COMPUTATIONAL LITERACY AT WORK

Children's construction of digital material

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ABSTRACT

We explore the characteristics of children's construction of dynamic systems in a school context. This is done through analyzing children's activities when working hands on with a modelling task, and also through informal interviews and exhibitions where children described their work to peers and teachers who had not taken part in the activities. Our results suggest that handling the technology, relating to others, and negotiating ideas, are prominent aspects in these activities. Based on these results, we discuss the different activities involved in learning to create digital constructions and how these relate to several important topics that are emphasized in educational research that draws on socio-cultural perspectives on action and learning. These include the social context, the role of artefacts and technology, and the ability to articulate, express, and discuss.

1. INTRODUCTION

Different means of communicating and expressing one's ideas and knowledge to fellow students, to friends and family, are core aspects of most human activity. People express themselves and communicate verbally, but also through other forms of expressions such as making pictures, writing texts or through playing musical instruments. Also, different media are appropriate for expressing different things, for instance, dynamic processes might be difficult to express only with still pictures.

The long-term ambition with our work is to support people to become "computationally literate". Computational literacy is not to be mixed up with "computer literacy", which concerns the ability to use a personal computer. By computational literacy we mean the ability to understand, and to make oneself understood through computational materials, for instance to create an animated game or to understand an interactive story created by a friend. It has been argued that computational literacy will become increasingly important for future generations as computation becomes more and more embedded and ubiquitously integrated in our everyday environments (diSessa 2000). Also, an increasing part of the media content around us are made with digital tools, and the ability to produce – and in a sense program – own such media, e.g. dynamic illustrations, interactive toys, and games, are becoming new important aspects of learning and communication. We would like to emphasise that this does not have to imply that people should learn to program a computer in the traditional sense. Instead new ways to express computations are needed, and also expanded understandings as to what situations people may find such representations useful.

This paper contains an empirical section where we explore some characteristics of a digital construction activity with middle-school children. This section ends with an analysis of children discussing their understanding of the usefulness of digital construction activities in school for peers and teachers that had not been involved in this activity. At this occasion a researcher who had not taken part in the construction activities were also present, asking the children how they thought digital construction could be used in school. Our analysis of these sets of data show that children's development of expressive, aesthetic, and social skills are more prominent than is usually assumed from such construction activities (Klopfer and Um 2002; Stieff and Wilensky 2002; Ioannidou, Repenning et al. 2003). We discuss how the different activities that we see as central in learning to create digital constructions relate to topics that are commonly emphasized in educational research that draws on socio-cultural perspectives on action and learning. These include the importance of the social context, the role of artefacts and technology, and the ability to articulate, express, and discuss (Collins, Brown et al. 1989; Säljö 1996).

2. EMPIRICAL EXAMPLES FROM CHILDREN'S ACTIVITIES

In this section, we will follow two children through a short episode of their process of designing and implementing a dynamic and interactive system. The episode lasted for about 15 minutes, and throughout this short time frame the children have to manage a whole range of different issues related to the solution of a specific problem in their design. Three short fragments have been selected that illustrate some issues that we have found to be characteristic of their work and that illustrate some important issues of learning to create dynamic and interactive systems. The fragments could have been taken from any group of children; however this particular sequence was selected because we found it representative both to the character of the activity as a whole and also with respect to what we see as central to computational literacy. We also see a value in picking examples from one and the same pair of children, since this highlights how all the three aspects are present in the same production process. The aspects that we would like to highlight are *negotiations of what solution to choose, managing the technology, and relating to friends and context*.

The data is taken from a modelling workshop where a group of middle-school children collaboratively worked on designing and programming dynamic models on the computer. A common theme throughout the workshop was endangered species, and a part of the goal was to explore how transparent modules of programming code (ref playground?) could be used to support learning within this particular domain. This domain has been used by several other projects and has proven successful as a basis for modelling of dynamic systems on the computer (Rader 1998; Ioannidou, et al. 2003). The activity was also part of an international project, and it was envisioned that the exchange and discussion of computational systems should provide efficient means for children to engage in collaborative knowledge building (Scardamelia and Bereiter 1996), across the barriers of spoken and written languages.

