Conceptualising tangibles to support learning

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ABSTRACT

We present a new way of conceptualising tangibles for learning. This scheme adopts Heidegger's analysis of the ways a user can treat a tool: either as 'ready-to-hand' or 'present-at-hand'. It also proposes two types of activity a learner can engage in when using a tangible: either exploratory or expressive activity. Finally, two types of models that a user can explore are proposed: theoretical and practical models.

Examples from the literature are described in terms of this framework and an example is given from our own work of an attempt to use this conceptualisation in design.

Keywords

Tangible, conceptualisation, learning, external cognition, embodied interaction

INTRODUCTION

> This role of the everyday world here is more than simply the metaphorical approach used in traditional interface design. It's not simply a new way of using ideas like desktops, windows, and buttons to make computation accessible. Instead of drawing on artifacts in the everyday world, it draws on *the way the everyday world works* or, perhaps more accurately, *the ways we experience the everyday world.* [11, p.17]

The 'tangible' approach to design is becoming increasingly viewed as an alternative to the traditional graphical user interface. Inspired by Weiser's vision of computation removed from the desktop box [27], and exploiting innovation in sensing technology, researchers are beginning to explore the coupling of physical objects with digital information to support users engaged in a diverse range of activities [11, 13]. Different design frameworks have been applied to the development of these systems, resulting in a rapid growth in terminology, including the use of physical objects as *tokens* to access digital information [12], the use of generic physical objects as *containers* to move information between devices [24], and *tangible interfaces* where physical artefacts are used to both represent and control digital information [23]. An example of a system designed in this spirit is Underkoffler and Ishiis' Urban Planning [26], where physical models of buildings can be manipulated on a table top to explore what shadows might be cast at different times of the day, and how different configurations might influence the pattern of airflow, through dynamic visualisations projected onto the space. The term *tangible* has been used in various ways, but is adopted in this paper generally to describe all examples of physical objects augmented with digital information.

In his recent book *Where the Action Is,* Dourish [11] has described the tangible approach to computing as part of an historical movement in HCI to design user interfaces that expand the range of human abilities available when interacting with computers. Specifically, he suggests that tangible (and social) approaches to computing allow work to be *embodied*[1] in the everyday environment. Dourish's notion of embodiment refers to a state of direct engaged action, a characterisation with its roots in phenomenological philosophy, particularly in Heidegger's notion of 'readiness-to-hand' [Heidegger, 1927, cited by 11]. This concept refers to the way that when working with a tool or representation we treat it almost as if it were invisible; instead focussing upon the task it is used for.

Taking into account our bodily engagement in the world contrasts with what Dourish describes as the dominant paradigm in cognitive science and system design, namely a Cartesian separation of cognition and action, with an emphasis on objective rational thought. Instead, an embodied approach follows Heidegger's position that the world is meaningful to us only through the ways we exist in it. Dourish argues that based on our familiarity and facility with the mundane world of objects and social interaction we should design computer systems that support those better.

However, as Chalmers [8] has recently pointed out, Dourish's focus on 'readiness-to-hand' has led to a neglect

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[1] The notion of embodiment is explored more generally in Clark [10].

of Heidegger's complimentary notion of 'present-at-hand': an attention to the tool or representation as the object of activity. We agree that this imbalance in emphasis is a weakness of Dourish's embodied approach. In contrast, we suggest that one of the strengths of tangible systems is their ability to act as both tools through which goal-oriented activity can be directed and objects or representations that can themselves be the object of focus. This dual nature is particularly powerful when the aim of the tangible system is to promote learning. We suggest that tangibles should be analysed in terms of their ability to be both 'ready-to-hand' and 'present-at-hand'. We share with Dourish a view of tangible computing as fundamentally embodied, aiming to develop tangible systems that will enable children to work through them in engaging activity. Moreover, augmenting physical artefacts with digital capabilities opens up the space of possible activities that children can engage in this manner.

However, we don't believe being engaged physically with a system to be sufficient for effective learning. Instead, we argue that in order to learn from experience, to exploit generalities and links between learning domains, children need to remove themselves from it periodically and to reflect upon it in more objective terms [1, 2, 9].

In this paper we describe what we perceive to be different approaches that can be adopted when designing tangibles for play and learning. All aim to support an embodied ready-at-hand interaction. However, we also point to differences in the way users can attend to the tangibles in a present-to-hand manner. In so doing we hope to provide some initial ideas inform the design of tangible systems for different activities. We propose two main classes of tangible systems: *(i)* expressive and *(ii)* exploratory.

