Exploring the role Physicalizations can play in STEM Learning

Sarah Hayes
Cork Institute of Technology,
Cork, Ireland
sarah.hayes@mycit.ie

Trevor Hogan
Cork Institute of Technology,
Cork, Ireland
Trevor.hogan@cit.ie

Kieran Delaney
Cork Institute of Technology,
Cork, Ireland
Kieran.Delaney@cit.ie

Abstract
We present an overview of our research into the role data physicalizations can play in enhancing STEM learning with young people. As objects that by their very nature embody and allow the manipulation of data, physicalizations present an ideal method for permitting students to engage with curriculum subject matter in more extensive modes and formats than traditional learning materials. In this paper we present the motivation and long-term aims of the research project will be discussed, as well as work completed to date and current studies being undertaken as part of this research project. Furthermore, we present a vision of the future directions our research will take over the next three years, which will cumulate in the development of a series of data physicalizations for use in the teaching and learning of STEM subjects in secondary schools.

Author Keywords
Data physicalization; Tangibles for learning; materials

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction

The importance of young people pursuing careers in Science, Technology, Engineering and Mathematics (STEM) is widely recognized [9]. It is also recognized that some of the most prevalent modern social issues, such as climate change, cancer research, famine and pollution, are more than likely going to be solved through work undertaken in STEM fields [13]. However, in order for these sectors to grow, it follows that more students in second level education must opt to continue studying STEM subjects. Therefore, an effort must be made to ensure STEM subjects are being delivered in an engaging and inspiring way.

Our research aims to contribute towards this effort by focusing on how physical data representations can be used to increase student learning and engagement with STEM subjects at a classroom level. The long term aim of this work is to develop a series of data physicalizations that can be used in a practical way in classroom situations by teachers and students to promote engagement and understanding of STEM concepts and datasets. The design and development of these objects will follow an iterative approach, with feedback from stakeholders (i.e. students and teachers) guiding design choices at every stage. Part of this process is the design of a study aimed at gaining an understanding of people's feelings about and perceptions of the materials that have most commonly been used to construct tangible user interfaces (TUIs) over the past decade. The methodology, stages and work related to this study will be outlined and discussed in subsequent sections of this paper.

The concept of designing data physicalizations for the teaching of STEM subjects is a relatively novel one, with little grounding in existing research. However, given the close connection between the fields of Data Physicalization and Tangible Interaction, the work completed in the latter area towards developing educational tools will be used to guide and inform our research. The following provides an overview of this related work.

Data and Tangibles for Teaching and Learning

The use of tangibles and physical apparatuses to support STEM learning is not a new concept, and has in fact been studied for over fifty years. A concise historical summary of this is provided by Patricia Moyer [14]. She comments on Jean Piaget's [15] research which suggested that children aged seven to ten years old work in primarily concrete ways and that the abstract notions of mathematics may only be accessible to them through embodiment in practical resources. More recently, Hollins [11] has contributed towards improving our understanding of the importance of tactical engagement and of using our hands in the learning process. Multiple researchers have suggested that TUIs have potential for supporting children's informal and formal learning [23; 6]. As one of the aims of using tangible interaction is to design user experiences that are embodied, natural and fun [8; 3] TUIs are therefore ideally suited to use by children. It is assumed that physical interfaces are easier to use, support learning and development, and can facilitate collaboration [4; 10; 22; 23]. For example, researchers have used child development theory to provide guidelines on how to design tangibles for children [1] and have compared how children interact with tangible versus graphical user interfaces [2].

Figure 1: Material samples used by Jung and colleagues during their material probe study

Figure 2: Soap-bubble interface used by Döring and colleagues

Tangible computing is highly suited to the design and development of children's learning activities because it leverages both familiar physical artefacts and digital computation. Hands-on learning provides outlets for children to expand their interests, and promotes growth of critical thinking [16]. Projects from the Transformative Learning Technologies Labs address this problem through developing a variety of physical-to-digital educational tools for STEM [5]. From the few examples provided above alone, the potential for this body of research for enhancing educational activities is easily apparent. Our research aims to contribute towards these existing efforts by approaching the issue from a Data Physicalization standpoint.