The first two sessions as well as the final session took place after school in the students' regular classroom, while the greater part of the activities took the form of a three-day workshop in one of our research labs, scheduled during the autumn holiday. The activities were introduced by discussing a static food-web model, which the children already were familiar with from school, and in the first two sessions the children got introduced to the programming software and made clay models of plants and animals that they wanted to include in their models. During the three workshop days the children worked iteratively on implementing their models on the computer. Approximately half of the time was spent working hands on with the programming tools, and half of the time with supportive activities away from the computer, such as discussing the workings of their models in the group and building new clay figures to use. All the modelling and programming activities were designed to be focused around relations and behaviours of living organisms.

The programming software used was an extended version of Toontalk (Kahn 1996). When building dynamic models in this tool, the children work with pictures that can be programmed to behave and animate in various ways. Pictures are controlled through "sensors" and "remote controls", representing properties such as screen position, size or whether on not the picture is colliding with some other picture. There are also system level sensors for detecting mouse movements, mouse clicks, and other system events. ToonTalk robots can be placed on the "back" of pictures to operate on its sensors and remote controls. For the user to manipulate the environment a virtual hand is used to control a number of different tools: a magic wand for copying objects, a vacuum cleaner for erasing and removing things, a bicycle pump for changing the size of objects, and notebooks for storing objects.

At the first modelling session, the children that we will focus on had made a model including a brown bear, blueberries, and a gun being the threat to the bear. The children originally also made a giant panda and a bamboo shoot, although these were not included in their later design. After the first day of the workshop, the children described their work in the following way on the web-based system: *"We are making a game "on" ToonTalk. You are a bear who are supposed to munch blueberries but you have to watch out for a gun, otherwise you get shot. But it is made like you blow up. We are working on it but we are not quite finished. Then there will be poisonous berries and fire that you have to watch out for."* The gun was later replaced by a hunter character, and a start and a goal sign were also added to their game. The episode that we focus on occurred at the second day of the workshop and starts with the children's observation that the hunter character was moving so fast that it was impossible to pass it with the bear, and ends with their final solution to that problem.

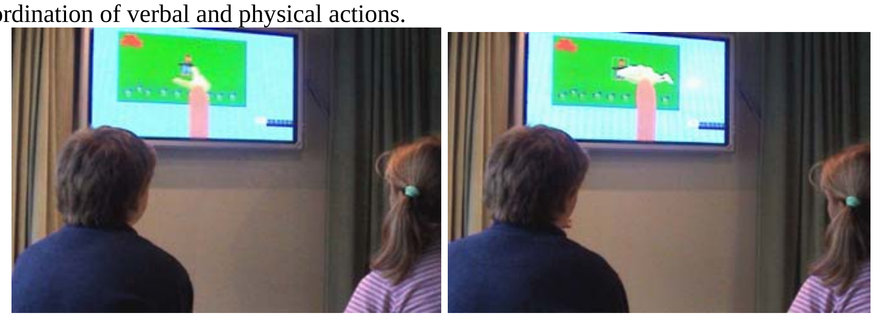
The transcriptions include the children's talk, actions in the programming interface, and relevant gesture. The denotation used is a subset of the conventions used in conversation analysis (Pomeranz and Fehr 1997): non verbal action is described in parentheses, micro pauses in talk are represented by (.), = represent latched talk, underlining indicates emphasised talk, (inaud) indicates inaudible talk. All names of the children in the transcription have been changed. The Swedish speech has been translated to English by the authors.

Managing the tools and the technology

The first fragment illustrates how the children deal with the technology they are working with. We present this fragment because it shows the characteristics of the interactions around the software throughout these kinds of activities. The technology used in this setting is complex for the children and exposes them to several issues that take considerable time and effort for them during their work. However, as time passes they develop methods for dealing with technical issues that arise without losing focus of the task at hand. In the following we discuss some of the strategies that the children use to manage the technology. A central aspect is that this technical handling also influences how they choose to solve a particular programming problem that they are faced with. Hence, managing the technology is not just an obstacle to overcome; it has conceptual consequences for the actual game that the children end up constructing. Thereby illustrating the problem of attempting to separate the children's learning from the tools they use in the construction process (Säljö 1996).