(i) Expressive

One class of tangibles embodies aspects of the user's actions with the system. Thus, when users attend to the tangible as present-to-hand, they can focus on an external representation of their own activity. We suggest, in line with a theory of external cognition [22], that representing activity in an external representation can aid objective reflective thought and support learning. By making explicit their own understanding of a topic, learners can make clear inconsistencies, conflicting beliefs and incorrect assumptions [9, 16]. As the learners create their own representations, we term this class of tangibles *expressive*: a categorisation adopted from Mellar and Bliss' [16] discussion of the ways children can learn with scientific models.

(ii) Exploratory

The second class of tangible interface does not embody the user's activity. We suggest that when attending to this type of tangible as present-to-hand, the user will be more likely to focus on the way the system works, rather than reflecting on the history of their own interaction with it. We term this class of tangible *exploratory* [16] as the learner explores a model presented by someone else. We can see two types of learning that could derive from this class of tangible. First, the learner can use the tangible itself for some task. The learning in this instance would be highly situated [5, 14]. That is, how to use a particular tool in a particular context. We call this type of reflective attention to the tangible *practical.* It can be exemplified by the type of question the learner might ask himself or herself. For example, "What can I do with this system?" Second, the tangible could encapsulate some theoretical model of the world. We call this way of orienting to the tangible *theoretical*. In this situation, the learner explores the model through their interaction with the tangible. As the model encapsulated in the system might be different to the learner's own naïve mental model, then learning might be expected to result from a comparison between the two world views [6]. The type of question the learner might ask in this context could be "How does this model relate to the real world?"

The classification of tangibles that has been developed here describes two ways that learners can orient to embodied learning: they can treat the tangible as *ready-at-hand*, working through it to complete a task, or they can focus on the tangible itself, treating it as *present-to-hand*. We suggest that productive learning results from a cycle between these two attentive styles. We also suggest two kinds of activity that the learner can engage in, which have implications for the manner in which they focus on the tangible: either *expressive* activity, where the tangible will embody the learner's activity, either physically or digitally, and *exploratory* activity, where the tangible embodies a model provided to the learner by the designer. Finally, we suggest two ways that the learner can explore a model provided by the designer: either *theoretically*, where the model embodies some theoretical description of the world, or *practically*, where the learner might reason about the mechanisms by which the tangible interface works. In the next section four examples of tangibles for learning will be introduced and analysed in terms of this framework.

TANGIBLES FOR LEARNING

Chromarium

Chromarium is a mixed reality activity space that uses tangibles to help children experiment and learn about colour mixing [21]. The framework developed in the course of this work looked at the notion of *transforms*: changes to the state of the world relative to actions upon it. Four types of transforms were investigated: physical (action)-physical (effect), physical-digital, digital-physical, and digital-digital. Of interest here is the physical-digital transform, where changes in the physical orientation of multicoloured cubes augmented with RF-tags and placed on a tag reader, provoked changes on a digital display showing the effect of mixing the colours on the cube faces (see figure 1).

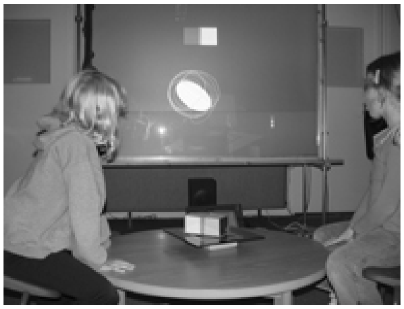

Figure 1: Chromarium – physical actions produce digital effects [21]

The tangibles used in the Chromarium system were found to support a fluid, embodied interaction. Children were able to interact with the coloured cubes as ready-to-hand, rapidly combining and recombining colours with immediate visual feedback. The type of present-at-hand attention supported by the Chromarium system was also exploratory and largely practical: the system has a fixed model of possible interactions, and it is the child's task to explore these possibilities. This characterisation is supported by the kinds of reflective discussion and activities that Rogers *et al.* [21] report children to engage in. In particular it was found that they spent much time exploring the parameters of the interface, for example, putting their faces on the tag reader, expecting them to be projected onto the screen, and pressing down on the cubes in the expectation that this would make the colours on the screen appear darker.

In their comparison of different types of transforms, Rogers, Scaife *et al.* [21] found the coupling of a *familiar* physical action with an *unfamiliar* digital effect to be effective in getting the children to talk about and reflect upon their experience. This finding is of importance for our framework, as it suggests that tangible-based learning might be particularly effective in getting children to alternate between the present-at-hand and the ready-to-hand.

