A multimodal approach to examining ‘embodiment’ in tangible learning environments

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ABSTRACT
Tangible and multitouch technologies offer new opportunities for physically interacting with objects and digital representations, foregrounding the role of the body in interaction and learning. Developing effective methodologies for examining real time cognition and action, and the relationship between embodiment, interaction and learning is challenging. This paper draws on multimodality, with its emphasis on examining the use of multiple semiotic resources for meaning making, to examine the differential use of semiotic resources by pairs of students interacting with a tangible learning environment. Specifically the analysis details the role of body position, gaze, manipulation and speech in shaping interaction. The analysis illustrates the interaction between these modes and ‘multimodal action flow’, particularly in terms of pace, rhythm and interaction structure, and the implications of this for interaction and the meaning making process.

Author Keywords
Embodiment, multimodality, action, manipulation, gaze, position, tangible, learning.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Human Factors, Theory.

INTRODUCTION
Tangible and tabletop interaction has been shown to offer new opportunities for physically mediated interaction in technology learning environments, exploiting more embodied forms of interaction. More specifically, they necessitate bodily arrangement, positioning and gaze in relation to the interface and one another creating differing perspectives; the use of physical objects as oppose to just visual representations; and actions, such as manipulation. However, the role of embodied interaction in mediating learning in digital environments such as these, remains little understood. One challenge is that of developing effective methodologies for understanding the relationship between bodily-based actions and real-time meaning making. Drawing on multimodal methods of analysis this paper presents a case study analysis of three pairs of students learning about science using a purpose built tangible tabletop environment, to examine in more detail how these embodied forms of interaction shape the learning experience.

Contemporary digital learning environments, such as tangibles and tabletops, are inherently multimodal, both in terms of representation modalities (e.g. texture, colour and shape of objects as well as digital representation) and interaction modes (e.g. talk, gaze, manipulation, gesture). Drawing on social semiotics, multimodality offers a valuable approach for analysing video data, as it systematically attends to the interpretation of a wide range of embodied communicational forms (e.g. posture, gaze, gesture, manipulation, as well as visual representation and speech) that are used for making meaning. Multimodality assumes that interaction is a part of meaning making, and that people orchestrate meaning through their selection and configuration of different modes. Multimodality focuses on people’s process of meaning making, a process in which people make choices from a network of alternatives: selecting one modal resource (meaning potential) over another [5]. Thus, students interacting in a multimodal environment will select and configure the modal resources (e.g. how they position their bodies, direction and length of gaze, how they manipulate objects) that are made available in different ways. In the context of exploring and analyzing concepts of embodiment and the role of the body in contributing to the meaning making process, a focus on multiple modes from body posture to gaze to physical action and manipulation as forms of communication is critical. The aim here, then, is to look at how embodied modes play out differently across different pairs and examine the implications for the knowledge construction process and making meaning.
Extending earlier research on the design of tangibles for learning [15], this work focuses on exploring multimodality as a methodological approach to examining embodiment and learning. New data on 10 pairs of primary school students aged 10-11 years were collected. Video and observation data illustrate how students use their modal resources differently, indicating different levels of, what we call here, ‘multimodal action flow’: in other words communication is distributed differently across the different modes of interaction. In particular, differences were noticed in terms of bodily positioning around the table, as well as the pace and rhythm of manipulation, gaze and speech. This paper, therefore, presents an analysis of three cases of students, which are illustrative of the different relationships between these dimensions, in order to gain insight into the structure of the relationship between how the pairs position themselves, structure their manipulation - the pace or rate of manipulation; their direction and length of gaze, and the level of talk (both quantity and quality). In so doing it aims to gain insight into the relationship between embodied interaction and learning activity.

