Quantifying Children's Engagement with Educational Tangible Blocks

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Abstract
Playful learning is a powerful method to enhance children's engagement with teaching material, often resulting in better learning. Several prior works demonstrated the existence of a relation between tangibles and engagement, but they did not characterize it with specific measures. Therefore, this paper aims to describe the degree of engagement with tangible blocks by quantifying children's proactive and passive actions during a learning session. Based on a user study with 36 kindergarten children, our findings show that tangibles support a higher degree of engagement, fosters attention and collaboration, and possibly lead to more active learning.

Author Keywords
Tangible interaction; Engagement; Learning; Collaboration.

ACM Classification Keywords
H.5.3. Information interfaces and presentation (e.g., HCI): Collaborative computing.

Introduction
Educators and researchers argue that students who are actively involved in tasks, such as analyzing, synthetizing and evaluating, gain a better understanding of teaching material than those who are

passively receiving information [6]. This process is called *active learning* and is linked with cognitive engagement activities that can be detected while students are learning, such as active manipulations (e.g., highlighting), constructive generations (e.g., notes, drawing) and interactions (e.g., discussing with peers, playing) [2]. Based on this framework, researchers claim that tangible interfaces – which blend digital and physical elements – are more engaging than traditional teaching methods because they promote interactive and constructive ways of learning, explorations supported by real-time feedback [10, 15] and self-expression through ideation [12]. However, while many researchers argue that tangible interfaces naturally support an engaging and fun experience that results in active learning (an activity known as *playful learning* [11]), and offer examples of interfaces that support this theory [10], few papers have attempted to describe and quantify the active engagement level of children using tangible interfaces for learning [3, 4, 8].

This paper contributes to the literature in the field by further exploring the relation between tangible interaction and active learning with a study specifically designed to analyze the level of engagement of 36 kindergarten children interacting with tangible blocks in three different pedagogical settings (traditional, tangible and collaborative). Our results provide additional empirical evidence supporting the use of tangible interfaces as a tool for boosting engagement and potentially increase the active learning of children.

Related Work

The seminal theoretical works promoting the usage of tangible interfaces for playful leaning [8, 11] are supported by a vast literature of empirical research. Researchers agree that the differences in learning when using physical, tangible settings (e.g., books, toys) or their digital counterparts (e.g., video, games) are not a direct product of the different interfaces, but rather the result of the level of engagement and enjoyment that these technologies provide [7, 13]. For example, Yannier et al. [15] demonstrate that simply adding tangible elements to a game interface does not directly enhance children's learning of basic physics principles. Instead, children's engagement and understanding are correlated with how immersive, interactive and physical the learning environment is. Analogous results have been reported for other augmented learning technologies, such as the FeelSleeve haptic interface for reading [14], the FingAR puppet system for promoting reasoning on emotional states [1], the Hunting of the Snark physical exploration game [10, 11] and the ActiveCubes by Jacoby et al. [5].

The common finding of these works is that physical environments provide higher engagement and enjoyment for children, and consequently more active learning [4, 13]. A second factor in support of tangible interfaces for boosting active learning is that they naturally lead to better collaborations and reduce conflicts, by promoting cooperation and discussion among children when faced with problem-solving tasks [16]. Tangibles also help to solve conflicts between team members, as children naturally learn to take turns and share control of physical interfaces more readily than when they use digital tools [9].

User Study

We designed a comparative study with kindergarten children to assess different levels of engagement – defined as "children's verbal expressions, consistent

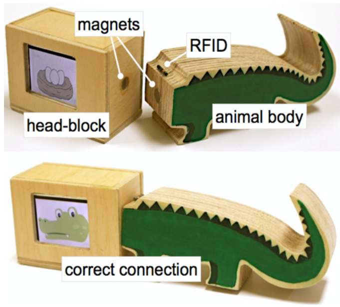

Figure 1. *Head* and *body* blocks.

