Improving Math Learning With Embodied Game-Based Mobile and Wearable Technologies

by

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Abstract

A field of research that is quickly becoming more prominent is the one related to embodied cognition, which states there is an important association between physical activity and cognition. However, research on the application of embodied cognition to education is still at its infancy. More research needs to be done to understand how motion can contribute to student learning, and even further, research is needed on how learning technologies might support physical activity while learning. This research sits at the intersection of embodied cognition, learning technologies, mobile devices, and mathematics education. It implements a novel learning technology platform created at WPI, called the Wearable Learning Cloud Platform (WLCP). Thanks to a child friendly app thats connect to the central web based system, the experience of elementary school children playing physically active games might be improved. This research also analyzes the importance of motor action in students' math learning: By using three different conditions of a game called the Tangrams Race requiring different levels of physical activity (i.e. embodiment), we compared differences between fine and gross motor actions in regards to learning. Results indicated that physically active mobile games can and do improve math learning. Results also show marginal significant effect in favor of the physically active mobile games ($p<0.1$, Partial Eta Sq.$=0.1$) over traditional tutoring systems on a computer.

Acknowledgement

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1. INTRODUCTION

Mathematics is a building block for future learning, as it helps develop abstract thought [2]. Math improves reasoning and with good reasoning comes better comprehension. Early mathematical skills are predictors of future academic success, having lasting effects on individuals, and predicting general academic success later on [1][18]. Beyond K-12 classrooms, math knowledge is important for getting into the workforce as an adult as differences in math achievement are related to substantial differences later in life such as academic degree attainment and employment [19, 20]. The importance of early math achievement on later success in school and the workforce calls for new approaches to teach math and engage students through effective learning activities.

The push to figure out the best ways to teach math to children at young ages has led to research on the connection between physical activity and cognition, such as determining what kinds of motor action best improve learning. Mobile technologies provide new opportunities to incorporate active learning games into classrooms as well as study the connection between physical activity and learning. The current project introduces an active learning game for elementary mathematics learners that utilizes mobile technology to play the game through our developed App. In particular, we investigated the impact of physical embodiment on mathematics learning by having students play the *Tangrams Race*, a physically active game that uses mobile and wearable technologies as 4th-5th graders learn geometry concepts.

We attempted to answer the following research questions: 1) Can Learning Technologies that support Motor Action-based math games help to improve math understanding?; 2) Do different motor action experiences influence the amount of learning, given different motor actions and salient features of the objects being manipulated?; in particular, which level of motor action within a game is best for student learning: Minimally motor (sitting down to use traditional tutoring and learning software on a laptop), Gross motor or Fine motor hand motions? 3) How can these technologies be improved to make the user's experience more enjoyable and engaging?

2. BACKGROUND RESEARCH

2.1 Learning Technologies and Educational Games

"Student centered" approaches to instruction have moved teaching practices towards students learning by themselves in exploratory activities, at their own pace, while being guided by a teacher. Those constructivist views of learning emphasize students being given ownership for their learning, they move at their pace and in a way, their learning is personalised. As students take more ownership in their learning process and teachers serve as facilitators, the role of technology is to facilitate this teaching model by offering a variety of learning platforms [8]. Technology can serve as a good tool for student-centered learning, where students follow their own trajectories through the material.

In STEM education contexts, technology has been utilized through the use of educational games that have been implemented in curricula to practice skills and benefit students through enhanced engagement, content interest, and performance [12, 13, 14]. Many students enjoy playing games and they would rather play games than be in class receiving a lecture from a teacher. For instance, Casano and colleagues (2017) showed how playing another game using the same software infrastructure of this paper yielded more gains than a traditional lecture only condition without these technology-based games, and that students preferred this game to traditional class instruction. The idea of combining games and learning is a win-win. Students can play games that teach concepts through practice with support such as immediate feedback . Research shows that educational games are useful and have a positive effect with regards to developing students' math intelligence [10].

2.2 Embodied Cognition

Motor action is important for learning: while theories of embodied cognition [15, 16] have been introduced more recently, research has shown that there is indeed a connection between movement and learning [4]. Broadly, theories of embodied cognition postulate that individuals' physical experiences, extending to actions and perceptions of the individual, shape cognitive processes and thinking skills and that this also applies to the development of mathematical thinking [15,16]. For instance, body movement can be utilized to connect abstract mathematical concepts with concrete examples, reduce cognitive load, and improve content retention [17], all of which could help students develop skills for mathematics. These findings support the stance that mathematical cognition is "based in perception and action, and it is grounded in the physical environment" [22]. From this growing body of literature, there is evidence to support the connection between mathematical cognition and physical experience. For instance, there is evidence to suggest that those who engage more in physical activity as they learn, retain more than those who are less physically active when learning, including differences between fine and gross motor movements [7]. Since the mind and the body are connected in a way that improves cognition, there are new trends of research to use these discoveries in helping children to learn math. However, that research is still at its infancy and generally does not involve learning technologies, with a few exceptions [23]. More research is needed to understand "what works" in relation of the connection between motion, action, gesturing and learning. However, not much is known about how different kinds of motor action (gross or fine) impact learning, nor how learning technologies might embrace motor action as a part of their pedagogical practices.

2.3 Research Questions

Following the facts from the literature mentioned above, and the areas that were not addressed, the research questions below are what we want to answer at the end of our studies.

1. Can Learning Technologies that support Motor Action-based math games help to improve math understanding?
2. How can these technologies be better improved to make the experience of the users more enjoyable and engaging?
3. Which level of motor action is best to improve student learning? Minimally motor? Gross motor? or Fine motor action?

3. WEARABLE LEARNING CLOUD PLATFORM

The Wearable Learning Cloud Platform (WLCP) is a system designed to support the creation and deployment of multiplayer physically active games via a web-based platform, hosted at *wearablelearning.org* [11]. Students carry mobile devices (e.g. cell phones) that serve as assistants in Augmented Reality experiences. The WLCP was created to allow students to play educational games in collaborative hands-on activities, as they find mathematics in the environment. The WLCP provides the following services: (1) communication with mobile devices; (2) maintains the state of individual players and games; (3) aids teachers/managers the general functioning of games (e.g. starting a game); (4) management of players/students; (5) keeping track of individual and team progress; (6) creation of new games through a "game editor" based on finite state machine diagrams. Any user can login to *WearableLearning.org* to access the game manager, game editor, or play as a game player. The WLCP has allowed for the creation of a few different games that have shown to improve student math learning in past studies, from before to after playing the games [24], and also have done better than control groups receiving traditional lecture-based instruction without technology [21]. The WLCP has also served as a platform for the study of computational thinking as students themselves create new mathematics games for other students to play [24].

4. METHOD

4.1 The Tangrams Race Game

The Tangrams Race game was designed in the WLCP, to involve fun as students learn math, and in the process, teach mathematical concepts. Tangrams race is a physical game designed to teach geometric concepts, which includes special angles, as well as parallel and perpendicular lines. The Tangrams is a seven-piece puzzle game invented in ancient China. The puzzle set includes seven flat shapes that can form many unique figures. Other shapes were included in this game to serve as distractors. Two rectangles, a circle and a hexagon were included in this game.

The Tangrams Race is a relay race game, which requires each team to get all the correct Tangram pieces that they need to complete a Tangram picture that was given to them (e.g. a boat, see Fig. 1). The end line needs one basket with 2-D geometric shapes per team; each piece of the Tangram puzzle is identified by a color code sequence (on a sticker pasted on each shape). The starting line has a table with a picture of a Tangram to be replicated in each level. To get all the pieces, players from each team take turns to run to the end of the room where a large set of candidate pieces are in a basket (including distractors). The phone gives the student-player mathematical descriptions of the specific shape they should retrieve; students communicate the phone they have found the shape that matches the description given, by entering the color code that describes the piece into the phone. For the student to enter that they had found a specific piece, they had to drag the corresponding color sequence that is placed on the shape (e.g. red, blue, black, red) and hit submit.

The phone provides immediate feedback: If they get it right, they run back to their teammates, tap the next playmate, and the next person runs to get the next shape. If they get it wrong, they stay at the end line until they find the right shape: they can try again, or ask for hints that are accessible to them by hitting one of the buttons on the interface. Once students have gone back and forth retrieving all the shapes they needed, they have to work together (as a team) to replicate the Tangram drawing provided; then the phone leads them to proceed to level 2. Each level involves the retrieving of pieces by individual team members, and the construction of a Tangram with said pieces. The first level was easier than the second; the latter having harder mathematical descriptions of the shapes, accompanied with good hints that explained the concepts we were trying to teach them.