BACKGROUND
Embodiment
Embodiment in the context of this paper centres around the notion that human reasoning and behaviour is connected to, or influenced by our physical and social experience and interaction with the world. This is seen as an iterative relationship, where reasoning and behaviour can shape interaction as well as the other way round, yet complex, because of the context, time, space, and emotion etc. in which the interaction takes place. With the emergence of ubiquitous technologies, current theoretical trends are placing more importance on the role of embodiment in understanding human behaviour (e.g. cognitive science, philosophy, psychology, sociology). Technologies, like tangibles, enable radically different forms of interaction than with traditional desktop computing, offering opportunities for interaction and learning to be more ‘active’, hands-on, directly related to physical contexts, with new forms of communication and collaboration promoting socially mediated learning [14]. While at one level all experiences can be considered to be ‘physical’, in this paper the focus is on changes in physical interaction through the particular kind of technology. This not only encompasses changes in physical space and structure; manipulation of physical objects (making the learning space very physical), but also that those changes impact on the actual experience. While concepts of embodiment are being increasingly foregrounded, empirical evidence supporting the assumed benefits of tangibility and physicality is lacking [22], and highlights methodological challenges in this area. By taking a multimodality approach, this paper offers a new way of describing and classifying ‘embodied’ forms of interaction to examine how embodied action can be played out differently in tangible learning environments.

Multimodality
Multimodal approaches provide concepts, methods and a framework for the collection and analysis of visual, aural, embodied, and spatial aspects of interaction and environments, and the relationships between these [7; 11]. While other modes of communication, such as gesture have been recognized and studied extensively, multimodality investigates the interaction between a variety of communicational means, and challenges the prior predominance of spoken and written language in research. Speech and writing, while significant, are seen as parts of a multimodal ensemble with an emphasis on situated action [20]. It provides resources to support a complex fine-grained analysis to get at the details of artefacts and interactions. Here meaning is understood as being realized in the iterative connection between the meaning potential of a material artefact, the meaning potential of the social and cultural environment it is encountered in, and the resources, intentions, and prior experience that people bring to that encounter. Changes to these resources and how they are configured are therefore significant for thinking about communication. Digital technologies are a site of particular interest for multimodality because the kinds of resources they make available for interaction differ, enable different combinations, and demand different ways of being interacted with, for example, in the digital environment discussed in this paper, the ‘light spectrum’ can be seen through a digital visual representation inside a physical ‘box’, but cannot be seen in reality or in common physics experiments in school classrooms. Furthermore, new problems of how to map the visual, digital and physical demand different kinds of work from those interacting with them to make them coherent and construct meaning.

Although multimodality is not currently prominent in HCI, it has considerable potential for researching digital representation and interaction, for example (and specifically relevant here) in relation to: (i) The systematic description of modes and their semiotic resources in ways that can support understanding meaning making in complex digitally mediated environments and the evaluation and design of multimodal digital artefacts, interactions and experiences; (ii) Multimodal investigation of interpretation and interaction with specific digital environments, how digital resources are used in specific contexts and how people talk about them, justify them and critique them in order to understand how semiotic resources are used to articulate discourses across a variety of contexts.

Tangible and multitouch interaction
Previous work has explored student learning in multi-touch and tangible tabletop environments, some of which touches on concepts examined in this analysis, but usually as discrete aspects rather than collectively, which brings the interaction between these different elements to light.

Studies with small groups of children interacting on a tangible or multitouch tabletop suggest ways in which they
might support collaboration through conflict. Pontual Falcao and Price’s [13; 14] studies showed a rapid pace of interaction with objects and changing configurations, that frequently resulted in the occurrence of ‘conflict’, while Fleck et al., [3] suggested the value of interference in ‘undoing’ others actions. While findings suggest that interference results from simultaneous physical action in the same space, these studies involved small groups of students, while the analysis here is based on pairs of students interacting with a tangible tabletop.

Rick et al, [18] explored collaborative interaction further through detailed video analysis, with three dissimilar cases to show how collaborative learning might play out in different ways. In contrast, to these findings, which focus on different forms of verbal communication, our approach drawing on multimodal methods takes a broader perspective to include how bodily position, action, gaze and speech might influence multimodal action flow.

While previous work suggests the benefits of physical manipulation for learning [9; 12], and offers some insight into interaction around tabletops, particularly the effect of position and orientation [e.g. 17] and awareness [6] on collaboration and participation, they tell us little about the collective roles of the body in shaping interaction. Furthermore, participants in these studies worked in triads placed around the table, while in this study students worked in pairs and were freely able to move around the table.

