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A cube to learn: a tangible user interface for the design of a learning appliance

Abstract In this paper we introduce the design and development of the Learning Cube as a novel tangible learning appliance. Using the common shape of a cube we implemented a general learning platform that supports test based quizzes where questions and answers can be text or image based. Exploiting the physical affordances of the cube and augmenting it with embedded sensors and LCD displays placed on each face, we present different learning appliances as playful learning interfaces for children. Based on the initial observations of the experience with children, we argue that breaking conventions about how a computer has to look like, and providing children with a playful interface is a promising approach to embed and integrate technology into children's everyday context and activities.

Keywords Tangible user interface · Learning appliance · Learning platform · Ubiquitous computing · Playing

1 Introduction

Ubiquitous computing technologies allow embedding of computing capabilities into everyday objects and environments. Integrating technology and its use into tasks creates a number of challenges and opportunities. While designing for such scenarios, the effect of embedding needs to be taken into account. Important factors are

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the environment and, more in general, the contexts in which activities take place.

In this paper we present a learning appliance called the Learning Cube. The design and development of this tangible learning appliance relies on two main considerations:

– Children learn better while playing and exploring in the physical world [6];
– Physical activity helps to build representational mappings [7].

The paper is structured as follows. First we motivate our approach by reviewing related work with a particular focus on learning. Then we discuss in general the concept of using a cube as a user interface. In Sect. 4 we introduce our Learning Cube design as a generic learning platform. Following the implementation described in more detail in Sect. 5, we discuss resulting constraints and opportunities. The paper concludes with reports of using our appliance with children.

2 Related work

As in Druin [3], novel learning opportunities can be designed to be integrated into school environments, activities, and culture. Children's activities are mostly disconnected from the desktop personal computer environment: children, especially young ones, play and move around in the real world, manipulate different objects, talk loud, and like to explore.

Besides its individual, static nature, the desktop PC presents some additional constraints for children: as reported by Smets [10], children encounter difficulties when interacting with control devices (e.g., the mouse) and a 2D screen, because action and perception are spatially separated.

Tangible user interfaces aim to provide direct manipulations by mapping between behavior of the tool and usage of such a tool (for example a physical wheel could be rotated to control the state of a digital object

such as a valve), and between semantics of the representing world (the control device) and represented world (resulting output) [5].

According to constructivist learning theories [6] children learn while exploring and actively being engaged in problem solving activities. Riesner [8] has shown that physical movement can enhance categorization and recall in tasks of perspective taking and spatial imagery, even when they typically fail to perform in symbolic version of such tasks. Recent neuro-scientific research suggests that some kinds of visual-spatial transformation (e.g., mental rotation tasks, object recognition, imagery) are interconnected with motor process and are possibly driven by motor system [11].

Taking this work into account, we look at the issue of teaching children space geometry. As in Gutierrez [4] "everyday life provides plenty of interactions between plane and space, and most of them imply the dissemination of some kind of spatial information by means of plane data (drawings, schemas, pictures, figures, etc.). But text books are still plane". Emerging technologies and the possibility to embed computing capabilities into playful tangible objects can support children to create, move, transform and analyze mental images of 3D objects generated from the information brought by a plane drawing.

3 The cube as interface

Orthogonal views are very common as representations of 3D objects in technical drawings: the object is supposed to be in a cube, and projected orthogonally on the six faces of the cube. Accordingly, very often orthogonal representation is explained with the concept of an unfolded box, whose faces are displayed on a plane.

The affordances of the cube as 3D object have been studied by Sheridan [9], suggesting a description of possible manipulations of the cube, based on action, description and events, that potentially provides a framework for the design of gesture based interaction techniques.

The engagement and playfulness afforded by the cube has already been exploited in several occasions: besides the popular Rubrik's Cube, or the simple dices, HCI research has looked at the cube as user interface. Zhi Ying et al. [12] explore the application of a foldable 3D cube interface, complemented with augmented reality technology, to the field of interactive storytelling. Camarata et al. [2] use cubes as physical blocks to navigate a data space in a virtual museum, thus exploiting the everyday understanding of 3D spatial relationship.

In a recent work [1], we realized a TV remote control appliance by exploiting the affordability of a cube, e.g., turning it and laying it back down, to scroll through a list of video streams representing six preferred programs. By turning the cube, one would zap through the programs and by laying the cube back on a plain surface, the top-laying video stream would be rendered on the TV. The cube did not have displays on its surfaces and was only used as an input media.

