Journal of Humanities and Social Sciences
Issue (3), Volume (3)
March 2019
ISSN: 2522-3380

المجلة العربية للعلوم و نشر الأبحاث
Arab Journal of Sciences & Research Publishing
AJSRP

A Study of the Challenges and design perspectives Affecting Physical Computing Teaching and Digital Education

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Abstract: The shift towards physicality and materiality in interaction design and the rise of the Internet of Things is likely to lead to a high demand for physical computing devices and experiences in the coming years. Previous researches have argued that design and development for physical computing require on a diversity of skills including physical design, electronics, computational logic and programming and collaboration. Recent trends in computing education (e.g., initiatives that seek to encourage engagement with computer science topics from a younger age) have the potential to make schools a highly promising site for the development of physical computing skills. Yet, we hypothesize that teaching and learning physical computing is likely to present a range of unique challenges that aren't addressed by programs that are primarily focused on topics of computing and computer programming alone. In this paper, we present a study that explores the extent and nature of physical computing teaching in the context of one high-profile computing education program: the UK's Computing at School initiative. Our study comprised a questionnaire that was distributed to teachers, and follow-up interviews with selected respondents. Our findings suggested that physical computing concepts aren't commonly taught in schools, despite physical computing tools being prevalent.

Keywords: Physical computing, learning by doing, games and gamification, computing at schools, electrical circuits.

INTRODUCTION

A simple definition for physical computing relies on building interactive constructions or systems through the use of hardware and software combined, with an instant feedback from the real world. This is to refer that learning electrical circuits, and other hardware components are as important as software programming. better learning mechanism can be achieved through following Papert's constructionism theory, as the theory matches the criteria of learning physical computing. We posited that physical computing concepts aren't commonly taught in schools, despite physical computing tools being prevalent.

Stankovic et al. define Physical Computing as "seamlessly integrating computing with the physical world via sensors and actuators" [77]. Examples include tangible computing, smart objects with network capabilities, sensor networking, and embedded systems [42; 62; 73; 81]. Physical computing devices and experiences are due to become increasingly prevalent in our society and economy. In the field of Human-Computer Interaction (HCI), we have witnessed a burgeoning interest in physicality and materiality in interaction [81]. Moreover, the continued growth of the Internet of Things (IoT) is expected to create substantial rise in the prevalence of physical computing, with the UK government forecasting that "the number of connected devices could potentially reach up to 100 billion globally by 2020" and "these technologies could have a global value of nearly £10 trillion" [69].

The increased demand for physical computing devices in the coming years will, in turn, necessitate the growth of a skilled workforce capable of designing and implementing devices and experiences that meld the digital and physical worlds. Camarata, Gross & Do characterize a diversity of skills required to create physical computing devices as: art, design, material and mechanical proficiency to create physical artefacts; electronics to work with sensors and actuators; programming and computational logic to respond to the sensor data about environment and interaction; and the ability to collaborate with others who have different disciplinary expertise across this spectrum of skills [61].

Recent trends in computing education stand to make our schools a highly promising site for developing such physical computing skills. High-profile government and industry-backed initiatives such as Computing at School (CAS) [9; 26] in the UK and Computer Science for All (CS4ALL)[9; 10] are seeking to make rigorous engagement with programming and computational thinking concepts compulsory from a much earlier age. Moreover, recent efforts by organizations such as the Raspberry Pi [26] and Micro: Bit [1] foundations have placed affordable hardware – with appropriate features to support the prototyping and development of physical computing devices – into a large number of schools. While these developments have much promise for supporting the teaching of physical computing skills in schools, we hypothesize that the topic is likely to present its own unique challenges that extend beyond those addressed by initiatives focussed primarily on computing education.

In this paper, we, therefore, seek to understand to extent and nature of physical computing skill teaching in the context of recent trends in computing education. In doing so, we aim to inform the development of teaching practices and supporting tools that are specific to physical computing. We focus our study on the UK's CAS initiative, which provides resources, training, and opportunities to exchange ideas to computing teachers via 150 regional hubs across the UK. We surveyed 57 people involved in the CAS initiative about their experiences of physical computing teaching. Our sample included: head teachers in UK schools. Our method followed a mixed qualitative approach, comprising an initial web-based survey and follow-up semi-structured interviews with selected participants.

