The Thinking Cap: Fostering Growth Mindset Of Children By Means Of Electroencephalography And Perceived Magic of Harry Potter Universe

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Fostering Growth Mindset Of Children By Means Of Electroencephalography And Perceived Magic of Harry Potter Universe

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ABSTRACT

In this work we introduce the Thinking Cap, a wearable system designed to resemble the Sorting Hat from Harry Potter, fitted with a commercially available Electroencephalography (EEG) headset and a Bluetooth speaker. The Thinking Cap can inform the user about their brain activity in real-time via a speaker. We designed and conducted a study with 48 elementary and middle schoolers to investigate the influence of a BCI device and perceived magic on the development of growth mindset in children. Our results suggest that interacting with the Thinking Cap has a positive impact on children's mindset, which was expressed through their communicated beliefs and task-based behaviors.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **User studies**; • **Social and professional topics**; • **Children**;

KEYWORDS

Mindset, Brain-Computer Interfaces, Pop-culture, EEG, Magic

ACM Reference Format:
Nataliya Kosmyna, Cassandra Scheirer, and Pattie Maes. 2021. The Thinking Cap: Fostering Growth Mindset Of Children By Means Of Electroencephalography And Perceived Magic of Harry Potter Universe. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '21 Extended Abstracts), May 08–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3411763.3451732

1 INTRODUCTION

Several psychological interventions have shown to improve the academic performance of young children and students [12, 52], many of which are intended to educate them about growth mindset: the idea that intellectual ability can be developed over time [13, 30]. We believe the existing frameworks for these mindset interventions pose several challenges in practice [16]. To be carried out properly, they require extensive training of participating faculty [8, 10] and extra effort to mitigate cognitive biases of the adults administering them, which limits their scalability and success rates [35]. Additionally, only within the last two years have contributions started to report on online-based interventions [53], which are still rare because mindset interventions are generally easier to perform in-person. This challenge is especially important to address in situations where the child and their caregivers might not have consistent access to school facilities and in-person teaching, such as those with lower socioeconomic status as well as health crises like COVID-19.

In order to overcome these challenges, we propose a prototype of a wearable intervention system, the Thinking Cap (Figure 1). Based on the Sorting Hat from Harry Potter, it is a wearable, electroencephalography (EEG)-based Brain-Computer Interface (BCI) which praises the user for their effort and ability. Its algorithm is pretrained on mental imagery of the user (8–12-year-old children, in our case) and is then used to test the effect of "perceived magic" on the user's motivation. The Thinking Cap uses Brain-Computer Interface (BCI) algorithms to recognize mental imagery of the child pretrained for a 2-class choice. In an initial phase, the hat recognizes and reports on the brain patterns of the user. We believe that demonstrating basic recognition of their brain signals will lead the child to develop trust in both the hat's ability to "know them" and in their own learning ability. Thus, when the hat in a later phase praises the child for their ability and/or effort on a task, the child is likely to listen to it and be affected by its suggestions in their subsequent performance. We hypothesize that using the hat can thus lead to fostering growth mindset.

Unlike any existing work, apart from our own recent findings in [23], we focus on presenting a set of hypotheses that aims to test the significance of the presence or absence of different components of such a system: audible feedback and EEG within a single form-factor, a hat, and a single magic universe, Harry Potter. We report on an experiment that involves the use of the prototype with 48 children.

2 RELATED WORK

The effectiveness of growth mindset intervention on children's learning ability has been extensively studied. Multiple studies demonstrate that students' academic abilities grow more when lessons on growth mindset are paired with background information about the neuroplasticity of the brain rather than in a context completely void of neuroscience [1, 3, 29]. Moreover, as schools are incorporating more innovative learning techniques into their classrooms, there are many new digital and robotic tools intended to foster growth mindset [3, 6, 23, 24]. These existing interventions

CHI '21 Extended Abstracts, May 08–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8095-9/21/05.
https://doi.org/10.1145/3411763.3451732

Figure 1: Left: The Thinking Cap system incorporating a Sorting Hat, an EEG headset as well as speakers inside of hat (not visible on this image). The image also features a small Sphero robot used in this study. This setup was used in FULL condition of our study. Right: Participant undergoing *Stage 3* of the study.

show that positive self-image can boost motivation, but they lack a growth-mindset-specific framework.

