], who have suggested activity theory as framework and method for the analysis and design of mobile computer-supported collaborative learning systems. Pamela and Butler [16] operationalized CHAT in analysis of collaborative processes in mobile learning activities. In turn, Mwanza-Simwami [17] explained how to use activity-oriented design methods for use in mobile learning research.

This paper contributes a better understanding of how Engeström's activity model can be applied in the analysis of mobile inquiry-based learning activities in the natural science classroom and it provides a characterization of learning with mobile devices outdoors in formal education contexts. In particular, the questions that are discussed in this paper are: 1) how do we apply second-generation CHAT in the study of learning supported by mobile devices? 2) how does the operationalization of second-generation CHAT provide us with analytical and dialectical tools for a better understanding of mobile learning?

3 Framework of Analysis: Cultural-Historical Activity Theory

Cultural-historical activity theory as suggested by Cole [18] has its roots in the Russian cultural-historical school founded by Vygotsky [19] in 1920. According to Daniels [20], we can distinguish three generations of CHAT that are incremental and overlapping. The first generation is associated with Vygotsky's theory of cognition and development of higher mental functioning. Vygotsky's work shows the role that tools and artefacts, along with people, play in the mediation of human actions and human development in a social setting [21]. The powerful mediation of human action is well illustrated in a simple triangle showing that the relationship subject-object is always mediated by tools. For Vygotsky [19] human beings seldom interact with the environment directly without using cultural artefacts (i.e. such as technical and/or semiotic tools) acting as mediators of human behaviour.

Vygotsky's triangle is further developed by one of his colleagues, Alexei Leont'ev. Leont'ev [22], [23] suggests a theory of activity that attributes a hierarchical structure to human actions, distinguishing three levels: activities at the top, actions in the middle and operations at the bottom of the triangle. Leont'ev's theory of activity contributes a refined understanding of the concept of object of the activity. According to Leont'ev, all human activities are directed

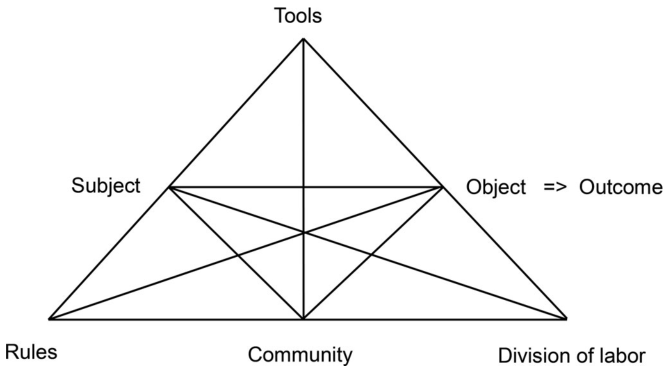

Fig. 1. The activity system model (Engeström, 1987).

towards objects that motivate actions, i.e. activities are understood as mediators of interactions between subjects and objects [23] and can be analysed on three hierarchical levels: activity, actions and operations. Actions are conscious and goal-directed, undertaken to fulfil the object of the activity, whereas operations are routinized, unconscious and automatic components of actions.

The concept of the object of the activity introduces thus the motives, intentions and pursuits of the human actions that become a valuable criterion for the distinction of different activities, especially collective (i.e. on the level of activity) and individual (i.e. on the level of actions and operations). Dynamic relationships between levels are common, ensuring transformations from one level to another level within the activity system. Leont'ev's model of activity is known as Activity Theory [24]. Activity theory is a descriptive tool as well as a theoretical framework that aims to understand human beings through an analysis of the genesis, structure and processes of their activities [24]. The framework uses the concept of activity, which is understood as the subject's purposeful interaction with the world, as the fundamental unit of analysis, and offers a set of concepts that can be used to conceptualize a model of activity systems.

Drawing on the work of Vygotsky and Leont'ev, Engeström [25] suggests a second-generation theory on an expanded view of the activity system. Such expansion takes account of social and institutional rules governing activity systems along with the notion of community and division of labour in terms of organizing the activity system. Precisely, Engeström [25] proposes an extended activity system model (see Fig. 1), including the subject-tool-object relation of Vygotsky but with a description of activity as a collective phenomenon, as opposed to Leont'ev, who almost exclusively focused on individual activities [24]. In order to account for the social structure of activities, Engeström [25] included three additional components: 1) rules that regulate the subject's actions; 2) the community of people who share a common object; and 3) the division of labour—how tasks are divided between the community members.