At the start of the fragment, the children have decided to make the hunter go slower because it is almost impossible to pass it with the bear. Before the transcripts starts they have been discussing what an appropriate speed of the hunter character could be, 500 or 450.

First, we would like to point out how the managing of the technology is a collaborative activity. Even though Tomas is not controlling the mouse or the keyboard, he is intensely engaged in the details of handling the tools and the objects in the programming environment. Throughout this fragment, he repeatedly provides input to how Rakel should perform actions in the programming interface. Most of the time his input is at a fine-grained level such as suggesting that Rakel should flip an object over or by simply confirming or rejecting a particular action proposed by her. A clear example of the close collaboration between the two children is seen in the following turns where Rakel is taking out the hunter character from the game in order set it up so they can access the properties for changing its speed. The collaborative process of achieving this is analysed in a detailed transcription of those turns, where closer attention has been given to the children's coordination of verbal and physical actions.



1. Rakel: should we have that one= (points with Dusty the vacuum cleaner at the hunter)
2. Tomas: =yeah
3. Rakel: (sucks out the hunter, spits it out)
4. Rakel: (points with the TT hand on the hunter on the floor)
5. Tomas: pick it up
6. Rakel: (picks up the hunter, flips it over, points with the TT-hand on the behaviour square to the right) that one huh=
7. Tomas: =yeah

8. Rakel: (picks up the right square tries to put it down) put down (puts the square down on the floor, points to the left square) that one
9. Tomas: no (.) yeah
10. Rakel: (picks up the square and puts it down on the floor, points to the robots box with the TT-hand)
11. Tomas: pick it up
12. Rakel: (gets the box and moves it to some free space on the floor) ... minus 600 ... minus 600 … minus 500

In these turns Tomas is actively monitoring Rakels's actions in the programming interface with utterance that directly refer to those actions (line 2: yeah) or such that suggests an appropriate next action (line 4: pick it up). Rakel is also making efforts to make Tomas become part in the details of finding the correct programming element. Rakel is throughout the fragment very sensitive to Tomas's utterances as she repeatedly delays her interface actions to get his response. For instance, in line 4 Rakel points to the hunter with the ToonTalk hand, thereby providing the opportunity for Tomas to suggest an appropriate next action as he does in line 5 "pick it up". This is also a way for Rakel to seek confirmation for the action she is proposing, which is also seen in lines 8 through 10 where she does not pick up the object she is pointing to until Tomas has confirmed it. Here the children are resources that structure each other others' actions (Lave 1988). This creates a relationship between the two where the actions of one of them is a requirement for the progression of the other.

The fine-grained coordination of verbal action, programming interface action, and gesture between the two children requires considerable work by both of them. This is necessary to achieve a mutual orientation towards the objects in the programming environment and what actions to perform on those objects. It suggests how the technology is not only tool that they have to manage to build their model, but it is actually an integral part in the mutual construction of the idea of the game. In other words, the evolution of the idea of what they are creating is closely integrated with its manifestation as a ToonTalk model. This requires both of them to be involved in all aspects of the activity. The collaborative handling of the technology is important for the unfolding of the activity as a whole and not only for achieving this particular portion of the activity. It is a way for them both to make sure that the other is equally involved in what they are producing so that the final product will be a joint achievement. It also makes both of them engaged in the construction of the game at a level that prepares them both to address future difficulties that might arise.