Narrative media also has a strong influence on self-image, as we tend to identify with fictional characters who have traits and experiences like ours [7, 46]. Such identification can lead to changes in one's future behaviors, self-esteem, perception of their environment [46], wellbeing [5], values [7], emotions [9], and personality [10, 11]. As a result, narrative media can be a good tool for installing growth mindset.

A few studies have shown that famous fantasy franchises, like Lord of the Rings or Harry Potter [38], are good examples of how pop-culture can provoke a personality or behavioral change in children [8, 10, 40, 43, 44]. Where Harry Potter concerns our study is the *magic* of the Sorting Hat artifact. When students arrive at Hogwarts for the first time, the magic school in Harry Potter universe, they need to be sorted into a distinct socio-academic House, a process conducted by the Sorting Hat (Figure 1). This magical artifact reads the mind of its user to determine which House best suits their personality [8, 47]. As a result, students feel a strong sense of belonging and loyalty to their assignment [33, 36].

The perception of magic has proven to be a valuable tool for enhancing children's mental and physical wellbeing in real life as well. Several programs like Healing Magic, Project Magic, Breathe Magic, and Hocus Focus use magic as motivation for better behavior and confidence [4, 19, 41], as well as treatment for neurological disorders [17] and therapy for addictions [18]. However, very few magical interventions have been used to directly promote a growth mindset [2, 23]; the most similar interventions to our proposal have been theoretical. We also refer the reader to [23] to check additional references of state-of-the-art research on growth mindset and academic interventions using pop-culture and neuroscience.

The goal of the current study is to combine these three areas — brain development theories used in growth mindset interventions, narrative media, and magic — to provide empirical evidence of the effectiveness of fantasy and neuroscience as a tool for promoting growth mindset in children.

3 SYSTEM DESCRIPTION

The Thinking Cap system is composed of the following hardware, software and feedback elements:

1. the "Hat", which represents a Sorting Hat replica from the *Harry Potter* franchise (Figure 1);

2. a pair of wireless Bluetooth speakers + one Velcro sticker to hold a speaker inside;

3. an EEG Emotiv Epoc headset [15]. Velcro stripes were added to the hat to hold the headset inside;

4. a feedback component – the current version "talks" to the child through a Bluetooth speaker;

5. a Macbook Air computer which runs a BCI algorithm to enable the detection of the brain signals as well as their classification.

6. a small rolling open-source robot from Sphero [42], which is used in the "intervention" phase of the study: the children can move or stop its movement (Figure 1, left).

In our study, we have 2 main conditions based on different combinations of the system's components:

1. **ACTIVE condition** incorporates all the components of the system, which includes the hat, the EEG headset as well as a feedback component. The sub-conditions of the "Active" condition include:

a. **FULL condition** includes a hat, an EEG headset, feedback component;

b. **EEG condition** includes an EEG headset, and a feedback component;

c. **HAT condition** includes a hat and a feedback component.

2. **CONTROL condition** does not incorporate any of the aforementioned components of the Thinking Cap system.

4 EXPERIMENT DESIGN

We designed an experiment to investigate a set of hypotheses regarding the impact of interacting with a Thinking Cap on children's expression of growth mindset.

More formally, we hypothesize condition dependent effects: **H1:** Participants in the ACTIVE condition will score higher on the post-mindset assessment questions compared to the control condition (CONTROL). **H2:** Participants in the FULL condition will score higher on the post-mindset assessment questions compared to three other conditions (EEG, HAT and CONTROL). **H3:** Children who receive praise for their effort will show more task enjoyment and more task persistence than children in the control condition. **H4:** Children in the control condition will receive pre- and post-mindset assessment scores in approximately equivalent numbers.