Engeström's model is richer in terms of the multiple relations and interrelations which it is possible to identify between the different components distinguished [26]. In line with the second theorization of CHAT, Rabardel's instrumental approach [27] helps to explain the non-neutrality of technological devices (i.e. mobile technologies) mediating human activities and introduces the difference between device (i.e. artefact) and instrument (i.e. when the device is appropriated at the levels of operations, actions and activity). The difference between device and instrument can be understood through a development of instrumentation (i.e. changes oriented to human action) and instrumentalization processes (i.e. changes oriented to the device in use). Rabardel's instrumental approach in relation to Engeström's theorization of CHAT is an important conceptual tool which underscores that:

> 'the instruments have a dual use within educational activities. On the one hand, they are tools for students and as we shall see, their use deeply influence the construction of knowledge and the process of conceptualization. On the other hand, they are tools for teachers in the sense that they can be considered as variables on which they can act for the design and control of pedagogical situations' [27, p. 1- our translation].

Engeström's activity system model depicts constitutive components of tool-mediated and collaborative activities, such as the mobile learning activity that is the object of study in the present article. For instance, the notion of division of labour stresses the collaborative aspect and provides a means for making a distinction between cooperative and collaborative processes [29]. Rules on the other hand regulate the relationship between a person and a community of which he or she is a member, as well as the relationship between a person/community and technology. Rules also emerge with the introduction of technology. Thus, the notion of rules and community allows us to analyse how the learning activities we study are regulated, facilitated, and constrained. Furthermore, the notions of hierarchical structure and dynamic transformation between activities, actions and operations facilitate an in-depth analysis of the transformations introduced by mediating artefacts such as, in our case, mobile devices.

The third generation of CHAT proposed by Engeström [6] pays attention to the ways in which people have to work and move across boundaries within networks of activities [21]. Here, we chose to operationalize Engeström's second-generation theory from students' conversations and interactions with the environment based on collected video data and transcribed conversations.

The choice of Engeström's model (see Fig. 1) for the analysis of the mobile learning studied corresponds to our interest in dialectically understanding the tensions and contradictions that emerge from the relations established between the different components of the expanded triangle and levels [21]. In particular, Engeström's second generation theorization allows us to look deeply at transformations within learning activities that were facilitated or constrained with the use of mobile technologies. In comparison with third generation of CHAT proposed by Engeström, the second generation model takes one activity system as the unit of analysis whilst third generation of CHAT suggests a minimum of two interacting activity systems as unit of analysis. This choice of the analytical model responds to the fact that in the situation studied, the designed activities facilitating the interactions between learners-learners and learners-teachers constituted one activity system as the components of the activities such as object, rules, community, division of labor and mediating artefact were shared by all subjects.

Moreover, we have chosen to pay attention to the interactions between the different components of Engeström's model displayed by Fig. 1 and to the concept of instrumental mediation introduced by Rabardel [27] which facilitated the understanding of transformations, more specifically instrumentations observed in the analysis of the mobile learning activity studied.

4 Methodology

The study here presented was part of the research project mVisible II aimed at investigating the use of mobile technologies in inquiry-based learning activities in natural sciences. The study we conducted consisted of small groups of students performing an inquiry-based learning activity supported by mobile technology. The activity observed was played out outside the classroom, to explore characteristics of species of plants and trees and their biotopes in the woods in the north Stockholm area, Sweden.

4.1 Participants

Participants of the research project consisted of 15 students from a primary school in Stockholm, Sweden. The students were in the fifth year and were between 10 and 11 years old.

The participants were divided into five groups of three. Two teachers participated in the research project. The teachers were responsible for constructing heterogeneous groups with respect to subject knowledge based on principles for collaborative learning [29].

4.2 Intervention Design Process

The design team consisted of two teachers, three researchers, one with expertise in pedagogy and learning design, the other in interaction design and the third in computer science. These three areas informed the design process of the mobile learning activity studied.

The design input from the learning design perspective was based on: 1).a literature review summarizing known problems and previous learning challenges in mobile learning studies, with a particular focus on findings presented in [31], for instance, concentrating on the sequencing of learning activities, the provision of scaffolding and orchestrating collaboration among the students, 2) utilization of the pedagogical framework of inquiry-based learning and 3) theories on scaffolding and collaborative learning [30], [32].

Inquiry-based learning, prototypically, involves learner-centred and non-structured investigations that are based on students' own choice of questions, hypothesis and observations of phenomena [33]. However, it is argued that more structured and guided inquiry activities are preferable if the students are young and lack experience of inquiry [33]. As this was the case with our study, we chose to apply a high degree of structure in the students' tasks in order to guide them through the inquiry-based learning activity.