Our findings suggested that physical computing concepts aren't commonly taught in schools, despite physical computing tools being prevalent. Perhaps, the usability of microcontroller devices in the classroom is not reflecting the major purpose of why they are made. Indeed, these devices are a greater gateway to learning computer programming as they combine learning with entertainment. However, our findings indicated that these devices were used to provide a limited understand the subject of physical computing, or mainly used for just learning software programming.

literature review

The study of Mikael Wiberg indicated that the revolution of material interaction is extending beyond the disappearing computer[82], which indicates a noticeable interest towards materiality interaction in the field of human-computer interaction (HCI). This includes tangible computing, smart objects with network capabilities, sensor networking, digital fabrication and embedded systems [35; 42; 62; 73; 81]. According to the study of John A. Stankovic, Insup Lee, Aloysius Mok, and Raj Rajkumar, the group of these technologies is defined under the term physical computing systems [72]. The study indicated that physical computing creates a new development of an infrastructure for a technical, economic, and social revolution, as its advantages are focused on providing assisted living, emergency response systems for natural or man-made disasters, and protecting critical infrastructures at the national level [72].

The potential of using physical computing systems is clear. For the context of this study, we aim to focus on the benefits of physical computing in children's education. Studies demonstrated that physical computing may ease understanding many aspects of computing [32; 68]. This is due to the fact that physical computing provides a real-time feedback in the real world [6; 71], which causes a solid connection to the cognition [6]. Physical computing devices are popular in the classroom [1; 5; 52; 57]. Studies found that using these devices can lead the children to learn to compute in a more concrete way [19; 37; 44; 63; 78-80], as it promotes teamwork and collaboration with fun and engagement [19; 20; 74], and reduces the anxiety of learning new subjects [71] .

Within the literature, a vast number of studies showed the potential of using physical computing devices for children's education [5; 19; 39; 60]. Buechley and colleagues presented a curriculum to teach computing through building computational textiles as the major tools for learning [57]. Their results are summed by an increased level of comfort among students, interests in the subject, and enjoyment [57]. Yasmin Kafai and Gabriela Richard argued that making physical and digital games with physical computing devices have great learning values for children [60]. The study of Katterfeldt, Cuartielles, Spikol, and Ehrenberg, established a new paradigm for physical computing at schools, through a prototyping approach producing new physical module designs to aim for better engagements to raise the learning curve [39]. The studies indeed emphasized on the potential of utilizing physical computing for learning computer subjects.

However, only a few studies focused on generalizing the approach of learning the subject matter. Paulo Blikstein explained the learning phases with physical computing devices for children as selective exposure, analysed the usability of computationally enhanced toolkits, and created a framework for future design[6]. Their framework categorized the levels of learning the subject of physical computing to achieve a better understanding of electronics, crafting, and computing [6]. The selective exposure includes introducing the subject gradually starting by presenting abstract concepts of physical computing [6]. The study emphasized on learning through enhanced computational construction kits, identified design approaches and techniques, explained by three categories: kit devices that isolate the technicalities, kits that expose the inner backbone behind the functions of the device, and devices that act as stand-alone computers[5]. Our study aims contribute to the subject by extending the research beyond using the construction kits, to explore other possibilities that enable children to learn physical computing in schools.

Computing at schools (CASs) is an organization and a community that provides various resources and training for the teachers who teach computing in UK schools, founded in 2008 [10]. The ultimate objective of the initiative is to raise the learning standards in learning the computing subject in schools. CASs has established a solid relationship and a vast number of collaborative projects with the Raspberry Pi Foundation. With putting all the efforts to produce a physical computing manual for children, CAS members were able to design an educational manual for using Raspberry Pi microcontrollers[26]. CASs are aware that the new UK national curriculum includes learning physical systems [9]. However, the obstacles can be identified by the following: First, the limitations of knowledge in the subject matter as most teachers do not come from a Computer Science (CS) background [25], Second, the availability of devices, or giving the priority to other subjects such as computer programming and computational thinking.