The following is required to run the Tangrams race: a large space for each of the teams to run from a beginning to an end line (each of which has a table), wearable technology (mobile devices) with WiFi access. Mobile phones were strapped to each student's wrist, an each student logged in to *wearablelearning.org* as a player, where the game had been activated for those users.

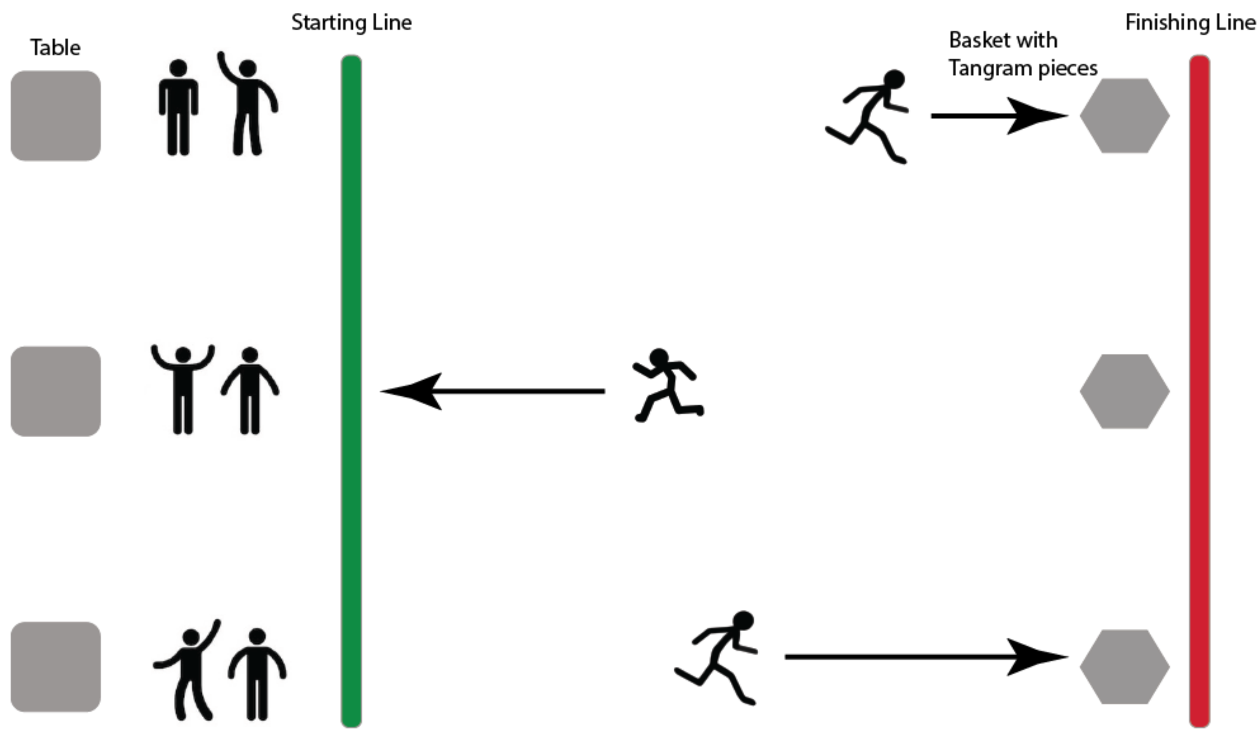

Fig. 1 Diagram showing Tangrams race

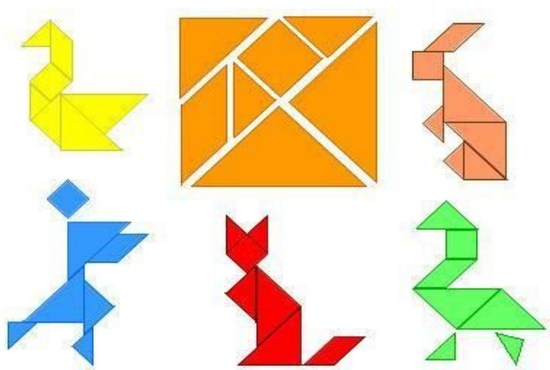

Fig. 2. Tangram

Fig. 3. A student playing Tangrams race

4.2 AfterSchool Program Study

For the AfterSchool Program study, we ran the Tangrams Race. The Tangrams Race was implemented using the WLCP (Wearable Learning Cloud Platform). During this study, the development of the android app was at its infancy and I planned on gathering feedback from the students playing the Tangrams Race on the WLCP and use the feedback to develop the android app and make it better.

4.2.1 Participants, Conditions and Measures

Thirty-two (32) students from an afterschool program at an afterschool program in Massachusetts, USA, participated in the study. We spent 1 hour, 2 days a week for 8 weeks running the study. The participants were 3rd, 4th and 5th graders with varying math competences, and students from all three grades were assigned to all conditions.

Students were randomly assigned to one of three conditions: Embodied Fine Motor, Embodied Gross Motor, or Digital. In the Embodied Fine Motor condition, the group worked with small-sized Tangram pieces, about 2 inches tall (EMB-S). In the Embodied Gross Motor condition the group worked with larger Tangram pieces (about 1-foot tall) that involved bigger hand movements while putting the puzzle together, rotating and holding the pieces (EMB-L). The only difference between the two embodied conditions (EMB-S and EMB-L) was the size of the Tangram pieces. Finally, the Digital (minimally motor) control condition group worked on an equivalent activity on a computer, which had exactly the same questions and help/hints inside of a tutoring system, and constructed a “virtual” Tangram at the end.

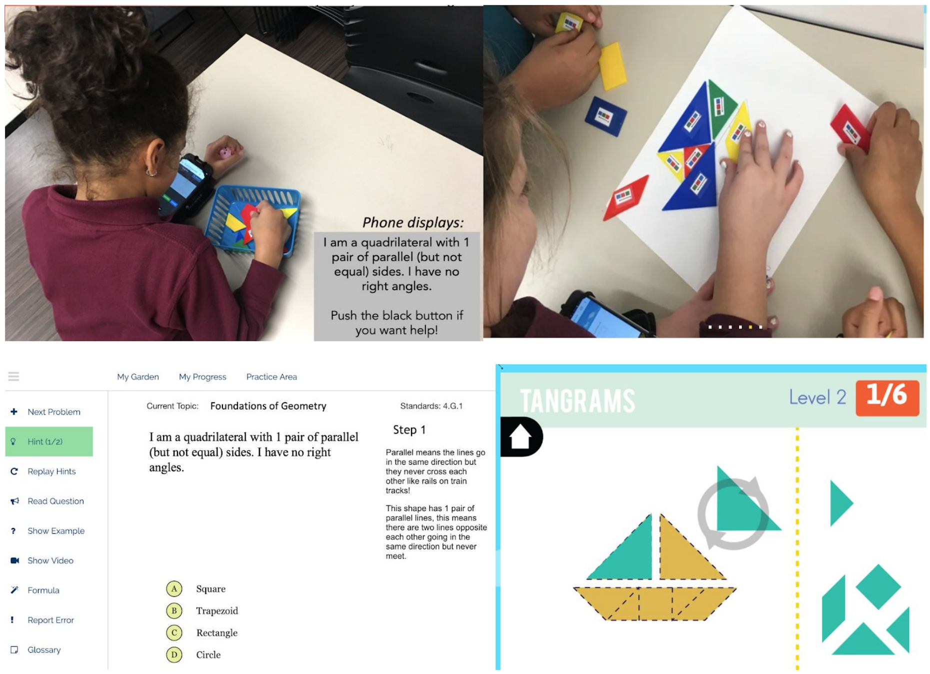

Fig. 4. From left to right, top to bottom: a) student choosing a Tangram piece given math description on the phone (EMB-S condition); b) students collaboratively building the Tangram Puzzle (EMB-S condition); c) The equivalent math problem in MathSpring.org (DIGITAL condition); d) The "virtual" Tangrams puzzle, rotating/dragging pieces via mouse (DIGITAL).

In the first two conditions (small and large-piece Tangram Race conditions) students followed exactly the same format for playing the game: nine (9) students at a time, split into 3 teams of 3 students, played the Tangrams Race math game. Meanwhile, the students who participated in the DIGITAL condition logged in to mathspring.org, which was set up to answer nine (9) questions that were identical to the questions of the quests on the game, and they had exactly the same hints/help from the game as well. Note both conditions had immediate feedback, and help on demand upon the push of a button. Next, the control condition built also a Tangrams Puzzle on a web site (*abcya.com*) that required assembling a Tangram and dragging pieces and rotating them with the mouse. This way, the students in the control condition would an equivalent digital version of what their colleagues did when solving the Tangrams puzzle.

