Mathkinetics: Solving Arithmetics While Running out of Breath

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Abstract: To benefit from most of the current digital educational technologies, learners are required to sit down and look closely at a computer monitor or smart device screen for hours, which can have side effects on learners' health and lifestyle. As an attempt to address this, we developed MathKinetics, an application designed to support the practice of cognitive skills such as arithmetic while engaging in physical activity by integrating the principles of Multimodal Learning, Life Kinetik, and Gamification. MathKinetics is a variant of an endless running game where users control an avatar through their body posture and dodge obstacles. At the same time, they pick up arithmetic problems whose answers need to be verbalized. In this paper, we present an exploratory evaluation of MathKinetics and its user experience. We conducted user tests with 20 participants. Results from our tests indicate that MathKinetics is a fun way to practice arithmetic skills and train executive cognitive functions such as task switching.

1 INTRODUCTION

Mere access to information is no longer an educational challenge, as current technologies like smartphones allow us to have all of humanity's knowledge at our fingertips. Access to information, however, is not sufficient for learning and developing competency, especially if we want to do so in a way that promotes a healthy lifestyle and is efficient. To address this challenge, we developed MathKinetics, an application designed to help the practice of arithmetic skills while exercising, which is grounded in the concepts of Multimodal Learning, Life Kinetik[1], and Gamification.

Multimodal Learning has been shown to enhance efficiency in learning (Ward et al., 2017). Multimodal Learning is a compound that combines learning with a blend of multi as multiple and modal as a modality. "Multimodal Learning refers to an embodied learning situation which engages multiple sensory systems and action systems of the learner" (Seel, 2012). It refers to the combination of two or more modalities for learning. These modalities can be anywhere from visual inputs, such as colors, pictures, illustrations, text, etc., auditive inputs, such as speech, and music, or physical input, such as movement, gestures, and much more. There is evidence that Multimodal Learning enhances learning compared to unimodal learning across multiple cognitive domains, spanning executive functions, working memory, planning, and problem-solving (Ward et al., 2017; Gellevij et al., 2002).

The majority of the current digital learning technologies require learners to sit down for an extended period of time while looking closely at a computer screen. As a result, learners have the proclivity to increase their risk and severity of myopia (Morgan & Jan, 2022; Singh, 2020) and cardiovascular diseases (McGavock et al., 2006; Mainous et al., 2019) among others. Even short bursts of exercise spread during the day can improve the peak oxygen uptake in Sedentary young adults (Jenkins et al., 2019). Therefore, we argue that the inclusion of Life Kinetik in educational technologies has the potential to mitigate some of the health-concerning side effects of current educational technologies.

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Life Kinetik aims to increase the ability to act and adapt to different situations more quickly. It is a German concept or brand that was created by Horst Lutz. Unlike Multimodal Learning, the goal of Life Kinetik is not to acquire knowledge, but to promote general performance, like any kind of sport. Life Kinetik combines mental and physical exercise, which relates to other educational approaches. According to Montessori, for example, “Movement and cognition are closely entwined, and movement can enhance thinking and learning” (Lillard, 2017). To solidify the impact of MathKinetics, we used the concept of Gamification, which denotes the use of game elements in non-game contexts (Uppalike, 2022). It thus helps transform an activity into a game, changing the simple task of solving arithmetic on paper into, in the best case, an engaging game, like in MathKinetics.

The contribution of this paper is (1) to show how the concepts of Multimodal Learning, Life Kinetik, and Gamification have been used to inspire the development of MathKinetics, and (2) to present results from exploratory user tests where we investigated the experience of users interacting with MathKinetics. The following research questions guided our study:

RQ1 What is the user experience of MathKinetics from the point of view of a learning application?

RQ1a To what extent can MathKinetics support the training of cognitive tasks such as arithmetics?

RQ1b To what extent can MathKinetics motivate people to combine cognitive and physical exercise?

2 MATHKINETICS

In this section, the theoretical foundation of MathKinetics is introduced as the rationale for key features and design decisions. We then present the dynamics of the app and its gameplay, before providing insights into the required equipment, setup, and technical implementation.