4.1 Participants

Forty-eight children between the ages of 8 and 12 years old (age M = 11.23, SD = 1.08; 24 females) participated in the study. Participants were randomly assigned and counter-balanced across the conditions with respect to their age and gender. This age range was selected in order to ensure that the children would be able to understand the metaphor of Harry Potter, as well as the principles of functioning of a Brain-Computer Interface system. The protocol 1806420285 was approved by the IRB of Massachusetts Institute of Technology (MIT). Each caregiver and child received a $15 check as a thank-you for their time.

4.2 Protocol

The experimental protocol followed five stages, each of the approximate duration of 15 minutes: 1) welcome, briefing and pre-assessment questionnaires, 2) solving a math exercise sheet, 3) intervention (type of intervention depends on the condition), 4) solving another exercise sheet of child's choice, 5) post-assessment questionnaires and debriefing.

4.2.1 Stage 1: Welcome, Briefing and Pre-assessment questionnaires. The experiment would begin with the child filling out a mindset assessment questionnaire, based on Dwerk's mindset questionnaires from [12] as well as [21, 31]. We refer the reader to [23] to check the specific examples of the questions.

4.2.2 Stage 2: Solving Math Problem-1. All the children were asked to work on a set of math problems, containing 30 expressions with multiplication, division operations or fractions. The set of math problems was strictly built based on the corresponding notions of the grade the children were in. We obtained and compiled the problems from one source, a series of workbooks [50]. After the children completed the set of problems, they were asked to rate their task persistence, task enjoyment, and performance quality on a scale from 1 (not at all) to 6 (very much). All the aforementioned measures were taken from Dwerk's studies [30]. We refer the reader to [23] to check the specific examples of the questions.

4.2.3 Stage 3: Intervention. Stages 1 and 2 were the same for all four conditions, but stage 3 was different for each of the conditions.

FULL condition. Once stage 2 was over, the experimenter brought over the Thinking Cap equipped with the EEG headset and the speakers, as well as a computer and a robot. On the computer the experimenter had launched a BCI system from [23, 25, 26] to control a robot using three mental commands: imagining a soccer ball, imagining a red card, and staying in resting state (no imagination). Due to the nature of BCI, the system needs to be trained on each participant individually (brain activity varies across people, for a single person over several sessions as well as within a single session); thus we needed to calibrate the system for each child separately. The duration of the training is typically around 3 minutes. We provide the details on the BCI system used in this study in the end of this section, as it is the same one used for both conditions FULL and EEG, as conditions CONTROL and HAT were not using any BCI.

Once the training was performed, the child performed two tasks (Figure 1, right). In the first task, for the duration of 5 minutes, the child tried to move the robot using his/her brain signals. For the second task of the same duration, the experimenter took the robot away and explained to the child that he/she can now continue imagining a ball or a red card, but that instead of moving the robot, he/she will hear the hat "talking" to him/he, meaning that the hat will provide the real-time feedback about what the child is imagining. Only the child was able to hear what the hat is saying. The computer logged the classification results. Before the actual task, we played to the child a short phrase, *"Hello, can you hear me well?"* to ensure that they can hear the speaker being inside of the hat. We have asked a student from the arts department to try to mimic the voice of the actual Sorting Hat from Harry Potter, and we recorded the following phrases: "*It seems that you are imagining a ball", "It looks like you are thinking about a red card", "Oh, could you please think about it again, I am a bit old and seemed to miss it", "You seem to work hard! Looks like you are going to be great in math today!"*. The first two phrases were triggered each time the BCI system classified a ball or a red card that the child imagined; the third phrase was used when the classification decision was impossible to perform; and the phrase about the math was used once the child performed both tasks.

EEG condition. EEG condition was the same as the FULL condition with a few differences related to an absence of the hat. The condition had as a wearable artifact the EEG headset and the Bluetooth speaker attached to it (see Table 1). The phrases that were delivered by the speaker were recorded with the voice of a male English speaker, the same person who we recorded for our FULL condition.