The design process was also informed by the end-users, that is, students and teachers. More specifically, we used a participatory interaction design methodology consisting of future workshops to discuss, test prototypes, evaluate, redesign, and implement the learning design. Design input from the students and teachers drew attention to desired practices and issues with current ones.

Fig. 2. The three sub-activities in the outdoors field phase.

4.3 The Inquiry-Based Learning Activity

The inquiry-based mobile learning activity could be divided into three main phases, namely an indoor introduction phase, an outdoors field phase and an indoors post-phase.

The *introduction phase* provided the students with an opportunity both to familiarize themselves with the technology intended to be used in the outdoors activity, and to create an understanding of the tasks they were to perform—guided by the attended researchers and teachers who facilitated the process and provided instructions. The technology used consisted of a smartphone and a pad.

The *field phase* started with a group of students arriving at one of four different nature squares in the forest behind the school. Each student had a smartphone, and there was one common device, a pad, located in each square. The squares were designed for the purpose of the study and contained the flora to be investigated by the students.

The field phase was designed as a sequence of three activities (see Fig. 2) playing out as follows; before the first sub-activity all three students in the group used their mobile devices to *scan the QR code for the nature square* they arrived at. The code initialized the mobile devices to show a list of the species available in the current nature square. The common device also provided students with further task instructions. The *first* sub-activity to be performed was to identify the species in the nature squares. The *second* sub-activity was to read information about the scanned species. Mobile devices assisted the students to scan QR codes attached to each species and access information about them. The *third* sub-activity was to use the phone camera to capture what the students believed characterized the species.

The mobile device provided the students with in situ descriptions of species and their biotopes and allowed for multimodal data collection in the form of pictures and videos. The pad, on the other hand, constituted a common tool that scripted the collaboration between the students by forcing them to provide individual codes each time a task instruction was needed from the pad. That being so, the use of the pad encouraged the students to create a joint task understanding and receive equal task information in order not to empower the students asymmetrically. The role of the teacher in this particular activity was to intervene and support the students only when they actively asked for help with a phone call.

The *indoors post-phase* was designed to let the students analyse the collected multimodal data from the field activity. Collaboratively, they had to interpret and transform the data collected and summarize it into conclusions and new representations. The activity ended up with the students displaying multimodal presentations that were discussed with the whole class. Two available teachers scaffolded the students' work during this post-activity.

4.4 Data Collection and Data Analysis

The qualitative data were collected with a handheld video camera, used for each group in the mobile learning activity. The camera followed each group of students conducting the activity and seven hours of outdoor activity video data were collected, approximately one hour per group, in one day. The three researchers transcribed the conversations of the students. These transcribed conversations supported the video analysis that was conducted in the following manner. First, the whole outdoor mobile learning activity was divided into three sub-activities, identifying species, reading about species, and documenting characteristics of species. Each sub-activity was analysed separately in two phases, informed by Roth and Lee's [34] and Jonassen's [35] advice to start CHAT analysis with a descriptive analysis of activity system components followed by an analysis of the dynamic and dialectical relations between the components in terms of emerging contradictions and tensions.

Consequently, in phase one, a descriptive analysis of the sub-activities was conducted, in this case, focusing on the tool component in Engeström's model. More specifically, analytical attention was paid to children's instrumentalization of the mobile technologies (i.e. mobile devices and tablets), and to the meditational role of the mobile technologies in facilitating and constraining the activities (i.e. the tool-object relation). For instance, in sub-activity 1 (identify species), leaning towards video data and transcribed conversations we asked ourselves how QR codes are used by different students and how/which objects attract attention.

In phase two, we employed the dialectical method, analysing emerging contradictions in students' activities and guided by the conviction that it is important to take into account the contributions of technologies in constraining actions in authentic settings [22]. For instance, in sub-activity 2 (reading about species), we started by identifying tensions arising from students' avoiding reading information provided to them. When tensions were identified we asked ourselves if they could be explained by contradictions between components in the activity systems.

5 Results

In the following, each of the three sub-activities in the outdoor inquiry-based activity observed, i.e. identifying species, reading information about the species and documenting characteristics of species, are analysed separately from the perspective of Engeström's activity theory model. All these sub-activities were mediated by technology (mobile devices and tablets). The separate analysis of the sub-activities also exposes the relations and transactions between them.

This section is organized as follows. We examine each sub-activity starting with the tool mediation process, and ending by examining contradictions which emerged within the activity systems studied.