4.2.2 Measures

We gave students mathematics pre and post tests as measures, 10 items extracted from the MCAS (Massachusetts Comprehensive Assessment System) 4th grade geometry standardized exam, which aligned with the topics covered in the learning activities. Both math tests were given on the paper. Pre tests were given at the beginning of the study to assess the student's mathematics competencies and hence have a baseline (a few days before the experiment started). The post test was used to determine if there had been any improvements in their knowledge of mathematics, immediately after playing the game, or finishing the digital version of the control condition. Students took the math pretest one day, and played the game on the second day, and also took the posttest on the second day.

4.3 Redesign Based on last study

4.3.1 The Android App

During the AfterSchool Program study, we interviewed the students to get their opinions on the game; what they liked about it, what they didn't like about it and what they will change about it. Based on the interviews, I decided on some major changes to implement with a new App. The app is not specific to the Tangrams race, it can be used by any game in the WLCP. The ultimate goal for the app is to make it more user friendly and look like a more modern game environment.

For the purpose of creating this app, I used android studios, which uses xml for the front end and Java to handle the back end. The backend connects to the WLCP Game server via an API.

The WLCPGameServerAPI designed in collaboration with Matthew Micciolo, uses the STOMP (Simple Text Oriented Messaging Protocol) which is non-language specific. Multiple developers can use different languages and still be able to send and receive messages. The WLCPGameServerAPI provides a client interface to the WLCPGameServer. It does this by using websockets. The API provides a means of interfacing as a client and provides methods to connect and disconnect from the server as well as provide a means to send data to the server such as Button Presses or Input Text. The API also provides a callback interface that allows the client to asynchronously receive data from the server such as text or photos to display on the clients screen or requests for button presses for display on the device.

During our study, we observed that one of the major frustrations the students had was dragging the colors to form the color sequences. We had a few students verbally complain about it and some suggested using styluses to make the dragging easier. To that end, I changed the dragging functionality: I eliminated the dragging of colors to form a color sequence and replaced that with a “push the color” to form a color sequence. I changed the font to be more kid friendly and fun. Each state has different length of texts. In the current WLCP, the font size is fixed. In the new app, I implemented a functionality that changes the size of the font depending on how much text there is in that particular state.

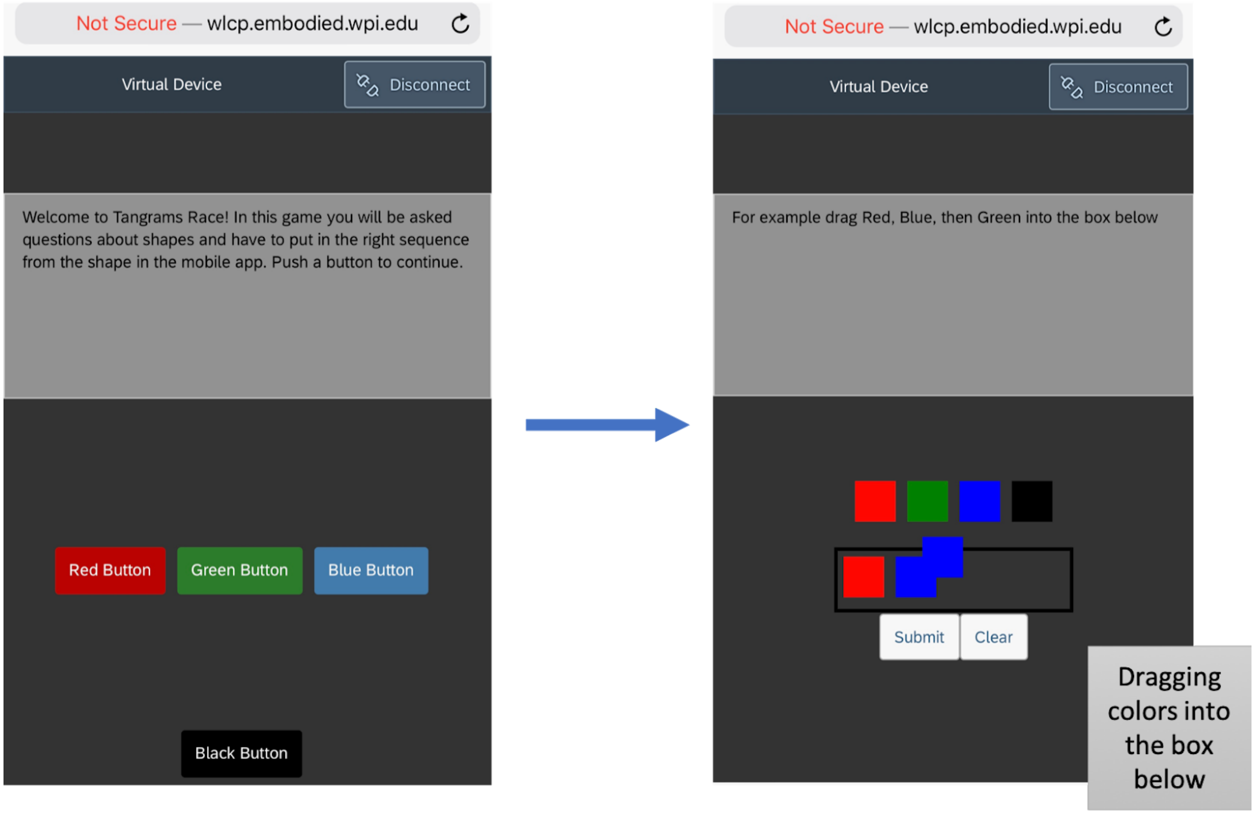

Fig. 5. Current WLCP view of games

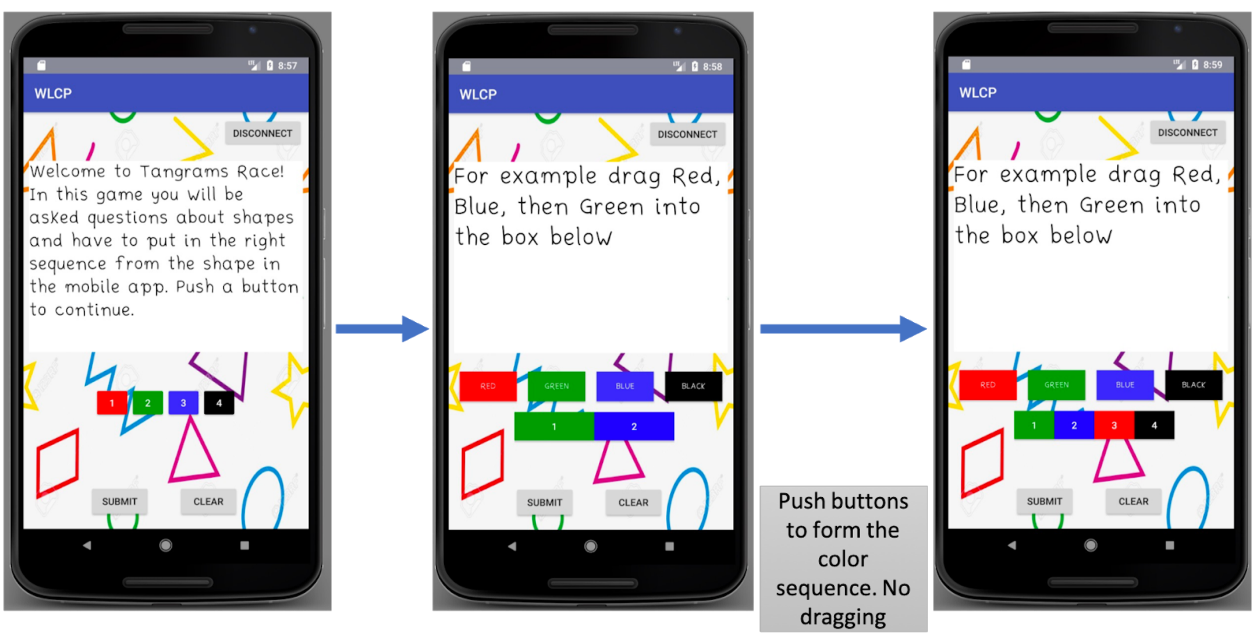

Fig. 6. New app design with the dragging component eliminated, font size adjusted based on text length, friendlier background and font.

4.3.2 Survey for teachers

In order to evaluate whether the new App would be better than what we had before, I surveyed 7 teachers who were part of a Professional Development workshop on WearableLearning.org and had been using the old HTML player. Teachers saw a video of the new App at:
https://www.youtube.com/watch?v=9FD0PgvJRrY&feature=youtu.be

After seeing the App. The questions I asked teachers were:

1. You saw Esther's new APP for our games. Do you think the APP would make the children's experience more enjoyable and engaging?

