International Journal of Computer and Information Technology (ISSN: 2279 – 0764)
Volume 04 – Issue 02, March 2015

Using a Serious Game with a Tangible Tabletop Interface to Promote Student Engagement in a First Grade Classroom: A Comparative Evaluation Study

Sébastien Kubicki
National School of Engineering
European University of Brittany
Brest, FRANCE

Denis Pasco
Department of Educational Sciences
European University of Brittany
Brest, FRANCE
Email: denis.pasco [AT] univ-brest.fr

Ingrid Arnaud
Department of Education
District of Brest
Brest, FRANCE

Abstract— **This study considers to what extent a tangible tabletop interface can enhance student engagement in a serious mathematics game compared to regular interaction with the same game in a classroom. The participants were eleven first grade students randomly assigned to three groups. Each group played the standard game in a classroom environment and then the same game again, this time implemented on an interactive tabletop. Task completion times for each student were measured via video recordings of the games. The results indicate that the time students spent on game tasks while using the tangible tabletop were significantly higher than the times for the same tasks when playing the game in a classroom setting. However, the results vary somewhat depending on inter-individual differences. In addition, the data shows that students engagement is mostly asynchronous when playing the game on the interactive tabletop, but mostly synchronous when playing in the classroom. We relate these results to (1) tangible tabletop affordance for student engagement, (2) the need to link technology implementation with changes in classroom teaching practices, and (3) the opportunities that a tangible tabletop interface provides for engaging students in collaborative learning.**

Keywords—Serious Games; Interactive Tabletop; Tangible Interaction; Evaluation; Task Time; Elementary School; Comparative Study

I. INTRODUCTION

Playing video games is a popular free-time activity among children and adolescents. Rideout *et al.* [32] reported that 60% of individuals aged 8-18 played video games regularly in 2009, compared to 52% in 2004, and 38% in 1998.

Over the last 10 years, educational researchers have investigated the relationship between video games and school learning through the design, implementation, and evaluation of serious games [6]. Klopfer *et al.* [18] defines a game as "a voluntary activity structured by rules, with a defined outcome (*e.g.*, winning/losing) or other quantifiable feedback (*e.g.*, points) that facilitates reliable comparisons of in-player performances". Serious games can be viewed as games set in a digital world with the intended outcome of learning about an academic domain.

Over the years, Human Computer Interaction (HCI) research has contributed to the emergence of new technologies such as smartphones, tablets, and interactive tabletops. These technologies offer new ways for users to interact with a digital world (*i.e.* via "tactile", "multi-touch", or "tangible" interfaces). According to Ishii and Ulmer [15], tangible user interfaces "augment the real physical world by coupling digital information to everyday physical objects and environments" (p.236).

The purpose of our study was to evaluate the extent to which a tangible tabletop interface can enhance student engagement with a serious game in mathematics compared to regular practice of the same game in the classroom.

II. RELATED WORK

This study links to two major research areas: how serious games impact student learning, and the potential of interactive tabletops for serious games. Related work is presented on both these areas.

A. How serious games impact student learning

Many serious games are intended to improve student learning. For example, Dimension M is a multiplayer video game in mathematics where students improve their algebra skills by accomplishing 20 missions [38]. In the science area, Quest Atlantis immerses players in multi-user environments to learn and apply scientific knowledge [43]. In the Taïga world, players find themselves in a state park where the stock of fish in the river is plummeting. They work as field investigators to collect evidence about this catastrophe. As they explore the park, they meet and interview different characters to obtain their perspectives on the problem. They collect and test water samples from different locations to gather data. They propose different solutions, and can travel forward in time to observe the consequences of their solutions. Civilization is a multiplayer strategy game where players establish and lead a civilization from the Bronze Age into the Space Age [28]. As they strive to protect their civilization, players learn and use historical knowledge.

The effects of playing these serious games on student academic achievement have been investigated [48], [44]. In a research review based on more than 300 articles, Young *et al.* [48] found some evidence that video games improved language learning, knowledge of history, and physical fitness, but found little support for any academic benefits for science and mathematics. Despite a decade of research emphasis on science, technology, engineering, and mathematics (STEM) education, the authors found few peer-reviewed articles published on serious game-based learning. Only five studies employed academic achievement as a primary dependent variable of the empirical data. They determined that "to date, there is limited evidence to suggest how educational games can be used to solve the problems inherent in the structure of traditional K-12 schooling and academia" (p.62). They point out: "Many educationally interesting games exist, yet evidence for their impact on student achievement is slim" (p.61). Tobias *et al.*'s [44] research review found some evidence for near and far transfer from games to external tasks when the game and task called for similar cognitive processes. However, the authors noted that many games are poor teaching tools, and instructions are ineffectively integrated into the game, to the detriment of student learning. Nevertheless, both research teams concluded that there are reasons to be optimistic about the educational impact of video games despite a shortage of definitive evidence to that effect.

One of the factors that Young *et al.* [48] highlighted about how serious games impact student learning is the lack of interaction between players and the digital world. Designers should facilitate greater interaction of each player with the game in order to foster affordances (*i.e.* action invitations), a key element for promoting users' immersion and academic outcomes. Unfortunately, most serious games still use keyboards or game controllers, which do not provide a sufficiently natural interaction with the game world. However, research in HCI over the last decade points to new technological platforms that may drastically improve interaction with that digital world.