Relating to their friends work

Before the beginning of the following fragment Rakel and Tomas have tested their game quite a few times and still have not managed to find a speed for the hunter that they are satisfied with. They have slowed it down even further and the speed is now 375. At the start of the fragment Rakel is testing the game:

1. Rakel: ne ne ne ne
2. Tomas: their sun flower in the middle of-
3. Lisa: really (.) seriously speaking their sun flower
4. Rakel: (continues working on the game)
5. Tomas: (inaud) not really pretty (inaud) don't you think
6. Rakel: I thought that (inaud)
7. Malin: Hi (walks in front of the screen) it seems like it's going bloody well for you but bloody bad for us
8. Rakel: (tests the game) I'll make I'll make I'll make it noo:h
9. Tomas: I'll make it I'll make noo:h
10. Malin: Rakel I took our buffalo
11. Tomas: make it small (.) it could be a baby bear
12. Rakel: no but do know what we'll do (inaud)
13. Malin: Rakel let our buffalo (inaud)
14. Rakel: I know what I did wrong (gets the hunter out of the game)
15. Tomas: (looks away) li- how small they are
16. Rakel: no he started moving

17. Tomas: I thought it was bigger (.) you think that only because when you saw the picture pictures (.) but the sun flower is (.) pretty big
18. Rakel: no he's running away (.)we have to pause it
19. Malin: look hu your old grass

Throughout this fragment Rakel is mostly focused on testing the game while Tomas is talking to Jonna who is now sitting to the right of Rakel. Tomas is commenting on Sebastian's and Jonathan's model in which they have included a picture of a sun flower. Tomas is suggesting that the sunflower is not very nice or stands out somewhat from what most others have done. Jonna seems to agree on this by also commenting on the sunflower in a less positive tone of voice. A couple of turns later (line 7) Mimmi enters in front of the screen calling for attention and suggesting that Rakel and Tomas are progressing much faster than they are. In the following turns Mimmi also asks Rakel to include the buffalo that she and Sara has made into their game as well.

The most important aspect of this episode from our point of view is not how the children exchange specific ideas about how to implement something nor that they find suggestions relevant to their own work by studying what their friends are doing. Instead, what we find to be most important is that the children continuously throughout the session relate and compare what they are doing to the work of their friends on a social level. Most of the influence in this fragment is not in terms of the specific content of the models they are building. It is rather about comparing and discussing each ones work in relation to everyone's overall progression, and also how what they are building are complying to what seem to be the agreed upon overall purpose of the activity. The two girls, Mimmi and Jonna, seems to be coming over to Rakel and Tomas to compare with their own work, to discuss the work of the Sebastian and Jonathan, and to try out the game that Rakel and Tomas have built. Hence, the role played by these social influences for the modelling and programming of their system is mostly as a motivator for the progression of the activity as a whole, rather than having implications for specific design and programming considerations.

Negotiating different solutions

In the following fragment the researcher Ylva comes up to Rakel and Tomas to see how they are progressing. They are still trying to get the hunter to move at an appropriate speed.

1. Rakel: okay
2. Ylva: so how are things here
3. Tomas: it's going really well
4. Rakel: really it's going really well but we want to know (inaud)
5. Tomas: (inaud) test it (inaud) really fast
6. Rakel: really we have worked really much with speed (inaud) we never know
7. Rakel: (tests the game with a smaller bear)
8. Rakel: like that (.) do do do do noo you don't make it
9. Tomas: he he (.) no no noo you don't make it
10. Rakel: I think (inaud) make it even smaller
11. Tomas: lets make it so that he doesn't dance (inaud) better idea
12. Rakel: no but it's cool
13. Tomas: Let's decrease the speed (.) what did he have now
14. Rakel: three hundred seventy five
15. Tomas: then let's give him (.) three hundre::
16. Rakel: three hundred
17. Tomas: no
18. Rakel: yeah
19. Tomas: it's gonna be wa:y too slow (.) three hundre- really it's only like (.) three hundred seventy two is enough
20. Rakel: nope
21. Tomas: three hundred
22. Rakel: three hundred seventy

23. Tomas: do you really think three hundred seventy is reasonable
24. Rakel: no (inaud) three hundred fifty (inaud) three hundred fifty
25. Tomas: (inaud)
26. Rakel: no I promise
27. Rakel: (takes out the game, gets the hunter and changes the speed to –350, Tomas is helping, Rakel puts the game back together)

We would like to emphasise that the children considered a number possible solutions throughout the whole episode of which this fragment is part, including increasing the speed of the bear, changing the size of the hunter. Until now they have mostly been focused on changing the speed of the hunter which they have done in a number of iterations. At the beginning of this fragment they are trying out a version where they the bear has been made smaller in order to provide more time (or space) to get past the hunter. This was talked about as "making a baby bear", which suggests the importance for the children of having a believable narrative as ground for the solution they finally implement.

