FUNCTION HERO: AN EDUCATIONAL GAME TO AFFORD CREATIVE MATHEMATICAL THINKING

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The enhancement of educational processes at all levels of education can be achieved by implementing Game Based Learning (GBL), engaging students to the educational objectives affording the "Flow" mind state in which individuals optimize their actions scaffolded by intrinsic motivation. In mathematics, most of the games are based on arithmetical or logical thinking due the software's limitation in assessing user's inputs. Aiming to develop a game about functions affording Creative Mathematical Thinking (CMT), we used a Dynamic Cinderella Software (DCS) called Cinderella, the Game Development Environment, Unity and the Kinect Sensor from Microsoft. In this paper, we presentdesign elements of the game Function Hero that affords CMT.

Keywords: game based learning; technology in education; mathematics; functions;

INTRODUCTION

The emergence of motion-controlled technologies within the increasing usage of embodied cognition and augmented reality environments open new doors for students to use their different senses into their learning process. Nowadays, students can *experiment* mathematics more than just listening and watching what happened on the blackboard overcoming the traditional approaches in teaching mathematics, moreover, having fun during the learning activity.

Creating fun in learning environment is not only to make up the content or the activity. Having fun means that the individual entered in a engagement state known as "Flow", optimizing its motivation and relaxation. Relaxation enables a learner to take things more easily, and motivation enables them to put forth effort without resentment (Prensky, 2007). This mental state also contributes to creativity. When in flow, the creator ignores the external environment, apart from the action which is performed, the distractions don't effect the individual and one's mind is fully open and attuned to the act of creating.

In the flow state, the challenges presented and the ability to solve them are almost perfectly matched, and the individual often accomplish things that they thought they couldn't, along a great deal of pleasure. To keep a person in the flow state the designer must consider that making things too easy, the players become bored and stop. Making thing to hard, the players stop because they become frustrated. The same rule can be applied at the educational tasks. The representation of the concept of flow is shown on the figure below.

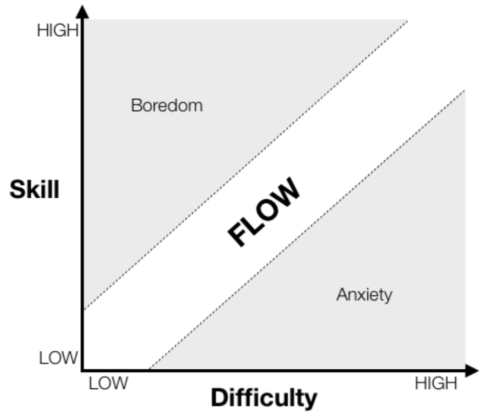

Figure 1: Flow, boredom, and anxiety as they relate to task difficulty and user skill level. Csikszentmihalyi, 1990.

Mathematicians profess that performing mathematics is a creative activity (Hadamard, 1954). Technology supported inquiry based learning is a possible way to put students in situations where their creativity is needed and can be expressed (Blumenfeld et al., 1991). In this article, we first introduce the concept of Creative Mathematical Thinking. We then present the educational resource under consideration in the reported experiment, the game "Function Hero".

CREATIVE MATHEMATICAL THINKING

Based on the literature review on creativity (Guilford, 1950; Kaufman & Sternberg, 2010), mathematical creativity (Sriraman, 2004; Leikin & Lev, 2007; El-Demerdash, M. & Kortenkamp, U, 2009) and mathematical thinking (Tall, 2002; Blinder, 2013), the CMT (Creative Mathematical Thinking) can be understood as the combination of divergent and convergent thinking in mathematics. Starting from this principle we created the concept of "Creativity's Diamond" (Lealdino F, et al, 2015) (Figure 2).