Figure 2. Examples of connected blocks and a game challenge. In the background, a page from the digital book used in the study.

involvement and desire to continue interacting and playing" [11] - in three common pedagogical scenarios: 1) a digital illustrated book read aloud by an adult (e.g., [7]), 2) a tangible block interface supervised by an adult used by a single child (a situation that resembles how children could use the system at home with a parent), or 3) the same tangible block interface used by two children simultaneously (a situation resembling a learning activity in a kindergarten with a supervising teacher).

Book learning content

We designed a digital pictorial book with custom learning material for the experiment and displayed it on a touch-screen device as an interactive slideshow with sound (digital book). The material we designed is an illustrated description of six different animals living in Africa: a lion, a zebra, a giraffe, a leopard, a hippo and a crocodile. Each animal features five knowledge units: 1) the written name of the animal in the local language and 2) in English (the second language); 3) the color/textures of the animal's skin; 4) the animal's living habits, such as where/how the animal lives (e.g., ground vs. water/alone vs. in group) or what it eats (e.g., meat vs. plants); and 5) unique characteristics (e.g., lions are predators, zebras live with giraffes, giraffes are the tallest, leopards climb trees, hippos have webbed toes, crocodiles lay eggs). All of the material in the book is presented using simplified native language for children in 24 illustrated pages.

Tangible learning platform and interaction

In our tangible system, 2 types of blocks representing different animal parts (bodies and heads) can be connected (similarly to the ActiveCubes [5]). They provide feedback to users about the correctness of the match (Figure 1). Using several layers of machine-carved wood-sheets glued together, we built unpowered blocks representing the bodies of the six animals described in the illustrated book. On the neck is a magnet for supporting connections with a head-block and a tiny RFID tag for unique identification. The bodies are painted, and their maximum dimensions are 16.5 x 8 x 3.6 cm thick. The head-blocks, on the other hand, are powered components and consist of a micro-controller (Arduino Mini Pro), a 1.8" color TFT LCD display, an RFID reader (ID-12LA), a magnet and a Li-Po battery, all encased in a wood box measuring 33 x 70 x 47 mm. When a head-block is connected to an animal's body-block, the RFID reader detects and deciphers the RFID tag to determine if both body parts belong to the same animal. Graphical feedback on the screen notifies about the correctness of the match.

The blocks are meant to support playful learning through a simple puzzle-like interaction. At the beginning of the game, the blocks are not connected. Once started, the display located in the head-block shows a *challenge,* by means of an image picturing one of the animals' properties described in the illustrated book (Figure 2). To solve this challenge, children have to find and connect the head-block with the animal body that best matches the question. If the question is answered correctly, the head of the animal appears on the LCD screen, completing the figure. If the match is not correct, then negative feedback is displayed on the screen and the children are encouraged to try a different head–body combination. Finally, using a special RFID card, it is possible to pass on to the next question. In total, the game comprises 30 challenge questions presented in random order (6 animals x 5 properties).

Participants
We recruited 36 kindergarten children (19 females) aged 5 to 6 (M: 5.4, SD: 0.5). On a scale from 0 to 3, children reported (with the help of their parent) a level of native language reading ability of 1.4 (SD: 0.9). 32 children had previously learned some English (second language) but the average reported reading-ability was 0.3 (SD: 0.6). On a scale from 1 to 5, children reported familiarity with touchscreen devices of 3 (SD: 1.2).

Evaluation method and measures
Following a between-subjects design, 12 children were assigned to each of the 3 conditions: *book*, *tangible* and *tangible team*. In the *tangible team* condition, the teams were generated by pairing children who already knew each other. Each condition consisted of a prologue, a learning session – in which children were asked to memorize the information in the book – and an epilogue. Each session was video-taped for later analysis and supervised by a trained and nationally certified school teacher in "electronic information and communication" with experience teaching children.