METHODOLOGY

The method of research followed a mixed qualitative approach that contains an online survey questionnaire. The survey discussed the teaching of physical computing as a subject matter, addressed the challenges and the approaches of teaching. The survey questions were mainly open-ended questions for more varieties and freedom in the answers. In-depth details were investigated in semi-structured interviews using skype, google hangout, and in-person interviews. The length of each interview varied from 30 min to one hour. The frequency of repetitive patters, is selected through linking the survey and the interviews with the literature. The methodology described here was reviewed and approved by the Ethics Committee of [ANONYMIZED INSTITUTION].

The study followed a qualitative structure using a thematic approach. Thematic Analysis (TA) is a "method for systematically identifying, organizing, and offering insight into patterns of meaning (themes) across a data set. Through focusing on meaning across a data set, TA allows the researcher to see and make sense of collective or shared meanings and experiences" [7]. The analysis and coding structure of the study followed the understanding of Virginia Braun and Victoria Clarke in their classification of the approaches in which Thematic analysis can be useful. In addition, coding techniques and qualitative data analysis information were applied to the book of Pat Bazeley, and Kristi Jackson [2]. The design structure of the coding was inductive from the nature of the data, but also main theme codes were added to answer the following questions: (1) What is the current status of physical computing in schools? (2) What challenges prevent it from happening? (3) What is working already? The data collection was from the online survey and media captures of audio and video for the interviews.

Participants

The targeted participants are those who teach at the Key Stage 3 (KS3) level. The reason for selecting KS3 is due to its critical transition in the level of complexity in the computing subject. The recruitment of participants followed a selection from the Edubase database, provided by the educational department of the UK government. In addition, the recruitment was also via selecting random contacts from the CASs website. The survey concluded 57 responds, containing a variety of head teachers in UK schools, CASs master teachers. 32 responds were from computing departments. 14 responds were from the computer science department, 2 responds were from the design and technology, 4 responds were from the business and computing department. The remaining responds were from the Information Communications Technology (ICT) departments. 8 interviews were conducted with professional teachers or former teachers. Most participants were selected based on their long term experience in the field of teaching computing for children.

FINDINGS

The findings showed that the majority of teachers use microcontrollers in the classroom. Only 12% of the 56 respondents do not use microcontroller devices in the classroom. We conclude that the findings indicated that the major challenges that faced the teachers in teaching the subject of physical computing are due to cost and availability, lack of knowledge, time, complexity, or less interest in the subject.

Despite the fact that microcontrollers are popular in most UK schools, our findings indicated that only 36.8% of respondents do use electrical circuits in their computing class. This low percentage implies that microcontrollers are mostly used as computers to understand software developments rather than utilizing them for the purpose they are made for such as understanding embedded systems, robotics, mechanics, and other STEM subjects with the integration of the learning of computing.

As reviewed, learning electrical circuits plays a major role in the future of education. Our findings indicated a number of teachers who already use circuits in their class using different approaches. 15 respondents preferred the use of real hardware components using breadboards. Only 5 respondents included soldering in their class. Few teachers indicated that soldering may be inappropriate for the Key stage 3 level as they may be dangerous. 11 respondents preferred to use soft circuits such as the Raspberry pi GPIO interface, or PCB sockets.

A minority of respondents approached teaching physical computing successfully. Their success in teaching the subjects is due to their long experience with physical computing education, and the available facilities. Their approaches can be summed as follows: (1) the use of ready-made simulations. (2) encouraging and engaging the student by introducing the subject of the things that children like such as designing a game console, then designing a game for the console. (3) using simplified electrical circuits interfaces to produce a balance between the software and hardware, relying on that circuits are taught in other subjects. (4) using robotics. 3.5% of respondents used simulation and animation. An N respondent stated: "I wrote an online python simulator for BBC micro bit so students could try out, debug, extend and share their code". The animation was also a preferred approach to one teacher "I created an animation generation spreadsheet which pupils can use to create micro python code which is then used to create weird and wonderful animations on the micro: bit".