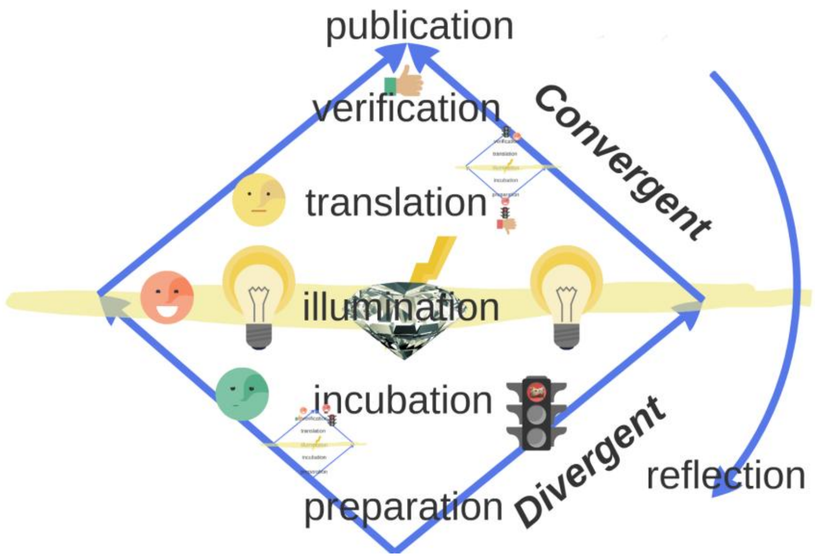

Figure 2: Creative Process

This idea is based mainly on Guilford's and Walla's models of creativity. Guilford emphasized the distinction between convergent and divergent thinking. In 1976 he introduced the model of Divergent Thinking as the main ingredient of creativity. Guilford appointed the following characteristics for creativity:

- Fluency: The students' ability to provide many responses or to come up with many strategies to solve a mathematical problem or challenge.
- Flexibility: The students' ability to provide different/varied responses or to come up with different/varied strategies to solve a mathematical problem or challenge.
- Originality: The students' ability to come up with unique (original) responses (solutions, strategies, representations, etc.) to a mathematical problem or challenge.
- Elaboration: The students' ability to describe, substitute, combine, adapt, modify, magnify, extend the usability, eliminate or rearrange mathematical situations.

Wallasoutlines four stages of the creative process - preparation, incubation, illumination, and verification - dancing in a delicate osmosis of conscious and unconscious work. These phases go as follows:

- Preparation: The problem is investigated in all directions as the thinker readies the mental soil for the sowing of the seeds. It's the accumulation of intellectual resources out of which to construct new ideas. It is fully conscious and entails part research, part planning, part entering the right frame of mind and attention.
- Incubation: Next comes a period of unconscious processing, during which no direct effort is exerted upon the problem at hand - this is where the combinatory play that marked Einstein's thought takes place. Wallas notes that the stage has two divergent elements - the "negative fact" that during Incubation we don't consciously deliberate on a particular problem, and the "positive fact" of a series of unconscious, involuntary mental events taking place. "*Voluntary abstention from conscious thought on any problem may, itself, take two forms: the period of abstention may be spent either in conscious mental work on other problems, or in a relaxation from all conscious mental work.*
- Illumination: Following Incubation is the Illumination stage, which Wallas based on French polymath Henri Poincaré's concept of "sudden illumination" - that flash of insight that the conscious self can't will and the subliminal self can only welcome once all elements gathered during the preparation stage have floated freely around during incubation and are now ready to click into an illumination new formation.
- Verification: The last stage, unlike the second and the third, shares with the first a conscious and deliberate effort in the way of testing the validity of the idea and reducing the idea itself to an exact form.

THE GAME FUNCTION HERO

To develop the artifact used in this study, the Kinect sensor was used. Kinect is a motion detection device, equipped with RGB camera, infrared depth detection sensor, microphone and a dedicated processor. Originally designed to be a gaming accessory for the Microsoft Xbox 360 gained popularity within developers and a windows compatible version was released.

To integrate the affordances from kinect sensor we use two main softwares: Unity and Cinderella. Unity is a game development environment where is possible to create 2D and 3D experiences and afterwards exploit to many platforms, whether android, iOS, Windows, Linux or macOS. Providing a wide range of possibilities in creating digital content to be used in education.

The other software, Cinderella, is a dynamic geometry software developed to provide an environment to develop high-end educational applications to teach geometry. It has its own programming language, called CindyScript, which afford the possibility to create with considerable freedom, interactive digital content, either for geometry or physical simulations. This software was used in the study to translate the data received from Kinect in function graphs.