5.1 Sub-Activity 1: Identifying Species through QR Codes

In this sub-activity, the children identified species in a designated area in the woods. A list of species to identify was provided to the students through the mobile devices. QR codes were attached to one exemplar of each species in the list. As anticipated, we observed that the physical existence of the QR-codes attached to the different tree species examined, scaffolded students' attention by directing them towards the relevant learning objects, in this case, the species to be investigated. By identifying the QR code in the woods, the students also identified the target species:

S1: *The rowan tree is the only one left to find but I can't find it.*
S2: *Have you looked properly?*
S1: *Yes*
S3*: Just look for the QR code you haven't scanned*.

This excerpt illustrates how students seek specific species to identify and how the QR codes supported them in that. Thus, in a natural, dynamic and complex environment with rich information such as the woods, QR codes may reduce complexity and direct students towards the relevant learning objects.

5.1.1 Contradictions and Tensions

One of the contradictions identified within the activity system emerged from the relationships of the following activity system's components: tools (i.e. the QR codes), rules (i.e. to reflect on the identification of species) and the intended object (i.e. reflective identification of species). The contradiction is that the QR codes (the tools) became an object in themselves instead of a tool for reflecting on how species could be identified (see Fig. 3).

Such a contradiction problematizes the scaffolding role of QR codes designed to orient students' attention towards relevant learning features. Our expectation was that the students engaging in a searching activity would also reflect on how the species could be identified, differentiated from others in natural, authentic environments, and that they would only rely on QR codes for identification purposes if needed. However, we observed that the majority of the students instrumentalized the QR codes as a tool for identifying

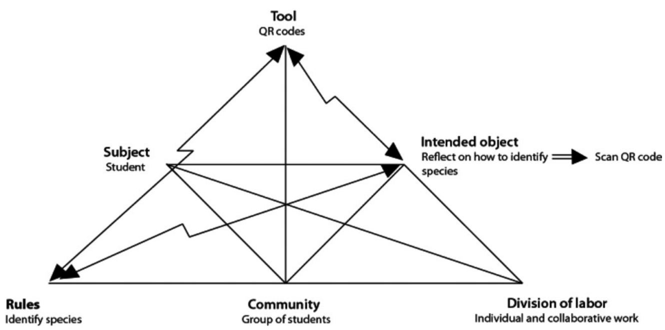

Fig. 3. Contradictions in students' activity (identifying species).

the species in a mechanical and unreflective way (see [36]), i.e. seeing the object as 'scan QR code', instead of the intended object 'reflecting on which criteria to rely on whilst identifying specific species'. One possible reason for the emergence of this particular contradiction is that the activity system, for instance in terms of a more present teacher, did not intervene in the regulation of students' instrumentalization of the QR codes. The reasons why students instrumentalized the tools in a unintended way were many. For instance, the students might have been unconscious of the intended object or did not value it higher than the object intended to be pursued in the activity. The latter alternative is probable for two reasons. First, for students familiar with traditional tools in the classroom, the utilization of new technology, in this case QR -codes—as an object in itself—may have been more attractive than the environment they were meant to study. Second, the technology played a central role in the outdoor activities, designed to mediate all three sub-activities and their corresponding actions (i.e. identifying species, reading information about species, collecting data, receiving task instructions, communication with teachers, etc). Thus, the valuation of technology by the activity system, in itself may have further encouraged students to associate the technology with a valued object rather than see it as a mediational tool for reaching intended objects.

5.2 Sub-Activity 2: Reading Multimodal Information About the Species in Situ

This sub-activity consisted of scanning the QR codes attached to the species in order to access and read multimodal information about the species. We observed that the extent to which students read the texts differed between groups and between students. Those students who actively read and internalized the texts instrumentalized the texts in two ways.

First, the texts were instrumentalized as a tool for communication and collaboration with peers. That is, the students reading the texts initiated conversations with peers on the information displayed in the texts provided by the mobile devices:

S1: *It says that a pine tree has a long stem, but this tree does not.*

S2: *Is it a pine tree then?*

S3: *It could be . . . maybe it is a small pine tree that will grow larger.*

This excerpt shows that student S1 instrumentalizes information provided by the mobile device for communication and collaborative reflection with fellow peers.