2.1 Theoretical Grounding

Learning is a process that can be explained through multiple theories. Early theories focused on physiology, behaviors, and conditioning (Watson & Rayner, 1920), basically referring to drill and practice approaches. Some other theories use cognition and thinking to explain learning, such as the four stages of cognitive development (Piaget 1977), learning via problem-solving (Köhler, 1927), etc. More recent, constructivist approaches stress the role of culture, prior experience, and interactions with the environment where multi-sensory experiences and aesthetic stimuli can foster learners’ imagination (Dewey, 1934). It was Piaget though, who related games as a kind of activity to learning: “Play is in reality one of the aspects of any activity [...] or one particular type of activity among others”(Piaget, 1977). So, play can be considered a learning activity.

With these general theories about learning and play in mind, we started to conceptualize MathKinetics to develop a multimodal learning application that would prompt users to practice arithmetic skills while physically exercising. To achieve this goal, we built MathKinetics on three main pillars: Multimodal Learning, Life Kinetik, and Gamification. Multimodal Learning refers to a learning situation where the learner is engaged through multiple sensory and action systems (Seel, 2012). This means Multimodal Learning aims to use different teaching methods by addressing multiple senses, referred to as modalities. Multimodal Learning aims to stimulate multiple senses/modalities simultaneously, which is supposed to be beneficial for cognition and skill development across multiple cognitive domains such as essay writing (Fleming & Mills, 1992). It has further been shown to enhance executive functions, working memory, planning, and problem-solving (Ward et al., 2017). MathKinetics exemplifies the integration of Multimodal Learning principles by utilizing visual, auditory, kinesthetic, and verbal inputs.

The second pillar of MathKinetics is Life Kinetik, a training concept that is a combination of perception, brain-jogging, and movement to improve our brain's networking and the use of all brain areas (Lutz, 2017). The parallel-ball exercise is a typical example of Life Kinetik, where a player stretches out their arms in parallel in front of their body while holding a ball in each hand. Then one throws both balls in the air and catches them with crossed arms, which means the right hand catches the ball that the left hand throws and vice versa. It takes approximately two minutes to master this exercise (Joung, 2023). The learning objective, however, is to adapt more quickly to new situations and be able to perceive things faster and act accordingly (Life Kinetik, 2023). So, when a person can perform a task in its rudimentary form, they continue with a higher difficulty or change the exercise to be rechallenged with a new situation (APA PsycNet, 2023; Anguera et al., 2022). MathKinetics incorporates some of the principles of Life Kinetik, especially the combination of cognitive and motoric exercises and quickly changing situations.

The third pillar of MathKinetics is Gamification. Gamification is the integration of game elements into a non-game scenario that does not primarily serve entertainment purposes (Uppalike, 2022). Gamification in learning scenarios usually addresses users' sense of engagement, immediate feedback, and a feeling of accomplishment and success after overcoming challenges (Kapp, 2012). An example of Gamification in an application is "Zombies, Run!". It uses immersive audio drama to enhance the running experience while offering a mini-game to play after a running session. In MathKinetics, the training of arithmetic skills through multimodal learning and Life Kinetic is wrapped in a game-like scenario where users sort obstacles while solving arithmetic problems to improve a high score.

The design of MathKinetics was inspired by two pedagogical theories also used within gamification: flow and the ARCS model of motivation. The theory of flow describes learners who are in a constant state of interest. This can be achieved by constantly adapting the challenge level and making the game neither too difficult nor too easy (Nakamura & Csikszentmihalyi, 2002). MathKinetics further aims at the flow experience, which describes the optimal state of experience, enhanced action execution, high self-esteem, positive state of mind, and high life satisfaction (Brandstätter et al., 2013). To address this, exercises start out easy with few obstacles and gradually increase their frequency in the game.

The ARCS (Attention, Relevance, Confidence, and Satisfaction) model describes an instructional design to motivate learners by grabbing the learner's attention, portraying the relevance of the material, assuring the learner's confidence to solve a task, and providing a satisfactory experience to the learner who then continues (Keller, 1987). MathKinetics, for example, grasps learners' attention by presenting an engaging environment and interface in-game while supporting play without a controller. Furthermore, the relevance is provided as arithmetic, and multitasking are part of our daily lives. Moreover, MathKinetics aims to build confidence in becoming better at overcoming the game challenges and technically never losing since the game has no end. Lastly, satisfaction is addressed as learners can measure their progress through the distance score in-game.

