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AN INTERACTIVE SPATIAL ABILITY TRAINING APPROACH FOR STEM EDUCATION

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ABSTRACT
While governments around the globe have been promoting science, technology, engineering, and mathematics (STEM) education for years, reports are pointing out the difficulties in learning for students. In response to the urge to improve the STEM education approach raised by society, numerous scholars proposed providing spatial ability training to students could be a possible solution. While spatial ability, especially mental rotation, has been proven by numerous researchers to be essential for success in STEM education, yet the implementation of spatial ability training in STEM education is still absent or insufficient. Our study focuses on proposing a spatial training approach with physical elements. This paper will discuss our attempts at converting the spatial training assignment into a physical educational toy. With our tests conducted in assessing the spatial ability before and after using our educational toy, we may conclude the success and limitation of the toy in improving a person's spatial ability. Thus, we propose conducting similar research with a larger sample size and try recreating a similar result to prove the success of our toy Turnit-In.

Keywords: Spatial ability, primary education, STEM, mental rotation learning of geometry

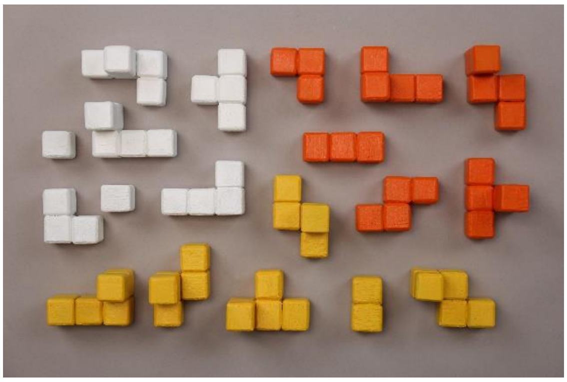

Figure 1. Turnit-In Final Design

1 INTRODUCTION
It is said that primary education is a crucial phase for a child's growth. During the primary education, different basic skills would be taught which are all essential for achieving comprehensive development in the future. Primary school learning goals should seek to perpetuate students' whole-person development, which includes improving students' language proficiency, strengthening their self-directed learning skills, developing their potential, and assisting them in adopting a healthy lifestyle. By going through all the levels of teaching, the child would become more independent and capable of handling their future study or personal development.
However, Hong Kong is widely recognized as an *exam-oriented place*, Hong Kong students are known for their lack of retention, creativity, life skills and communication. By receiving the cramming education, children are told to "recite" their learning material without thinking and understanding. They are not allowed to explore the outside world. Hindering other aspects of development can be destructive to children, children studying under the exam-oriented education system will result in low-stress tolerance and poor interpersonal relationships, further leading to stress, anxiety, and fear problems.

An interdisciplinary teaching approach named Science, Technology, Engineering and Mathematics (STEM) might be a cure to change this problematic situation. As a problem solving-based model, STEM requires the students to design and develop their knowledge, thus applying it to solve the real problem. Meanwhile, the academic ability is trained up and their mental strength as going through the trials and errors strategies that make them adapt to work with failures and mistakes and hence become more capable of working under pressure. The following chapter will discuss how STEM can apply better to the current situation.

2 OBJECT DESIGN

Research has already shown the significant benefits of spatial and mental rotation ability to STEM education, yet we believe the existing training methods are often test-orientated and not entertaining. Therefore, our study proposes an improved physical spatial ability training tool that appeals to children.

2.1 STEM educational tools

By inspecting the existing STEM educational tools in the market, we may understand the limitations of current STEM products in spatial ability training. To study the effectiveness and success of a STEM product, we propose six criteria in measuring: visual appeal, replay-ability, product complexity, problem difficulty, spatiality, and interaction between players. Through our market research, we discovered that existing STEM products lack interaction among players and generally have a lower spatiality level. In order the improve the spatial and mental rotation ability among primary one to three students, we believe we must enhance the spatiality aspect. With more opportunities for interaction among players in toy playing, students may also improve their spatial presentation skills.

Figure 2. STEM educational tools

2.2 Soma Cube

During our market research, we discovered Soma Cubes can be a foundation for our design to improve one's spatial and mental rotation ability. Piet Hein designed the Soma Cube in 1933. It is an irregular shape created by putting three or four identical cubes together on various faces. There are seven distinctive Soma Cubes, two of which are mirror images. It contains six tetracubes and one tricube, which can be put together in 240 distinct ways to form a 3x3x3 cube with a total of 27 unit-cubes.

