Scalebridge VR: Immersive Proportional Reasoning Game for Children with Brain-Computer Interface for Difficulty Scaling

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Figure 1: A player of Scalebridge VR grabbing (left), moving (center) and releasing a lego block onto the bridge scale in order to balance it. Neurosky Mobile brain-computer interface is used to measure the attention and meditation levels in order to dynamically determine the most effective difficulty level.

ABSTRACT
We present the design and evaluation of Scalebridge VR, an immersive educational game that teaches children the mathematical skill of proportional reasoning. The game uses brain-computer-interface-based adaptive level difficulty to modulate difficulty of the game based on the player’s attention and meditation state. The game is an adaptation of previously introduced Scalebridge game that did not use virtual reality, but was shown to be an effective tool for learning proportional reasoning.

CCS CONCEPTS
• Computing methodologies → Virtual reality.

KEYWORDS
proportional reasoning, virtual reality, immersive learning, STEM, mathematical skills, VR game, freehand interaction

ACM Reference Format:

1 INTRODUCTION
Proportional reasoning is an important mathematical skill that develops in children between the age of seven and ten enabling them to think about numbers in relative, rather than absolute terms. It is an essential cognitive skill for tasks such as comparing prices per weight. Previous research indicated that proportional reasoning is an acquired rather than inborn ability [Siegler and Vago 1978]. While seven-year-old children can learn proportional reasoning, if properly taught, ten-year-old children find it difficult to use proportional reasoning rules, if not previously taught.

Due to its importance in everyday life as well as mathematical development, understanding the mental landscape of proportional reasoning has been an area of active research for over forty years [Siegler and Vago 1978]. Huizenga [Huizenga et al. 2007] identified proportional reasoning as an essential part of early development of mathematical skills. It is also known that children learn proportional reasoning faster if the tutoring process is not based on verbal instructions only, but allows to manipulate objects [Kwon et al. 2000]. Thus, we designed a VR version of Scalebridge game where players manipulate virtual objects using freehand interaction: virtual hand, virtual pointing, and raycasting [Pietroszek 2018a,b,c].

2 SCALEBRIDGE VR DESIGN
Scalebridge VR is a game designed for children between ages seven and ten. The game starts by presenting to a player a bridge that connects a road over a river (Figure 1). The game starts with a configuration of lego blocks on the left side of the bridge that results in the bridge being unbalanced. The player’s goal is to exactly balance the bridge so that cars waiting on each side of the bridge can cross it. To do so, the player must drop lego blocks onto the right side of the bridge in a configuration that will exactly balance the left side. The game uses Leap Motion for freehand interaction with the blocks, with three gestures: "closed hand", for grabbing of the lego blocks, “index finger pointing”, for directing the lego blocks, and "open hand” for releasing the blocks. There are five positions where lego blocks can be placed on the right side of the bridge. Lego blocks to be used rest on the platform near the deck.
of the bridge. Blocks change color from green to red when the player’s hand is about to grab them. Once the block is dropped onto a specific position on the bridge, the block changes color to grey, indicating that it is no longer selectable. If the block cannot be placed in a specific position, it returns to its original position.

Scalebridge VR game mechanics are based on concepts most children are already familiar with: “choose a lego block” and “put the lego block on top of another block” in order to “balance the bridge”. The weight of each block is the same. Each difficulty level consists of five balancing trials. A trial times out at 60 seconds. The player plays up to 35 trials: a maximum of 5 trials per each 7 levels of difficulty. The difficulty consists of two aspects: the allowed actions, and the sum of blocks. The sum of blocks determines number of blocks that have to be used to balance the bridge. The larger the sum, the more blocks, in average, need to be used to balance it.

2.1 Adaptive Difficulty Model

The learning time required to acquire proportional reasoning ability through learning varies from individual to individual. Yet, in a non-adaptive version of the game, the players are required to progress through levels that may be too easy or too hard for them. This could result in the player’s lack of engagement. In order to keep the player in the state of flow [Nakamura and Csikszentmihalyi 2014], we propose an adaptive difficulty model that affects how a player progresses through the levels using information on their performance and focus/relaxation.

While the players of the non-adaptive version of the game must play all 35 trials, the adaptive difficulty game allows some participants to skip some trials and thus progress through the game faster. Whether or not the player is allowed to skip a trial is a function of two factors:

- previous trial completion status
- focus of the player

In every level, we consider the status of the last three trials played. The completion status is either ‘win’, meaning the player balanced the bridge within 60 seconds of the play time, or ‘loss’ when the player was unable to balance the bridge within the allowed time.

We also measure the focus level of the player using Neurosky MindWave device, which is a low-cost brain-computer interface providing information on the current attention (focus) and meditation (relaxation) of the player.

The adaptive game progression conditions are the following:

1. Focused and winning (F/W) → go level up or progress to the next difficulty level
   If the average Neurosky meter values during time play were 60 or more and the participant balanced the bridge within the available 60 seconds time play at least two times out of three consecutive trials, this is considered a F/W situation that is counted toward fastest progression.

2. Focused and losing (F/L) → the player will be shown an example ‘how to balance’ video and will be asked to finish playing the level.
   If the average Neurosky meter values during time play were 60 or more but the participant was unable to balance the bridge within the available 60 sec time play two times out of three consequent trials, this is considered a F/L situation and is not counted toward fastest progression. The player have to play trials 4 and 5 of the same difficulty level before progression to the next level.

3. Not focused and winning (NF/W) → go two levels up or skip one difficulty level
   If the average Neurosky meter values during time play were less than 60 but the participant balanced the bridge within the available 60 sec time play at least two times out of three consequent trials, this is considered a NF/W situation that is counted toward fastest progression.

4. Not focused and losing (NF/L) → repeat the level
   If the average Neurosky meter values during time play were less than 60 and the participant was unable to balance the bridge within the available 60 sec time play three consequent trials, this is considered a NF/L situation and is not counted toward fastest progression. The player is asked to repeat the level after three trials.

3 EVALUATION AND CONCLUSION

The design of Scalebridge VR follows the play-centric game design methodology. Throughout the iterative design and implementation process, we asked players to evaluate the game mechanics, the free-hand spatial input, and the gameplay itself. We used the collected feedback to improve the game’s implementation. In general, players enjoy the VR version and experience no difficulties in grabbing, positioning and releasing the blocks. Tahai et al. [Tahai et al. 2019] previously showed that the non-VR Scalebridge is an effective tool for teaching proportional reasoning. In this work, we present the version of the game for virtual reality. The early feedback from the players may indicate that the VR version of the game is enjoyable and the use of freehand spatial input is an appropriate choice of an interaction technique. Is there a benefit of re-designing the game for Virtual Reality, with freehand interaction? Is the game more engaging? Does the VR version of the game keep players in the state of flow for a longer period of time? These questions constitute our future work.

REFERENCES