While designing our learning appliance we looked at the cube as interface for diverse learning tasks targeted at children of different ages. Such tasks included: recognition of the same picture, a word-picture association, a vocabulary trainer, and matching multiple different 2D views. These applications build on the explorative affordance of the cube and on the design of a semantic link between physical control and digital output. The proposed appliance for learning spatial geometry moves a step forward by creating a semantic link between physical control, digital output and abstract concept, thus providing a redundant learning interface.

4 The cube as learning platform

The presented appliance relies on a generic Learning Cube platform. The Learning Cube is a digitally augmented physical cube. It is enriched with a display on each of the six faces and a speaker inside. The display and the speaker are controlled by an embedded hardware platform.

In Fig. 1, in the left part of the image, the opened cube with the hardware in the base and wires going to the display on the opened side of the cube are shown. In the right part of the image the closed cube, with the vocabulary trainer appliance running, is shown.
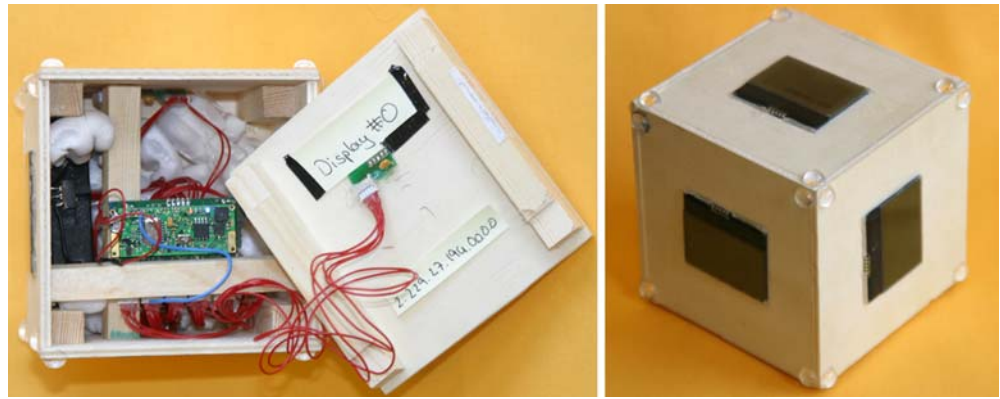
The cube is a good platform for quizzes and tests. The affordance of the device is known to every potential user. The device can be picked up, rotated and played with, it can be thrown and shaken, and be put down again. This holds true for all age-groups, from young children to adults. Additionally, relying on the experience with dice games, people expect to find different information on each side of the cube. This information can be textual or figurative.

The basic platform offers the function of a multiple choice test system. In each step one question and five answers are used. One of the answers is correct, the others four are wrong. The question is shown on the top display; the answers are randomly distributed to the other displays. The interaction operated by the user is to turn the cube to the side with the right answer and then shake it. If the right site is selected, the program moves on to the next question; if not, the user can try again. Questions and answers can be pictures or text.

This basic multiple-choice function can be used to create a variety of applications. In this paper we present different applications that are all based on that basic function, and support learning with a physical and tangible device.

One application is a vocabulary trainer. The vocable that is to be translated is displayed on the LCD currently on top. On each other side of the cube, possible trans-

Fig. 1 The Learning Cube. The cube is built around a microcontroller platform and has a display on each side. Acceleration sensors allow the detection of orientation and movement

lations are presented. If the correct translation is found, it is to be selected by the user by shaking the cube as gesture input.

Another application is a quiz that exploits the three-dimensional physical affordances of the cube. Again, the top side is the starting point and a top view of an object, e.g. a car, is presented. On the remaining sides, the views of the same object from the respective sides are presented. One side contains a false view that does not match the initial object: either it is a different object, or the view is e.g., from the bottom but should be a side view.

Further applications (a math trainer and a game where you have to match letters) have been implemented. Some more issues are discussed in Sect. 7.