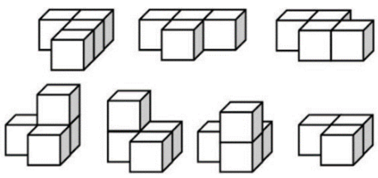
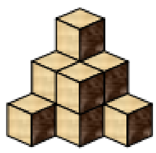

Figure 3. Seven distinct Soma Cubes (L); Figure 4. Example of Soma Cube combination (R)

Soma Cube has different combinations of building methods, for example, a sofa, a chair, a castle, a tunnel, a pyramid. A lot more combinations can be formed, in the process of variety, need to use spatial and mental rotation ability. For example, if only one can use three soma cubes to build the solid shape in figure 1, one needs to imagine the front, side, top views of the reference figure and find out three of the soma cubes can match, requires spatial and mental rotation ability.

2.3 Advance

To propose a toy to develop spatial and mental rotation ability for primary one to three students, the difficulty of basic Soma Cube set is easy to handle. In addition to the standard set of Soma Cubes, other combinations of Soma Cubes represent different difficulties. For example, using only four Soma Cubes in figure 2 can be combined into a 3x3x3 cube.

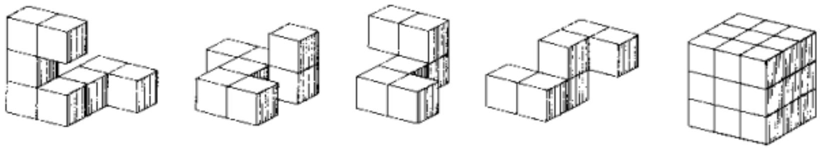

Figure 5. Example of 3x3x3 Soma Cubes advance combination.

However, different combinations of Soma Cubes in 3x3x3 cubes are not enough to develop into a toy; the final proposal of the combination is to change from 3x3x3 cubes to 5x5x5 cubes. Figure 3 is a 5x5x2 cubes combination.

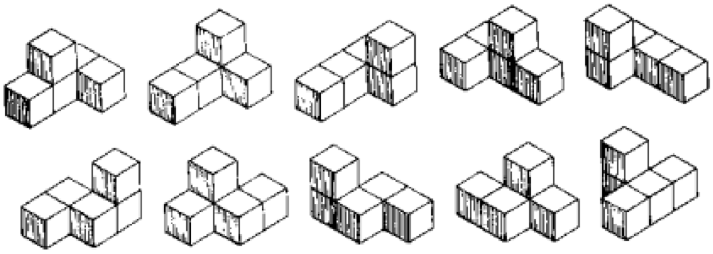

Figure 6. Example of 5x5x2 Soma Cubes advance combination.

We found inspirations from the Soma Cubes' form, thus elaborate its playstyle by enriching the spatial ability and balancing training content. We then modified the combinations of blocks to increase the complexity and playability. Our toy consisted of 2 sets of 5x5x2 cubes combination and 1 set of 5x5x1 cubes referenced from the basic Soma Cube set, in total 28 items of 3D objects, providing more possibilities for children to develop their combinations. To prove the effectiveness of our design, we conducted an experiment and compare the spatial and mental rotation ability of our participants before and after two weeks of the experiment.

3 METHODOLOGIES

3.1 Participants

We gathered 12 children to participate, ages from 7- to 10-year-olds, with 7 boys and 5 girls. The sample was predominantly Asian children in Hong Kong. All the participants are from primary one to primary three students. In that 12 children, 4 boys and 2 girls, have STEM school backgrounds, and the other 3 boys and 3 girls do not.

3.2 Material

The material of the experiment included a spatial and mental rotation ability training toy and two tests based on existing spatial and mental rotation ability questions as a task for participants to solve personally. To provide a tool to help participants learn spatial and mental rotation, a toy, Turnit-In, is designed by us to train the spatial and mental rotation ability. Turnit-In consisted of 28 items of 3D objects, one set of cards about the front, side, top of 3D objects. Two of the participants in one group play the Turnit-In. Before and after two weeks of training with Turnit-In, we would provide players with a spatial and mental rotation ability test for recording the data, mainly including the time-taken and the accuracy of the test. We used the mental rotation test proposed by Vandenberg and Kuse (1978) for the experiment. The test consists of 24 items of 3D objects (two sets of 12 each). Each item is made up of four target figures on the right and one reference Figure 4 on the left. The participants were instructed to find the two right choices that were identical to the reference figure on the left.