As mentioned before, there are applications with functionalities more or less similar to MathKinetics (e.g., Zombies, Run!). Some of these applications are designed to train arithmetic skills while moving, such as Jumpido (ODD, 2023a) and One-Shot-Gesture (Junokas et al., 2018). A study showed that Jumpido, for example, can support the ability of kids to remain concentrated for longer periods and that it motivates kids to improve and solve their homework faster (ODD, 2023b). Jumpido and One-Shot-Gesture require users' body gestures to solve arithmetic problems, whereas users of MathKinetics speak arithmetic solutions while using body gestures to sort obstacles.

2.2 Game Mechanics and Setup

MathKinetics is a running game where the objective is for the avatar to cover as much distance as possible while dodging obstacles and solving arithmetic problems before time runs out (see Figure 1). The avatar in the game mimics the actual player's movements. When the player moves to one side, so does the avatar. When the player crouches, the avatar crouches. When the player extends both arms to the side and moves them down, the avatar jumps.

The avatar has to dodge obstacles by moving left and right, crouching, or jumping to avoid being penalized with time. Obstacles include upper brick walls where users need to crouch to bypass them, lower brick walls where users need to jump, and bombs that can be bypassed by moving left or right. Touching obstacles will subtract additional time from the countdown (brick walls 10 seconds and bombs 15 seconds).

To gain time for running greater distances, the avatar needs to pick up yellow-question-mark-cubes to trigger arithmetic tasks (see Figure 1, the top middle). Users can stack up to five problems (See Figure 1). To get the bonus time from the arithmetic problems, the player has to clearly pronounce their solution. If in doubt, the player can move to the subsequent arithmetic problem by saying: "Next". Speaking out loud the correct arithmetic result will add 5 seconds to the timer. The arithmetic problems were randomly generated. The first part was to randomly select the operation i.e. addition, subtraction, multiplication, and division. In a later step, the operands were randomly selected (1 to 60 for division, 1 to 11 for multiplication, and 1 to 30 for addition and subtraction) allowing only for problems that provide a natural positive number as their result.

The subtracted and added time numbers can be adjusted in the code and were chosen after playtesting the game a few times for a good feel of not being too quick or too hard on the player.

The distance is the score that will determine how well the player has performed in the game and give a sense of competition to invigorate the players to become better and play again. To prevent the player from getting used to patterns of movement or getting bored, all obstacles and game objects are continuously and randomly generated. Moreover, more bombs are spawned the more the game advances.

Figure 1: MathKinetics screenshot of the running application.

The player interaction is performed through body movements and voice inputs. The general setup is shown in Figure 2. The player should stand around three meters from the camera and the screen. We utilize a camera to identify the player's posture via pose estimation libraries. Similarly, for voice recognition, audio is recorded and analyzed using available libraries. The game itself is rendered by a dedicated machine on a large screen.

Visual feedback is an essential aspect of the game design. The distance, which is represented by the score and the timer, is already part of the visual feedback. It provides information to the player on how the game is progressing. Colored text pops up on the screen informing users whether their answer to an arithmetic problem was correct or not. Every time the avatar hits an obstacle, an animation of a dust cloud or explosion will appear to signal the collision. In addition to this visual feedback, sound effects are played upon certain events, such as jumping, collisions, etc.

2.3 Implementation

The current implementation of MathKinetics was developed on a Windows 10 operating System using the Unity Engine Version 2021.2.7f1. To capture the body posture of the player and translate it into the avatar movements, we used Pose Cam[2] and PoseAI[3]. Pose Cam is an iPhone application utilizing the iPhone camera to send data regarding the player's body posture via UDP to the PoseAI libraries running on a PC. With this input, the PoseAI libraries create the avatar animation mimicking the player's body posture in (almost) real-time. MathKinetics uses the KeywordRecognizer class of the Windows Speech Recognition Engine to track the user's voice input (i.e., verbalized answers to arithmetic problems). This solution allows MathKinetics to identify predefined keywords, such as numbers. The selection of these technologies was based on the author's familiarity with them.