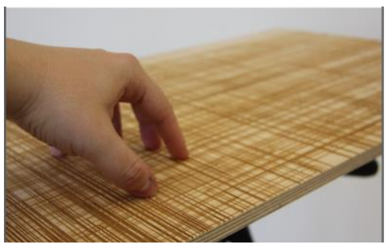
Material Survey

The first study we are completing as part of this research is an investigation into the current state of the materials space for the development of TUIs. This study will explore people's perceptions of common TUI materials. The study of experiences prompted by materials is not a new idea – indeed, there are many examples of related studies that have sought to understand different aspects of materials. Tholander and colleagues investigated the idea of agency in relation to the emerging properties of materials and demonstrated how interaction design is often driven by the characteristics of materials [19]. Additionally, Schmid and colleagues identified the importance of the role of materials in TUI design by proposing an inverted design process that places materials at the forefront of the design cycle [17]. Research into people's experiences of materials has also been completed. Jung and colleagues [12] used a 'material probe' approach that invited people to tell stories and play with a set of various materials, before exploring how they differ or compare to digital devices. Döring and colleagues [7] conducted a related study in which a soap-bubble interface (fig. 2) was used to explore a materials-centred approach to tangible interaction. As this study includes only one type of material, it prompts the concept of exploring peoples' perceptions of a larger number of TUI materials - something we aim to achieve through our current research focus.

Current Research Focus

Currently, we are focused on completing an ongoing study into people's perceptions of materials used to create TUIs. Thus far, we have completed an extensive literature review of conference proceedings and online resources to form a list of frequently used materials for developing TUIs. Examples of TUIs from which materials were identified can be seen in Figure 3. This list will be used to identify materials used in the next phase of our study, which we are in the process of implementing at this point in time. This phase involves the completion of a blended Repertory Grid (Rep Grid)/ focus group study which will explore people's perceptions of a set of twelve materials. This study will take place over the course of an hour and a half session, during which twelve participants will be asked to first interact in small groups with the twelve materials before engaging in a group Rep Grid session to elicit personal constructs associated with each material. Materials will be presented in form of an approximately 20cm by 30cm rectangle, in an effort to encourage people to think of them as 'materials' rather than 'objects'. The Rep Grid aspect of the study will involve all participants forming one group, and being

a. **Sand:** Inner Garden [18]



b. **Wood:** Tangible Scores [20]

c. **Rubber:** MagnetoWear [21]

Figure 3: A selection of examples from our material survey.

asked identify a similarity between two or more materials of their choosing, and a contrast between these materials and at least one other. For example, one participant may identify two materials as being ‘bendy’, and another as being ‘rigid’. Once a group consensus is reached on whether or not a suggested construct applies, it is either included and recorded on a whiteboard, or excluded and discarded. Data will be collected in four ways during the study - (1) transcriptions of the Rep Grid filled out by the researcher on the whiteboard, (2) audio and video recordings of the session, (3) transcripts of group discussions and (4) field notes taken during the session. This data will be used to both feed into the next stage of the study (see Future Work section) and to provide qualitative data to further clarify participant opinions and choices of language and meaning.

Future Work

The immediate goal of our research following the completion of the Rep Grid stage is the undertaking of a large scale analysis of all materials used in TUIs. The qualitative data collected during the Rep Grid phase will then be used to form categories in a survey to investigate how each material is perceived by a wider audience. Participants will access this survey using Amazon’s Mechanical Turk[1] service. This will allow us to collect data from hundreds of participants. The data collected from this stage of the study will provide the basis for a useful tool for analyzing, selecting and designing with materials for TUIs. For example, it could be consulted by designers during the prototyping process to aid in the selection of materials for a TUI.

After completing the present study into the materials space for TUIs, we intend to explore how augmenting different materials with technology affects people’s interactions with them. Building on the insights established during the materials study phase into the associations and experiences people have with the studied materials, we will begin a series of exploratory activities into how these perceptions alter or are enhanced by the addition of multi-sensory technologies. Additionally, we will begin engaging with stakeholders (i.e. teachers and second-level students) in exercises exploring how data physicalizations can intersect with the current STEM curriculum in Irish secondary schools. Through a series of semi-structured interviews, focus groups and interactive workshops, we will work towards arriving at a series of openings for our research to complement and improve upon the current educational materials for STEM learning. This will provide a starting point for initiating the design process for our artefacts.