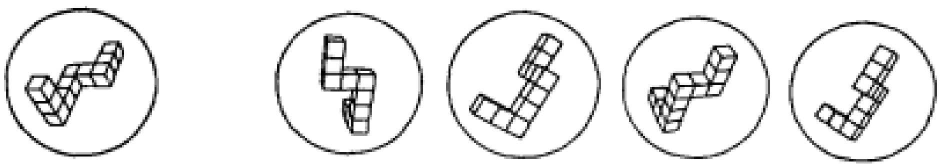

Figure 7. Example of mental rotation test sample items from Vandenberg and Kuse (1978).

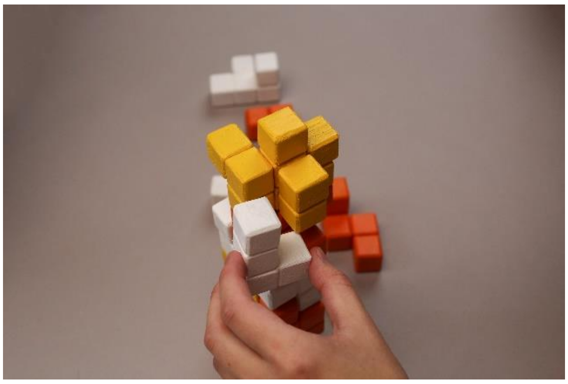
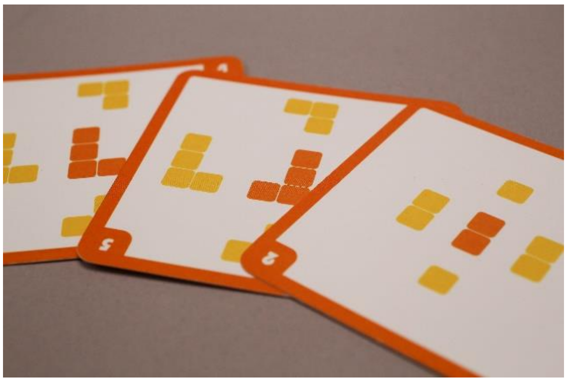

Figure 8. Game demonstration of Turnit-In (L); Figure 9. Cards of Turnit-In (R)

3.3 Testing

We provided the mental rotation test proposed by Vandenberg and Kuse to primary school students, and we discovered the difficulty of the test was challenging for primary one to three students in Hong Kong. To adjust the test's difficulty, we proposed that each item is made up of three target figures on the right and one reference figure on the left. The participants were instructed to find the one right choice identical to the reference figure on the left.

3.4 Procedure

Participants were asked to do the experiment in a studio. Children first received a spatial and mental rotation ability test provided individually. The test needed to count the time taken and the accuracy before playing Turnit-In. When the children finished the first test, they were separated into six groups, two in one group to play Turnit-In. Children were asked to draw a card randomly to get a front, side, top view of the parts. Recognize the part that matches the card and stack the parts up, from the base plate. Trying to balance and construct the taller blocks. The one whose blocks fall is considered a loser. The children would be asked to play three times per day, three days per week, Monday, Wednesday, and Friday, the toy given would let the children play two weeks in the studio. The children came after school and played with their partners. After two weeks of training with Turnit-In, the children were asked to do the spatial and mental rotation ability test again with different questions again. Collecting the data of the time taken and the accuracy again. Comparing the pre-test and post-test of playing Turnit-In data to analyse if there is any improvement of the children spatial and mental rotation ability.

4 DATA & ANALYSIS

In this study, 12 local students studying in primary school in the academic year 2021- 22 were selected in the age groups of seven to ten years old (P1 - P3) as the samples. Half of the students are from STEM approach school while the remaining half is from or non-STEM approach school. The accuracy and the time taken for both pre-test and post-test is recorded in Table 1. The description and analysis of the data will be included in section 4.1.

Table 1. Result of pre-test and post-test of 12 participants

STEM School	Pre-Test		Post-Test	
	Accuracy	Accuracy	Accuracy	Accuracy
P1	0	05:36	1	06:01
P1	1	06:41	1	06:13
P2	2	05:12	2	04:54
P2	3	04:03	2	03:58
P3	2	03:29	3	03:20
P3	4	04:10	4	03:58
Non-STEM School	Pre-Test		Post-Test	
	Accuracy	Accuracy	Accuracy	Accuracy
P1	0	06:35	0	06:28