    Choose one: Yes / No / To some extent. Can you explain why?

2. You saw Esther's new APP for our games. Compared to the Old Tangrams Race on the cell phones, how easy is it to use this new APP?

    Choose one: Easier / Similar / Harder / Can you explain why?

5. RESULTS

5.1 Results of AfterSchool Program study

Table 1 shows mean outcomes for the 3 different conditions: Embodied Game with Small Tangram Pieces (EMB-S), Embodied Game with Large Tangram Pieces (EMB-L), and the Digital Tutoring System, followed by a Virtual Tangram Puzzle on the Computer (DIGITAL). Variables correspond to percent correct score in the pretest and posttest, and mean improvement from pretest to posttest.

Note that the Small Tangram Pieces group (EMB-S) increased by 15.6%, the Large Tangram Pieces group (EMB-L) increased by 14.7% and finally the digital group (DIGITAL) decreased by 4.1%. However, as can be seen in table 1, we had students with various math competencies in all three conditions. Because each student group started with different pretest scores depending on condition, and in order to be fair to this difference, we also computed a Proportional Learning Gain measure, which corresponds to (posttest - pretest) / (100 - pretest). This metric has been used before in many different research studies with similar issues.

Two sets of ANOVAs were computed. The first one predicted Raw Gain, with Pretest as a Covariate, and Condition as independent variables. We found a marginally significant effect for raw learning gain, suggesting that at least 2 of the conditions had different learning gains. Contrasts revealed that the marginal significance is due to the difference between the students in the EMB-L condition and the students in the DIGITAL condition. This implies that there is a marginally significant difference in improvement in math problem solving between the embodied game condition that used Large Tangram pieces, compared to the group that sat on the computer to do the same activity without much physical motion.

The second analysis evaluated the general impact of embodiment on learning, by grouping the students from the two embodied conditions together into a single "embodied" condition. An ANOVA for proportional learning gain with digital/embodied as an independent variable, yielded a significant effect ($p<0.05$) favoring the embodied conditions as opposed to the digital condition (Partial Eta Squared=0.12), and a marginal significant effect for raw learning gain ($p<0.1$, Partial Eta Squared= 0.099). These results suggest a large effect in favor of the embodied conditions, despite the low number of cases.

We can conclude that students who played the *Tangrams race* with both the Small and Large Tangram pieces improved in their mathematics problem solving performance, while the students who had minimal movement did not improve but rather did worse, after 30 minutes of exposure (to either the physically active game or the digital version of the learning experience).

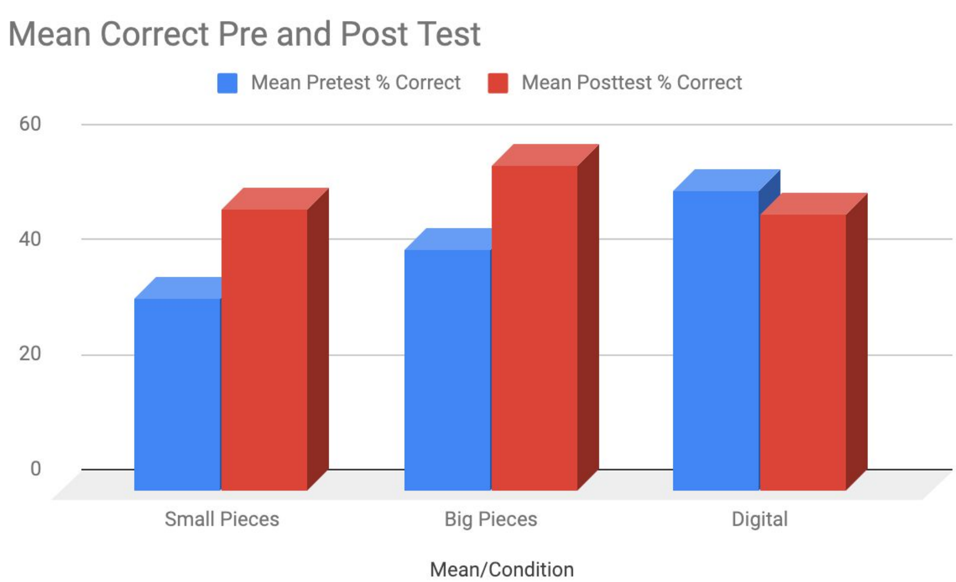

Fig. 7. Mean percent correct answers to the mathematics tests given to each group of students, before and after being exposed to the mathematics learning activities

Table 1. Mean Math Pretest, Posttest, Gains, and Standard Deviations (in parenthesis)

Condition	N	Mean Pretest% Correct	Mean Posttest% Correct	Mean Raw Gain	Mean Proportional Learning Gain
EMB-S	9	33.3 (11.8)	48.9 (23.7)	15.6%	20.3%
EMB-L	9	41.9 (24.2)	56.7 (19.4)	14.7%+	12.5%
DIGITAL	14	52.1 (25.8)	48.1 (26.1)	-4.1%+	-25.9*

**Significance Level for ANOVA Test of Between-Subjects, at $p \leqslant .05$*
+Significance Level for ANOVA Test of Between-Subjects, at $p \leqslant .01$

5.2 Results of App Redesign

From the survey we gave to the teachers from the professional development workshop, the results indicate that indeed students will find the new App more engaging and enjoyable to use than the previous version of the HTML-based player. 85.7% of the teachers indicated that the app is more enjoyable and engaging. The results we got from the teachers regarding how easy the app is to use, about 43% of the teachers think it will be easier to use for the kids. About 29% of the teachers think that the new app is similar to the current WLCP and another 29% didn't have a response to this question.

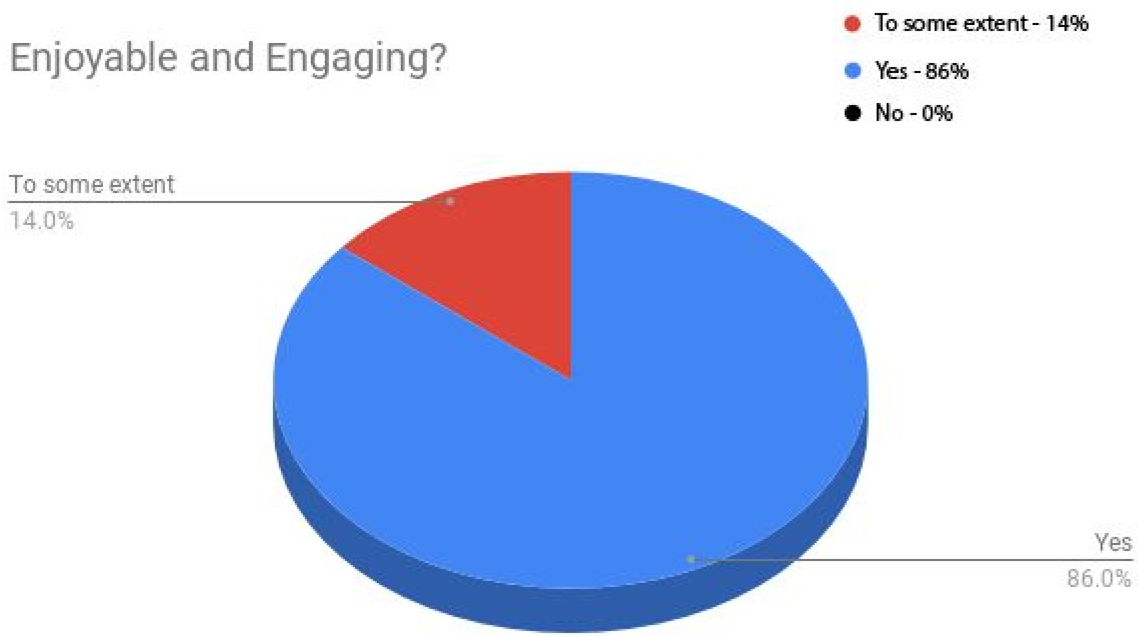

Fig. 10. Chart showing how engaging and enjoyable the new app is perceived by teachers