Two participants used games as a tool for learning the subject matter. An N participant stated "children never get tired of games. Creating game consoles as learning projects (using ps joysticks) could lead to the better learning outcome . 3 participants from the interviews indicated that using simplified circuit interfaces and circuit gadgets is ideal for teaching the computing subject. Using PCB gadgets is a key to apply the concept of electrical circuits in a short period of time "For computing, students won't have the time to build the circuits from scratch, but it is good to use gadgets, interfaces, and soft circuits". 3.5% use robotics as an approach to teach physical computing. "we teach process then students decide what buggy robot etc they want to make on a laser cutter or by hand".

As for the popularity of devices, the findings indicated that 66% of the respondents preferred to use the BBC MicroBit. This is due to its availability for every student free of charge, and also because of its easy resource and platform accessibility. 25% of respondents preferred the Raspberry PI for its extra capabilities as it acts as a standalone computer. The Arduino is the least used for Key stage 3 as it is considered suitable for a higher level. The findings indicated that the popularity of these devices in class is based on the fact that both controllers provide the programming languages Scratch and Python.

22% of the respondents are using microcontrollers to teach programming through problem-solving, group works, and project-based learning. The teamwork enables students to learn from other students. An N respondent stated that working in groups is "Encouraging more able students to support less able, so everyone is advancing. 6 participants from the interviews confirmed that project-based learning is the most effective approach to teach the subject matter. An N participant stated “Practically the approach of teaching was by developing a number of projects through the design and technology and computing such as controlling vehicles or making lighthouses. This provided finished systems that connect different curriculum". 7% approached teaching with the use of microcontrollers by providing ready-made examples. 19% of the respondents followed the general approach in teaching which lessons, instructions, and tutorials are introduced first, then practice is applied.

56% of the teachers are aware of the benefits of physical computing. This is due to the real-world feedback and active learning that it provides. They claimed that physical computing is fun and engaging and brings a new kind of knowledge. 33% of the respondents included that learning physical computing is fun and engaging. 21% respondents referred to physical computing as it is a great opportunity to apply proper active learning. An N participant stated, "Pupils get to see something physically happening and get them involved in the idea of programming and the result that comes from programming”. Two respondents stated that teaching with microcontrollers is similar to teach standard programming “Same as normal programming, but using physical outputs". However, the trends in where technology is going indicate that the material turn in computing has come [62; 81]. The respondents stated that physical computing is keyed to "Learning about embedded systems and smart devices” and they are “Interactive and hands-on, gives a good introduction to embedded computer systems”. 7 participants confirmed that physical computing is a great introduction to STEM, the internet of things, and embedded systems.

The issue of the cost and availability of the physical computing devices can be due to the additional hardware and kits requirements. Considering that the average class in a UK state school is 30. 21% of the respondents complained about cost issues. An N respondent stated that a number of funds received for the computing class is 100£ per year which limits practicality. However, for other teachers, the cost problem was avoided through different approaches such using simulation, animation, or collaborations with other departments. Also, an N respondent stated that the Raspberry Pi foundation is willing to provide a number of controllers free of charge if the school asked for the devices. In addition, an N respondent stated that limiting the number of other less important devices such as tablets, or laptops can solve this problem permanently.

40% of responses claimed that the real challenge in teaching physical computing is in class preparation. An N respondent stated "it can be very difficult to manage a large class when trying to program with breadboard and electronics. This is due to the high potential of mistakes when setting up the components". An N respondent stated "Lots of physical components. Hard to manage with a class of 30". The most frequent comment on class preparation demonstrated the difficulty in managing 30 students for teaching subjects that involve hardware troubleshooting as well as software debugging, due to time limitation. An N respondent stated that preparing the circuits is the major obstacle "It needs too much time to setup, so time management was the biggest challenge as the time given for the computing class is only a 50 minutes a week". An N respondents stated "usually there will be a failure in the construction of the circuits and there is no time to troubleshoot every project. A solution is to provide precise and fixed ideas and project with clear direction but this will be boring for students as it limits creativity". This explains a major challenge that prevented teaching physical computing.