Second, some of the students who actively read and reached the intended object (i.e. internalization of the texts), instrumentalized this object as a tool supporting the documentation and examination of the characteristics of the species in the subsequent activity. That is, these students based their decisions regarding which characteristics to take pictures of on the internalized information about species provided in the uploaded texts:

S4: *According to the text, the birch leaf should have jagged edges and have a heart shape [referring to the multimodal text provided by the mobile device]. I want to take a picture of a birch leaf.*

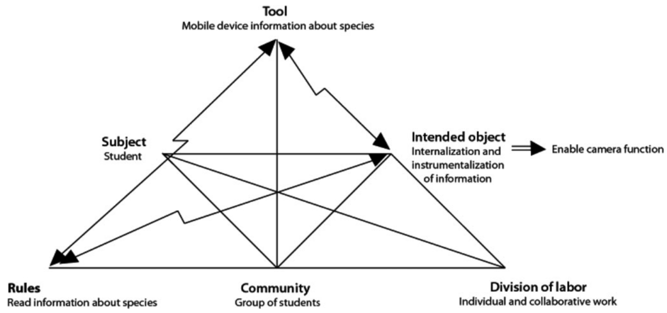

Fig. 4. Contradictions in students' activity (read information about species).

S5: *Well, I think you have several right in front of you on the ground.*

S4: *I know, I just scanned this tree.*

In this excerpt, student S4 instrumentalized information previously read on the mobile device as a conceptual tool for identification of birch leaves on the ground and for learning what to take pictures of. Thus, some students indeed instrumented the information about species provided in the multimodal texts available on the mobile devices in interesting ways. Previous project experiences [37] also suggested that students who utilized the QR codes to access and read contextual information about species significantly outperformed students who did not use them.

5.2.1 Contradictions and Tensions

Another contradiction was identified in the analysis of how students read information provided to them about the species in situ. The contradiction was between the rules (i.e. reading information), the tools used (i.e. mobile devices) and the intended object (i.e. 'reading/learning to identify species'). The information about the tree species was provided to the students as soon they scanned the QR codes attached to the species. After the information was provided, an instruction was given to the students to take pictures of the characteristics of the species. We observed that some students tended to use the mobile device (tool) only to scan the QR code and enable the camera function (the object followed) without reading the provided information (see Fig. 4), a behaviour that correlated negatively with performance [37].

The tools used confused students' understanding of the instruction 'to read the information' in two ways. First, the software displaying the multimodal texts may have been difficult to instrument in the way intended because of technological limitations (i.e. challenging to read because of a restricted screen displaying both textual and visual information). Second, as pointed out earlier, the activity system made it possible, and also encouraged students, to instrumentalize the mobile technology in unintended ways towards unintended objects. Furthermore, we consider that the activity of taking pictures in the subsequent activity was probably valued higher than reading and making sense of information in this activity. Since the activity system allowed it, students may have overlooked the object in this activity and instrumented the technology to mediate the object in the subsequent sub-activity. Such activity-crossing instrumentations could probably have been prevented if the intended activity objects in the different sub-activities were

Fig. 5. Students engaged in taking pictures.

dependent on each other; for instance, if we had made reading the information a prerequisite for taking pictures.

5.3 Sub-Activity 3: Documenting and Examining Characteristics of the Tree Species through Taking Pictures

One of the technology-mediated actions performed in this activity was collecting data and experiences as part of the inquiry-based learning process. This was operationalized through taking pictures with the mobile phones, which the students did quite successfully in terms of engagement, reflection and discussion. We observed that some students became really engaged during this particular phase when pictures were to be taken (see Fig. 5). That was reflected in the number of pictures taken, on average three pictures per species and student, and the length of discussions about them. Taking or retaking pictures became an activity per se for some of the students, requiring the following actions: 1) a thorough observation of the characteristics caught in the picture, 2) a reflective activity in relation to the information about the species, and 3) discussion between group members.

Although digital cameras certainly could support the particular action of taking pictures, and the specific goal of capturing information in a visual modality, the advantage of mobile technology here is its ubiquitous character and that the process of taking pictures can be scaffolded (in this case the mobile application guided the students towards the characteristics of the species).

5.3.1 Contradictions and Tensions

Three contradictions were observed when we analysed the pictures taken individually by the students. The predefined rule of this particular activity was to work towards the object of 'pictures reflecting salient characteristics of the species'. The first contradiction observed was enacted when some students redefined the primary object of the activity to 'taking aesthetic pictures of the species' excluding a focus on the salient characteristics of species. We observed indications of this shift of focus when students began to take pictures of the trees in their entirety, from a large distance, showing less interest in details like leaves and berries. The focus on aesthetics was also indicated in that several students explicitly mentioned their wish to take aesthetic pictures.