It is important to note that the effort they have to invest in finding the correct speed is a consequence of their deep engagement in finding a design of their game that will be exciting for an imagined person that will be playing the game. This again, relates to questions of designing for an audience. Clearly, the fact that they are building something specifically for someone else has important consequences for how they approach the modelling activity. The children repeatedly consider how their model will be received by a potential user such as their friends and they also modiy their solutions according to such considerations. This is a central goal in all knowledge building activities, to utilise the power of designing something for someone else when learning through construction of digital artefacts. Hence, in the present example they could not just decrease the speed of the hunter to a really low number since that would make it way to easy to pass it and the excitement would be lost. They are experimenting with different speed levels to find one that makes the game the most challenging but still possible to succeed with. This is also seen in the intense testing that they continuously return to, as for instance in lines 7-9. When the version with the smaller bear seems too difficult Rakel suggests making it even smaller. Tomas provided an alternative suggestion which would be to remove the "dancing"-behaviour from the bear. This would provide more space for the bear to pass the hunter. However, Rakel rejects that by arguing that the dancing bear is a "cool" feature that they should keep (line 12). Tomas accepts this and reintroduces the solution to decrease the speed of the hunter (line 13). Now they enter a discussion of what speed to choose for the bear. Rakel suggests decreasing the speed to 300 which Tomas says is "way too slow" supposedly because he believes that they are close to a solution and instead suggests 372. After some negotiation they end up choosing 350.

In summary, the significant effort they invest in finding an appropriate speed for the hunter comes as a consequence of their deep engagement in finding a design of their game that will be exciting for an imagined person that will be playing the game. The primary objective for the children in this fragment is to create an artefact to be used and enjoyed by others, rather than reasoning about the science of endangered species that their model could be viewed to represent. This objective leads them to not just simply decrease the speed of the hunter to a really low number since that would make it way too easy to pass it and the excitement would be lost.

Children reflecting on the activities and its values in school

At the end of the workshop, the children presented their work to their peers and to their teachers who had not taken part in the workshop activities. When presenting their systems to the whole class, including their teachers, the descriptions did to a large extent refer back to the concepts and ideas about endangered species, as had been the general theme of the activities. However, when asked specifically about what they found most interesting about the activities, this related more to issues such as those highlighted in the fragments above, rather than learning in the specific domain. Rakel and Tomas did for instance emphasise planning as an important learning outcome, and to learn how to make things realistic and believable in the final game. After the short presentation to the whole class, all the systems were presented on different computers so that the children could present their work in a more fair-like manner. It was then clear that amongst their peers, the children did not relate to their work as scientific investigations, but as games.

Several months later, a researcher who had not participated in the workshop also conducted informal interviews asking the children how they thought construction activities, such as the ones they had taken part in, could be useful in school situations. In these interviews, the children expressed thoughts about being able to make school more fun and easier for the younger students, for instance to produce interesting adventures and computer games, which they said would be more fun than only reading books. One girl described an idea of making computer games for other pupils to learn from: *"I know a lot about for example Gustav Vasa, that I have learned in school this year", "… those who begin in forth grade next year can learn Gustav Vasa in a much more fun way by my digital adventure game."*

From a teacher's point of view this might be regarded mostly as a way of gaining an understanding of the girl's knowledge, and also as method for pupils to deepening their understanding of the topic at hand. However, for the child, the main quality appears as the possibility of explaining something in a more interesting way to other pupils. This means that the children themselves see values beyond the digital construction itself and that they are concerned with how to improve aspects of their current school situation, both for themselves and for others. This is partially addressed also in Kafai's (1995) work with children's own game design in classrooms.