One of the purposes of this study is to understand the difficulties that the children face when learning physical computing, seeking to find new design patterns that enhance the learning curve. For instance, the frustration of debugging is considered a major obstacle that may prevent the children to learn physical computing the right way as the debugging here is not only limited to the code debugger, but also this includes the electrical circuits. An N respondent stated "Devices are great for high ability and well-motivated students but can be frustrating and counter-intuitive for others. Debugging code can be much harder on microcontrollers and embedded devices compared to using an IDE for web/desktop/mobile

Physical computing is a subject that draws on skills from multiple disciplines, but school teaching is discipline focused. Our findings concluded that the problems in the cross-curricular teaching can be summed in the following: (1) Each department has its own agenda and workload. An N respondent stated "we have developed some projects to work with other departments such as the science department. Linking curriculums are recommended and great but cross subjects are most difficult. It is really hard to work with other departments that has its own agendas and workloads. How to say that this is not going to increase your work at all". (2) Children find difficulties in transferring knowledge from subject to another.

When we asked one of the teachers about how electrical circuits should be taught, he stated that it should be shared between departments "there are many aspects when it comes to teaching electrical circuits. There is the Design and technology (D&T) aspect, the computing aspect, and the science aspect. They all should link together but it is hard to do the linking as there is not enough time to do so for the secondary level. For computing, students will not have the time to build the circuits from scratch, but it is good to use gadgets, interfaces, and soft circuits. The D&T should cover the soldering and the crafting of the circuit. Science should provide the theory behind all of this, what do components do?".

Therefore, it seems that simulation and simplified circuits save more time than other approaches, which gives the teacher the ability to manage the class better. Simulators are accessible from any place which gives the students the ability to practice at home even if they do not own a microcontroller. The downside here is excluding the physical aspect and relying completely on the virtual learning, Robotics are also interesting to most children and it promotes the idea of learning by playing following a constructivist approach. However, cost and availability for this approach may become a major obstacle.

Our findings suggested that physical computing concepts aren't commonly taught in schools, despite physical computing tools being prevalent. Perhaps, the usability of microcontroller devices in the classroom is not reflecting the major purpose of why they are made. Indeed, these devices are a greater gateway to learning computer programming as they combine learning with entertainment. However, our findings indicated that these devices were used to provide a limited understand the subject of physical computing, or mainly used for just learning software programming. Troubleshooting circuits and debugging codes in one class full of students is perhaps a difficult mission for the teachers. We argue that learning electronics, electrical or digital circuits in specific, are the missing elements in the computing discipline. If the theory behind electronics is introduced in science classes, computing should cover the practice of the theoretical understanding of electronics. Both subjects of Electrical circuits and software programming should be combined and condensed to fit the school curriculum as they share the same learning mechanisms. They both promote learning by trial and error, active learning, solving problems, and computational logic and structure. Physical computing as a subject can be understood as a combination of computer science, engineering, and arts. However, we suggest that physical computing should be focused driven that goes under computing.

Our findings indicated that the participants who taught physical computing for computing classes in UK schools followed an active learning approaches such as problem-solving by applying group projects. Learning theories provide a great foundation to establish new design methods and approaches for education. This study suggests considering the constructivist approach as a theoretical background as it promotes learning by playing and doing [14; 54], and social interaction [77]. Constructivism is a theory of understanding the world through experiences [14; 58]. Following the approach of Lev Vygotsky [77], and Piaget [50], considering the four stages of cognitive development: sensorimotor skills, pre-operational, concrete, and formal learning [4]. Furthermore, we suggest the constructionist perspective following the work of Seymour Papert [51], established epistemological concepts to provide concrete methods of knowing. The constructionist approach assumes that the knowledge is constructed by itself in the mind through learning computers by sharing tangible objects.

Our findings indicated major obstacles that prevented physical computing to be taught as a standalone subject in UK schools. First, software programming is prioritized over other computing subjects. Second, the challenges that include cost and availability issues, class management, complexity, and cross-curriculum problems. The teachers are aware of the importance of physical computing, but the challenges addressed in our findings are preventing them to do so. In addition, there was a minority of respondents who approached teaching physical computing through one of the following techniques: (1) using robotics and simulation (2 Tangibles (3) gamification or games. Within the literature, the vast majority of studies that investigated learning computing for children included one or two of the four techniques indicated from a minority of responses in our findings. The following discussion investigates these techniques and tools to understand which is the most appropriate design for learning physical computing and electronics.