STUDIES

The tabletop environment
The tabletop system consists of a table with a frosted glass surface, which is illuminated by infrared LEDs. While the system bears some similarities with *Illuminating Light* [21], the technology, the application domain, and the targeted users are distinct. A variety of hand crafted plastic objects are used as input devices (Figure 1).

The designed effects in this application are based on the physics of light. Thus, the torch acts as a light source (causing a digital white light beam to be displayed when placed on the surface), and objects reflect, refract and / or absorb the digital light beams, according to their physical properties (shape, material and colour) (Figure 2).

**Figure 2. Students place different kinds of objects on the interactive surface to produce different effects**

The torch, when placed on the surface, is ‘always on’, while the other objects only produce digital effects if they are placed in the digital light beam pathway. In other words, if an object (other than a torch) is placed on the surface and is not hit by a digital light beam, no effect will be seen on the surface. To see the digital effects, various arrangements can be made on the surface using the different objects and the torch. The digital effects change when someone directly manipulates the objects - either by taking them off the table or altering their position on the table - which causes the light beam to be interrupted or redirected. The table has no particular ‘way up’, configurations can be made from any side of the table, and due to their nature cannot be a ‘right’ way up. Only one ‘end’ of the table has a small are that is not interactive. During the studies, objects were placed in this area. Children could choose an object at any time to use on the interactive surface. During interaction, objects were sometimes returned to the table edge and other times left on the interactive surface even if not in use.

**Figure 1. The tabletop and the input devices**

Each object is tagged with a marker called a ‘fiducial’. When tagged objects are placed on the surface they are tracked by an infrared camera, recognized by the computer system and programmed digital effects are projected onto the table surface [see 19 for more technical detail].
at intuitive interaction, using independent exploration in these environments for learning. This is important in terms of informing about pedagogical and design implications for these environments.

All students were reminded how a white light beam can be split into different colours when shone through a prism. The aim of this was to ensure that they knew that a while light beam is made of several different colours, since this is an important basis for understanding the behaviour of light with different coloured objects. Each pair of students spent approximately 20 minutes interacting with the LightTable. They were given three consecutive tasks: (i) to explore how light travels from the torch, to find out what is happening to the white beam of light with the different ‘things’ on the table, (ii) to explore what happens when using the same coloured things on the table [here they were given more objects several of the same colour], (iii) to investigate how and why different textures reflect light differently (here they were provided with new textured objects). All students were asked to do the tasks together, with no guidance given by the facilitator.

They were informed that after they had completed the tasks another researcher would talk to them about their experience: what they had been doing and what they had discovered. Interviews were undertaken using three different methodological approaches: semi-structured interview, semi-structured interview with video recall of the interaction, and interview with the LightTable itself [16].

ANALYSIS
The aim of this analysis is to explore ideas of embodiment articulated earlier (see Background) in an example digital environment, i.e. a tangible tabletop. A themed approach was taken to video analysis with two researchers. It was apparent from the data that the pairs of student chose to position themselves differently around the table, that is using the modal resource of space in different ways, with three key patterns of positioning: opposite one another throughout; adjacent to one another along one side of the table (figure 3) throughout; or moving positioning in relation to one another.

**Figure 3: Student positions around LightTable**

This appeared to influence and shape the nature of their interaction, as the pace and rhythm of the activity were found to differ, as did the affordances for modes including gaze direction, and patterns of manipulation, both with the tangibles on the LightTable and with one another. Our analysis aimed to explore ways in which these bodily-based differences may importantly shape the action and strategies for learning. In addition, some students were observed to be more verbal than others, which in turn influenced their use of other modes. Thus, three contrasting pairs were selected to subject differently configured multimodal ensembles to detailed analysis: pair 1 were two boys positioned opposite one another, and engaged in a consistent level of verbal articulation; pair 2 were positioned next to one another, but periodically exchanged places, and verbal articulation was minimal throughout the activity; and pair 3 were positioned adjacent, with ongoing verbal articulation, primarily by one student throughout the activity.

