BrainExplorer: An Innovative Tool for Teaching Neuroscience
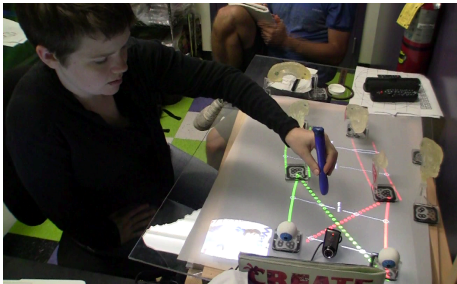

Figure 1. A user interacting with BrainExplorer.

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Abstract

Neuroscience has recently brought many insights into the inner workings of the human brain. The way neuroscience is taught, however, has lagged behind and still relies on direct instruction or textbooks. We argue that the spatial nature of the brain makes it an ideal candidate for hands-on activities coupled with a tangible interface. In this paper we introduce BrainExplorer, a learning environment for teaching neuroscience. BrainExplorer allows users to explore neural pathways on a custom tabletop platform. We conducted an evaluation with 28 participants comparing students who learned neuroscience content through using BrainExplorer with students who learned by reading a textbook chapter. We found that our system promotes learning along 3 dimensions: memorizing scientific terminology, understanding a dynamic system, and transferring knowledge to a new situation.

Author Keywords

Neuroscience; Learning; Tangible Interface; Tabletop

ACM Classification Keywords

H.5.2

General Terms

Design, Human Factors.

in parts tagged with fiducials
IR pen
Eyes Webcam
Projector
Wiimote Camera
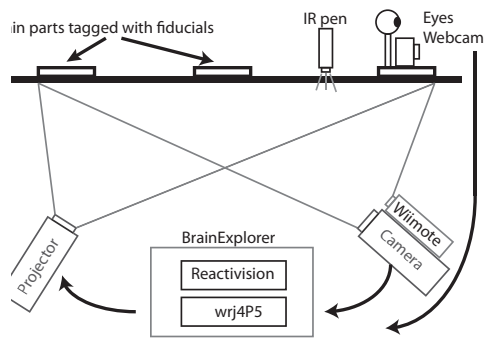BrainExplorer
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Figure 2. The setup of BrainExplorer.

Introduction

Neuroscience is a rapidly evolving field, and the brain's complexity has traditionally been thought of as the domain of advanced undergraduates and graduate students. However, in recent years, researchers have begun to advocate for the benefits of bringing this topic closer to younger audiences. In this paper, we first describe the construction of BrainExplorer and the way various learning theories informed our design. Following, we present an experimental study comparing the effectiveness of our system as a learning tool compared to textbook instruction.

Related Work: Educational Tabletops and Tangible User Interfaces

The field of education has a long history of using manipulatives for learning: from Pestalozzi, who used to say "things before words, concrete before abstract", Montessori (1870-1952) who constructed a diverse set of manipulatives for poor children in the Italian suburbs, to Bruner who advocated an evolution from enactic to iconic and symbolic reasoning. Researchers have recently regained an interest in this domain now that technology can augment those manipulatives in rich and diversified ways. Projects that embody this idea are called Tangible User Interfaces (TUIs [2]).

Tabletops have been the privileged platform for developing TUIs. We review here a few projects that have tried to take advantage of the specific affordances of physical inputs: in molecular biology, Gillet et al. [1] created a TUI that overlays 3D representations on a molecular model, In geography, Illuminating Clay allows users to explore a landscape augmented with various simulations, such as the influence of water flows or solar radiation [3]. In genomics, Shaer et al.

[6] designed and evaluated G-nome Surfer, a tabletop interface for fostering inquiry-based learning of genomics; they found that compared to a multi-mice implementation, their tabletop increased physical participation, encouraged reflection, fostered collaboration and facilitated interaction among participants. Finally, the Tinker Table developed by Zufferey, Jermann & Dillenbourg [7] allows apprentices in logistics to control a simulation of a small-scale warehouse by moving physical shelves (a projector then displays an additional layer of information based on the location of the shelves - e.g. forklifts influencing the fluctuation of the stocks). Based on those studies, We propose that TUIs have an interesting potential to improve education by lowering the degree of abstraction and providing more adequate scaffolds for highly spatial problems. Since the human brain is a complex 3D structure we propose that neuroscience is a particularly well-suited domain for developing neuroscience environments with tangible inputs.

BrainExplorer

Given that the brain is a dynamic 3D system, we propose that it is extremely difficult to teach neuroscience with standard tools. Our system, BrainExplorer, takes advantage of recent technological developments, including infrared camera technology and webcam-based tracking (Fig. 1), to create a tangible user interface to study the human brain.

Design Decision and Process

Our system was targeted to a wide range of educational settings. Its primary purpose is as an inquiry learning tool for middle and high school students to engage in scaffolded investigation about the brain. Our system draws heavily from the constructivist theory of learning
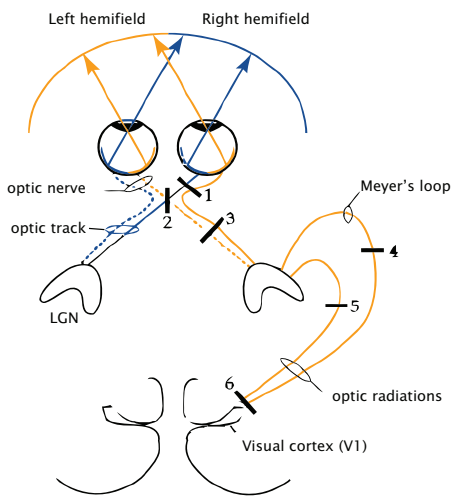
Left hemifield   Right hemifield

optic nerve

optic track

LGN

Meyer's loop

optic radiations

Visual cortex (V1)

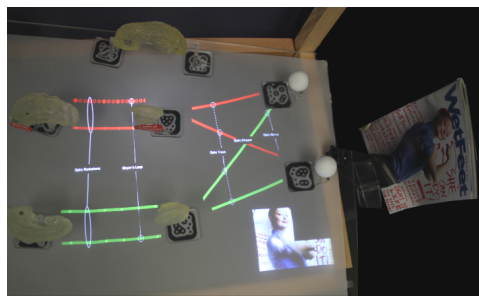**Figure 3.** The organization of the visual pathways in the human brain.