HAT condition. HAT condition was similar to the previous one, except we did not include any EEG headset and thus, no BCI system was present in this condition. The condition was represented as a system which included a hat with a Bluetooth speaker inside. The child played with the robot for 3 minutes, using the computer interface to initiate its movement or a stop. They were not wearing a hat at that time. The experimenter then put a hat on the child, we verified in the same way as during FULL condition that the child is able to hear "the voice" of the hat, and the hat pronounced the following phrase to the child "*You seem to work hard! Looks like you are going to be great in math today!*".

CONTROL condition. Finally, CONTROL condition did not include any hat, BCI system or Bluetooth speaker (Table 1). The experimenter took a copy of the child's math task he/she just solved during Stage 2, looked through it for 1 minute and then repeated the exact same phrase as the hat was saying in other conditions "*You seem to work hard! Looks like you are going to be great in math today!"*

End of *Stage 3* for all conditions: Once this stage of the experiment was over, children in all four conditions also rated their task persistence, task enjoyment, and performance quality on a scale from 1 (not at all) to 6 (very much).

4.2.4 BCI System Used During Stage 3. We chose to use a single-trial BCI system, as the goal of this study is not to measure the performance of the BCI at first place but to explore the influence of the system on the child's performance and growth mindset. We used an architecture from [23, 26] as it is a real-time BCI system that only needs a small amount of data (1 trial) to be functional. For EEG acquisition, we used the Emotiv EPOC which has 14 electrodes [15]. The main motivation behind this choice was related to the fact that this headset is relatively compact and could be fitted easily inside the hat (some current EEG devices that have a form-factor of a cap would be harder to set up for our study). EPOC was also shown to be used in different mental imagery scenarios with children and adults [23, 55]. For more details about the implementation, artifact removal and limitations of the proposed system, please refer to [25, 26], and we refer the reader to paper from [23, 24] to know more about the underlying mental imagery processes.

The training step was standard for BCI systems. A computer screen showed the images representing the commands for the robot: soccer ball, red card and resting state (no command, no imagination process involved). These mental commands corresponded to physical commands to a robot: the robot would move if mental imagery of the soccer ball was detected and stop moving if mental imagery of red card was detected. The resting state was not associated with any command for the robot. Children had to imagine the associated image so that we could capture a training signal for each of the classes. Once the training was over, the participants had the opportunity to control a robot with their brain signals as described in Stage 3 of the protocol for FULL and EEG conditions.

4.2.5 *Stage 4: Solving Math Problem-2.*

Once stage 3 was over, the children had to choose one of three proposed tasks to complete, regardless of the condition they were assigned to. This task was adapted to their grade and age group. One task represented a math sheet similar in difficulty and exercises to what they had solved during *Stage 2* of the experiment. Sheet 2 represented another math sheet, but of higher difficulty. Finally, sheet 3 represented a reading task of medium difficulty. After the children completed the set of problems they chose, they responded to the same set of questions that was administered during *Stage 2* of the experiment.

4.2.6 *Stage 5: Post-assessment Questionnaires and Debriefing.*

Once *Stage 4* was completed, participants completed a mindset assessment questionnaire which we described in the *Stage 1* section. We then debriefed them shortly to 1. make sure that they would not leave the lab with any misconceptions about the scientific theories which underlined this study and study goals; 2. answer any additional questions that might have arose; 3. collect any additional feedback and comments from the children they wanted to express; 4. assure that all children left the experimental setting proud of their performance.