P1	0	05:56	1	06:04
P2	1	03:57	0	02:45
P2	2	04:50	3	04:52
P3	3	04:16	3	03:51
P3	3	03:32	4	03:28

Table 2. Average accuracy rate and time for the mental rotation test

STEM School	Pre-Test		Post-Test	
	Accuracy rate (%)	Time taken (min)	Accuracy rate (%)	Time taken (min)
P1 average	12.5	06:08	25.0	06:07
P2 average	62.5	04:37	50.0	04:26
P3 average	75.0	03:49	87.5	03:39
Average	50.0	04:51	54.2	04:44
Non-STEM School	Pre-Test		Post-Test	
	Accuracy rate (%)	Time taken (min)	Accuracy rate (%)	Time taken (min)
P1	0.0	06:35	0	06:28
P2	37.5	05:56	1	06:04
P3	75.0	03:57	0	02:45
Non-STEM School Average	37.5	04:50	3	04:52
	Pre-Test		Post-Test	
Total average of both school	43.8	43.8	43.8	43.8

4.1 Task data analysis

In this test, we set the accuracy rate of the task as the measurement of spatial ability. The accuracy rate for the 4 questions from the mental rotation test proposed by Vandenberg and Kuse has raised moderately (4.2%) for the STEM approach school students, while it raised moderately (8.3%) for the non-STEM approach school students. For both test and school types, the accuracy rate is highest in P3 and lowest in P1. It is also found that STEM school students perform better than non-STEM school students. A notable effect could be observed, particularly in non-STEM schools, where the average correct answer increased from 1.5 to 1.83 within 4 questions. Performance of both P1 and P3 students has improved by 12.5%, noted that the accuracy rate of P1 raised significantly when there is no syllabus about three-dimension taught in school. This improvement in mental rotation ability can be considered as the effect of the toy.

4.2 Behavioural data analysis

Our findings revealed that the toy was in favour of children's response to mental rotation processing. The average time taken by P1 to P3 students in both STEM and non-STEM approach schools has slightly shortened, by 1.55% (from 4.51 minutes to 4.44 minutes) and 3.80% (from 4.51 minutes to 4.34 minutes) respectively. A significant improvement could be seen when comparing pre-test and post-test, especially for the P3 students. A similar effect in favour of P2 students was observed when comparing the average time taken to complete the tasks. This analysis indicated that the toy provides somewhat a stronger impact to P2 and P3 students on the response to mental rotation tasks than P1 students, even though both have medium effect sizes.

5 DISCUSSION & CONCLUSION

5.1 Result

This study was designed to investigate the effect of Turnit-In on mental rotation performance among participants. Firstly, the P3 students were found to score higher than the P1 students, followed by the P2 students. And the students studying in the STEM approach school perform better than those who study in the non-STEM approach school at the same level. We ascribe this to an increase in overall processing

speed and rotation rate with age. Another factor that is attributed will be their school programmes, notably STEM courses, which may significantly contribute to improving their visuospatial ability.
Secondly, we noted that the P1 students struggled during the test, even though the Vandenberg and Kuse mental rotation tests had been adjusted. A lack of fundamental information about space might be one of the reasons. We believe that further experimental investigation will be required to elucidate the situation, particularly for this group. However, the current findings suggest that the toy may be sufficient to increase mental rotation ability in P2 and P3 students in the near term. Besides, owing to the pandemic, this study will not be able to run a big group. One of the limitations of this study was the lack of a big group to analyse and compare the effectiveness of Turnit-In. Hence, it is uncertain whether the same findings will hold for a larger sample of students. Yet, our experiment confirms the toy can improve spatial abilities in terms of accuracy or responding time. The development of mental rotation ability with Turnit-In can be wielded throughout the school programme, regardless of a game or toy playing during recess time, and/or a teaching tool for assisting the school syllabus. It tests students' ingenuity and knowledge.

5.2 Conclusion

Our research analysed the existing STEM toys in the market by assessing their level of visual appeal, replay-ability, product complexity, problem difficulty, spatiality, and interaction between players. We then discover that the existing products lack spatiality train in their design. Our research finds that the Soma Cube is a well-designed spatiality training method; hence, we developed our Turnit-In with Soma Cube as one of our references.
To examine the successfulness of the spatial training capability of our design Turnit-In, we researched testing the player's spatial ability before and after they play with our toy for a period. We invited six children from STEM schools and six from non-STEM schools to participate in the test. Our result shows that the players may improve their spatial ability after playing with our toy. Comparing the pre-test and post-test results, we discovered their accuracy rate has improved, and their time in completing the task has shortened. Therefore, we conclude that our toy Turnit-In may help players improve their spatial and mental rotation ability. We will conduct a similar experiment with a larger sample size in the future. We will then further prove the success if we can recreate the result.

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