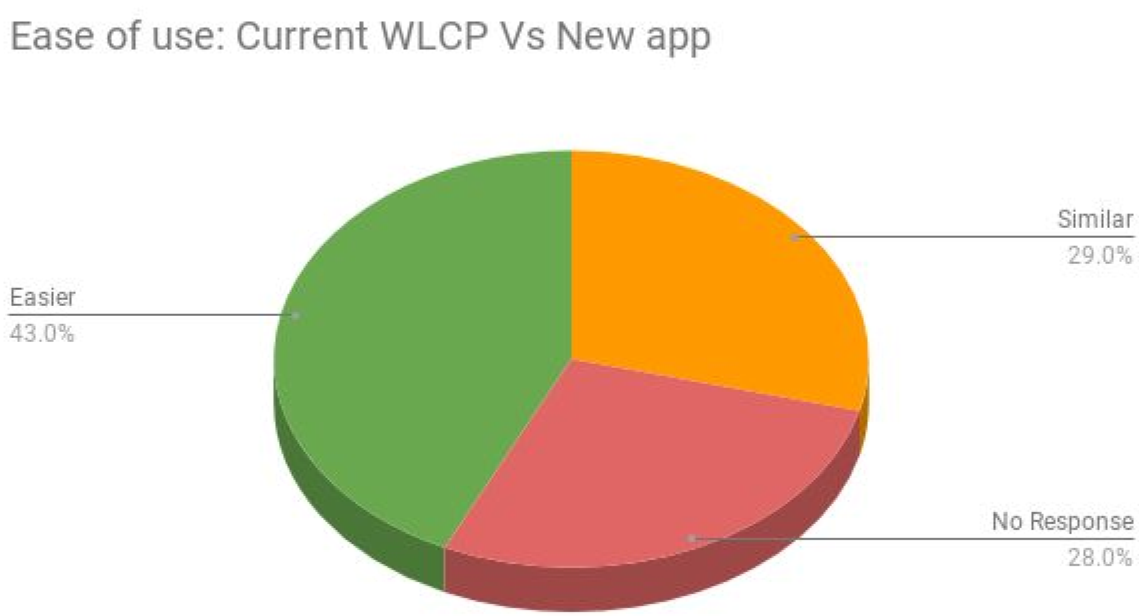

Fig. 11. Chart comparing ease of use of the current WLCP versus the new app is perceived by teachers

One of the teachers from the professional development group that is currently using the WLCP showed her students the new app design and asked them to critique it. They loved the new look and feel of the new app but they had some suggestions for further improvement:

1. Less text to read;
2. Sound to indicate answering a question correctly like “hooray!”;
3. Read aloud of all the text displayed.

6. DISCUSSION

The results indicate a significant advantage for the Embodied Conditions over the Digital "sitting down" condition. However, a major question regarding the results is what could explain why the control group did even worse in the posttest than the pretest, rather than just staying at the same level if they did not learn at all. A few possibilities are that: a) Maybe students in the *MathSpring* condition just flunked the posttest --students do not like taking posttests in general, however why would these students do it while not the other students in the two experimental embodied conditions?; b) Maybe there is a difference mediated through engagement: students in the embodied condition might have been excited during the Tangrams Race game and that affected their posttest performance, while maybe students in the digital condition did not pay much attention while answering questions on *MathSpring.org*, and were disengaged during the activity (maybe they did not seek for help, maybe they did not enjoy the activity, showing a metacognitive or affective failure), and that disengagement translated into the posttest. In the digital group, the students were not required to physically find shapes based on clues given to them, because of that, most of them ended up guessing and selecting all the options until they selected the right answer. Mathspring showed the information for each student and it shows this disengaged behavior; c) Because students do not like to take posttests, maybe the means of all groups are deflated, and the improvement for the Tangrams race is actually more than what is shown in the results; this would imply a real benefit for the embodiment and physical action with hands-on materials in the experimental conditions, over the digital "sitting down" condition; d) all of the interventions are able to raise students up to a comparable level of performance, with the digital students being already at that level on the pretest.

Table 2. Mean Engagement of students in the DIGITAL condition.

Kind of Behaviors	Behaviors in a math problem	Mean % (across 14 students)	Mean % Engagement
Engagement Behaviors	SOF	44%	68%
	SHINT	11%	
	ATT-SC	13%	
Disengagement Behaviors	GUESS	9%	29%
	SKIP	12.5%	
	GIVEUP	0%	
	NOTR	7.6%	

SOF=Solved Correctly on First Attempt; **SHINT**=Solved correctly after seeing hints (and making mistakes); **ATT-SC**=Student attempted incorrectly, and self-corrected after one incorrect attempt; **GUESS**=Student quick guessed until they got the right answer, 2 incorrect attempts or more; SKIP=Student skipped the problem, did not start working on it; **GIVEUP**=Student started working on problem but Gave up in the middle and moved on; **NOTR**= Student answered too fast to even have read the problem

In order to consider the first possibility (a) and the last possibility (d), we discarded the top and bottom 5th percentiles of students according to their pretest score, to further even out the scores of the groups at pretest time; however, results still yielded a marginal significant effect in favor of the embodied conditions ($p<0.1$, Partial Eta Sq.=0.1), despite the lower number of cases ($N=26$); thus we don't believe the effect is simply because of students starting at different places, as the effect size is still large.

To analyze possibility (b), we considered whether students had been disengaged inside of the DIGITAL version. The figure below gives a summary of the students' behavior while they were using *MathSpring.org.* This shows that students were somewhat disengaged (29% of the time) while using the MathSpring.org software. Students used the hints 11% of the time on average, almost the same percent of the time that they quick-guessed, or skipped a problem. Unfortunately, we only have anecdotal evidence for comparison of engagement in the Tangrams Race (videos of students playing), which showed students were incredibly engaged as using the Tangrams Race. Logging of user events in the Wearable Learning Cloud Platform, to analyze behaviors such as those displayed in Table 2 for MathSpring.org is currently under development, and should allow for a much more detailed understanding of students' cognitive and affective processes as they are involved in math learning activities.

Given the evidence presented, we conclude that the Embodied Conditions performed better than the stagnant DIGITAL condition, probably due to both the physical activity (physical rotations of figures, cognitive conflict resolved by help use, as well as collaborative discussions), and probably because a high level of engagement that was observed during the Tangrams Race conditions.

We discovered that while playing the game, some of the students were not vast in some of the terminologies used in the shape descriptions and the hints. Even though the hints were designed to use real life objects to explain those terminologies, such as explaining that parallel are like train tracks, they travel in the same direction, but they never cross each other. It was still a little difficult for some of them to grasp. In for them to continue playing the game we had to use some hand gestures to explain.

This has already been enhanced in the system, and now the games themselves can show students gestures similar to the one shown in Figures 8 and 9. Also, a research study is currently being run to test on the potential benefit of these images over text-based explanations.

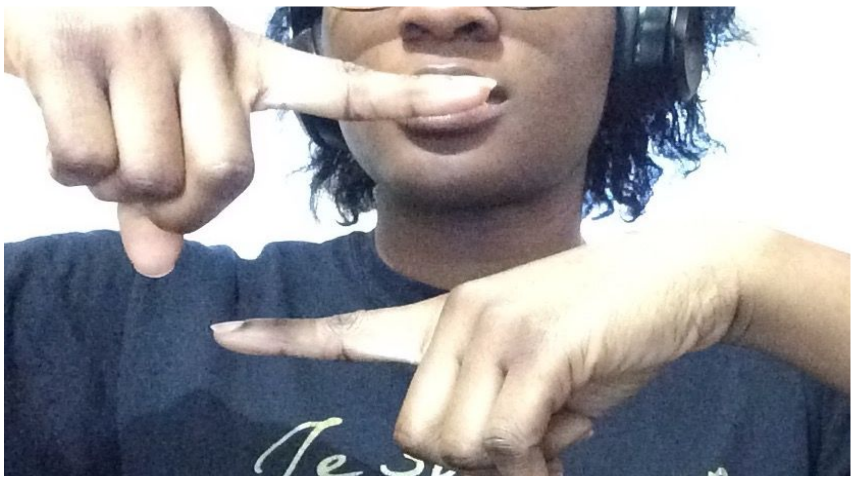

Fig. 8. Hand gesture used to explain parallel lines

Fig. 9. Hand gesture to show a right angle

With regards to the new app, and the results from the teachers, the second question didn't get as many responses as I hoped for. In hindsight, I can see how the questions may have been misleading. In addition to selecting one of the options given to them, they made comments that suggested that the question was misleading.

7. FUTURE WORK AND CONCLUSION

The goal of this study was to determine whether learning technologies that support motor action-based math games and learning activities can improve math learning, and whether adding physical activity and hands-on motor actions (both gross and fine motor) to traditional learning technologies can improve Math learning. We also were interested in whether varying the materials, which would change the motor action level might affect learning. Last, we also wanted to determine ways in which these learning technologies might be improved to better facilitate learning. We have been able to get results to help to start answering these questions. We will now go through each of these research questions and give a summary of the results we found for each.