The prologue and epilogue were the same across the conditions. In the prologue, the children – accompanied by a parent – were introduced to the experiment. We provided a refreshment for the child along with an ice-breaking session. Meanwhile, the parent signed a consent form and provided basic demographic information about the child. In the epilogue, the children filled out two pictorial paper questionnaires to assess their level of self-reported interest and the accuracy of learning the material.

The learning sessions of the experiment were consistent across the conditions, with the role of the teacher being that of a mere facilitator and supervisor rather than a knowledge provider, as in more traditional settings [7]. The teacher ensured that the child remained focused on the topic by asking and answering questions, using the child native language. In the *book* condition, after displaying the content for each animal (five knowledge units), the screen displayed an interactive quiz with five randomized challenges, which the children had to solve independently. Each challenge consisted of an image representing an animal property on one side and the icons of the six animals on the other. A correct match resulted in prompting the next challenge, while a mistake required the children to try again. A button on the screen allowed children to review the material related to the challenge, and the teacher read aloud the content displayed.

In the *tangible* and *team* conditions, for each of the 30 challenges provided by system, the children were allowed to freely connect the blocks and attempt to match them correctly, or to navigate through the book content using the touchscreen. Also in these conditions the children were encouraged to ask questions and explore block combinations.

We collected 2 types of measure for engagement: the first was a short self-assessment questionnaire that asked children to evaluate their level of interest on an iconic 3-point Likert scale (similar to [15]) for both the content and the tools used in the experiment. Moreover, we analyzed and transcribed the video recorded during the study and extracted the results of the challenges, as well as the occurrences of passive and proactive behaviors. We classified the children's actions into five groups: engagement with questions (e.g., children answering questions only when directly asked vs. children asking questions or speaking without solicitation), focus (e.g., losing attention vs. making eye contact with the teacher), content engagement (e.g., reviewing the book material upon the teacher's suggestion vs. spontaneously), body feedback (e.g., leaning one's head on the table vs. maintaining an engaged posture) and language feedback (e.g., sighing or complaining vs. verbal expressions of interest).

In the tangible *team* condition, similarly to [9], we extracted actions indicating conflicts (e.g., blocking, complaining), collaborations, and request for control. Learning performance was measured using a paper quiz with 30 pictorial questions (the same as the practice challenges), in randomized order. Each question was an image describing a unique animal feature that had to be matched with one of the six animals' icons. No written text was used, as most children in the study could not read.

Results

The numbers of occurrences of proactive and passive actions from the video analysis were classified into five groups (Figure 3). Since the assumption of homogeneity of variance-covariance matrices was violated, we did not run a MANOVA. Instead we considered the average normalized percentages and analyzed them using a single one-way ANOVA followed by post-hoc analysis using Bonferroni CI adjustments, with $\alpha=0.05$.

The average normalized percentages revealed differences for learning environment ($F_{(2,33)}=13.3$, $p<0.01$, $\eta_\rho^2=0.44$), with the tangible and team conditions having significantly more proactive actions (i.e., fewer passive actions) than the book condition ($p<0.01$). In the self-assessment questionnaires, the interest in the teaching method received an average score of 2.8 of 3 (0.42), and the material received a score of 2.9 (0.36), with an interclass correlation coefficient of 0.78 (95% confidence interval 0.54-0.89). A Kruskal–Wallis non-parametric test revealed no differences in the scores across conditions. In terms of learning performance, we found no differences in the quiz scores (M: 23.8/30, SD: 3.5), but in the practice quiz we recorded significant changes in the total number of wrong matches ($F_{(2,33)}=7.3$, $p<0.01$, $\eta_\rho^2=0.3$) and failed challenges ($F_{(2,33)}=8.9$, $p<0.01$,