Consequently a contradiction was established between the predefined rule of the activity and the students' redefined objects. In this case, the activity system gave the students an unregulated agency to redefine the object, resulting in a contradiction. However, the unregulated agency given to the students with regard to the main object of this sub-activity, namely 'pictures of characteristics of species', was not negative per se, as a subset of the students enacted their agency to redefine the object as the combined object 'aesthetic pictures of species characteristics'. Such redefinition of the object may have been a way for the students to overcome the tension between the instruction to 'take pictures of salient characteristics' and the object desired by the students ('aesthetic pictures'). The subset of students working towards the combined object demonstrated stronger engagement compared with students only interested in taking aesthetic pictures.

The second contradiction observed was established between the rules of the activity and the tools in use. The instruction for this particular activity was to take pictures based on what the students understood from their own analysis of the main characteristics of species; the main tool used, i.e. the mobile device, acted as an authority on the characteristics of species.

In some instances, the characteristics emphasized by the mobile device were difficult for students to observe physically. For instance, in one of the groups, two students read on the mobile devices that a juniper bush had blue berries, inter alia. However, the juniper bushes physically available in the limited environment investigated by the student did not have berries. The consequence was that these particular students had a lengthy discussion about whether the juniper bush in front of them was a juniper bush or not. In the end, they seemed confused and took one picture of the whole bush instead of capturing detailed characteristics:

S1: *Maybe this is a juniper bush.*
S2: *But the juniper bush should have blue berries according to the phone.*
S2: *Shall we take pictures of this bush?*
S1: *I don't know, maybe not then.*
S2: *But we can't find a good juniper bush.*
S1: *Let's take a picture of the whole bush.*

The conversation shows a tension between S1's perceptions and information provided by the mobile device that was resolved through an adaptation of an unintended object (i.e. 'complete the activities quickly') at the expense of reflective action. We also observed several other students unreflectively and mechanically informing their actions by following the information given from the mobile devices to the letter, rather than by elaborating on their own reflections and analysis of the environment. Thus, for these students, the mobile device as a tool was not purposive in the sense it drew too much attention from reflective action and encouraged students to follow information mechanically.

The third contradiction emerged when some students in the same group finished taking pictures whilst others were still portraying the environments. The students who finished taking pictures first were forced to wait until the others in the group had completed their tasks. When fast students finished this activity, they were forced to wait until