In answer to our research question of "Can Learning Technologies that support Motor Action-based math games help to improve math understanding?" the results drawn from the mathematics pre and post test analysis suggest that the Tangrams Race implemented and deployed through wearablelearning.org can and does improve math learning, after 30 minutes of being involved in the math learning activities that we designed, aided by mobile devices. The students who played the game with the Small Tangram Pieces (EMB-S) increased by 15.56%

and the students who played the game with the Large Tangram Pieces (EMB-L) pieces increased by 14.73%, from before to after playing the game, in reliable standardized test math questions that were related to the mathematics topics addressed by the educational game.

With regards to which might be the best level of motor action to improve student learning, we initially thought there might be a difference between the two sizes of shapes, as this might impact the salient features of objects and the physical rotations of objects, which might end up transferring into mental rotations that are necessary to master and solve geometry problems. However, the difference in math gains between the Small Tangram Pieces group (which mostly had students use finger motions as the pieces were small) and the Large Tangram Pieces (which predominantly involved students using coarse-grained hand motions to rotate the pieces, which were larger than a hand) was not significant. Thus, we decided to combine the students in the Small Tangram Pieces and Large Tangram Pieces condition into a single "Embodied" condition. From the results, we observed that the embodied group gains were higher than the digital group gains --who actually did not improve in their math problem solving at all after the 30 minutes of exposure in the digital version of the game. We conclude that the Tangrams Race, which incorporates important motor actions as part of the game, can play a part in improving student learning of 4th-5th grade Geometry.

The *wearablelearning.org* web site is still under implementation. Thus, the Tangrams Race, as implemented in the WLCP was not too kid friendly (only text based, the font was small). Based on the feedback we obtained from students about their experience playing the game, there are a few improvements that can be made, according to them, gathered from informal interviews after playing the game. One of those improvements regards making the variety and forms of input types much easier to use for kids, such as adding QR codes and RFIDs for easy input after scanning the environment (dragging colors required some kind of dexterity and precision that was somewhat challenging for them, at least given the size of the colored blocks to be dragged to construct the desired color code). Something else that students suggested would improve the experience is the ability to show pictures and visuals in the phones. We think this would probably also increase engagement further, and especially lead to more effective and constructive hints and support that could visually show important features of the shapes being sought for. We believe that the games designed and implemented through the *wearableleearning.org* technology have the potential to improve further by including adaptive and personalised item selection, varying the challenge of each question to the ability of the student. With that personalization, students' learning should be improved further, as students would be able to get through the material at their own pace and in the best way that works for them [9].

Regarding the second research question, there was at least a marginally significant difference (and a large effect size) between the embodied conditions and the digital "sitting down" condition, even after making the groups even at pretest time by discarding students who were outliers in pretest scores. However, follow up studies should be conducted to continue to explore the difference between embodiment and digital conditions, with a larger number of students. Despite the fact that the N (number of participants) were not that many, we observed that Embodied Learning Technologies have an advantage over Digital "sitting down" Learning Technologies. However there are still unanswered questions about how these two Learning

Technologies compare to each other, so I propose a follow up study with a much larger N (number of participants) and a more efficient way to motivate students to take the post test seriously. One thought can be to run the study as part of a classroom activity. That way, it is part of their school work, they will certainly be motivated. Also, it is understandable that running a study for math in an afterschool program means working with tired students who don’t want to do anything that resembles “school work”.

With regards to the app development, I would like to expand the follow up studies to involve using the current WLCP Game Player view and then introducing the new app in order to get feedback about the app from a student’s perspective. I will like to see the app continue to be developed and made better. Eventually, an iOS version of the game will be made to accomodate iPhone and iPad users.

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APPENDIX A
Pretest

Tangrams Race

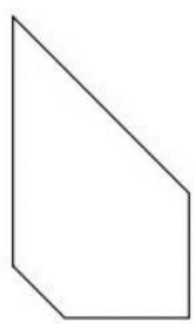
Pretest

Name:____

Please answer the following questions as best as you can. If you don’t understand the question, please put an X next to the question.

This test should take roughly 15 minutes to complete.

1. Britney has the shape shown.



What is the total number of right angles Britney’s shape appears to have?

a. 0
b. 1
c. 2
d. 3

2. Gianna drew an X on two sides of a triangle, as shown below.

Which statement is true about the sides that Gianna drew an X on?

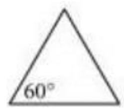
a. The sides are parallel.

b. The sides are perpendicular.

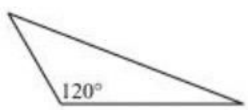
c. The sides form an acute angle.

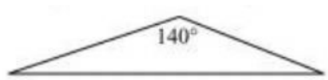
d. The sides form an obtuse angle.

3. Which of these is a right triangle?

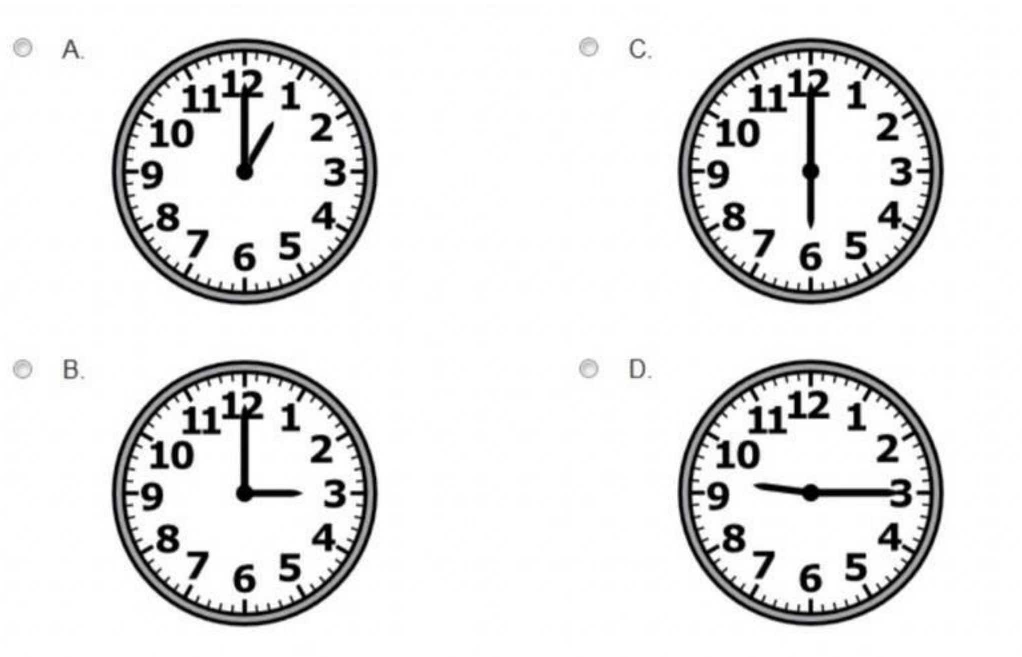
a. 

b. 

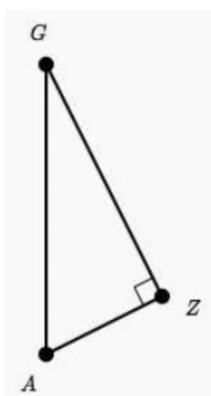
c. 

d. 

4. On which clock do the hands show a 90° angle?



5. Which of the following pairs of sides in Δ GAZ are perpendicular?



Choose 1 answer:

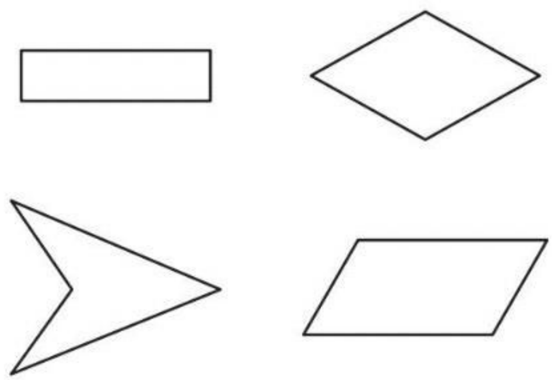
a. $\overline{GA}$ *and* $\overline{AZ}$

b. $\overline{AZ}$ *and* $\overline{GZ}$

c. $\overline{GA}$ *and* $\overline{GZ}$

d. No sides are perpendicular

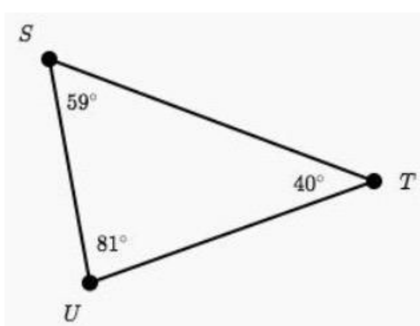
6. Mr. Jacobs showed these shapes to his class.