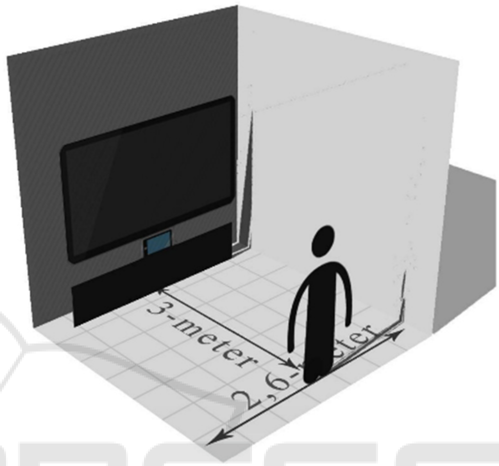

Figure 2: An illustra.tive example of room setup and user position.

3 METHOD

To investigate the user experience of MathKinetics, we conducted user tests where participants played MathKinetics. To investigate the user experience of MathKinetics, we conducted user tests where participants played MathKinetics. 20 participants (7 females, 13 males) were recruited for that task, whereby the participants' ages ranged from 22 to 35 years. Due to the lack of accessibility of the application and conducting research at the lab, volunteers were selected from the social network of the first author.

The procedure of the user studies consisted of the following steps. In the first step, participants receive explanations about the game and its features. Then the experimenter played MathKinetics in front of the participants to show them how it works, showing how to dodge obstacles, collect problems, and provide

2 Pose Cam. https://apps.apple.com/mr/app/pose-cam/id1555012109

3 Pose AI, Home | Pose AI. https://www.poseai.co.uk/

answers. Participants then played MathKinetics for a minimum of two rounds to get a good feel of it.

After playing, participants answered a user experience survey (see Table 1). The survey was designed with Google Forms, and answers were submitted anonymously. Besides the survey, the experimenter took note of important events (e.g., competitive behavior, playing longer, pose recognition issues, etc.) that happened during the participants' interaction with MathKinetics.

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Table 1: Questions of the User Experience Survey.

Question	Category	Question Type
1.) Using the app is good for practicing arithmetic skills	Learning	10-point-Likert scale
2.) Would you like to see variations of the app for training other types of cognitive skills?	Learning	3 Options
3.) What, if anything, do you feel like you learned from using this app?	Learning	Open
4.) I would like to use the app again.	Motivation/fun	10-point-Likert scale
5.) Do you enjoy the idea of being able to burn calories whilst also practicing mental skills such as arithmetics?	Motivation/fun	10-point-Likert scale
6.) I had fun using the app	Motivation/fun	10-point-Likert scale
7.) Which game features do you think would make the application feel more engaging?	Motivation/fun	Open
8.) Have you ever used an application similar to the one you just tested?	Bias Test	3 Options
9.) How would you rate your usability experience with the application?	Usability	10-point-Likert scale
10.) What improvements would you make to this application to make it more intuitive and user-friendly?	Usability	Open
11.) Any additional comments and/or feedback	General	Open

4 RESULTS

The duration of the played rounds ranged from 60 to 180 seconds (M=100; SD=25.78) depending on how well participants played the game.

When investigating the use of MathKinetics as a tool supporting learning, the following results were obtained via open and closed questions (see Table 1). For closed questions, we received 20 responses each. When asked to rate MathKinetics as a tool for practicing arithmetics skills (Q1), participants provided an average score of 8.9 (SD=1.41). Participants were further asked whether they would enjoy variations of MathKinetics, which would require them to solve other types of mental problems such as providing answers to flashcards (Q2). In response to that question, 19 participants agreed and one was indecisive.

We then asked participants what they learned while playing with MathKinetics (Q3, n=18). The most common answer (8 participants) relates to the development of "task switching". Task switching is an executive function that relates to the concept of cognitive flexibility. It involves the ability to rapidly and efficiently adapt to different settings without being conscious of it (Scott, 1962). Another common answer was related to the practice of arithmetic skills (4 participants).

Participants were further asked to evaluate the fun and motivation to use MathKinetics (Q4). Results from the survey show that participants would generally like to use the app in the future (Mean=8.1; SD=2.15), (Q5) that participants generally liked the idea of burning calories while solving arithmetic problems (Mean=8.45; SD=2.01), and (Q6) that participants had fun using the app (Mean=8.45; SD=1.67). According to participants, improvements to make MathKinetics more fun and engaging (Q7, n=16) comprise the addition of power-ups (6 participants), a greater variety of obstacles and moves (3 participants), more explicit positive feedback, additional levels (2), additional multiplayer options (2 participants), training different mental skills (2), and the addition of online high scores (1).