B. *The potential of interactive tabletops for serious games*

During the last ten years, several researchers have utilized interactive tabletops in serious games. The principle question has been whether the interactions supported by interactive tabletops enhance player collaboration.

Kelly *et al.* [16] developed a serious game (called Solar Scramble) on a multi-touch interactive tabletop aimed at 5 to 10 year olds. The game's objective was to teach the placement of the planets in the Solar System. The game's evaluation by five child education experts revealed the potential of interactive tabletops for multi-user interactions by supporting the children's collaborative activities. Harris *et al.* [12] has also studied the use of multi-touch interactive tabletops for collaborative child learning. 45 children (21 boys, 24 girls) aged from 7-10 took part in a classroom study where they manipulated digital objects on an interactive tabletop. The results showed that the children's participation was significantly higher when utilizing a multi-touch method instead of single-touch. In other words, multi-touch encourages collaborative interaction. A recent literature review [13] showed that interactive tabletops could significantly benefit collaborative training.

A few studies have considered the combination of interactive tabletops and tangible objects [15], including how the handling and use of objects can benefit children's training [2]. For example, Montessori noted that: "Children build their mental image of the world, through action and motor responses; and, with physical handling, they become conscious of reality" [5]. There are clear educational advantages to associating interactive tabletops with tangible objects. For instance the study by Sluis *et al.* [40], based around their read-it application, showed how the pairing of an interactive tabletop and tangible objects promoted the reading skills of 7 to 9 year olds. Marco *et al.* [25] also evaluated this combination with a serious game involving imaginary world (story creation) development, aimed at 3 to 4 year olds. More recently, Bonnard *et al.* [4] investigated how a serious game for geometry training with tangible interactions could help 10 to 12 year old children. Shaer *et al.* [37] have also studied how multi-touch interactive tabletops can encourage collaborative activity. Their study of a serious game called G-nome Surfer involving 18 students (17 girls, 1 boy; aged 18-21) revealed the collaborative advantages of the interactive tabletop, particularly for reflection, increased participation, and more intuitive and effective interactions.

Despite these cited works, this research field is still a young one. There is a lack of empirical data located in real situations (such as in a classroom setting). This makes it difficult to offer conclusive evidence on the effectiveness of interactive tabletops and serious games for promoting children's training [48], [13]. Our work is aimed at supplying more data on this question by focusing on the classroom environment. Is an interactive tabletop with tangible objects capable of promoting children's involvement in a mathematical serious game compared to traditional practice on paper?

III. THE DEVELOPMENT OF A SERIOUS GAME FOR THE INTERACTIVE TABLETOP

Just as computers and technologies such as interactive whiteboards have become standard equipment in schools [11], [14], we believe that interactive tabletops will become progressively more popular. As schools evaluate them, it will become clear how interactive tabletops allow young children to work in a recreational way, either individually or collectively. For instance, pupils can work together around an interactive tabletop, manipulating objects with the assistance of their teacher.

A. *The context of our work*

This research, which began in 2012 but follows on from earlier work [19], is in partnership with the National Department of Education, and aims to provide teachers in elementary schools with a set of tools, including interactive tabletops, that improve student learning. This paper focuses on our work on the serious mathematics training game *The Game of Towers*. It is usually employed in classrooms by elementary school teachers in a paper format. We have designed and built a digital version of this game for the *TangiSense* interactive tabletop.

B. A general presentation of the serious game

The original motivation behind the development of *Game of Towers* comes from its support for activities proposed in a book by Dominique Valentin [46], a mathematics professor at the University Institute for Teachers Training. These activities help nursery and primary school children discover the world of mathematics.

Figure 1. A situation where the children have different points of view of the objects on the table

1) Pedagogical objectives

The different activities have several pedagogical objectives. The first is to make children aware of how an object higher than another can hide the one below. According to a child's viewing angle in space (*e.g.*, in the classroom), they will realize that when two objects have the same form but different heights, then one can mask the other.

The second objective is to have the child use numerical information within a spatial framework. For instance, imagine there is a constraint on the number of objects in the scene, such as four objects of the same form but having different heights (labeled as sizes 1, 2, 3 and 4). The child should realize that the tallest object (size 4) can hide the other three. Similarly, the size 3 object will hide the two shorter ones (sizes 1 and 2) but not the object of size 4, etc.

Yet another objective is to have the child consider several constraints at the same time. For example, the previous four objects can be aligned to impose two constraints on the child. There is a “north” point of view, where the child will see three objects (*i.e.* sizes 1, 2 and 4), but from the “south” point of view only two objects will be visible (sizes 3, and 4), as illustrated in Figure **1**.

2) Rules of the game

The game's pedagogical objectives motivate the relatively simple playing rules for the game. The children have a set of objects representing towers (each tower is an assembly of cubes). A tower may have a height ranging from 1 to 5 stacked cubes. The game contains 17 towers: one tower of size 5, and four towers each with heights of 4, 3, 2, and 1.

The game board is a sheet of paper that represents either a “band” of 5 boxes or a “grid” of either 3x3 or 4x4 boxes. On each end of a band is a number ranging between 1 and 5. A grid uses similar numbers on the ends of each row and column, ranging between 1 and 4 (see Figure **2**).