The Co-Space Simulator software is a clear example for the use of gamification with robotics for the purpose of learning physical computing. The application was developed by the Advanced Robotics & Intelligent Control Centre (ARICC) of Singapore Polytechnic, aimed to enhance children's computational thinking and education [55]. However, a study claimed that the use of hardware is inconvenient as it may cost and also difficult for the teachers to use [31].

The robotic construction and programming is indeed a great asset to promote engineering and computer science education [48]. Various studies indicated the effective role of robotics in education [18; 45; 48; 55; 76]. The key benefit of using robotics in education depends on the relevance of different pedagogical theories including constructionism and social constructivism [38]. However, our findings suggested that the use robotics in a class setting may not be appropriate as this may introduce another level of complexity. The responds of the teachers from our survey indicated that class management is a major issue to prevent the teachers from introducing a proper electronics foundation for physical computing projects. This includes time limitation, cost, and availability. A study confirmed that the use of the Lego Mindstorms for education is effective, but requires extra management skills for running a successful class [38].

Yasmin Kafai and Gabriela Richard argued that making physical and digital games with E-textiles have great learning values for children, following a constructionist approach using scratch games with different microcontrollers [59]. The study relied on reactive interaction, varying from the majority of the studies that use "interaction in one direction, by either concentrating on screen-based interaction or focusing on physically interactive responses" [59]. The category of which this kind of interaction is best described is within the area of embodied interaction. Physical objects provide a great connection to the real world and may utilized as a great tool for learning. The work of Amanda Williams, Eric Kabisch, and Paul Dourish investigated the design possibilities for such embodiment, incorporating physical objects with sound interaction and games, found that such installations are great assets for social interaction [83]. The system created by Paul Dourish and his team illustrated the effectiveness of using embodied interaction and sound interaction for the purpose of learning [15; 16; 83] [16].

According to Salen and Zimmerman, " A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" [66]. Some studies found that the learning value in digital games is not within the content, but it's in experiencing the interaction to solve problems [8; 22]. Various studies showed that playing games can have different positive effects and benefits including increasing the cognitive abilities of children and enhancing their high-level thinking skills [24; 34; 36; 47; 49; 67; 70]. Games encourage the active learning approach and provide a great kind of situated understanding [8; 21; 22; 75]. Games are fun and engaging, and can be utilized as a powerful learning tool.

However, the major problem that faces educational games is the inability to link engagement to learning [43; 56]. "Educational games frequently consist of repetitive, superficial tasks with limited transfer or poorly disguised attempts to sugar coat learning, which can leave the student feeling patronized or deceived" [43]. A study that used a practical approach to the problem by enhancing commercial known video games, implementing the learning value in the game mechanics so they don't become obvious to the players [3]. The study acknowledged the fact the educational games are boring, and thus, gaining skills and knowledge was smoothly implemented in a meaningful form by enhancing the massive multiplayer online game (MMOG) Sea Game, resulting in an effective gain in the learning outcome [3]. The study of Larisa V. Shavinina investigated high intellectual and creative educational multimedia technologies to show various examples of the quality and efficiency of educational multimedia, found that it is mainly connected to content and developers and for the most part, they are limited by content issues[70]. The research of Shavinina aimed to provide the missing elements that make educational multimedia more effective relying on different theories that defined psycho edutainment and some psychological mechanisms to enhance digital interactive education [70]. On the other hand, Sebastian Deterding and his co-authors redefined the term Gamification, to conclude that it means creating gameful experience, using game design in a none- game context [11-13]. Gamification has broader audiences and provide a better opportunity to be used for educational purposes [12; 27; 41]. Perhaps Gamification has proved its potential as creativity and skills enabler. Leading to enforce social interaction within a community that shares the same interest [12], to improve user engagement [27], and to be used as physical exercise system [28].