Figure 4. Representation of the visual system in the BrainExplorer environment. In this example, Meyer's loop is severed on the left side of the brain, which occludes the top right quadrant of the vision.

[5], which emphasizes the need for students to construct their own theories about the world based on knowledge and intuitions they already possess. Scientists, including neuroscientists, construct their theories about the world by performing experiments. Therefore, our system is designed to let the user to be the scientist and to allow him or her to replicate experiments that neuroscientists might actually perform in a lab. We also wanted the user to be able to begin with a whole brain and deconstruct it into individual pieces. This design decision was based on users' emotional reactions—taking something apart is a profoundly satisfying way of learning. As a consequence, we built a custom-made table where a physical model of the brain can be taken apart. Departing from a polymer-based replica of the brain sectioned into 6 parts, each part was tagged with a fiducial from the Reactivison toolkit [4].

Figure 1 describes the final setup of our system. A matte surface supports the brain parts tagged with fiducials. Users cut connections by using an infrared pen; the IR signal is detected by a Wiimote underneath the table. A high-resolution, high-frame rate camera (PS3 EyeToy) sees the location of each fiducial and transmits its location to the software. An additional webcam is located between the two eyes of the physical model and "sees" what the brain would perceive based on the lesions made by the user. The program retrieves the input from the Wiimote via Bluetooth and the two cameras images via USB and displays the results through a short throw projector. A custom-made table supports the brain parts, the projector, the Wiimote and the two cameras. Thus, BrainExplorer allow users to cut different visual pathways and observe the impact of their actions on the visual field of the human brain (Fig. 4).

Evaluation

We used a between-subjects design to compare our system with a control condition where users had to read a text on the visual pathways. Our post-test measured learning on 3 dimensions: memorizing scientific terminology, understanding a dynamic system, and transferring knowledge to a new situation.

Participants: 28 undergraduate and graduate students took part in the study (13 males, 15 females; average age = 28.2, SD = 5.7). None of the participants took a class in neuroscience before or had existing knowledge on the topic.

Procedure: The evaluation took place in a private room and both conditions used the same space for the experiment. We kept the lighting conditions identical for each subject in order to assure the stability of the tracking system. Upon their arrivals, users were welcomed and thanked for their participation. An experimenter then explained to them the purpose of the task and tested their existing knowledge on the topic by presenting them a schema similar to Figure 2 (see "Material" for more details). Participants with no prior knowledge were then randomly assigned to one condition ("Text" or "Tabletop") and given specific instructions. In the "Tabletop" condition, subjects were told that they would have 15 minutes to use BrainExplorer in order to explore how the visual system of the human works. Their only task was to find 2 rules that would help them explain to a peer how vision is processed by the brain. Finally, they were also instructed to think aloud during the session. The episode was videotaped for further analyses. Participants in the "text" condition were told to read a text on the same topic for 15 minutes. In both
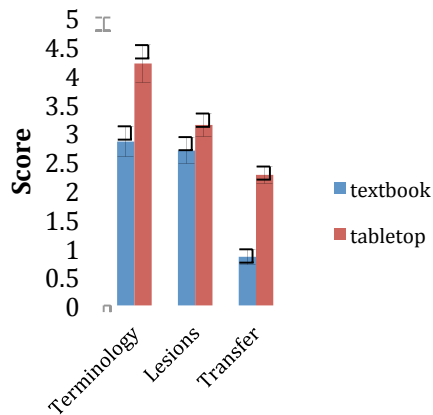
Figure 5. Results of the learning test.

conditions, the experimenter told the users that they would have to complete a test at the end of the activity. After completing the task, subjects filled out a demographic questionnaire and answered a computerized test in which reaction times and answers were recorded (see the "Material" section for more details).

Results: We measured the learning gains with the post-test since none of our participants had prior knowledge in neuroscience. An ANOVA revealed that subjects in the Tabletop condition scored significantly higher than those reading a text: $F(1,26) = 15.77$, $p < .001$ (mean = 9.6, SD = 2.16 for the tabletop condition; mean = 6.38, SD = 2.1 for the text condition); see figure 5 for more details. subjects in the "tabletop" condition significantly outperformed the participants in the "textbook" condition for learning the brain terminology $F(1,26) = 5.18$, $p < .05$, for the transfer questions $F(1,26) = 24.98$, $p < .001$. The difference for the lesions dimension was not significant $F(1,26) = 1.02$, $p = .32$.

Discussion

In our evaluation we found that participants in the tabletop condition learned more about the visual pathways compared to the text condition. Our results have interesting implications for neuroscience education; it shows that tangible systems may have some benefits for teaching the way complex systems work (compared to a traditional instruction). It should be noted that this study has one main limitation; there are confounding variables between our two conditions. In the tabletop condition, users had access to a 3D model of the brain (compared to a 2D schema in the text condition), they were asked to discover concepts

by themselves (in the other condition concepts were directly explained to them) and finally they had to think aloud (whereas other users had to read a text). Future work should disentangle those variables to discover how the positive learning effect found in our study takes place.

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