5 RESULTS

We first compared the distribution of mindset scores, both before and after feedback from each of the conditions. Our hypothesis is that before intervention, there should not be any statistically significant differences in the mindset score distributions **(H4)**. In the post intervention setting, we expect that some conditions (specifically EEG and FULL) could potentially lead to statistically significant differences in mindset scores. In both the pre-setting and the post-setting, the distributions are not normally distributed (Shapiro-Wilk significant: W = 0.90227, p = 0.0007448; W = 0.93268, p = 0.008572). We cannot apply the standard linear model with a normal distribution, so instead we used a generalized linear model (from lmer in R). Analysis of variance with a Gamma distribution (suitable for strictly positive values, which is always the case here) and with the favorite subject (pre: variance explained v.e.=0; post v.e.=3.666e-12), least favorite subject (pre: v.e.=1.312e-05; post: v.e.=2.176e-05) and subject chosen (pre v.e.=0; post v.e.=3.666e-12) as random effects. The fixed effect was the condition. For the pre-distribution, we have AIC=141.4 and BIC=156.4 with a significant ANOVA (Chisq= 0.2129785, df=q, p=0.644): as per a post-hoc Tuckey test corrected for repeated comparisons, EEG is significant at p<0.02 compared to CONTROL and HAT is significant at p<0.03. FULL is at p=0.06. Therefore, our **first hypothesis (H1)** is not rejected, the presence of the EEG headset or the hat equally improves mindset scores, although the effect size is small (less than 0.5) (Figure 2, top).

In the post-setting we have AIC=156.3 and BIC=171.3 with a significant ANOVA (chisq= 53.22, df=3, p=1.646372e-11), EEG condition (p<0.001), FULL condition (p<0.001) both had significant differences over CONTROL condition, while HAT condition (p<0.07) was borderline. The differences between the CONTROL and HAT conditions are significant for both pre and post intervention phases with a comparable effect size. Thus, for HAT condition, we have the same small placebo effect in both pre and post results. On the other hand, the addition of EEG alone improves mindset scores by two points on average, and the addition of EEG and the hat (FULL condition) leads to a difference in average mindset scores of 3 points. Based on the observation that the placebo effect of the hat is the same in pre and post, we can conclude that adding the hat to the headset leads to a non-linear cumulative effect **(H2)**.

We will now similarly examine the effect of the condition on task 1 and task 2 persistence scores **(H3)**. The score distributions for task 1 and 2 are not normally distributed (Shapiro-Wilk W=0.86428, p=5.326e-05; W = 0.91318, p=0.001723). We use the same generalized linear model, with the condition as the fixed effect and the favorite, least favorite and chosen subjects as the random effects. The random effects explain little of the variance as none explain more than 2e-4 variance, which indicates that they do not confound the fixed effect. For task 1, we have AIC=102.8 and BIC=117.8, with a non-significant ANOVA (Chisq=1.614011 df=3 p=0,6562171), meaning that none of the conditions influence task persistence. For task 2, we have AIC=133,4 and BIC=148,3. A Tuckey post-hoc corrected for multiple comparisons indicates that the only significant difference is between FULL and all the other conditions (p<0.01 for all three cases with an average effect size of 1 point. Thus, we can conclude that only FULL leads to a significant persistence scores increase (Figure 2, middle). We finally examine the effect of the condition on task 1 and task 2 engagement scores **(H3)**. The score distributions for task 1 and 2 are not normally distributed (Shapiro-Wilk W=0.86862, p=7.056e-05; W=0.91974, p-value=0.00291). We use the same generalized linear model, with the condition as the fixed effect and the favorite, least favorite and chosen subjects as the random effects. The random effects explain little of the variance as none explain more than 1e-4 variance, which indicates that they do not confound the fixed effect. For task 1, we have AIC=116.3 and BIC=131.2 with a non-significant ANOVA (Chisq=1.119024, df=3p=0.7724838), meaning that none of the conditions influence task engagement. For task 2, we have AIC=137 and BIC=152. A Tuckey post-hoc corrected for multiple comparisons indicates that there is no significant difference between CONTROL and HAT conditions, but that both EEG and FULL conditions show significant differences from the other two (p<0.01 all pairs involving them). While the effect size is almost nonexistent for EEG condition alone (difference of medians close to zero), the improvement from FULL condition, leads to an average increase of 1 points of engagement score (Figure 2, bottom).