Conclusion

We are witnessing a great transition in technology. As the material turn has come [81]. With the rise of the internet of things, automation, and digital fabrication, the design of interaction for learning should be shifted towards a totally new direction [62; 81]. New designs to ease learning with embodied systems and physical computing [73]. This transition can't be done instantly but over time by balancing the use of the virtual platforms with its connection to the real world.

Our study indicated that physical computing devices and kits may not provide an equal opportunity for students to learn physical computing in schools. This is due to the cost and availability, lack of knowledge, or time management issues. Simulation and educational games can lead to better learning results as they illuminate the problems of cost and availability. However, not every form of digital interaction can remain effective with the current technological evolution. Educational games and simulation may not interest a vast number of children as learning is completely virtual and boring, following different old structures of learning. On the other hand, robotics may solve this issue, but indeed learning with robotics may not be available for every student as they are expensive. Thus, we aim to find an alternative approach that provides the properties that focus on instant feedback results in the real world, with less cost and easier accessibility.

One alternative approach that may provide a similar real-time feedback is using the sound waveform as a learning tool. An absolute pattern recognition can be preserved through identifying different sound sources and melodies, which modern day computers will never be able to regenerate [30]. The approach of design that we are considering follows the fundamental concepts of Sonification. Sonification is the science that aims to provide a meaning to none- speech sounds, by translating data into acoustic sounds [29; 30; 40]. Different Sonification techniques can be tested to understand how learning can be achieved. Using a sonified auditory system as a primary interface is beneficial due to its complexity, power, and flexibility [30]. A model-based sonification technique may require minimal visualization, which works as a complementary to the auditory system [17; 30; 40]. This can be utilized as a game to structure a new game system that aims to teach electrical circuits trough sound.

In Conclusion, the study aimed to understand new approaches to design a framework for learning physical computing in the field of human-computer interaction (HCI). Sound design and game simulation can lead to a deeper learning in the subjects that requires interactivity in the real world, as sound is a natural form. Paul Dourish defined embodiment as a physical and social experience that is spread over real time and space within our world and emphasized the importance of integrating sound interaction for such systems [15; 83].

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دراسة التحديات ومنظور التصميم الذي يؤثر على تعلم الحوسبة المادية والتعليم الرقمي

الملخص: إنه من المتوقع أن يؤدي التحول المادي في التصميم التفاعلي وتنامي استخدام إنترنت الأشياء إلى زيادة الطلب على أجهزة الحوسبة والتجارب والخبرات خلال السنوات المقبلة. وقد ناقشت الأبحاث السابقة أن تصميم وتطوير الحوسبة المادية يتطلبان مجموعة متنوعة من المهارات بما في ذلك التصميم المادي والإلكترونيات والمنطق الحسابي والبرمجة والتعاون الإلكتروني. حيث إن الاتجاهات الحديثة في تعليم الحوسبة (على سبيل المثال، المبادرات التي تهدف إلى تشجيع التفاعل مع موضوعات علوم الحاسوب في أعمار صغيرة) لديها القدرة على جعل المدارس موقعا واعدا ومميزا في تطوير مهارات الحوسبة المادية. ومع ذلك، فإننا نتوقع أن يقدم تدريس وتعليم الحوسبة المادية مجموعة من التحديات الفريدة التي لا تعالجها البرامج التي تركز في المقام الأول على مواضيع الحوسبة وبرمجة الحاسوب وحدها. وفي هذا الصدد، فإننا نعرض دراسة تستطلع مدى وطبيعة تدريس الحوسبة المادية في إطار برنامج مميز لتعليم الحوسبة: مبادرة الحوسبة المدرسية في المملكة المتحدة. وقد اشتملت الدراسة على استبانة تم توزيعها على المعلمين وكذلك متابعة المقابلات مع مجموعة مختارة من المشاركين. حيث تشير النتائج التي توصلنا إليها إلى أن مفاهيم الحوسبة المادية لا تُدرس عادة في المدارس على الرغم من انتشار أدوات الحوسبة المادية.

الكلمات المفتاحية: الحوسبة المادية، التعلم من خلال التطبيق، الألعاب، الحوسبة المدرسية، الدوائر الكهربائية.