Snark

This finding was confirmed in the Hunting of the Snark, a playful learning experience designed as an adventure game to explore the role of tangibles in engendering playful learning [17]. By collaboratively interacting with a variety of tangibles, children can discover different aspects about a virtual imaginary creature called the Snark, for example, its emotional state, its personality. Again the framework underlying this design was that of 'transforms', in this case focusing the design on creating changes in the state of the world in novel and unexpected ways. In one activity space the children interact with the Snark by feeding it in a virtual well. To lure the Snark they use various pieces of physical instantiations of food embedded with RF tags. These are transformed into digital counterparts in the water, to be eaten by the virtual Snark. The Snark is designed to show its likes and dislikes of the food, enabling the children to reflect on why it behaves in a certain ways each time it is fed some food. This series of chained physical-virtual transforms had to be understood by the children to enable them to continue to interact with the Snark.

This experience also shows ways in which tangibles can facilitate an 'action and reflection' process. Similar to Chromarium this was triggered by combining a familiar action with an unfamiliar effect. When feeding using a familiar action (placing food on the virtual well surface) did not trigger events as expected, children had to re-evaluate their actions and perform different actions to trigger the desired response. In this case the Snark retrieving and eating food they were feeding it. The children appeared to be able to seamlessly move between the dual process of action and reflection, thus enabling them to experience something and then step back from the perspective of what they are doing and think about how it fits into the larger picture. Again this suggests the effectiveness of tangibles in enabling children to move between the present-at-hand and the ready-to-hand.

Illuminating Light

Illuminating Light [25] is a system designed at MIT to allow the rapid prototyping of laser-based optical layouts. The system comprises a large workspace where tangible elements representing objects like lasers, lenses and mirrors can be manipulated. The system senses the orientation of these elements and projects dynamic simulations of laser light onto the workspace surface (see figure 2).

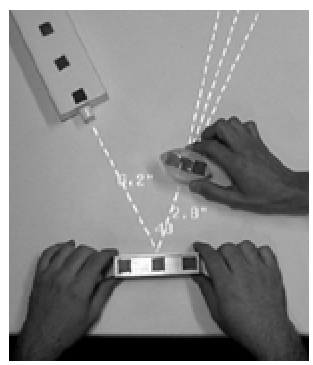

Figure 2: Illuminating Light [25]

The Illuminating light system affords the user the potential to engage in a ready-at-hand interaction, working with the objects to produce different patterns of light. In our framework, the kind of present-to-hand attention the user can pay to the system is exploratory, as the user is presented with a model of optics to explore and where no kind of history of interaction is constructed. It is also theoretical as the model is a simulation of how patterns of laser light might be produced in the real world. The design, like the Chromarium and the Snark, suggests that tangibles can support both ready at hand and present to hand interaction.

TellTale

TellTale is a tangible system that allows young children to practice literacy skills through oral language [3, 4]. A toy caterpillar was designed, comprising of a number of modular segments, each of which allows a short sound recording to be made and which can be rearranged in any order (see figure 3).

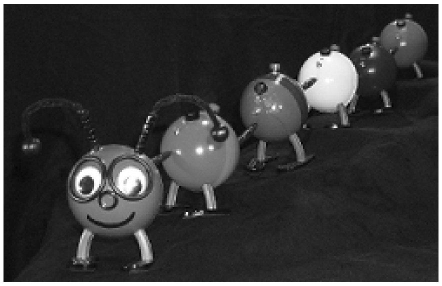

Figure 3: TellTale system [3, 4]

Children use the recording facility of TellTale as a tool to create short oral stories, finding the recording interface straightforward to use [4]. Thus, the focus of their attention can be directed through the toy to the recording and story-telling task: an engaged, ready-at-hand interaction.

Two aspects of TellTale's design support reflection by the children on the storytelling activity. First of all, the system allows the children to record their composition in an external medium. In the framework we have been proposing this can be seen as an expressive activity. Making digital recordings facilitates the separation of language from the context in which it is created [15], aiding more objective present-to-hand attention to the story. The ability to think about language removed from context is an important predictor of later literacy [7].

The second aspect of TellTale's design, relevant to the framework being developed here, is its physical form. TellTale embodies the segmented and linear structure of traditional narrative [e.g. 18]. Focussing on the structural elements of the toy's design provides children with a model of narrative to explore. A comparison of the stories produced by children with segmented and non-segmented versions of the toy showed that children playing with the segmented version produced longer and more cohesive stories with more traditional story endings compared with children playing with the non-segmented version [7]. In terms of our framework this supports present to hand *theoretical* activity through the use of the caterpillar structure.