6 DISCUSSION, LIMITATIONS AND FUTURE WORK

To summarize the results, our two hypotheses were not rejected: participants in the FULL (ACTIVE) condition scored highest on the post-mindset assessment questions; and children in the control

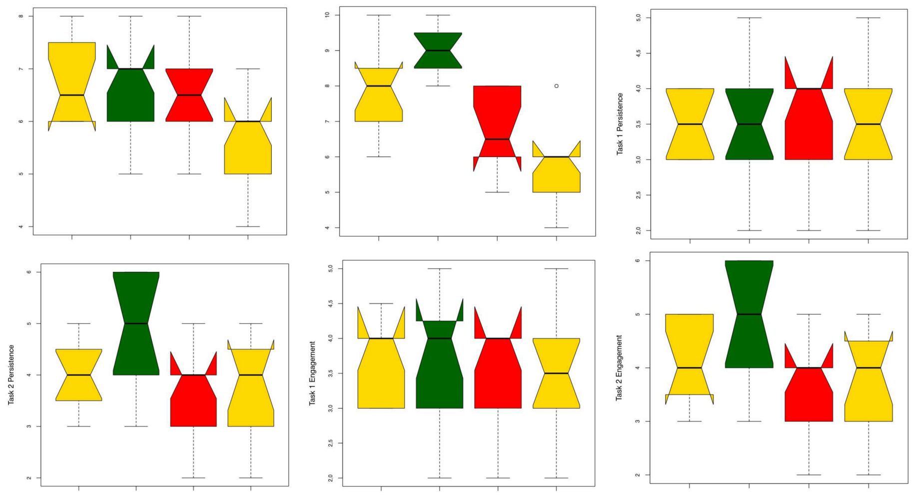

Figure 2: Top Row. From Left to Right: Pre-/ post- mindset scores in all four conditions, persistence on Task 1. Bottom Row. From Left to Right: Task 2 for all four conditions after the intervention took place; Engagement from performing Task 1 and Task 2 in all four conditions after the intervention took place. Column 1 represents "EEG" condition; column 2 – "FULL" condition; column 3 – "HAT" condition and finally the last column represents "CONTROL" condition.

condition obtained pre- and post-mindset assessment scores in approximately equivalent numbers. These results can be explained by the element of perceived magic [27, 37]. These results, though interesting, should be interpreted as preliminary.

There are also several limitations to be acknowledged in this work. First, the system is based on only one magic universe, Harry Potter. The children might have felt an obligation to rate the hat high because it was the only available experience. Second, we embedded an existing EEG headset, which 5/24 children mentioned felt "heavy" — limiting accessibility and scalability. We would also like to see the experiment re-run with other

BCI algorithms and more children per test group. Another limitation is the duration of the intervention. Though several works in the community also performed short and "pin-pointed" interventions [31, 34], it still must be tested if such an intervention makes a difference on academic performance on a longer time scale.

Finally, some children might have been primed to the experience because they perceived the hat system as "cool" before engaging with it. This excitement might be inevitable with fantasy-related objects and it most definitely influences growth mindset [14]. We thus plan to conduct more studies to better understand the dimension that fantasy affects growth mindset, by deploying a more standalone system which could be shipped to families and used over a period of several weeks.

7 CONCLUSIONS

In this work we proposed the Thinking Cap, a wearable system designed like the Sorting Hat from Harry Potter, fitted with a commercially available EEG headset and a Bluetooth speaker. The Thinking Cap can inform the user about their brain activity in real-time via a speaker. We designed and conducted a study with 48 children to investigate the effect of using the Thinking Cap to foster their growth mindset. We believe that early prototypes like our system might pave the way to future systems to be tested *in-the-wild* and as *at-home* interventions, which in some situations like a COVID-19 health crisis might be largely beneficial. Ultimately, there is also a tangible element to our system, as opposed to the many online-only mindset interventions that currently exist, which might encourage more interactions and potentially a longer-lasting effect in children. This must still be tested and verified.

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