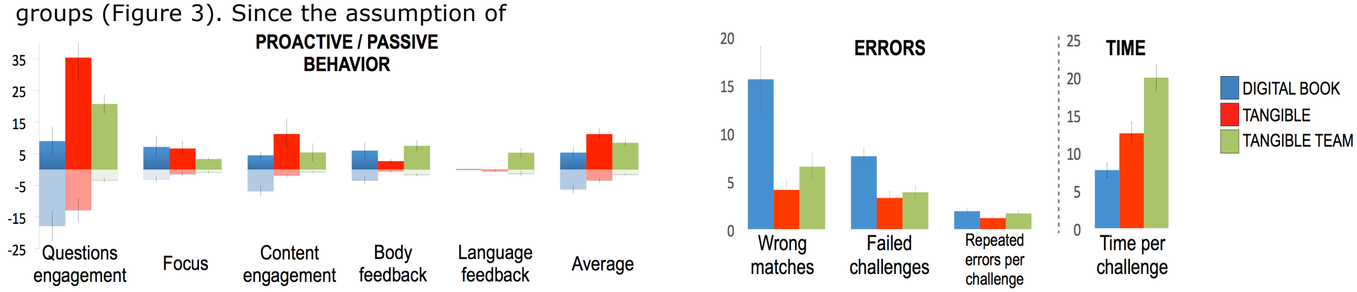

Figure 3. Passive (light tint) and proactive (dark) action groups for each learning environment (book, tangible, team) in five categories and on average (left). Average number of errors and time for the practice challenges (right).

Figures 4. Children using tangibles together. Establishing rules for turns (A) and sharing of control (B). Two children perform an action together on one (C) or two (D) blocks.

$\eta\rho^2 = 0.35$), with the book condition performing worse ($p<0.01$). The average time per challenge was also different across the conditions ($F_{(2,33)}=21.6$, $p<0.01$, $\eta\rho^2 = 0.56$) with all pairwise comparisons significant at $p<0.05$ (see Figure 3 – right).

Discussion

Based on this study, we report 3 main findings. Firstly, the children were clearly more actively engaged when using the tangible blocks than not the digital book alone. The high values for *questions* and *content* engagement show that the children were more interested in asking and answering questions or autonomously reviewing the material when using tangibles. Moreover, the high number of errors, in conjunction with the fastest response time for solving a question in the book condition, indicates that the children working on a challenge did not take enough time to think carefully and opted for a trial-and-error approach. These combined results suggest that the higher level of engagement provided by tangibles is a powerful tool, not only for critical thinking and problem solving [e.g., 8, 10, 15] but more generally for supporting active learning.

A second result stems from the different usage patterns with blocks in the solo versus collaborative modes. Collaborative learning does not increase the overall amount of proactive actions performed by children, but it reduces the number of passive actions. These results can be explained by examining the collaboration patterns among the children: most of the teams adopted a turn-taking approach to solve the challenges, so that each child worked on only roughly half the total challenges. It is therefore not surprising that the individual number of proactive actions per child decreased, as only one child at a time was engaged with the blocks. However, the fact that the number of passive actions also decreased showcases that the children, as in previous work [4], remained attentive outside their turn: *"I enjoy studying with friends using blocks,"* said a child.

Finally, the last result concerns collaborative learning and conflict resolution. In the *team* condition, few conflicts arose and the children were capable of autonomously dealing with them. Most of the teams came up with rules and turn-taking strategies for using tangibles on their own. In Figure 4A, for example, a child indicates a *two-turns-each* policy using fingers. Otherwise, the children spontaneously gave up control (4B) or asked the teacher to mediate. In case of conflicts, they children resolved them by collaborating together. For example, they grabbed and moved a single block together (4C) or a block each to form a single match (4D).

Limitations and Conclusions

This paper presents a study that quantitatively characterizes children's level of engagement when learning with a digital book vs. tangible blocks. We found that the high degree of engagement provided by tangibles fosters attention and proactive attitudes among the children, resulting in more active learning, and reduced conflicts. The limitations of this work are related to the generalization of the results to other tangible interfaces and the possible novelty effects of the tangible blocks during the study. Future works will attempt to investigate alternative physical form factors and collaborations with larger teams.

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