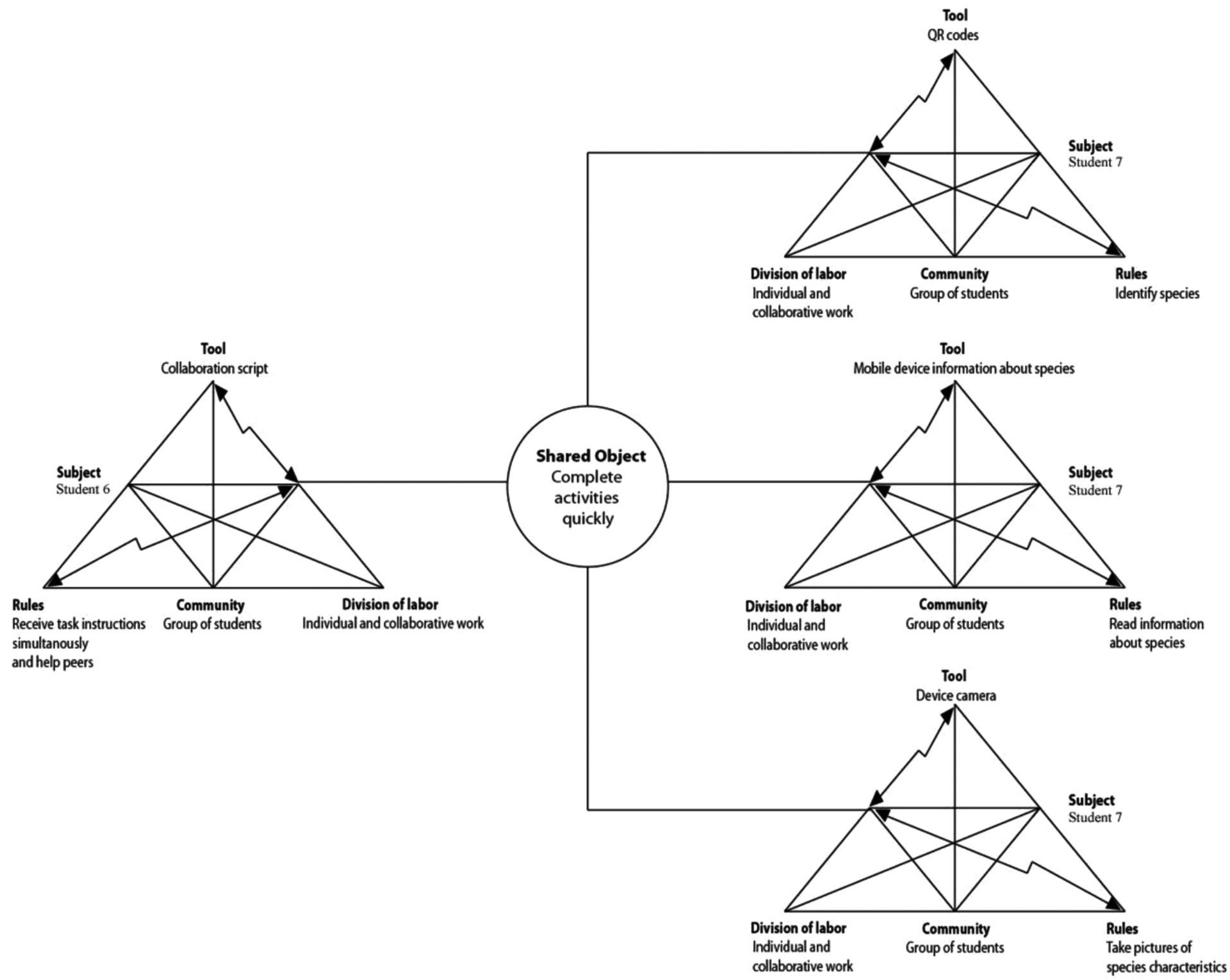

Fig. 6. Contradictions injected from a student's activity system to another student's activity systems.

the remaining group members had completed their tasks before they could start a new round of explorations in a different area in the woods. The pad software was designed to provide task instructions simultaneously to all students after group completion.

We observed in previous mobile learning projects that asymmetrical distribution of task information lead to asymmetrical division of labour and consequently to collaboration difficulties. That being so, our expectation was that simultaneous provision of task instructions, from a common tablet, would become a collaboration script for the students, preventing individuals from advancing too quickly in the activities, leaving group members behind and hampering collaboration processes. That expectation was met in part, as we indeed observed that the collaboration script introduced a tension that affected fast students as they were forced to wait until the remaining group members had completed their tasks. However, teachers' lack of control of students' activities meant that four out of five students handled the tension negatively as they initiated conversations off-topic, distracted peers or/and urged peers to complete their activities quickly:

S6: *Do you have much left to do?*
S7: *Yes, have you finished yours?*
S6: *Yes, you don't need to read the texts, just take some pictures so we can go to the next square.*

The outcome of the collaboration script can also be framed in terms of shared objects. Before the collaboration script was triggered, students S7 and S6 lacked a shared object. However, after the collaboration script was triggered, student S6, bound by the command to wait for task instructions and help his peers, started to work towards constructing a shared object with his peers by advising them to adopt his object ('complete the activities quickly'). Unfortunately, student S7 took S6's advice and transformed her object to 'complete the activities quickly' (i.e. the shared unintended object) instead of continuing on her learning trajectory towards the intended objects, as did others in the groups. Thus, the effect of the collaboration script was that the quicker students, who all belonged to the subset of students tending not to read the provided information about the species and take fewer pictures, by creating a shared unintended object injected contradictions and unintended objects into the activity systems (spanning all three activities) of their peers (see Fig. 6).

In the above figure, we see that Student 6 influence Student 7 to adopt the object "complete activities quickly". When Student 7 adopts this object, it becomes a shared object between these peers. As a result contradictions are injected in Student 7's three activities; namely, 1) contradictions between the intended tool use and the shared object, and 2) between the rules (i.e. task instructions) and the shared object.

6 Conclusion

The CHAT analysis conducted in this paper demonstrated that the introduction of mobile technologies in the context of formal education is not unproblematic, something occasionally overlooked when the role of mobile technologies in the field of mobile learning is discussed. By tracing students' instrumentalizations of the mobile technologies provided, we identified several contradictions and tensions in the activity systems, suggesting the introduction of learning constraints and the unfolding of learning activities that can be characterized as mechanical rather than reflective.

Three reasons have been identified in the CHAT analysis for students' tendencies towards mechanical rather than reflective action and their attention to unintended implementation objects at the expense of the intended learning objects. First, the activity systems allowed, and in some cases encouraged, students to instrumentalize the mobile technologies in unintended ways towards unintended objects resulting in contradictions and tensions.

Second, the mobile technologies were the central tools used in the outdoor activities, designed to mediate all three sub-activities and their corresponding actions (i.e. identifying species, reading information about species, collecting data, receiving task instructions, communication with teachers, etc.). In a sense, following the technology became a superior object in itself, motivating students' more than the environment intended to be studied. A possible explanation is that the technology, by playing a central role and thus being highly valued in the activity systems, may have encouraged students to associate the technology with a valued object.