5 The technology implemented

5.1 Hardware architecture

The Learning Cube platform is based on the particle architecture for small-scale embedded devices [11]. It is a low-power embedded microcontroller board with wireless communication capabilities and several built-in sensors and actuators (e.g., a movement sensor or a tiny speaker). Attached is a standardized connector for the so-called "add-on boards" which extend the capabilities of the base particle. The particle platform in general provides a basis for rapid prototyping of ubiquitous computing applications. As add-on board to the base platform the particle display board is used [9] (see Fig. 2).

This sensor board provides an interface to six Barton BT96040 displays which are connected via I^2C bus and two two-axes Analog Devices ADXL311JE analog acceleration sensors. Each display has 40 by 96 pixels and supports black and white. The choice of displays for the initial prototype was because of the ease in implementation. In a later version we would expect to use larger high resolution color displays.

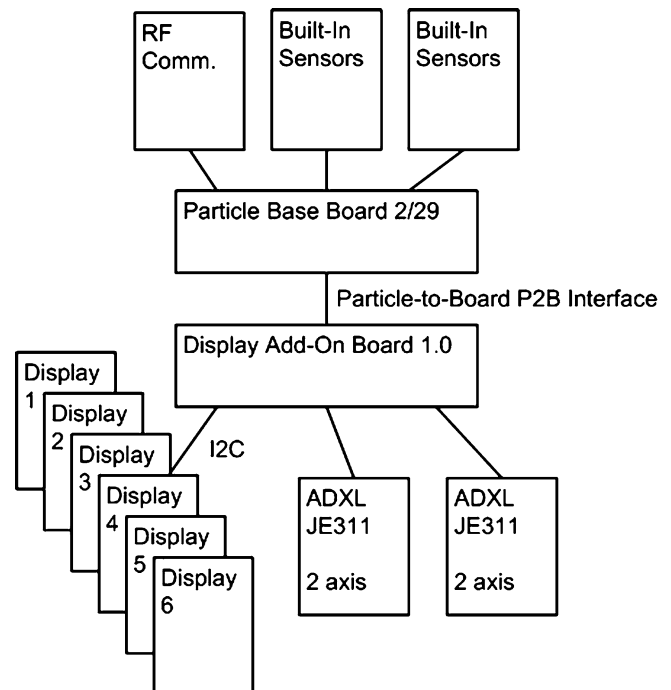The two axes of each acceleration sensor are orthogonal, as are the two sensors.

Fig. 2 Hardware architecture overview. The displays are connected via I^2C and the sensors are attached on the analog input ports. Communication and processing is handled on the particle computer

This results in three axes that are orthogonal to each other (X and X_2 share one axis). With this setup, moving the Learning Cube in 3D can be tracked.

The complete hardware is fitted into the cube and fixated to the housing so that the hardware cannot be moved. The acceleration sensors are calibrated for delivering meaningful information about the extent and the direction of the movement of the Learning Cube. It is now possible to determine which face of the cube is on top (parallel to the floor plane).

As the acceleration sensor can only measure acceleration along their respective axis, rotation of the cube can only be detected and measured along two dimensions (see Fig. 3).

A next version of the cube interface could be equipped with compasses to overcome this problem: these will allow sensing the orientation on the three axes, thus opening additional possibilities for appliance design. In the current version we decided for a design without compasses to make the appliance more power efficient and to allow longer operation.

5.2 Software architecture

The overall software architecture of the Learning Cube appliance is described in Fig. 4.

The main loop executed by the application on the particle in the cube is depicted in Fig. 5. Sensor data from the last loop is stored in an appropriate data structure for making the history of sensor values available for later access. New sensor data is acquired and preprocessed. Now the application tries to figure out if the cube was shaken hard enough to trigger the answer procession. This is a difficult part as we want to distinguish movements as rotation or translation (which occur while the user tries to find the correct answer displayed on the sides of the cube) from shakes that we consider as input events. If a shake is detected, it is checked whether the correct answer is printed on the display currently on top of the cube. If so, the user gets positive feedback and the next question is displayed on the cube. If the answer is incorrect, that is if any other face than the one with the correct answer is facing up, the answer is considered as false. Negative feedback is given to the user showing that this answer is incorrect. The loop is then started again.
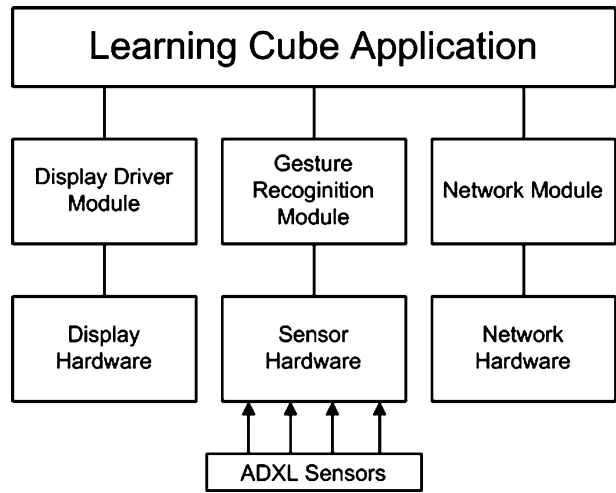

