An Approach to Model Children's Inhibition During Early Literacy and Numeracy Acquisition

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Abstract. Early literacy and numeracy skills are developed during childhood at kindergarten level. Among the many factors that influence the development of such skills, the literature shows that the executive function of inhibition – *i.e.* the blocking out or tuning out of information or action that is irrelevant to the learning task – is one of the most important. There are many tests to assess children's inhibition skills; however, such tests are generally time-consuming and have a short lifespan. In this context, we propose a computational approach to model children's inhibition skills by using only student traces from a learning app as input. We propose a mathematical formalization of three related inhibition features, which could be used as input to classification algorithms.

Keywords: Learning · Student model · Inhibition · Executive function

1 Introduction

The development of early literacy and early numeracy skills begins at a very young age. Children's acquisition of competences, such as reading and math, is critical to their long-term academic and career success [10]. A child with problems acquiring literacy and numeracy skills will continue to face academic issues in the future [7]. It is thus essential to identify and help such students.

Among the many factors that influence the acquisition of early literacy and numeracy, the cognitive executive functions play a major role [6]. Executive functions are *"high-level cognitive processes that facilitate new ways of behaving and optimize one's approach to unfamiliar circumstances"* [3].

Miyake and Friedman [8] define three different skills of executive functioning: *updating* (constant monitoring and rapid addition/deletion of working memory contents), *shifting* (flexible switching between tasks or mental sets), and *inhibition* (deliberate overriding of dominant or prepotent responses).

I. I. Bittencourt et al. (Eds.): AIED 2020, LNAI 12164, pp. 203–207, 2020.
https://doi.org/10.1007/978-3-030-52240-7_37

According to the related literature, inhibition is particularly important to child development. Compared to other self-regulatory skills, the inhibition function is found to be the most important variable related to early literacy and early numeracy ability at kindergarten level [1]. Inhibition is generally assessed through specific tests that measure verbal and visuospatial abilities.

There are many specific tests to assess children's inhibition; however, for those under the age of 8, the options are more limited [4]. Moreover, such tests are also time-consuming and deliver results that are valid only for a short-term period of time. So, a computational assessment of inhibition from learning data could be a very interesting tool. The possibility to easily identify children's inhibition skills both in a short-term or in a longitudinal study could allow responses tailored to the needs of children with inhibition dysfunction during their first learning.

Searching the literature, we did not find any papers addressing the automated identification of inhibition. Therefore, we propose a new approach to automatically collect inhibitory features from students traces at kindergarten level. We collected the learning traces from an app used to aid children from 4 to 5 years old in the development of such skills. We identify and derive three distinct features by combining different definitions of inhibition from the literature of psychology and neuroscience. Then, we propose three strategies to model these features based on the students' traces (Sect. 3). To the best of our knowledge, this is the first attempt to isolate inhibitory features.

2 Conceptual Foundation

Early literacy could be defined as the acquisition of the skills, knowledge, and attitudes that are the developmental precursors of conventional forms of reading and writing [11]. On the other hand, early numeracy refers to a lot of concepts and skills that develop together following the same learning trajectory [10].

According to Diamond, inhibition *"involves being able to control one's attention, behavior, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead do what is more appropriate or needed"* [2]. Another well-known definition of inhibition is given by Miyake et al.: *"one's ability to deliberately inhibit dominant, automatic, or prepotent responses when necessary"* [9]. In both definitions, it is clear that the notion of inhibition is related to a **deliberate** suppression/override of a (wrong) predisposition/response. There is an important difference between this effort-aware suppression of prepotent answers and automatic suppression of a wrong answer. In the first case, the executive function of inhibition is required (interest of this paper). The second case is when a correct behavior/answer is already internalized.

Despite having clear definitions and tests, designing an approach to predict inhibition is still very challenging. How can we identify and isolate the effort-aware behavior to suppress a wrong answer? In this sense, Henry and Bettenay [4] define Executive Dysfunction as the opposite of inhibition functioning, i.e., *deficits in the ability to inhibit well-learned patterns of behavior and derive new ways of solving problems*. The authors affirm that children with such deficits become trapped in "repetitive cycles" of a previously learned pattern, and also have some troubles to accommodate their behavior to novel situations. Such "repetitive cycles", on the other hand, are easier to be identified, from the students' traces, than an effort-aware behavior of inhibition.

3 Proposed Inhibition Features

We describe the three proposed variables used to model the dysfunctional behavior of inhibition. Our input data is made up of student traces resulting from their interaction with a learning application we have developed. In the remainder of this paper, we will use the following notation. Let $S = \{s_1, s_2, ..., s_{|S|}\}$ be the set of all students and $A = \{a_1, a_2, ..., a_{|A|}\}$ the set of all proposed activities. $R_{sa} = \langle r_1, r_2, ..., r_{|R_{sa}|}\rangle$ is the sequence of responses the student s has given to the activity a. Each response ($r_i \in R_{sa}$) also belongs either to the set of possible wrong answers $W_a = \{w_1, w_2, ...w_{|W|}\}$, or to the set of possible correct answers $C_a = \{c_1, c_2, ..., c_{|C|}\}$ of a specific activity. The responses r also carry information about the time demanded to the student answer. We also have $R_{sa} \cap W_a$ the set of wrong answers given by student s in activity a and $R_{sa} \cap C_a$ the set of correct answers given by student s in activity a. Note that this last set is either the empty set, if the student gave no correct answers, or the singleton that corresponds to the correct answer if the student gave the correct answer.