Summary

We have briefly reviewed four tangible-based learning systems, describing each in terms of our tangible framework. We have seen that all support both 'embodied' ready-at-hand, and more 'removed' present-to-hand activity. The colour mixing task in Rogers, *et al.*'s [21] Chromarium study presents learners with an unfamiliar form of interaction to explore and make sense of. Price, *et al's* Snark game allows children to physically interact with a virtual character to engender creative reflection. Underkoffler and Ishiis' [25] Illuminating Light presents users with a theoretical model of optics to explore and prototype systems with. Fourthly, Ananny's [3, 4] TellTale both provides young children with a structural model of traditional narrative and allows them to interact expressively, recording and listening to their own oral narratives.

In the next section we describe our attempt, using this framework, to design a tangible-based system to promote reflection within a larger digitally augmented learning experience. The project called the Ambient Wood [20], was designed to help children learn scientific skills while on a field trip in a digitally augmented environment.

DESIGN OF A TANGIBLE LEARNING SYSTEM

We designed a large-scale learning experience, called the Ambient Wood, based around the idea of a digitally-augmented field trip [20]. The project aimed to help children learn about the nature of scientific enquiry through discovery, reflection, and experimentation. Pairs of 11-12 year old children initially explored different habitats in a large woodland environment, taking light and moisture readings and having information about the organisms living in the wood 'pinged' [19] to them on PDAs, relative to their location. In this way they received augmented information about organisms they could see in the wood as well as those that were inhabitants but not readily visible to the children, for example, caterpillars and woodlice.

We used our tangible framework to design an activity for the second phase of the learning experience, getting children to reflect upon and consolidate the knowledge they had gained both from their physical exploration of the wood and from information they had received on their PDAs while doing the exploring. We specifically wanted to support children in thinking about the relationships and interdependencies between the organisms they had observed. Thus, we wanted pairs of children to compare the information they had about two different habitats in the wood. This would provide them with further information, requiring them to collaborate and discuss. In so doing, we wanted to facilitate them in transferring from the concrete (of their explorations) to the abstract (of their conceptual understanding), to move from the focussed individual pieces of information they had found to a more wholistic understanding of the ecosystem. This phase was to take place in a 'den': an informal classroom-type environment in a marquee erected in the wood itself.

In line with our framework we focussed on activities that allowed both embodied activity, where the tangible was treated as ready-to-hand, and a more reflective present-at-hand attention to the activity embodied in the tangible. To this end, we conceived of a tangible system that children could use to collaborate in constructing a picture of the woodland habitats they had explored. Through this expressive activity, we hoped the children might make explicit their understanding of the relationships between organisms they had discovered in the habitats. However, we were concerned that simply constructing a picture of the woodland might not be enough to make children think deeply about the relationships between organisms. Thus, we decided to also incorporate elements of an exploratory activity. This was to take the form of the system monitoring the children's activity in relation to its own model of the ecosystem and informing them when they either deviated from this model or when they incorporated elements that could be related at a higher level of abstraction. Thus, for example if the children incorporated pictures of brambles, and a type of bird called a chiff-chaff, the system played an animation showing the chiff-chaff nesting in its natural habitat under the brambles. If on the other hand, the children placed thistles in the woodland habitat (where they did not grow), the system alerted the children to their mistake and asked them to try again.

Two studies were carried out to develop and determine the effectiveness of our system based on the tangibles framework.

Study 1

The first task we designed was one where children had to use digitally augmented tokens to build up an external representation of the two habitats in the wood. The two pairs of children were required to each build up a picture of the habitat they had explored in the wood by placing RF-tagged tokens representing the organisms on a tag reader. We were initially interested in having the children explore the notion of change over time, so one tag reader represented the wood in autumn, while the other represented the wood in spring. Placing a tagged token would cause a picture of that organism to appear on a large display, representing both habitats in the wood. By making explicit the composition of the wood in different seasons, the aim was to enable the children to better understand the changing relationships between organisms.