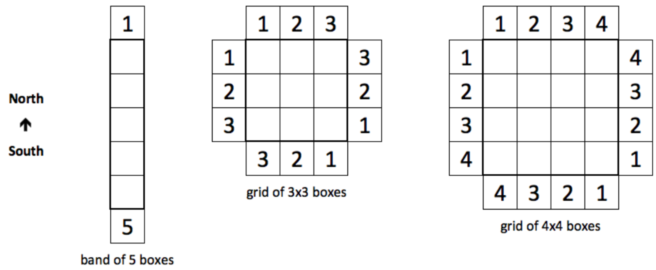

Figure 2. Game board examples: one band and two grids with different constraints

A pupil must place his towers (which he picks from the initial set of 17) so they match the numerical constraints at each end of a row or column. Each constraint specifies the numbers of towers that can be seen from that constraint's point of view -- North and South for the band, and North, South, East, and West for the grids.

For the band on the left of Figure **2**, one solution would be to place towers of sizes 5, 4, 3, 2, 1 in the squares from North to South. From the “North”, a pupil will only see one tower (the one of size 5), but a pupil at the “South” point of view will see all five towers (from the shortest to the tallest). In this way, the constraints at both ends of the band are satisfied.

The problem is similar for the grids, but the pupil must respect the constraints along both the rows and columns. For a grid, the game has two alternative rules: (1) to allow two towers with the same height on the same row/column (easier), or (2) to prohibit two towers of the same height on the same row/column (more difficult). During our evaluation, the teacher let the children use rule n°1.

C. Description of the TangiSense interactive tabletop

The *TangiSense* interactive tabletop, designed by the RFIdées Company, offers tangible interactions, unlike most tabletops which support only tactile interactions. A collection of tangible objects can be placed on its surface, and Radio Frequency IDentification (RFID) technology detects them. Each object's RFID tag functions as both a reader and transmitter since it consists of a chip containing memory, connected to an antenna that can send and receive radio waves (see Figure **3**).

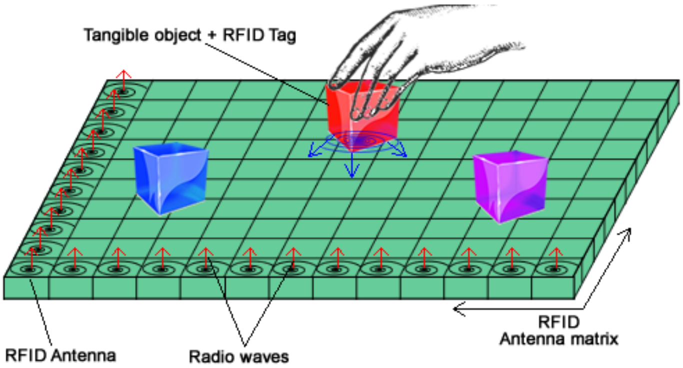

Figure 3. RFID and the *TangiSense* interactive tabletop

The use of RFID means that tags can be uniquely identified, and read remotely. Several tags can be read at the same time by a single reader, and superimposed objects can be detected.

The interactive tabletop version used in our work is the *TangiSense* 2 (see [20] for the *TangiSense* 1's features), which is made up of 24 tiles covering a total surface area of 90cm*60cm (6 by 4 tiles, as in Figure 4). Each tile contains 16 RFID antennas (in a 4*4 grid configuration).

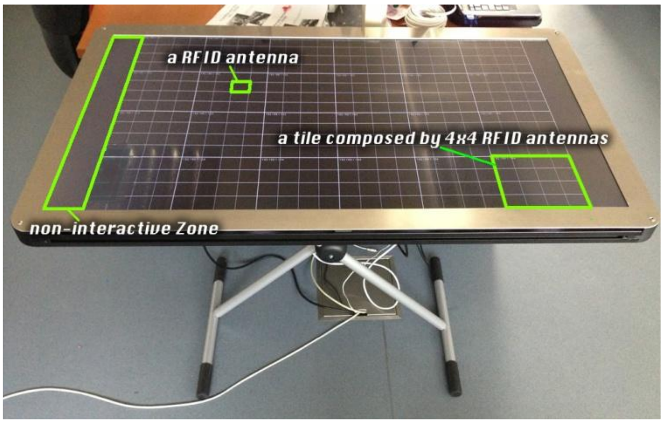

Figure 4. The *TangiSense* 2 interactive tabletop

It is simple to increase or decrease the tabletop size by adding or removing tiles. Each tile contains a DSP (Digital Signal Processor), which can read data coming from the 16 antennas on the tile. The reading strategies are prioritized, and the code is distributed between the processors for the antennas. Each tile is connected to the host computer by an Ethernet link, which provides good communication speeds.

The *TangiSense* 2 comes with a 47" LCD screen that can display virtual objects which the tangible objects on the tabletop surface can interact with. The surface has two "non-interactive" zones on the left and right, each approximately 7 cm wide. These allow a user to place tangible objects on the tabletop without them being detected (*cf.* Figure **4**). The TangiSense software utilizes multi-agents that make it possible to define interaction rules between the agents (an agent can be a tangible object or a virtual object) [23].

D. Adapting the paper-based game to the interactive tabletop

The porting of the paper-based game involving bands and grids (as shown in Figure 2) to the *TangiSense* interactive tabletop was implemented in Java using the *TangiSense*'s API. The application was written as part of a computer science project by 5 students from our engineering school. This first version was developed over 12 weeks with the help of a Pedagogical Advisor from the National Department of Education who proposed the basic specification for the application.