A detailed transcription of the multimodal interaction of the three selected pairs was then completed. This comprised a parallel record for each student, including: time stamps; record of body positioning and changes in bodily position; manipulation i.e. each placing and changing of position of objects or torch on the tabletop, selecting objects, pointing, gesturing; gaze; and speech. This enabled access to the following forms of data: rate at which objects were placed, replaced or repositioned; number, pattern and manner of turn taking during the activity; number of combined modes used at one time – intensity of modal resources used in the flow; and quantity and quality (e.g. drawing conclusions or describing behaviour of objects) of verbal articulation.

**Pair 1 [C1 & C2]**
Pair 1 positioned themselves on either long side of the table opposite one another. For most of the interaction they remained standing, but towards the end of the interaction they both knelt on the floor with their faces closer to the table surface. Their positioning and posture meant that they had different points of view of the table, and sometimes one student reconfigured the same arrangement of torch and objects from his own side of the table. Their gaze towards activity on the table surface was generally for short periods, and in multiple directions.

Their total interaction time was 16.11 minutes. Throughout the interaction they made numerous changes to the configurations on the table adding, removing, exchanging objects or the torch over 100 times, often changes being made rapidly by one and then the other, or simultaneously. The torch was handled primarily by C1, which gave him control of the configuration space, and several times he took objects out of C2’s hand. In general, they appeared to work separately with different objects, often undoing each other’s actions and redoing their own configurations, creating interference as described in Pontual Falcao and Price [13]. Their manipulation comprised frequent changes of objects, with C1 rotating the torch position with one hand while placing objects with the other, and C2 placing objects on the table, but often at the same time picking up objects and putting them back down at the end of the table without using them, and sometimes without looking at
them. Their rotations of objects often involved ‘twizzling’ as oppose to careful controlled movements.

This pair focused on looking for differences between the various objects’ interaction with the torch, particularly in terms of visible change, ‘this one has a rainbow, this one doesn’t’; ‘transparent doesn’t do anything’. To do this their pattern of interaction comprised trying one object (or two) then moving it to one side to try another.

While they did not always appear to work towards the same goal, or build on each other’s interaction, they did comment on what they were seeing from their own and sometimes each other’s actions. Thus while some modes were not coordinated across their activity, the mode of speech was highlighting both the work of their talk to produce a coherent narrative, and the import of looking beyond talk when examining interaction with digital environments.

There were 3 clear episodes when they were coordinating their action, which enables us to explore the relationship between modes: (i) related to whether or not the spectrum was visible with an object. Here they systematically placed each object in the light beam, removing each to other end of the table to ‘see which ones worked’ i.e. displayed a spectrum; (ii) when C1 suggested they try building a configuration using multiple red objects. Here they both placed objects on the torch beam and reflected red beams in several positions on the table; and (iii) towards the end of the activity when they explored the effects of the ‘rough’ surfaced objects. Here they coordinated the placement of objects and moving the torch.

Speech was fairly steady throughout, with C1 talking more than C2, although both engaged with various forms of ‘talk’: (i) instructions, for example, ‘lets try this’, ‘Put this one there’, ‘Spin it around’; (ii) descriptions of object behavior, ‘So it makes an arrow. And it makes different coloured spectrums’ and expected object behavior, ‘Don’t think it works. The light should go around it’; (iii) making predictions, ‘Red will probably make it red. And it does’, ‘I reckon these two will work and these two won’t’; (iv) giving explanations, ‘It makes a kind of angle according to what angle the torch is pointing at’, ‘Oh but this is a rough surface, so it reflects off everything’; (v) summarizing their activity, ‘Ok so what colours have we done so far?’; and at one point they drew a conclusion ‘So different colours block other light’.

**Pair 2 [C3 & C4]**

This pair positioned themselves adjacent to one another along one long side of the table (figure 1). C4 walked round C3 to get object from the end of table a total of 6 times during the activity, and stayed at the object end of the table for two periods of time during the interaction, thus they readily exchanged positions. However, they both reached across each other easily and smoothly, to pick up objects from the end of the table. Their point of view was the same, and when one was moving objects or the torch, or removing and placing new objects on the table the other was watching. That is they coordinated their use of modes over time, as one of turn taking across modes. Their gaze, then, could be described as extended and targeted in a specific direction. Generally when one peered closely at a configuration so did the other, mirroring each other’s posture and modal interactions.