Therefore, using the technology available and taking into account the kinesthetic learning approach, where students use their bodies to perform and react in accordance with what is being demanded by the game. We expect to enrich the repository of digital tools to teach mathematics and at same time, to enhance student's motivation towards learning mathematical functions using game based learning approach, promoting efficient learning and fun for those who play the game "Function Hero"

The game was played by various students and exposed in some science or mathematics fairs. Following the same gameplay of games like Guitar Hero, Just Dance, Rock Band and more, the player must perform the graph of the functions, given in their algebraic expression, with its body. The choreographies are created by the rival players and sent via a web page. Then, the game shows the expressions on the screen as goals to be performed by the user. See on the figure below the game in action.

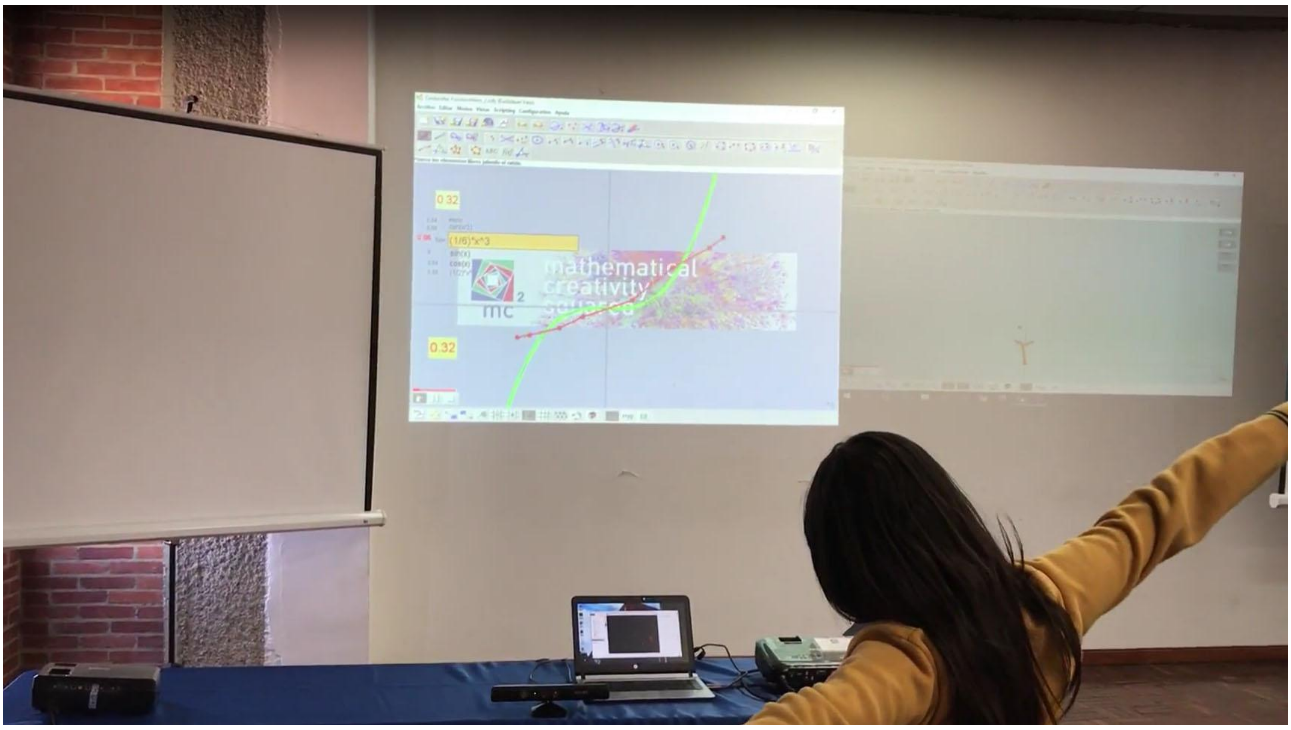

Figure 3: Student playing the Function Hero

DESIGN ELEMENTS THAT AFFORDCMT

For CMT affordances we started from Gibson's (1979) theory of affordances. Gibson considers affordances as properties in the environment that present possibilities for action or as cues in environment such as substances, surfaces, objects, that hold possibilities for action. In a technological environment, and according to Akrich and Latour (1992), affordance is a legislator within a sociotechnical system, e.g., what a device allows or forbids from the actors, what it prescribes and what permits. Therefore, CMT affordances of a technology are about its properties, features, its structure or organization, its inherent conditions or qualities, which:

- Mathematical content: Consist of open and/or non-standard problems that connect (i) multiple representations of the same concept, (ii) different mathematical fields, and (iii) different knowledge areas and mathematics.
- Mathematical processes: Offer interaction with the technology that allow engaging with and making sense of mathematics by exploration of, experimentation within, and formulation of mathematics problems.
- Creative Mathematical Thinking skills: Foster the users' cognitive processes of Fluency, Flexibility, Originality and Elaboration by stimulating/encouraging students to make and check conjectures, find multiple solutions and/or strategies for the same problem, think and reflect on their mathematical work, generalize mathematical phenomena.
- Social Aspect: Value the mathematical communicative skills.
- Affective aspect: Promote engagement by generating a feeling of (aesthetic) pleasure because of the narrative, some game features of the flow of the mathematical activities.

RESULTS

After the game was introduced in the classes, the students had one week to change their choreographies on the web site. The set of functions created by them where played in a sort of tournament. The engagement of students was more than expected, they created the choreographies and played along the tournament supporting their colleagues and vibrating with the scores.

Team	Choreography
0	abs(sin(x)), cos(x)+2, x^(-2), log(x), exp(2*log(x)) , exp(-x) , 3*x , -x^(10)
1	abs(x),log(-x+4),log(x+6),cos(x),tan(-x),0,sin(x-2),exp(x^2),cos(x^1/2),cos(-x),(x-3)(x+5)
2	5*x^3,sin(86)+arctan(1515),abs(sin(x)),arccos(x^69)),1/(1+6*x^2),arccos(x^1664)
3	ln((-3+2*x)^(-1)),heavyside(x),-x ,x^3,cos(x),log(exp(sqrt(x))),tan(x),sin(exp(x)),log(x^2)
4	(x+2)^1, abs(x)+2,(-(x)+1)^1,-abs(x)+1^3,sin(-x),x^3+1^4,-(x^3)+1^2, 2+(17^12)x*0, x^-2*log(x)
5	2*x,log(x+2),x^(-2),exp(x), ch(x+1/2)
6	log((-3+2*x)^(-1)),-x^3,-x ,x^3,cos(x),log(exp(sqrt(x))),tan(x),sqrt(-x)
7	(x+2)^1, abs(x)+2,(-(x)+1)^1,-abs(x)+1^3,sin(-x),x^3+1^4,-(x^3)+1^2, 2+(17^12)x*0

Table 1: Teams' choreographies for the Function Hero Tournament

CONCLUSION

The game Function Hero was created with the intention to provide another technology to the mathematics education scenario allowing to promote motivation and engagement using an educational game. It differs from the other game in the aspect of its design, which doesn't ask user closed answers.

Following the CMT affordances elements (Table 1), we developed a game which doesn't present standard problems since the goal is to create sets of functions representing choreographies to be "danced" by others. The multiple representation of the same subject, functions, is seen when students must think about the algebraic expression, translate it into machine expression and imagine the graphical result in accordance body movement that fits well the function thought by them.

The social aspect with other players was encouraged promoting the Function Hero Tournament, which teams faced each other dancing the choreographies created by themselves and by other teams.

The affective aspect is present in the game itself, providing scores which students can verify their movements and evaluation of the algebraic expression in real time.

Analysing the choreographies, it's possible to trace some elements of divergent thinking listed as Fluency, Flexibility, Originality and Elaboration. For instance, we notice that the Team 2 shows more fluency in trigonometric functions while the Team 4 in quadratic and cubic functions. The Team 6 elaborated their choreography using some redundant expression to make harder to the other teams to recognize but easy to themselves (log(exp(sqrt(x))).

Thus, the game allows the evaluation of any gesture of the student giving points in accordance to it. Some further studies will be conducted to verify if there is a learning gain on the recognition and understanding of functions using the game.

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