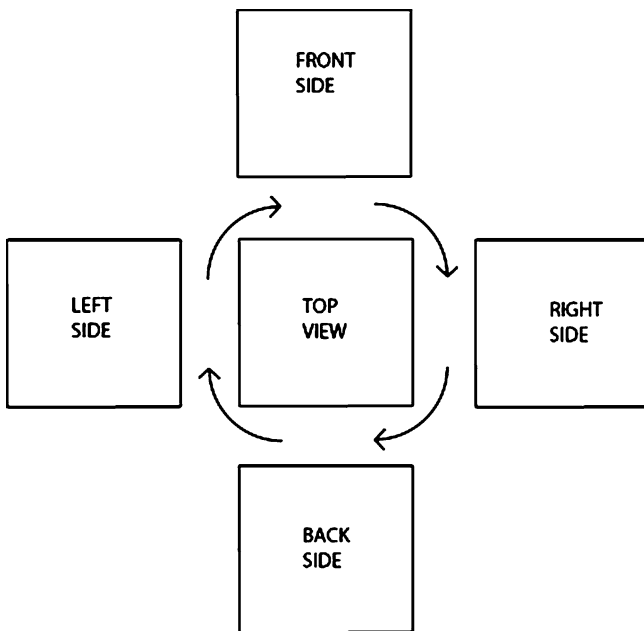Fig. 4 Appliance architecture of the Learning Cube

Fig. 3 Only rotation from the current top side of the cube to any of its adjacent sides is detectable, but not horizontal rotation
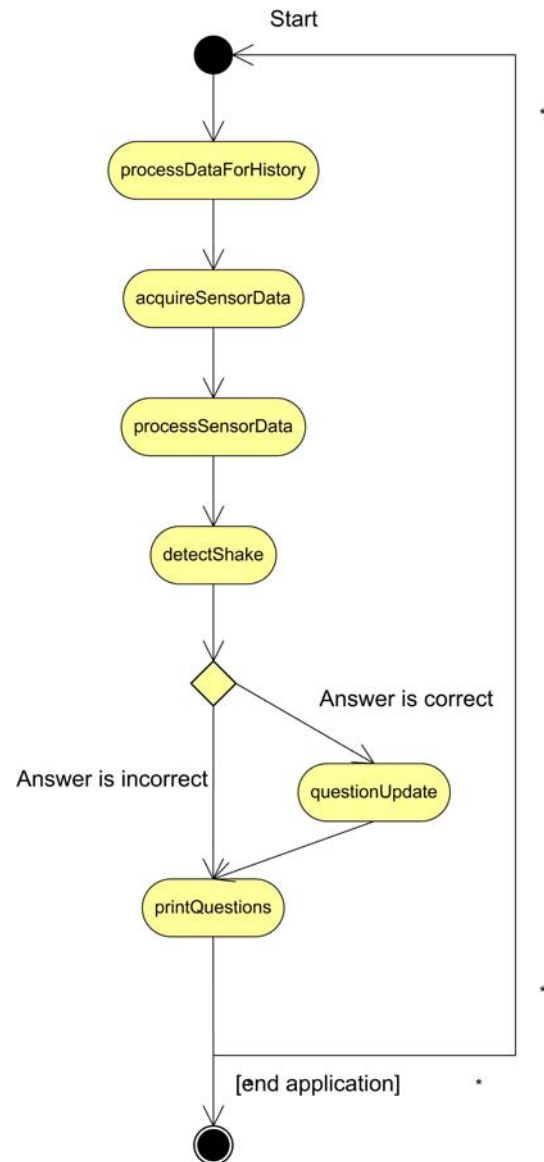