Their total interaction time was 16.25 minutes, comprising of 30 configuration episodes. For most of these episodes they used one block on the table at a time, occasionally 2, and only had more than this (3-4) when they were specifically exploring light behavior with several objects of the same colour. A configuration episode typically consisted of placing a block in the torch beam, rotating the block or the torch. Adding another block usually changed the configuration. C3 instigated 17 of the configurations, while C4 instigated 10, and for 3 configurations they coordinated the configuration. For example, in one instance C3 picked up an object, handed it to C4, who placed it on the table; in another where they were building a configuration, which entailed adding several objects of the same colour, both students added and moved objects as they explored the configuration in a synchronous manner. No ‘clashes’ or ‘interferences’ were observed, showing mutuality and coordination. Their choosing and picking up of objects seemed careful, and their rotations and replacing of objects and the torch was controlled and considered.

Verbal interaction for this pair was minimal. They relied on other modes, foregrounding gaze and manipulation, posture and position. C3 made a total of 10 utterances, and C4, 17. Apart from one piece of dialogue (below) these are all short comments, primarily instructions e.g. ‘try this one’; ‘stop, stop’; ‘don’t do that’; or descriptions of configurations, e.g. ‘this one’s flat’; ‘it’s a rainbow’.

Positioning: C3 [girl] adjacent at side of table; C4 [boy] adjacent at object end of table

**C3 Hands blue object to C 4 ‘Put it back again’**

**C4 Places blue object back on light beam ‘That’s ...what?...Why? Oh yes its reflecting and that .. Points to ’rainbow inside object ’look the blue one’s missing. Interesting’**

**Exchanges blue object for purple. Moves torch across object**

**C3 Look in this one – see? Points inside**

**C4 Looks inside ‘It’s taken out again. Reflected’**

**Pair 3 [C5 & C6]**

This pair also positioned themselves adjacent to one another along the long side of the table throughout the activity, C6 closest to the object end of the table. Their point of view was therefore the same, and their gaze, similar to pair 2, was in specific directions for sustained periods of time. When one was creating configurations, describing or
explaining the other watched and observed. Like pair two they were involved in multimodal turn taking, seeing and constructing through their action the interactional surface as one space, as oppose to pair 1 who saw it as two spaces.

Their total interaction time was 20.41 minutes, comprising of 28 episodes of configuration creation, primarily instigated by C5, with only 5 new configurations instigated by C6. This meant that C5 reached across C6 regularly to access objects. This pair tended to have only one or two blocks on the table at one time, and for the first 7 minutes of interaction only used one block with the torch.

Their pattern of interaction was quite distinctive throughout. Generally one student (usually C5) would place a block in the torch beam, give a verbal description of what was happening while gesturing, by pointing and following beam pathways with their finger, followed by an explanation (see figure 2): a clear multimodal sequence - action, description, explanation. Sometimes one would give a description and the other followed up with an explanation. Their pattern of interaction, therefore, comprised smooth turn taking, with evidence that they were building on each other’s ideas, both physically and verbally. Like pair 2 they selected and picked up objects with consideration, and rotated and replaced objects and the torch with deliberation. Their focus was frequently on physical properties of the objects beyond (yet including) colour, such as ‘roundness’ ‘smoothness’ ‘opaqueness’ ‘edges’.

While C5’s verbal articulations were greater in number than C6, they both engaged in the following kinds of dialogue: (i) description, ‘So I think here the light bounces off and reflects, and this is the angle it is reflecting at. So the light goes through and its there, and reflects coming through here’; (ii) explanation, ‘because that’s transparent it lets the light go through because this isn’t transparent it doesn’t’ ‘Looks like the light is splitting up here, and that’s why you have the different colours’; (iii) prediction, ‘We can compare different colours together and see what would happen’; (iv) conclusion/ summary, ‘So its just like the red one. It bounces off. It's not see through’.