Nevertheless, we find the most feasible explanation for students' tendencies towards unreflective actions regarding unintended objects in the lack of available teachers regulating students' selection of objects and their instrumentalization of the tools used. An available teacher monitoring the activities could have scaffolded the students by directing them towards relevant learning objects and relevant tool instrumentalization. Such a teacher could also have scaffolded students to resolve emerging contradictions and tensions in constructive ways. For instance, in sub-activity 3 a teacher could have encouraged the students who chose to hurry and distract their peers when a tension was faced to resolve the tension by encouraging them to further discover the environment on their own or help their peers.

Consequently, the main conclusion that can be drawn from the study conducted is that orchestration of formal mobile learning activities is indeed a challenging task, as students may redesign and instrumentalize technologies used in unintended ways—negatively affecting the unfolding of activities. That main conclusion also stresses that orchestration of outdoor mobile learning activities is strongly dependent on teachers monitoring and orchestrating students' activities in situ. Finding such a role for teachers in mobile learning activities can however be a challenging endeavour in itself, taking into consideration constraints such as the number of students per class, physical distances between students and teachers in outdoor environments, and so on. All together, this acts as a reminder of the importance of critical examination and discussion of the role of mobile technology in formal educational settings.

7 Discussion

In the analysis of the mobile learning activity here studied, second generation CHAT was invoked to be used as a lens and orienting device to structure the analysis. The analysis was conducted by paying attention to the concept of instrumental mediation introduced by Raberdel [27], as well as by examining emerging contradictions and tensions in the activity system studied.

First, by attending to the components of Engeström's Activity System model, in particular the tool component (supported by the concept of instrumental mediation), we were able to trace students' constructions and interpretations of objects, their instrumentalization of the mobile technologies used, and the transformations introduced by these technologies. Thus, CHAT's emphasis on tool mediation, as noted by Timmis [21], allowed us to 'reinstate the contribution of the digital tools and artifacts in use as part of the analysis of interactions, whilst resisting technological determinism and causality' (p. 7). Also, by paying attention to the tool-object relationship, we could better understand what sustains learners to engage in the activities and how their choices of mediated actions connect with the intended educational objectives.

Second, by undertaking a dialectical analysis of emerging contradictions and tensions in the activity systems, we were further supported in clarifying objects and goals of different actors and how these objects changed over time. More importantly, the dialectical analysis of contradictions helped us to reveal disturbances in the activity systems and the constraints introduced by the mobile technologies used. Thus, in tune with Roth and Lee [34], we emphasize that the dialectical method indeed gives CHAT explanatory power, in that the method is both 'unifying and problematizing, allowing us to interrogate the different goals and objects in collaborative activity and explain why disturbances occur' (pp. 3.)

Third, by conducting an analysis of contradictions and tensions in the activity systems, we were provided with information that can be used to inform design guidelines and adjustments in future activities. For instance, the contradiction analysis conducted revealed that several emerging contradictions might have been avoided if a teacher had been present to monitor and regulate the activities. Therefore, we believe that CHAT could be applied as an evaluation tool supporting iterative designs of learning activities.

Finally, CHAT proved to be a fruitful tool for the analysis of mobile learning activities, providing a good starting-point for 1) understanding relevant features that shape learning situations, 2) exposing the role technology plays in mediating and transforming learning processes, and 3) facilitating the characterization and evaluation of learning activities.

In the field of mobile learning research, CHAT has been proposed [8] as a potential analytical framework for the study of how mobile devices mediate learning activities, however, few are the scholars who have operationalized CHAT and actually demonstrated the potentials of this analytical framework for the study of mobile learning.

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Jalal Nouri received the MSc degree in mathematics, the MSc degree in education, and the PhD degree in information society and is a researcher and a teacher in the Department of Computer and System Sciences, Stockholm University, Sweden. He is a committee member for the IADIS Mobile Learning conference. His research interest has a strong focus on pedagogical design aspects of technology enhanced learning in general and of mobile learning in particular.

Teresa Cerratto-Pargman is an associate professor of human-computer interaction (HCI) in the Department of Computer and Systems Sciences (DSV), Stockholm University (SU). She has a particular focus on design, adoption, and use of technologies for reflective and collaborative purposes. She has published more than 70 articles in international journals, refereed conferences, books, and technical reports. She has also been presenting and giving lectures about her work in Sweden and abroad. During the last years, she has been serving as a program committee member in a number of international scientific conferences.