Which word describes **all** of the shapes?

a. Squares
b. Triangles
c. Rectangles
d. Quadrilaterals

7. Classify Δ STU by its angles.



a. Acute
b. Obtuse
c. Right

8. Which TWO of the following shapes are quadrilaterals?

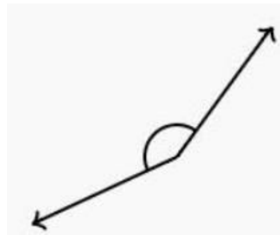
a. 

b. 

c. 

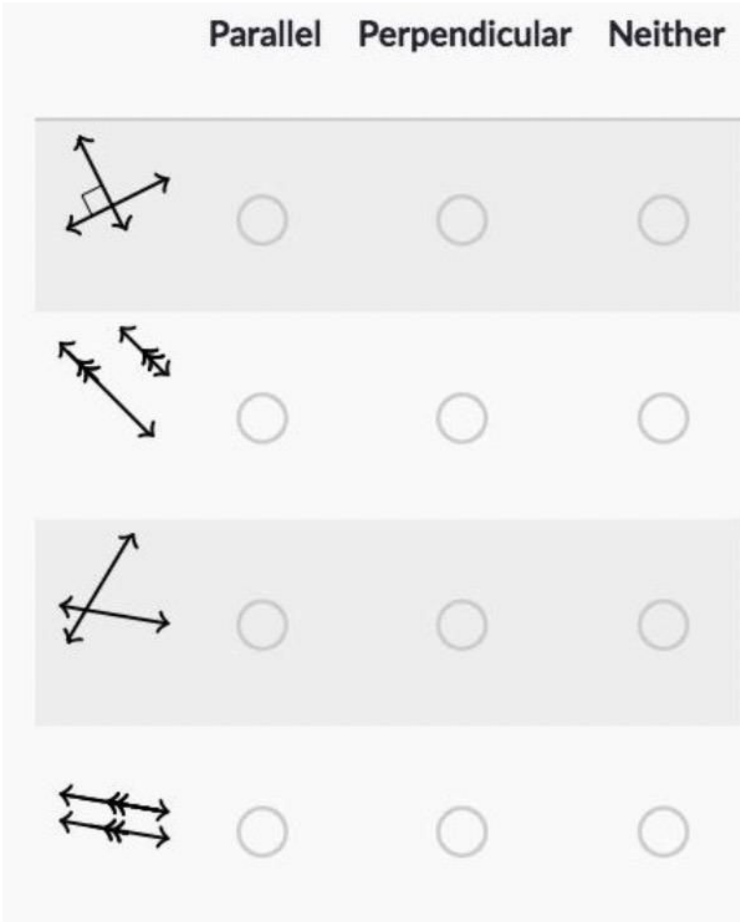
d. 

9. Is the following angle acute, right obtuse or straight?



   a. Acute
   b. Right
   c. Obtuse
   d. Straight

10. Is each pair of lines parallel, perpendicular, or neither?



APPENDIX B
Post test

Tangrams Race

Post Test

Please answer the following questions as best as you can. If you don't understand the question, please put an X next to the question.

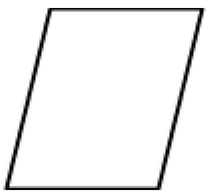
This test should take roughly 15 minutes to complete.

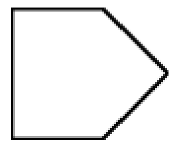
1. Ms. Curran wrote three clues about a shape, as shown in this box.

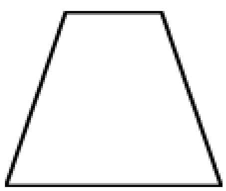
Clues

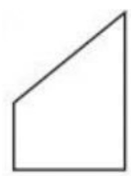
- It is a quadrilateral.
- It has two right angles.
- Two of its sides are parallel.

Which of the following shapes matches all three clues?

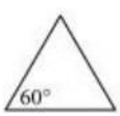
a. 

b. 

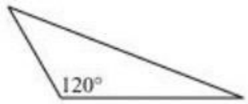


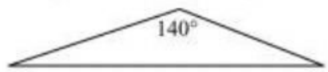
d. 

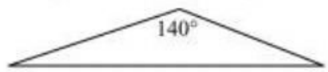
2. Which of these is a right triangle?

a. 

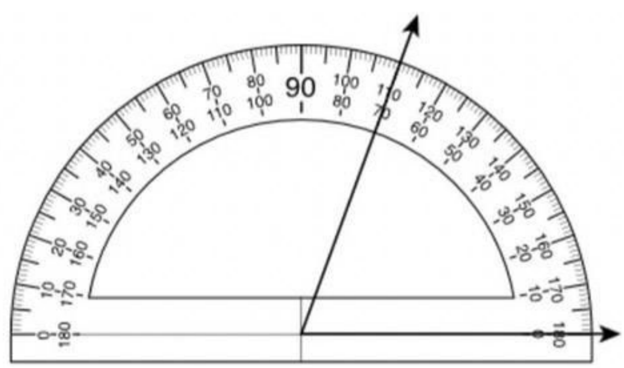
b. 

c. 

d. 

e. 

3. Kelly drew the angle shown.



Which value is closest to the measurement of Kelly's angle?

a. 40°

b. 70°

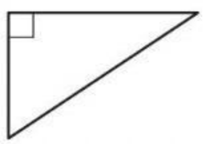
c. 110°

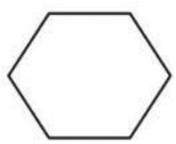
d. 180°

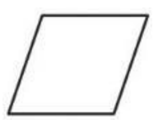
4. Which **three** shapes appear to have at least two parallel sides?

a. 

b. 

c. 

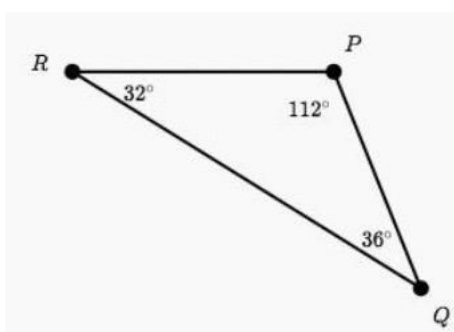
d. 

e. 

5. Which statement about the Marunouchi Line and the Yurakucho Line is correct?

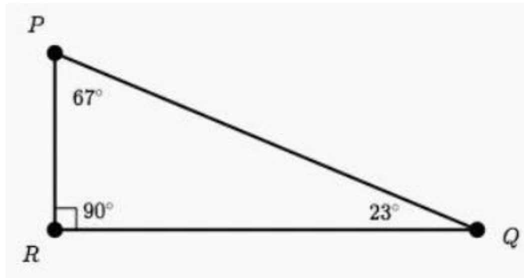
a. The Marunouchi Line is parallel to the Yurakucho Line
b. The Marunouchi Line is perpendicular to the Yurakucho Line
c. The Marunouchi Line is neither parallel nor perpendicular to the Yurakucho Line

6. Classify Δ PQR by its angles.



a. Acute
b. Obtuse
c. Right

7. Classify Δ PQR by its angles.

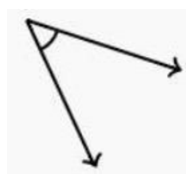


a. Acute

b. Obtuse

c. Right

8. Is the following angle acute, right obtuse or straight?



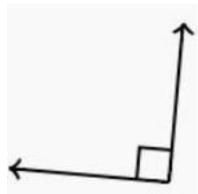
a. Acute

b. Right

c. Obtuse

d. Straight

9. Is the following angle acute, right obtuse or straight?



   a. Acute
   b. Right
   c. Obtuse
   d. Straight

10. Which if the statements below describe a square?
    a. A square has 4 equal sides and 4 right angles.
    b. A square has only two equal sides
    c. A square has only two right angles
    d. None of the above

APPENDIX C
Tangrams race Questions and Hints

Tangrams Race Messages

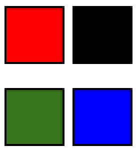
Team Count : 1
Players Per Team : 3

Game Wide Start Instructions:
Welcome: Welcome to Tangrams Race! In this game you will be asked questions about shapes and have to put in the right sequence from the shape in the mobile app. Push a button to continue.
Button Press: Any press (single press)

Example: For example drag RBG into the box below.
Keyboard Input: RBG

Right Answer: That was the right sequence! Push a button to continue..
Button Press: Any press

Wrong Answer: That was not the right sequence, push any button to try again!
Button Press: Any press



Level 1:

Level 1: Welcome to level 1! You will be given a description of a shape. You need to run across the room to the basket containing the shapes and find the shape that fits the description. Now wait for the organizer to tell you when to start.