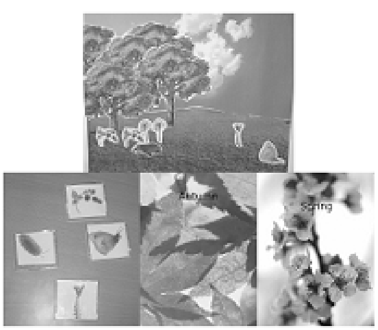

Figure 4: Materials used in study 1

(Top – paper cut-out 'display', bottom left - some of the tokens used, bottom centre and right - 'tag readers' representing seasons)

In order to develop this task and provide concrete design solutions, a low-tech version was initially produced. Plastic tokens were created with pictures of the organism they linked to printed on top. Paper cut-outs of the organisms were also produced to mimic the pictures that would appear as visualisations on the display in response to a token being placed on the RF-reader (see figure 4).

Method

A study was designed where pairs of 11-12 year old children were first asked to imagine they were exploring a wood while they walked around the school playground. Images of the organisms found in the wood were presented to the children on a PDA coupled with information such as what the organism eats, where it lives/grows etc. The aim of this part of the study was to mimic the exploration phase of the ambient wood experience itself and to put the tangible task in context. Images of the organisms found in a woodland habitat were presented to one pair of children, while images from a clearing habitat were presented to the other pair.

The pairs were then brought together in a large room in the school. The children were asked to work together to build up a picture of what the two habitats would look like first in autumn (the time of year the study was carried out) and then in spring. The children performed this task by placing the plastic tokens on the relevant 'RF-reader'. An experimenter played the role of the computer placing paper cut-outs of organisms on the mock display. The children were encouraged to both work together and to talk about their reasons for placing each token.

Findings

Findings from this low-tech study were particularly revealing about the sort of activity necessary to engage children in the task using the tokens in a ready-to-hand manner. The children did not find the activity of placing tokens on the RF-reader to be a particularly engaging one, often just throwing the tokens down on the reader with very little thought as to why they were placing them in that particular location.

We reasoned that this lack of engagement might be due to the children having little control over the placement of the paper cut-outs on the display and the manner of interaction not being direct enough to support the kind of embodied activity we wanted to support. This prompted us to redesign the way the children interacted with the paper cut-outs in the second half of this study. Instead of having them place the tokens on the RF-reader, we asked the children to take over the role of the experimenter, placing the paper cut-outs on the mock-up display.

The children found this activity to be much more engaging than the last. They discussed the placement of the cut-outs to a greater extent and talked about some of the relationships between organisms. For example:

C1: “Where shall we put the trees?”

C2: “Put the trees there, so you can put the chiff-chaff on them.”

C1: “Butterfly…”

C2: “Stick it on the bluebells. Make sure you stick it the right way up this time”.

We concluded from this study that embodied interaction was better supported in the task, when children were able to work directly with the representations themselves, rather than controlling the placement of the representations more indirectly through the placement of more abstract tokens.

Study 2

Based upon our findings from the first low-tech study, we redesigned our task to allow children to work more directly with representations of the organisms in the wood. Instead of having the children build up a picture on a display through placing tagged tokens on a reader, we decided to have them work with representations of the organisms similar to the paper cut-outs used in the low-tech study.

This was accomplished by printing pictures of the organisms onto static-cling film. This film could then be stuck onto a shiny board with areas representing the habitats in the wood. In order to link the placement of these pictures to the computer model of the habitats, small RF-tags were attached to each of the pictures and two RF-readers were placed behind the two areas on the board representing the clearing and woodland habitats. A display was placed next to the board. This set up is shown in figure 5.

Figure 5: Set up used in study 2

Method

This study was run as part of the larger Ambient Wood project (see Rogers, *et al* [20] for a more detailed description of this project). At this stage of the learning experience, the children were introduced to the tangible system. RF-tagged pictures printed on static-cling film were laid out on a table in front of a board with two areas representing the woodland and clearing habitats. A facilitator showed the children how to stick the pictures onto the board, and to describe the relationships between the organisms. The children were then asked to work together to complete pictures containing all of the organisms that lived in each habitat. The children were encouraged to give reasons for each picture they stuck to the board, and to describe the relationships between the organisms. The system was designed to provide feedback in the form of animations and sounds if the children either stuck a picture in the wrong habitat, or if they stuck a combination of pictures that could be related at a more abstract level.