DISCUSSION
A multimodal methodological approach focuses equally on the role of various modes, such as posture, gaze, action and speech in the meaning making process, and on the interaction between these modes. This analysis illustrates the different ways that pairs of students used these semiotic resources – their multimodal orchestration - particularly in terms of bodily posture, pace and structure of activity, and verbal articulation. The implications of this for the process of meaning making, in an independent exploration activity learning about the science of light are discussed.

Position and gaze
Students had free access to three sides of the table, and were left to decide how to position themselves around the table. Of all 10 pairs in the study only one student moved from one side of the table to another during interaction. All others remained on the side(s) chosen at the beginning of interaction. Our analysis suggests that position choice effects how action and activity evolve. Different positions give different opportunities for interaction, for example, where to look, point of view, ease of access to tangible objects at the side of the table, and on the table itself.

Pair 1 positioned themselves opposite each other, giving them equal access to the objects at the side of the table and to those on the table i.e. it was equally easy for each student to pick up a new object from the side, and to manipulate any already on the table. This positioning and equal access to objects enabled each student to pick up blocks and place them on the table easily and simultaneously, or at similar times, and led to ‘clashes’ of action and ideas, and to repositioning one another’s blocks while creating a configuration on the tabletop. In contrast, with pairs 2 and 3, who were both adjacent to one another, one had easier access to objects at the side of the table than the other, who had to either reach across his peer or walk behind them. Access to objects already on the table was similar for both, but in each case required reaching across the other for some of the objects. These pairs experienced no clashes of this kind, nor physical removal or manipulation of objects while their peer was building a configuration. Once a configuration was built then the other student may modify this, but did not do this simultaneously.

Point of view also affected interaction. Pairs 2 and 3 had the same point of view, which made sharing and gesturing to one another straightforward. Indeed during the interview pair 2 said they chose to stand in the same place so that they could ‘see together’. Pair 3 gestured frequently while giving verbal descriptions and explanations of the different configurations, seemingly exploiting their mutual point of view. On the other hand, for pair 1 their different points of view sometimes required the other to lean over to look from a similar angle, in some instances, not to notice at all, and others to reconfigure the set up to be the same, but from their own perspective. For example, when pair 1 C1 moved the torch from the further side of the table to ‘shine’ on the same object from his own side of the table. Furthermore, since their gaze was split between what they each doing themselves and what their peer was doing, the time spent focusing on observing each other’s actions, rather than simultaneously ‘doing’, was less than with pairs 2 and 3.

Pace and rhythm
The analysis showed that pace of interaction differed across the pairs. For pairs 2 and 3, who were positioned adjacent the pace of interaction was significantly slower than that of pair 1, and in general seemed more considered and purposeful. For pair 1, positioned opposite one another, the pace of simultaneous access to objects meant that they could both pick up and place objects on the table at the same time, contributing to a faster pace of interaction. By
this we mean the number of different objects placed on the table, and the changes in configuration were greater throughout the period of the activity (e.g. over 100 for pair 1 versus 30 for pair 2 and 28 for pair 3). While it can be argued that this offers the opportunity for exploring a greater number of ‘light and object’ configurations potentially exposing the students to more ‘experiences’, our analysis suggests that it also reduced the amount of considered ‘reflection’ time before any one configuration was changed. This contrasts with pair 3, where the degree of verbal articulation and reflection was greater than with pair 1 (see next section). This ‘reflection’ time was important both in terms of understanding the science and in enabling them to consider how they structured their activity i.e. choose what to do next. Thus, the activity with pairs 2 and 3 seemed more ‘purposeful’ as oppose to the more ‘opportunistic’ approach conveyed by pair 1.

While a slower paced structure to the activity suggests a more methodical, and considered, approach to exploring the tasks, the students engaging in a faster paced interaction showed other forms of ‘systematic’ activity. In particular, when they placed each object in the light beam in a planned way, to find out which ones displayed a spectrum and which ones did not; and when they summarized which of the different coloured objects they had used. This systematicity differs from pair 3, the motivation underlying the way they structured their activity being different. Pair 3’s methodical approach was driven by exploring the combined physical-digital effects, and what this might mean in terms of light behavior, while pair 1 were driven by the features of the different objects themselves.