The approximately 4000 lines of code can be divided into five functional groups: (1) game administration, including the selection of a game board, (2) grid generation, including a checking algorithm for a grid's feasibility, (3) a correction algorithm that helps the students during the game, and a validation algorithm for the completed grid, (4) RFID tags management for the objects on the tabletop, and (5) graphics (game board rendering on screen) and sound.

1) Design and presentation of the tangible objects

The tangible objects used on the interactive tabletop must respect certain constraints. For example, they should closely match the objects used in the paper-based game. Also, because young children will use the objects, they must not be dangerous or sharp.

Our student-engineers explored several possible designs for the objects. Three were explored in detail: (1) objects carved from wood, which are inexpensive but require some hours of work to produce and specific tool knowledge. Also, painting or varnishing the objects must take into account their safe handling by children; (2) object creation using a 3D printer. This allows a wider range of forms to be considered, but prototyping tests were disappointing. Printing time were excessive, the rendering below expectations, and the costs excessive; (3) a design based on LEGO® bricks, which are already used by the children in the classroom version of the game.

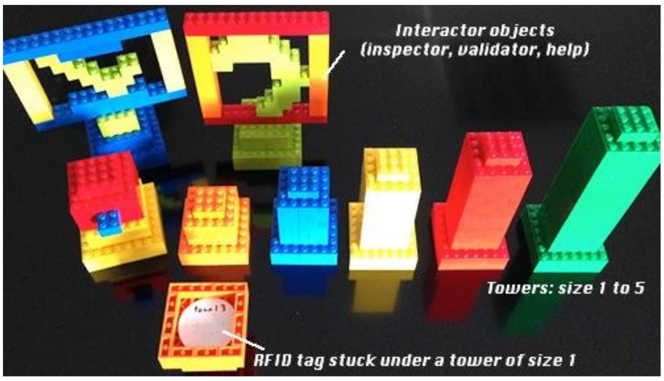

Figure 5. Different objects conceived with LEGO® bricks

We finally chose the LEGO® design, as shown in Figure **5**. LEGO® bricks are designed for children, so meet our requirements for safety. Since the bricks are completely modular, they make the design of objects in the necessary dimensions a straightforward task. The cost of five LEGO®

boxes (the quantity necessary for manufacturing our objects) was very reasonable (an average of 5€ for each design).

Two types of objects were developed: (1) towers of heights 1 to 5, following the rules of the game, and (2) "*interactors*" objects [24] that communicate with the tabletop. There are three objects of this latter type: (1) an “inspector” object for checking the towers’ positions. Any errors are reported, and the child's attention is focused on the incorrect game side; (2) a “validator” object which verifies the finished band or grid, and announces the result (correct/incorrect); (3) a "help" object which suggests a row or column which the child should consider again because it contains an error.

One common aspect of these objects was the presence of a RFID tag, which allows the tabletop to identify each one. An example object with its tag visible is shown at the bottom of Figure 5.

IV. Method and Evaluation

In this section, we describe our protocol for comparing student engagement in the classroom game with the interactive tabletop version. We consider the participants, data collection techniques, and measurement approach.

A. *Participants and protocols*

After we had obtained the consent of parents and guardians, eleven first grade students participated in our study (9 females; 2 males; Mage: 6 years, 11 months; SD: 3.9 months). The students were randomly assigned to two four-person groups and one group of three. Each student was issued with an anonymous 4-digit code starting with 01 for the first group, 02 for the second group, and 03 for the third group. After we had reminded the students about the game's goals and rules, each group played the game in the classroom. They collaborated to find a solution, and asked the teacher to validate their answer. If their solution was incorrect, the students were asked to keep searching for a solution. A typical game session is shown in Figure **6.**

Figure 6. Four students playing The *Game of Towers* in the classroom

During the same day, each group also played the game with the tangible tabletop interface. After we had explained how to manipulate the objects on the interactive tabletop, students once again collaborated to find a solution (one such game is shown in Figure **7**). When they thought they had found an answer relative to one side of the game, they placed a "validator" object on an 'eye' box positioned on that side of the tabletop (two of the four 'eye's can be seen in Figure **7**). The validation process would finish by emitting a sound (“applause” for a correct solution and “cries” when it was wrong). Students could check their solution for each side of the game using the relevant eye box on that side, or place a "validator" object on a single green box to validate their answer for the entire game (using the same sound protocol).

Figure 7. Students playing The *Game of Towers* on the tangible tabletop

Student activity in the classroom and with the interactive tabletop were videotaped with a camera placed on a tripod pointing over the game area.

B. *Measures*

We compared student engagement during game-play in the classroom against the tangible tabletop interface by utilizing “time on task”. This is the total amount of time students spend actively engaged in a chosen learning task [7], and is an important predictor of student learning and achievement [33],[42],[22]. As a student's active engagement in a task increases, the more opportunities he/she has to learn. We chose the timed task to be that of moving objects to find a solution to the game, with the unit of measurement specified in seconds.

Two researchers separately examined both the classroom and tabletop videotapes to determine student time spent on object movement A Fleiss’ Kappa analysis was applied to assess the reliability of the timing agreement between the researchers (using SPSS®, v.21).

V. Results

According to Landis and Koch’s table [21], the Fleiss’ Kappa analysis indicated a strong degree of agreement between the two researchers (K=.927; p<.000), probably due to the use of videotapes where students’ engagement can be precisely measured. As a consequence, we recommend the videotaping of student activity to insure data reliability.