Findings

Findings from the second study suggest the potential of tangibles for supporting recollection and discussion between the children. With little encouragement from the experimenter, the children used the tokens on the table as a focus for a discussion about what they had found in the habitats they had explored as shown in the following example:

C1: “We saw a woodlouse”

C2: “We found a thistle”

C1: “We found moss…came up on our screen and it grows in dark damp areas”

This finding supports our suggestion that focusing on the representational form of the tangibles in a present-at-hand manner might facilitate reflection and discussion between the children. Some comparisons between the two pairs as to the organisms they had encountered were also made. For example:

C1: “I saw a butterfly, a white one…just in there [points to wood]

C2: “We didn’t see any butterflies. We saw birds…”

However, the task was not as successful as we had hoped in encouraging the children to construct an external representation of the two habitats. In terms of our framework, this was largely due to technical and practical issues. First, the static-cling film in the outdoor environment rapidly became quite dirty, making it very difficult to get the pictures to stick to the board. This resulted in the children spending most of their time attending to the pictures in a practical present-at-hand manner, focussing on the pictures as a difficult to use tool, rather than working through the tool in the embodied construction task we had designed.

Secondly, the link between the placing of a picture on the board and the triggering of a contingent animation proved to be a temperamental one. Thus, the children were unable to make the link between their ready-to-hand activity and the exploratory model embodied in the system.

Another issue that arose from this study was the importance of context in engaging children in a tangible task. Whereas, the children in study 1 had found the picture construction task to be an engaging one, the children in study 2 found it to be less so. This may be due to its relationship to the rest of the ambient wood experience. In the first stage of the experience, the children had gained information in two ways: by actively probing the light and moisture readings in the wood, and by passively receiving information on a PDA relative to their location in the wood. The tangible task in the den was designed to help the children make links between the information that they had receive passively, which in this context they found less interesting than the information they had gathered themselves and which we propose they had a greater sense of ownership over. This suggests the importance of attention to the ways in which children receive or interact with information for future work. For example, a more active role for the children, to be in line with our focus on embodied interaction.

DISCUSSION

We have seen from the two studies presented in the last section that an attention to the ways in which physical artefacts support ready-at-hand interaction is crucial to the design of a tangible learning system. To engage children in a task, it is not enough for a system to just be tangible. As we saw in the first study, it is also crucial that the tangible be designed in a way that is appropriate to the task. Children found the placing of tokens on an RF-reader to be too far removed from the task of building up a picture to treat the tokens as ready-to-hand. It was necessary to make the children's engagement with the representation much more direct, in accordance with our emphasis on embodied interaction.

In the second task simple practical problems were enough to interfere with the children's ready-at-hand interaction with the tangibles. Instead the children focussed on the tangibles as a problematic tool in a present-at-hand manner, weakening their level of engagement.

We have also seen the importance of context in the implementation of a tangible for learning. A tangible learning system that works in a classroom context may not transfer readily to a different setting, e.g. the outdoor learning environment of our ambient wood, where this was one activity was embedded in a whole experience. We suggest that this may relate to the way children orient to the information being manipulated in the tangible.

CONCLUSION

We have presented a nascent conceptualisation of tangibles designed to support learning and given examples from the literature and our own work on how it might be applied. This scheme comprises three levels of description that can be used to determine how a tangible might be used in a learning system. First, we have proposed that tangibles for learning should be analysed in terms of their ability to be 'ready-to-hand' and 'present-at-hand'. We have suggested that productive learning will result from the learner cycling between these two viewpoints, acting both through the tangible, and focussing on the tangible itself. Second, we have proposed two styles of interaction with a tangible: exploratory activity, where the learner investigates a model presented by the designer of the task, and expressive activity, where the learner works to produce an external representation or artefact. We have suggested in line with a theory of external cognition [22] that through expressive activity, the learner can make explicit their own understanding of the domain of study, highlighting misconceptions or gaps in their knowledge. Through exploratory activity with a tangible learners can gain an experiential understanding of a model of a knowledge domain. We have also highlighted a distinction between theoretical and practical models that learners can explore. Theoretical exploration is of a model of external reality, as in the model of optics underlying Underkoffler and Ishiis' [25] Illuminating Light. A practical exploration of a model will be of the manner in which it can be interacted with, as in Rogers, *et al.*'s [21] Chromarium.

Of course these categories need not be mutually exclusive. Ananny's TellTale system [3, 4], for example, allows learners to interact both expressively, recording oral stories, and in an exploratory manner, focussing on the structure of traditional narrative embodied in the physical design of the toy. Our own attempt to design a tangible system as part of the Ambient Wood experience [20] tried to engage the learner in both exploratory and expressive activities. We consider this style of interaction to have much potential for the design of learning experiences.

Further work is required however, to both extend and flesh out this categorisation. For example, there has been little attention to the differing roles of physical and digital representations in tangibles. We aim to develop a more complete framework to suggest concrete design solutions for the role of tangibles in learning.

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