Finally, a prime objective in the immediate future of our research is to design and implement a series of digital literacy studies with user groups. Although it is generally assumed that teenagers have strong digital literacy skills, the extent, depth and variety of these skills must be explored in order for us to successfully design technological tools for these users. Similarly, the technical knowledge of teachers must be explored, to ensure user needs are being met within the constraints of their knowledge and abilities. Through the completion of each of the above exercises, we will move further towards the design and implementation of data physicalizations objects that can be used practically in classrooms. In doing so, we aim to arrive at an understanding of how data physicalization artefacts can be employed to further STEM learning and student engagement.

[1]See https://www.mturk.com/

References

1. Antle, A.N. 2007. The CTI framework: informing the design of tangible systems for children. In Proceedngs of the first international conference on Tangible and Embedded Interaction (TEI '07), 195-202.
2. Antle, A.N. et al. 2009. Hands on what?: comparing children's mouse-based and tangible-based interaction. In Proceedings of the 8th international conference on Interaction Design and Children. 80-88.
3. Baauw, E., and Markopoulous, P. 2004. A comparison of think-aloud and post-task interview for usability testing with children. In Proceedings of the 2004 conference on Interaction Design and Children: building a community. 115-116.
4. Bakker, S., Antle, A.N., Van Den Hoven, E. 2012. Embodied metaphors in tangible interaction design. Personal Ubiquitous Comput. 16, 4, 433-449.
5. Blikstein, P. 2010. A New Age in Digital Tangible Interfaces for Learning. Learning in the Disciplines: Proc. of ICLS 2010. ISLS.
6. Carbonneau, K. J., Marley, S. C. & Selg, S. C. 2013. A meta-analysis of the efficacy of teaching mathematics with concrete manipulatives. Journal of Educational Psychology. Vol 105 (2) pp. 380-400
7. Döring, T., Sylvester, A. and Schmidt, A. 2012. Exploring material-centered design concepts for tangible interaction. In Proceedings of the 2012 ACM annual conference extended abstracts on Human Factors in Computing Systems Extended Abstracts (CHI EA ’12). 1523.
8. Dourish, P. 2001. Where the action is: The foundations of embodied interaction. MIT Press, Cambridge, UK.
9. Duffy, M. 2016. "Michael Duffy: Stem Education Critical for Country’s Future". *The Irish Times*. Web. Accessed 20 Apr. 2017.
10. Hengeveld, B. 2008. Let me actuate you. In Proceedings of the 2nd international conference on Tangible and Embedded Interaction. 159-166.
11. Hollins, E. R. 2015. Culture in school learning: Revealing the deep meaning. Routledge.
12. Jung, H. and Stolterman, E. 2011. Material probe: exploring materiality of digital artifacts. In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction (TEI ’11). ACM. 153.
13. MacCraith, B. "It's Time To Get Serious About STEM Education In Ireland". *Silicon Republic*. 2014. Web. 21 Apr. 2017.
14. Moyer, P. (2001) Are we having fun yet? How teachers use manipulatives to teach mathematics. Educational Studies in Mathematics 47: 175-197. Netherlands: Kluwer.
15. Piaget, J. 1952. The Child's Conception of Number. New York: Humanities Press.
16. Resnick, M., & Silverman, B. 2005. Some reflections on designing construction kits for kids. Proc. of IDC 2005 ACM Press, 117– 122.
17. Schmid, M., Rümelin, S. and Richter, H. 2013. Empowering materiality: inspiring the design of tangible interactions. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction* (TEI '13). ACM. 91-98.
18. Sol Roo, J., Gervais, R. and Hachet, M. (2016). Inner Garden: an Augmented Sandbox Designed for Self-Reflection. In Proceedings of the TEI ’16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI ’16). ACM. 570–576.
19. Tholander, J. Normark, M. and Rossitto, C. 2012. Understanding agency in interaction design materials. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '12). ACM. 2499-2508.

20. Tomás, E. (2016). Tangible Scores. In Proceedings of the TEI ’16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI ’16). ACM. 669–674

21. Vijay, R. S. and Goyal, S. (2016). MagnetoWear. In Proceedings of the TEI ’16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI ’16). ACM. 597–602.

22. Xie, L., Antle, A.N. Motamedi, N. 2008. Are tangibles more fun?: comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In Proceedings of the 2nd international conference on Tangible and embedded interaction. 191-198.

23. Zaman, B., Van den Abeele, V., Markopoulos, P. and Marshall, P. 2012. Editorial: the evolving field of tangible interaction for children