The children also said that their games could be used in school to show others the usefulness of the digital tools. Thereby the games that the children produced did not only play a purpose of entertainment or for developing ones own understanding, they were also regarded as having communicative purposes, being "communicative actions" (Rommetveit 1972). The "communicative action" of making dynamic systems, also reflects children's every-day life where playing and learning with technology are central (Hernwall 2002).

The children's thoughts and expressions about the usefulness and playability for unknown younger children were unexpected and evokes questions about the different ways construction activities like these may be used in schools. Similar to our workshop on endangered species, constructionist activities are often aiming at supporting learning in specific domains (Klopfer et al 2002; Stieff et al 2002; Ioannidou et al. 2003). Aspects that tend to be forgotten, even though they were emphasized in Papert's (1980) early writings, concerns aspects of learning in a more general sense. One such aspect that our results reflect regards the issue of supporting children to learn to become a learner, for instance to reflect on the communicative value of building dynamic systems.

3. CONCLUDING REMARKS

The analyses of the activities, interviews and exhibitions give at hand interesting results. The activities that the children are engaged in while working with the digital material does not primarily concern any particular concepts from domains like modelling, simulation, or mathematics that traditionally have been in focus in constructionist usages of programming. We argue that the discussions that the children are engaged in; that of considering different solutions and their consequences for the game as a whole involves a number of important aspects to learn when constructing with digital material. This includes moving between implementation and testing of different solutions in a systematic way and foreseeing the consequences of a particular solution for other aspects of the game without having to implement and test it.

Our results suggest four issues that need further emphasis in learning with digital material. These include: learning to express ones ideas and turn them into computational form, learning to interpret material created with digital construction materials, learning to argue and discuss ideas with friends, and valuing how one's own knowledge may be appreciated by unknown others. In this paper we have empirically demonstrated three aspects that play a central role with respect to these four issues. *Firstly,* we have stressed the handling of the tools as an important part of the activity as a whole. The construction tools are complex for the children and expose them to several issues that take considerable time and effort, which they deal with in a collaborative fashion. *Secondly*, the social context plays an important part in the children's activities; particularly the comparison with others becomes a motivating factor. *Thirdly*, building dynamic systems on the computer requires explicit articulation and negotiation of ideas, in a way that is usually not required when expressing ones ideas in more traditional media. Similarly, Lindström (1980) discusses how making of pictures serve as "external workspaces", meaning that the properties of a picture - its shape, representation and content – are used to make otherwise abstract concepts more concrete. Children's digital constructions of games in school could offer a more advanced and expanded "external work-space" than is possible through construction of non-moving pictorial illustrations. Through making dynamic and interactive illustrations, the children can in a more varied way imagine the properties of for instance historical events, than they would though making more static media, and also in a sense let others experience this through playing their games.

Programming in non-computer science education has traditionally been considered mainly as a cognitive activity useful as a vehicle for learning in particular areas, rather than as a craft with qualities that is valuable as its own sense. In work describing constructionist approaches to science education, the activities that children engage in are often described by researchers as involving the “scientific method” (Smith & Cypher, 1999, p. 203) or as “a wonderful example of the scientific method” (Resnick, Berg, & Eisenberg, 2000, p. 22). It is certainly the case that examples like these involve properties of importance to scientific investigations, but, when looking at how most children explain their projects they rarely describe them as investigations into science and mathematics.

Our analysis of children’s activities with digital construction tools shows that they do involve learning of mathematics and science oriented issues, however a number of other issues, such as negotiation and argumentations regarding playability, aesthetics and collaborative handling of complex technology are more prominent in their activities. Additionally, our interviews with the children reveals that they foremost suggest usages of the technology in areas such as language, arts and history, hence areas which are not primarily mathematically oriented. In our research we want to initiate a move away from viewing creation of dynamic applications as a means to foster learning in particular domains and instead view this as an aesthetic activity – a form of expression that can be used to communicate and express ideas in a more general sense.

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