Students that Insisted on the Same Error: In their definition of Dysfunctional Behavior of the Executive Functioning, Henry and Bettenay [4] say that the person "becomes trapped in 'repetitive cycles' of a previous learned pattern". For this reason, we propose to look at the repetitive behaviors and, more specifically, to look at the sum of each sequence of recorded errors in each question.

Considering the dataset is ordered by timestamp, we can formally define: $SE_{sa} = \{r_i \in R_{sa} \cap W_a | \forall j \in \{1, 2, ..., k\}, r_i = r_j\}$. Where SE_{sa} is the same error a student s committed in an activity a. The reason why j starts with 1, is because we are interested in the errors the students committed from their first answer to each activity. The reason for that is once the students make an effort to change their first wrong answer, the executive function of inhibition is already put in place; since the inhibition serves to suppress a "prepotent response". The value k represents the minimum value for the answer to be characterized as a repetitive error. In our case $k = 2$. We get SISE (students that insisted on the same error) our first variable as a function of s: $SISE(s) = \frac{\sum_a |SE_{sa}|}{\sum_a |R_{sa}|}$. We divide $\sum_a |SE_{sa}|$ by the total number of traces/responses of the student s to get the proportion of this variable compared to all other traces.

Students that Failed Very Fast: The second of our three variables is based on Miyake's definition of inhibition (*"one's ability to deliberately inhibit* ***dominant, automatic, or prepotent*** *responses when necessary"*). The goal is to identify failures in suppressing the automatic, dominant, or prepotent responses by looking at the time information present in the student traces.

Our hypothesis is the following: the students that answered wrongly, and in a very fast way, present a dysfunctional behavior of inhibition. One prerequisite with this hypothesis is to define what is a "very fast" answer. To accomplish this, we need to look at the dataset and define what a fast answer to each activity is.

Since different activities demand different times to be answered, we need to isolate the set of wrong answers of each activity. Let AW_a be the set of all wrong answers given by the students for exercise a ordered by increasing timestamp. We then use the cut point ϕ_a of the first (lower) quartile as a reference to represent a fast answer to such activity. Quartiles are commonly used to split data because of their insensitivity to outliers and preserve information about the center and spread [5]. Once we get ϕ_a, the student's subset of answers representing a very fast failure attempt is easily defined as: $VF_{sa} = \{r_i \in R_{sa} \cap W \mid time(r_i) \leq \phi_a\}$.

Finally, $\sum\limits_a |VF_{sa}|$ is divided by $\sum\limits_a |R_{sa}|$ to get the proportion of these traces when compared to the whole set of the student traces, then: $SFVF(s) = \frac{\sum\limits_a |VF_{sa}|}{\sum\limits_a |R_{sa}|}$.

Students that Committed the Most Common Error in such Activity: This third variable was also inspired by the definition of inhibition as an effort-aware suppression of a prepotent response, but looking at the *Recorded Answer* information instead of the *Time Demanded to Answer*. The reason to do so is that the prepotent response can be seen as a previous knowledge/belief of the student, which demands effort to be suppressed. This belief can be identified as the most frequent error of each activity. For instance, if one of the activities requires that the student selects a regular pen, but instead, the student selects a pencil, and if most of the students make this same mistake in this activity, then we assume a high effort is required to suppress the response.

To isolate this variable, we need to list each most common error of each activity. Let mc_a be the most common error of each activity a defined as $mc_a = \arg\max\limits_r \sum\limits_{r'} \delta_{rr'}$, where $\{r, r' \in AW_a\}$ and δ is a Kronecker delta function. For each activity a and each student s, we then define the set of responses that correspond to the most common error as $MC_{sa} = \{r_i \in R_{sa} | r_i = mc_a\}$. The third variable is then: $SMCE(s) = \frac{\sum\limits_a |MC_{sa}|}{\sum\limits_a |R_{sa}|}$.

4 Conclusions and Future Work

The design and implementation of a computational approach to model children's inhibition skills is a challenging task. One of the reasons is that there is little literature on the computing field treating this subject. At the same time, this is a critical topic when treating children's skills at early numeracy and literacy. Since this is a subject already broadly explored in neuroscience and psychology fields, we took the seminal definitions of inhibition in these fields and proposed a mathematical formalization of three variables to model a dysfunctional inhibition behavior. To the best of our knowledge, this is the first attempt to model the inhibition behavior. As future work, we are interested in modeling not only the dysfunctional inhibition but also the functional inhibition behavior.

Acknowledgement. This work has received funding from the French Programme of Investments for the Future within the frame of the eFran LINUMEN project.

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