Fig. 5 Activity diagram of the Learning Cube application

6 Technology constraints as design opportunities

The impossibility to sense rotation in the plane parallel to the ground played a challenging role in the design of the appliance. In order to let users recognize the "right" orientation of the displayed output, so as to compensate the lack of orientation recognition, different design solutions could be imagined: labeling of the display, so that text orientation could be recognized, and graphical escamotages, such as arrows or fingerprints pictures, to suggest how to handle the cube and finger placement. These solutions would have somehow affected the simplicity of the interface. The solution we designed takes advantage of the limitations of the sensing capabilities by integrating it in the learning challenge. Orienting the picture in the right direction is part of the task the user needs to accomplish in order to provide the right solution. In this sense the constraint provided by the sensing capabilities was actually a stimulus for the design of the affordances of the displayed output. Our effort was then spent into a meaningful integration of technology capabilities and constraints, together with the design of affordabilities and learning task: this resulted in a learning appliance that would accommodate these aspects in a coherent redundant way.

7 Usage and user experience

Throughout the development of the Learning Cube appliance we have kept a dialog with people outside the development team to get early feedback on what works and what does not.

In an early phase we used a simple program that simulates a dice. The side that is up always shows 6, whereas numbers 1 to 5 are distributed to the other displays. During an event with about 20 external participants at our University, we gave people the appliance to play with. It was interesting to see that orientation was no real concern, as users just turned the cube so that they could see what was written on the faces. For users this appeared normal as this is what they do when they pick up a physical object with text on it. This suggests that the lack of sensing horizontal orientation can be compensated by users' intuition of how to orient text. Additionally, we realized that people are intuitively aware of what they can do with a cube, even if not instructed.

With the final version of the Learning Cube we conduct informal user studies with children. This work is ongoing. The prime goal of these studies is to understand how children handle the appliance. In particular we are interested in:

– What makes the interface interesting?
– What makes operation simple and what is challenging?
– How to tailor edutainment to an appliance?

– The relationship between physical appliance design, software, and user experience.

In our first experiment with children we had an application where letters had to be matched. On the top, a letter was displayed (e.g., A) and different letters were displayed on all other sides including another A. The objective of the game was to find the matching letter and then select it. The game was designed for children starting to learn letters. The cube gave the difficulty that they had to find the letter even if it is upside down or on its side. In our first version we only used letters that are still uniquely identifiable even if rotated. Figure 6 shows a 3-year-old girl playing with the appliance.

This first experiment showed that the turning made this simple game challenging for smaller children; similarly, the shaking was pretty difficult to do, so that these features kept the game interesting for a certain time and engaged them in trying out gestures and solutions. In some tests we had a low recognition rate for the shaking gesture, but the children still managed to play, and looked for a strategy to make gestures in a way that the system recognized them. It was interesting to see that they adapted to short comings of the implementation.

In the second experiment we played with kids in the age group of 7–12. The quiz was a basic math trainer.

Fig. 6 A small child playing with the Learning Cube. Even children as young as 3 years could instantly use the appliance

Fig. 7 The cube allows children to interact around the appliance and use it away from a desktop setting. They can hand it from one to another or look from different sides

Multiplication of single numbers, addition of numbers, and combined tasks in the domain below 300 were used. Children quickly understood the concept. Shaking and turning made them engage with the game and they seemed to like it. Additionally, we could observe that they played together, helping each-other, arguing, and showing solutions (see Fig. 7).

8 Conclusion

In this paper we introduced the Learning Cube as a novel learning appliance. Using the common shape of a cube we implemented a general learning platform that supports test based quizzes where questions and answers can be text or image based. The system is implemented stand-alone using a microcontroller system that has acceleration sensors and six displays connected.

Based on the appliance platform, we implemented several edutainment games. Our initial experience with children shows that having a different physical form and a different set of affordances prompts a great initial engagement. Children do not consider the appliance either as a traditional learning tool or as a computer, but rather as a toy. Distracting children from the learning task as conventionally presented and engaging them in a quiz game that they can play with others motivates them and challenges their skills.

From our preliminary experience it appears interesting to deliberately break conventions about how a computer has to look like. When demonstrating the appliance to people, several ideas about what this appliance could be good for emerged: this suggests that by providing computers with radically different shapes, it may be possible to access new application domains.

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