We present our results in two parts: firstly we focus on comparing student time on the moving task in the classroom

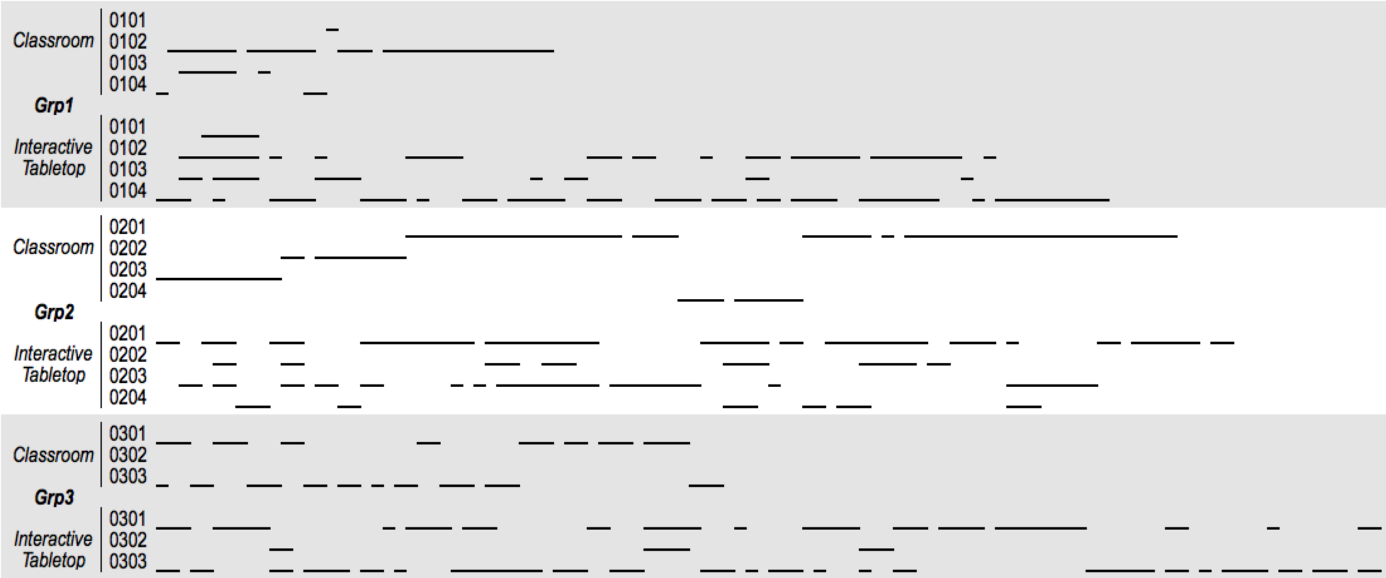

Figure 8. Chronological evolution of the moving task time for each student in the classroom and on the tabletop

with the time spent on the interactive tabletop; the second part of our results describes a chronological evolution of the time students spent on the moving task in the classroom and on the interactive tabletop.

A. Task time in the classroom and on the interactive tabletop

Table 1 presents the task time for each student, each group, and the total time spent playing the game. Results are divided between times in the classroom and on the interactive tabletop. P-values are included for each group and for the total time spent on the moving task (both in the classroom and on the tabletop).

	Time in second (% of the allocated time)	
Students	***Classroom***	***Interactive tabletop***
0101	3 (1.29)	11 (4.36)
0102	62 (26.72)	82 (32.54)
0103	11 (4.74)	34 (13.49)
0104	9 (3.88)	111 (44.04)
Total group 1	85*(36.63)	238*(94.44)
0201	109 (17.60)	125 (21.77)
0202	20 (3.23)	36 (6.27)
0203	22 (3.55)	88 (15.33)
0204	21 (3.39)	35 (6.09)
Total group 2	172*(27.78)	284*(49.47)
0301	29 (5.53)	57 (8.79)
0302	0 (0.00)	7 (1.08)
0303	24 (4.58)	62 (9.56)
Total group 3	53*(10.11)	126*(19.44)
Total	310*(22.54)	648*(43.96)

p<.05

Table 1. Moving task time in the classroom and on the interactive tabletop

For all three groups, the total time students spent on the moving task when playing on the tangible tabletop is higher than the time spent in the classroom. Students spent 22.54% of their allocated time (*i.e.* the time available for learning) on the moving task when they played in the classroom.

By comparison, the students spent 43.96% of their total activity time on the moving task when on the tangible tabletop. A Wilcoxon test on paired samples indicates that the task time on the interactive tabletop (M=8.91; ET=10.92) is significantly higher than the task time in the classroom (M=3.89; E-T=8.78), Z=4.253, p<.000.

The results show differences between the students even though all of them increased their moving task time when playing on the interactive tabletop as compared to in the classroom. For instance, student 0104 increased her/his task time by 40% when moving from the classroom to the interactive tabletop (from 9 sec to 111 sec). This large increase is not observed for all the students. For example, student 0101 increases her/his moving task time from 3 sec in the classroom to 11 sec on the interactive tabletop; no task time was recorded for student 0302 in the classroom but he/she only required 7 sec on the interactive tabletop. Interestingly, the most active students in the classroom (0102, 0201, 0301) were also the most active students on the interactive tabletop.