Button Press: Any press

First Run

Team 1 Player 1:

Object: Square

Question

Message: I have four equal sides. Drag the black box for a hint

Sequence: RBG

Hint

Message: "This is a squ.." Push the blue button to continue

Button Press: Blue

Correct

Message: Yes you are right! This shape is called a square. Push the green button to continue.

Button Press: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Button Press: Red

Team 1 Player 2:

Object: Triangle

Question

Message: I have 3 sides, with three corners and 3 angles. Drag the black box for a hint.
Sequence: BRG
Hint
Message: This is a tri… Push the blue button to continue
Button Press: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Button Press: Green
Wrong
Message: Oops! That is not correct, push any button to continue.
Button Press: Any Press

Team 1 Player 3:
Object: Triangle
Question
Message: I have 3 sides, with three corners and 3 angles. Drag the black box for a hint.
Sequence: BRG
Hint
Message: This is a tri… Push the blue button to continue
Button Press: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Button Press: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Button Press: Red

Second Run
Team 1 Player 1:
Object: Triangle
Question
Message: I have 3 sides, with three corners and 3 angles. Drag the black box for a hint.
Sequence: BRG
Hint

Message: This is a tri… Push the blue button to continue
Button Press: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Team 1 Player 2:
Object: Parallelogram
Question
Message: I am a 4-sided shape with opposite sides parallel and no perpendicular lines. Drag the black box for a hint.
Sequence: GRB
Hint
Message: The opposite sides are parallel which means the lines go in the same direction but they never cross each other like rails on train tracks!
Perpendicular lines means when two lines meet, they form a 90 degree angle.
Remember this shape has NO perpendicular lines, the shape looks like this /__/
Push the blue button to continue
Sequence: Blue
Correct
Message:You got that right! This shape is a parallelogram. Push the green button to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Team 1 Player 3:
Object: Rectangle
Question

Message: I am a 4-sided shape with two opposite sides equal in length and 4 right angles. I have two long sides and two short sides. Drag the black box for a hint.
Sequence: RGB
Hint
Message: Right angle means each corner is 90 degrees. This shape is like a square but it has two equal long sides and two equal short sides. Push the blue button to continue
Sequence: Blue
Correct
Message: You got that right! This shape is a rectangle. Push the green box to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Third Run

Team 1 Player 1:
Object: Rectangle
Question
Message: I am a 4-sided shape with two opposite sides equal in length and 4 right angles. I have two long sides and two short sides. Drag the black box for a hint.
Sequence: RGB
Hint
Message: Right angle means each corner is 90 degrees. This shape is like a square but it has two equal long sides and two equal short sides. Push the blue button to continue
Sequence: Blue
Correct
Message: You got that right! This shape is a rectangle. Push the green button to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to continue.
Sequence: Red

Team 1 Player 2:

Object: **Triangle**

Question

Message: I have 3 sides, with three corners and 3 angles. Drag the black box for a hint.

Sequence: BRG

Hint

Message: This is a tri… Push the blue box to continue

Sequence: Blue

Correct

Message: You got that right! This shape is a triangle. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to continue.

Sequence: Red

Team 1 Player 3:

Object: **Triangle**

Question

Message: I have 3 sides, with three corners and 3 angles. Drag the black box for a hint.

Sequence: BRG

Hint

Message: This is a tri… Push the blue box to continue

Sequence: Blue

Correct

Message: You got that right! This shape is a triangle. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to continue.

Button Press: Red

Check:

Message: At this point, your team should have 9 shapes. If you don't, let the instructor of the game know and they can help you out. If you have 9 shapes, push any button to continue. Everybody in your team should do the same!

Sequence (9 shapes): Any Press
Sequence (instructor): RED, BLUE (This should take them back to the beginning of the level to check what shapes have been gotten and do a quick rescanning to find what the missing shape(s))

Put the shape together
Message: Now that you have all the pieces you need, work together to recreate the shape in the picture given to you. When done, ask the instructor to verify and then you can press any button to continue.
Button press: Any Press

Level 2:

Message: Welcome to level 2! You will be given a description of a shape. You need to run to the basket containing the shapes and find the shape that fits the description. Press Any button to continue when you are ready to start!

Button Press: Any Press

First Run

Team 1 Player 1:
Object: Triangle
Question
Message: I have three sides and three angles. One of my angles is a 90° angle (right angle) and the other two are acute angles. Drag the black box for a hint
Sequence: BRG
Hint
Message: Right angle means one corner forms a 90 degree angle. Acute angle means that the angle is less than 90 degrees. I am a tri… push the blue button to try again.
Sequence: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Sequence: Green
Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to continue.
Sequence: Red

Team 1 Player 2:

Object: Parallelogram

Question

Message: I am a 4-sided shape with opposite sides parallel and no perpendicular lines. Drag the black box for a hint.
Sequence: GRB

Hint

Message: The opposite sides are parallel which means the lines go in the same direction but they never cross each other like rails on train tracks!
Perpendicular lines means when two lines meet, they form a 90 degree angle.
Remember this shape has NO perpendicular lines, the shape looks like this /__/
Push the blue button to continue
Sequence: Blue

Correct

Message: Yes you are right! This shape is called a parallelogram. Push the green button to continue.
Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Team 1 Player 3:

Object: Triangle

Question

Message: I have three sides and three angles. One of my angles is a 90° angle (right angle) and the other two are acute angles. Drag the black box for a hint
Sequence: BRG

Hint

Message: Right angle means one corner forms a 90 degree angle. Acute angle means that the angle is less than 90 degrees. have three sides and three angles. I am a tri… push the blue button to try again.

Sequence: Blue

Correct

Message: You got that right! This shape is a triangle. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Sequence: Red

Second Run

Team 1 Player 1:

Object: Square

Question

Message: I am a quadrilateral, all my sides are equal and my opposite sides are parallel.

Sequence: RBG

Hint

Message: A quadrilateral means a 4 sided shape. Parallel means the lines go in the same direction but they never cross each other like rails on train tracks!

This shape has two sets of parallel lines, and remember that all sides are equal. Push the blue button to try again.

Sequence: Blue

Correct

Message: Yes you are right! This shape is called a square. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Sequence: Red

Team 1 Player 2:

Object: Triangle

Question

Message: I have three sides and three angles. One of my angles is a 90° angle (right angle) and the other two are acute angles. Drag the black box for a hint

Sequence: BRG

Hint

Message: Right angle means one corner forms a 90 degree angle. Acute angle means that the angle is less than 90 degrees. I am a tri… Push the blue button to try again.

Sequence: Blue

Correct

Message: You got that right! This shape is a triangle. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Sequence: Red

Team 1 Player 3:

Object: Rectangle

Question

Message: I am a quadrilateral, not all my sides are equal, only my opposite sides are equal. I have two perpendicular lines and two parallel lines.

Sequence: RGB

Hint

Message: A quadrilateral is a 4 sided shape. Perpendicular lines: when 2 lines in a shape meet, they form a 90 degree angle. Parallel lines: lines that go in the same direction but never cross each other like rails on train tracks! This shape is like a square.

Sequence: Blue

Correct

Message: You got that right! This shape is a rectangle. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Sequence: Red

Third Run

Team 1 Player 1:

Object: Triangle

Question

Message: I have three sides and three angles. One of my angles is a 90° angle (right angle) and the other two are acute angles. Drag the black box for a hint
Sequence: BRG
Hint
Message: Right angle means one corner forms a 90 degree angle. Acute angle means that the angle is less than 90 degrees. I am a tri… push the blue button to try again.
Sequence: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Team 1 Player 2:
Object: Triangle
Question
Message: I have three sides and three angles. One of my angles is a 90° angle (right angle) and the other two are acute angles. Drag the black box for a hint
Sequence: BRG
Hint
Message: Right angle means one corner forms a 90 degree angle. Acute angle means that the angle is less than 90 degrees. I am a tri… push the blue button to try again.
Sequence: Blue
Correct
Message: You got that right! This shape is a triangle. Push the green button to continue.
Sequence: Green
Wrong
Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.
Sequence: Red

Team 1 Player 3:
Object: Trapezoid

Question

Message: I am a quadrilateral with 1 pair of parallel sides but not equal sides. I have no right angles.

Sequence: GBR

Hint

Message: I have a pair of opposite sides that are parallel. I am a tra...

Sequence: Blue

Correct

Message: Yes you are right! This shape is called a trapezoid. Push the green button to continue.

Sequence: Green

Wrong

Message: Oops! That is not correct, please return this shape back to the basket and look for the right shape that matches the description. Push the red button to try again.

Sequence: Red

APPENDIX D
New app code