While conducting the user test, the experimenter noticed that three participants were so enthusiastic they wanted to play longer. Nine participants were also very competitive about wanting to beat the other participants' high scores or reach the highest score possible. Three of these participants managed to reach the highest scores. In contrast to the other participants who did not try as hard and as long, these three started to lose their breath due to prolonged sessions and intensive engagement.

As we assumed the novelty factor of the application and one's attitude towards video games as potential bias, participants' motivation to use MathKinetics was evaluated (Q8). Therefore, we asked whether a similar application was used before. 14 participants had never used a similar application before, four were not sure, and two reported having used a similar application.

Participants were further asked to rate the usability of MathKinetics (Q9). The average rating given by participants was 7.05 (SD= 1.15) on a 10-point Likert scale, which shows the current version of MathKinetics has fair usability. When asked for improvements in terms of usability (Q10, n=19) and general comments (Q11, n=13), the number one concern was the improvement of speech recognition (8 participants), followed by the responsiveness of the motion capture (6 participants), the addition of a tutorial (6 participants), and the addition of some type of difficulty progression (2 participants). The experimenter also noticed that the size of the participants influenced the pose recognition of the app, where larger participants had more difficulty getting their gestures recognized.

5 DISCUSSION

With the help of user tests, we wanted to explore the user experience of MathKinetics as a learning application (RQ1). Results from the tests indicate that MathKinetics is a good tool to practice arithmetic skills (RQ1a). Even though other mental skills have not been tested, the user tests indicate the possible transferability of MathKinectic's concept to other skills and problems such as flashcards, and vocabulary training, as mentioned by the participants. Moreover, participants agreed that MathKinetics could be used to train task switching. This is an unexpected and positive result, as task switching is associated with academic achievement (Jacob & Parkinson, 2015).

The second important aspect of our research questions concerns the motivational aspect of using MathKinetics (RQ1b). We consider this aspect to be relevant because learners need to remain motivated for an extended period to develop their skills. Results from our study show that users tend to have fun while using MathKinetics, they would like to use it in the future, and they enjoy the concept of training cognitive tasks while being physically active. We consider this last point particularly interesting as it addresses some of the side effects produced by other digital learning technologies. Current digital learning technologies usually require learners to sit down for extended periods. A habit that can lead to an unhealthy lifestyle (Morgan & Jan, 2022; Singh, 2020; McGavock et al., 2006; Mainous et al., 2019).

This study has two main limitations. The first one is the number of participants. Gathering and evaluating responses from twenty participants does not allow a generalization of the findings. This is particularly true when considering the novelty factor for most participants of the user study, and their relationship with the experimenter.

The second main limitation concerns the method utilized for the data collection. There was no collection of the number of arithmetic answers nor mistakes, that could provide some hints regarding the arithmetic skills of the participants. Moreover, the utilization of standardized usability and user experience questionnaires would have provided more rigor and reliability of the obtained results.

Nonetheless, for a formative study, the results of the user tests reveal the potential of MathKinetics as a fun learning application promoting physical movements and cognitive training at the same time.

6 CONCLUSION

In this paper, we presented and evaluated MathKinetics, an application that is inspired by the principles of Multimodal Learning, Life Kinetik, and Gamification to support the development of cognitive skills while promoting physical movement. The results reveal that MathKinetics is fun to use and has the potential to support the practice and development of arithmetic skills and task switching. In addition, participants enjoyed the possibility of burning calories while training their mental skills.

With the addition of different types of problems (e.g., vocabulary training), the concept of MathKinetics could be used to support the practice of different cognitive skills and abilities. We thus want to start with the implementation of the mentioned flashcard scenario. Following the feedback on usability, the use of better and more available pose estimation and voice recognition models is planned.

Overall, we showed that Multimodal Learning, Life Kinetik, and Gamification can be integrated into a learning application such as MathKinetics, which is capable of supporting and motivating people to practice cognitive skills while engaging in physical activities. Hence, it presents a promising direction for integrating physical well-being with cognitive development.

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