B. Chronological evolution of the moving task time in the classroom and on the interactive tabletop

Figure **8** presents a chronological evolution of the task time of each student in each group when playing in the classroom compared to on the tangible tabletop. Student engagement in the classroom was mostly asynchronous, indicating that students manipulated the towers one after another in order to find a solution. We also observed that a few student engagements overlapped in group 1 while activities were totally asynchronous in groups 2 and 3. By contrast, when students from groups 1 and 2 played the game on the interactive tabletop, their engagements were mostly synchronous, since they manipulated the towers at the same time to find a solution. Student engagements from group 3 remained asynchronous when they played on the interactive tabletop.

VI. Discussion

The purpose of this study was to evaluate the extent to which a tangible tabletop interface can enhance student engagement with a serious mathematics game compared to regular practice in the classroom. We studied eleven first grade students, randomly assigned to three groups. They played the serious game in a classroom setting and, during the same day, the same game on a tangible tabletop. The game-play was videotaped in order to compare object moving task time by each student in the classroom and on the tabletop.

The results indicate a significant increase in task time when the students played on the interactive tabletop compared to in the classroom. However, the amount of engagement increase was not equal for all students. In addition, the tangible tabletop interface enhanced synchronous student engagement for two out of the three test groups.

These results highlight issues related to (1) tangible tabletop interface affordance for student engagement, (2) the need to link technology implementation with changes in classroom teaching practices, and (3) the opportunities that tangible tabletop interfaces offer for engaging students in collaborative learning.

Our study indicates that students spend 20% of the allocated time actively engaged in finding a game solution in the classroom, a result congruent with the literature in this area. Even though classroom time usage has changed over the years [7], results from early studies in the 70' have been confirmed. According to those studies, students spent between 20% and 30% of their allocated time actively engaged in learning tasks. The rest of the time, they listened to teachers, managed their learning environment, moved from task to task, or waited their turn to engage in a learning task.

Our results reveal that the time students spend actively engaged via a tangible tabletop interface finding a game solution is nearly double the time spent on the same activity in the classroom. This difference is significant. A tangible tabletop interface offers students opportunities to actively engaged in a task and learn through problem solving. This shows that the tabletop can be assimilated as an affordance in the learning environment. The affordance concept was introduced by Gibson [10] who defined it as what is significant for individuals in a given environment. In our study, students clearly recognized the tangible tabletop interface as a significant property in their learning environment because of the way it invites them to participate, increasing the time they spend on tasks. Other studies have shown the role of technology affordances in classroom [9], [29], and our results confirm Schneider *et al.*'s [36] observation that a multi-touch tabletop interface promotes collaborative learning in the classroom by significantly engaging students in learning tasks.

Our study shows that significant inter-individual differences exist even though all students increase their task time on the interactive tabletop compared to in the classroom. Although the tangible tabletop interface is an inviting way for students to find solutions, the students are not all engaged to the same degree. Some students significantly increase their task time when transferring from the classroom to the interactive tabletop, while others are only slightly engaged in the classroom and on the interactive tabletop. This highlights the issue of inequity of participation in technology use in the classroom. For example, Harris *et al.* [12] found some significant differences in participation between males and females when using an interactive tabletop. Clearly, the implementation of technology in the classroom cannot solve, by itself, the issue of students engagement with learning tasks.

Ruthven and Hennessy have studied math teachers' ideas about using technology in the classroom to improve students learning, and have observed the way those teachers integrate technology in their classrooms [34], [35] They conclude that technology integration must be supported by a change in classroom teaching practices to insure an equity of participation. Our results confirm this view, with special emphasis on classroom management (how teachers organize the class to foster student participation and engagement) and pedagogical content knowledge (how and when content is presented to students in order to foster learning).

Our results reveal that student engagement is mostly synchronous when playing on an interactive tabletop, and mostly asynchronous in the classroom. Other pedagogical studies have shown that student engagement in the classroom is mostly asynchronous [27]. Students solve problems on their own, answer teacher questions one after another, and ultimately learn as separate individuals sitting on separate tables. According to Slavin [39], "Cooperative learning methods are extensively researched and under certain well-specified conditions, they are known to substantially improve student achievement in most subjects and grade levels" (p.344). Cooperative learning employs instructional methods where teachers organize students into small groups, and group members work together to help one another learn academic content. Our work shows that a tangible tabletop interface promotes synchronous student engagement when playing a serious game. Consequently, this technology may be a useful tool for improving student learning through cooperative learning methods.

VII. Conclusions and Future Work

This research has presented three contributions. Firstly, it outlined a design process for implementing a serious game with a tangible tabletop interface. Secondly, it evaluated how a tangible tabletop interface can enhance student engagement. Thirdly, it offered empirical evidence that tangible tabletop interfaces foster student engagement and may be a useful tool for improving student learning through collaborative learning methods.

More studies are needed on the process of designing serious games with tangible tabletop interfaces before we can propose a comprehensive set of design requirements. Furthermore, we plan to carry out more research on the classroom implementation of tangible tabletop interfaces that offer collaborative learning methods for promoting student learning.

Acknowledgment

This research work was partially financed by the French Department of Education and Research, the Council of Finistère and the Council of Brest Aera. We would like to thank students from the Brest National School of Engineering who participated in the game design process, and the city of Brest. We also thank the teachers, parents, and children who participated in our study.

REFERENCES

[1] AlAgha I., Hatch A., Ma. L., Burd L. (2010). Towards a teacher-centric approach for multi-touch surfaces in classrooms. In *ACM International Conference on Interactive Tabletops and Surfaces (ITS '10)*, ACM Press, New York, NY, USA, p. 187-196.