**Speech (talk)**

Of these three pairs 2 (pairs 1 and 3) engaged in more verbal dialogue during interaction than pair 2. As well as differing in quantity the analysis shows that pair 2’s articulations also different in quality, or content. While their articulations comprised only instructions and basic descriptions of configurations, pairs 1 and 3 both extended their kinds of dialogue to include explanations, predictions, conclusions and summary. Since these two pairs engaged in different ‘bodily’ forms of interaction, demonstrating different forms of manipulation, patterns of gaze and strategies, their verbal articulation does not seem to be influenced directly by these. While from a research perspective verbal articulation gives some insight into the students thinking and their planning, pair 2 offers an interesting case for unpacking the role of action in the meaning making process. While there was no evidence (as with the other two pairs) of them providing descriptions, explanations, making predictions, or drawing conclusions during their activity, their interview (after activity but with the table) illustrated that they could both explain and interpret their experience despite little discussion or talking during the activity. They were asked to show what they had been doing and explain what they had found. They used the table to demonstrate as they talked as follows: they showed how you needed white light to make the interface work, placing the torch on the table; they then place red object in the white beam and explain about reflection; then they use the transparent object and explain that the colour will go through the transparent object ‘any colour will go through this one’; they explain that the ‘2D’ objects [smooth] have one line that reflects, while the ‘3D’ [rough] objects reflect more lines; finally they explain that if you put another object of the same colour then it reflects from another objects reflection. Both students contributed to the explanation without interrupting one another or disagreeing. This explanation and demonstration illustrated their confidence in explaining what they had been doing, and their ability to coherently integrate their understanding from across the tasks. In contrast to this shared narrative, pair 1 stayed at a descriptive level of their activity, describing the different aspects of the light behavior as distinct from one another, whereas the others produced a more conceptual coherent narrative integrating the whole experience.

The degree and type of talk during and after the activity may be influence by bodily positioning. While pair 2 stood adjacent to one another, their tendency to readily exchange positions meant that they both engaged in choosing objects, choosing configurations, while also seeing the dynamic table events form the same visual perspective. They could, therefore, see each other’s actions, as well as having explorative ideas themselves. This contrasts with pair 3 where one student was clearly dominant in organizing the activity and generating the narrative, and pair 1 who showed a higher tendency to engage in their own activities. This combination of sharing action and sharing ‘position’ – or gaze direction – may well influence the level of talk needed, but clearly enabled each of the students to engage with the activity and the domain learning concepts.

**CONCLUSION**

The aim of this paper was to explore a multimodal approach to analyzing embodied interaction in a tangible learning environment with pairs of students aged 10-11 years. This methodological approach offers a way of describing and classifying ‘embodied’ forms of interaction, which goes beyond looking primarily at language, or specific forms of action, by extending the analysis to include body positioning and gaze, and the integration of modes. By taking this approach, and examining multimodal action flow, we can see how embodied action can be played out differently in a learning interaction with pairs of students.

Specifically it illustrates how body positioning, gaze and different ways of manipulating the tangibles change the pace, rhythm and structure of interaction, and the kinds of participation that students take. For example, the analysis shows the different ways in which the representational resources on the table are taken up and differently used by students. Some forms of action, as in pairs 2 and 3 fostered slower forms of interaction, clearer turn taking and building
on one another’s ideas, while others engendered a rapid pace of interaction, with less clear turn taking and coordinated structure, being more fragmented and discontinuous. This is important in helping to understand how bodies are used differently in physical-digital environments such as these, and the implications they might have for the learning process.

The analysis also shows the place of talk in activity in different ways. In particular it demonstrates that meaning making for pairs of students can take place equally as well through action, experimentation, observation and demonstration. But to achieve this, our analysis suggests the important role of bodily positioning, perspective, gaze and turn taking as well as action through manipulation: or in other words the role of ‘embodiment’ in shaping multimodal action flow.

ACKNOWLEDGMENTS
This research is supported by ESRC RES-576-25-0027. We thank Will Farr for his role in data collection; students and teachers from Clapham Manor School; George Roussos & Jenn Sheridan for technical development of the LightTable.

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