[2] Alibali M. W., diRusso A. A. (1999). The function of gesture in learning to count: More than keeping track. *Cognitive Development*, Vol. 14, p. 37-56

[3] Apted T., Kay J., Quigley A. (2006). Tabletop Sharing of Digital Photographs for the Elderly. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06)*, Rebecca Grinter, Thomas Rodden, Paul Aoki, Ed Cutrell, Robin Jeffries, and Gary Olson (Eds.). ACM Press, New York, NY, USA, p. 781-790.

[4] Bonnard Q., Jermann P., Legge A., Kaplan F., Dillenbourg P. (2012). Tangible paper interfaces: interpreting pupils' manipulations. In *Proceedings of the 2012 ACM international conference on Interactive tabletops and surfaces (ITS '12)*, New York, NY, USA, p. 133-142.

[5] Burnett A. (1962). Montessori Education Today and Yesterday. *The Elementary School Journal*, Vol. 63(2), p. 71-77.

[6] Cruz-Cunha M.M. (2012). Handbook of Research on Serious Games as Educational, Business and Research Tools. Hershey, PA: IGI Global.

[7] Duncheon J.C., Tierney W.G. (2013). Changing Conceptions of Time: Implications for Educational Research and Practice. *Review of Educational Research*, Vol. 83(2), p. 236-272.

[8] Finkenzeller K., (2003). RFID Handbook: *Fundamentals and Applications in Contactless Smart Cards and Identification*. John Wiley & Sons, Inc., New York, NY, USA

[9] Gaver W.W. (1991). Technology affordances. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '91)*, Scott P. Robertson, Gary M. Olson, and Judith S. Olson (Eds.). ACM Press, New York, NY, USA, p. 79-84.

[10] Gibson J. J. (1979). The theory of affordances. In R. E. Shaw & J. Bransford (Eds.), *Perceiving, Acting, and Knowing*. Hillsdale, NJ: Lawrence Erlbaum Associates.

[11] Glover D., Miller D., Averis D., Door V. (2005). The interactive whiteboard: a literature survey. *Technology, Pedagogy and Education*, Vol. 14 (2), p. 155–170.

[12] Harris A., Rick J., Bonnett V., Yuill N., Fleck R., Marshall P., Rogers Y. (2009). Around the table: are multiple-touch surfaces better than single-touch for children's collaborative interactions? In *Proceedings of the 9th international conference on Computer supported collaborative learning (CSCL'09)*, Claire O'Malley, Daniel Suthers, Peter Reimann, and Angelique Dimitracopoulou (Eds.), Vol. 1, International Society of the Learning Sciences, p. 335-344.

[13] Higgins S., Mercier E., Burd E., Hatch A. (2011). Multi-touch tables and the relationship with collaborative classroom pedagogies: A synthetic review. In *International Journal of Computer-Supported Collaborative Learning*, Vol. 6(4), p. 515-538

[14] Hodge S., Anderson B., (2007). Teaching and learning with an interactive whiteboard: a teacher's journey. *Learning, Media and Technology*, Vol. 32 (3), p. 271–282.

[15] Ishii H., Ullmer B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, p. 234-241, New York, USA, ACM Press.

[16] Kelly A. R., Wallace J. R., Cerar K., Randall N., McClelland P., Mindy Seto A. (2010). Solar scramble: an educational children's game for collaborative multi-touch digital tabletops. In *Proceedings of the 28th ACM International Conference on Design of Communication (SIGDOC '10)*. ACM Press, New York, NY, USA, p. 27-32

[17] Khandelwal M, Mazalek A. (2007). Teaching table: a tangible mentor for pre-k math education. In *Proceedings of the 1st international conference on Tangible and embedded interaction (TEI '07)*. ACM, New York, NY, USA, p. 191-194.

[18] Klopfer E., Osterweil S., Salen K. (2009). *Moving learning games forward*. Cambridge, MA: Education Arcade.

[19] Kubicki S., Lepreux S., Kolski C., (2011). Evaluation of an interactive table with tangible objects: Application with children in a classroom, In *Procedings of the 2nd Workshop on Child Computer Interaction "UI Technologies and Educational Pedagogy", In Conjunction with CHI 2011 Conference*, May 2011, Vancouver, Canada.

[20] Kubicki, S., Lepreux, S., Lebrun, Y., Dos Santos, P., Kolski, C., Caelen, J., (2009). New Human-Computer Interactions Using Tangible Objects: Application on a Digital Tabletop with RFID Technology, In J. A. Jacko, (Ed.) Proceedings of the 13th International Conference, Human-Computer Interaction International 2009, Springer-Verlag, Proceedings, Part III, LNCS 5612, July 2009, San Diego, USA, Pages 446-455.

[21] Landis J.R., Koch G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, Vol. 33, p. 159-174.

[22] Langer J.A. (2001). Beating the odds : Teaching middle and high school students to read and write well. *American Educational Research Journal*, Vol. 38, p. 837-880.

[23] Lebrun Y., Adam E., Mandiau R., Kolski C. (2013) Interaction Between Tangible and Virtual Agents on Interactive Tables: Principles and Case Study, *Procedia Computer Science*, Vol. 19, 2013, p. 32-39

[24] Lepreux S., Kubicki S., Kolski C., Caelen J. (2012). From Centralized interactive tabletops to Distributed surfaces: the Tangiget concept, *International Journal of Human-Computer Interaction*, Vol. 28, Issue 11, p. 709-721.

[25] Marco J., Cerezo E., Baldassarri S., Mazzone E., Read J. C. (2009). Bringing tabletop technologies to kindergarten children. In *Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology (BCS-HCI '09)*. British Computer Society, Swinton, UK, p. 103-111.

[26] Martínez R., Collins A., Kay J., Yacef K. (2011). Who did what? Who said that?: Collaid: an environment for capturing traces of collaborative learning at the tabletop. In *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS'11)*. ACM Press, New York, NY, USA, p. 172-181

[27] Mayer R.E., Alexander P.A. (2011). Handbook of *Research on Learning and Instruction*. New York: Routledge.

[28] Moshirnia A., Israel M. (2010). The educational efficacy of distinct information delivery systems in modified video games. *Journal of Interactive Learning Research*, Vol. 21, p. 383-405.

[29] O'Rourke B. (2005). Form-focused interaction in online tandem learning. *CALICO Journal*, Vol. 22(3), p. 433-466.

[30] Piper A.M., Hollan J. (2008). Supporting Medical Conversations between Deaf and Hearing Individuals with Tabletop Displays. In *Proceedings of the 2008 ACM conference on Computer supported cooperative work (CSCW '08)*. ACM Press, New York, NY, USA, p. 147-156

[31] Piper A.M., Hollan J. (2009). Tabletop displays for small group study: affordances of paper and digital materials. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM Press, New York, NY, USA, p. 1227-1236.

[32] Rideout V.J., Foerth U.G., Roberts D.F. (2010). GenerationM2: Media in the lives of 8-to 18-year-olds. Kaiser Family Foundation.

[33] Rosenshine B.V., Berliner D.C. (1978). Academic engaged time. *British Journal of Teacher Education*, Vol. 4(1), p. 3-16.

[34] Ruthven K. (2009). Towards a naturalistic conceptualisation of technology integration in classroom practice: the example of school mathematics. *Éducation & Didactique*, Vol. 3(1), p. 133-152.

[35] Ruthven K., Hennessy S., Deaney, R. (2008). Constructions of dynamic geometry: a study of the interpretative flexibility of educational software in classroom practice. *Computers and Education*, Vol. 51(1), p. 297-317.

[36] Schneider B., Strait M., Muller L., Elfenbein S., Shaer O., Shen C. (2012). Phylo-Genie: Engaging Students in Collaborative Tree-Thinking through Tabletop Techniques. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM Press, New York, NY, USA, p. 3071-3080.

[37] Shaer O., Strait M., Valdes C., Wang H., Feng T., Lintz M., Ferreirae M., Grote C., Tempel K., Liu S. (2012) The design, development, and deployment of a tabletop interface for collaborative exploration of genomic data, *International Journal of Human-Computer Studies*, Vol. 70, Issue 10, October 2012, p. 746-764

[38] Gillispie, L.B. (2008). Effects of a 3-D video game on middle school student achievement and attitude in mathematics. University of North Carolina Willmington. http://www.edurealms.com/documents/Video_Games_Middle_School_Math_Gillispie.pdf

[39] Slavin R.E. (2011). Instruction based on cooperative learning. In R.E. Mayer & P.A. Alexander (Eds.). Handbook of *Research on Learning and Instruction*, New York: Routledge, p. 344-360.

[40] Sluis R. J.W., Weevers I., van Schijndel C. H. G. J., Kolos-Mazuryk L., Fitrianie S., Martens J. B. O. S. (2004). Read-It: five-to-seven-year-old children learn to read in a tabletop environment. In *IDC '04: Proceedings of the 2004 conference on Interaction design and children: building a community*. ACM Press, p. 73–80.

[41] Squire K.D. (2006). From content to context: Video games as designed experiences. *Educational Researcher*, Vol. 35(8), p.19-29.

[42] Stallings J. (1980). Allocated academic learning time revisited, or beyond time on task. *Educational Researcher*, Vol. 9(11), p. 11-16.

[43] Thomas M.K., Barab S.A., Tuzun H. (2009). Developing Critical Inplementations of Technology-Rich Innovations: A Cross-Case of the Implementation of Quest Atlantis. *Journal of Educational Computing Research*, Vol. 41(2), p. 125-153.

[44] Tobias S., Fletcher J.D., Dai D.Y., Wind A.P. (2011). Review of research on computer games. In S. Tobias and J.D. Fletcher (Eds.), *Computer games and instruction*. Charlotte, NC: Information Age, p. 127-222.

[45] Tse E., Greenberg S., Shen C., Forlines C. (2006) Multimodal Multiplayer Tabletop Gaming. In *Proceedings of the Workshop on Pervasive Games*, p. 139-148.

[46] Valentin D. (2004) Découvrir le monde avec les mathématiques [Discover the World with Mathematics]. Paris: Hatier.

[47] Wellner P. (1991). The DigitalDesk calculator: tangible manipulation on a desktop display. In *Proceedings of the 4th annual ACM symposium on User interface software and technology (UIST '91)*. ACM, New York, NY, USA, p. 27-33

[48] Young M.F., Slota S., Cutter A.B., Jalette G., Mullin G., Lai B., Simeoni Z., Tran M., Yukhymenko M. (2012). Our Princess Is in Another Castle: A Review of Trends in Serious Gaming for Education. *Review of Educational Research*, Vol. 82(1), p. 61-89.