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Developing a Science Simulation Program to Teach the Concept of Balance in Physics: Its Development and Application for Gifted Korean Elementary Students of Science

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Abstract

In this study, we focused on the development of a simulation program for a Gifted Education Center in South Korea. We introduced our simulation program, which focuses on the concept of balancing concept in physics, and analyzed students' reasoning and perceptions. According to Brunner's EIS (Enactive, Iconic, and Symbolic Representation) theory, the simulation was designed to be abstracted gradually from iconic to symbolic. A simulation in three stages was developed, including game-like, indirect questions such as finding the number of all cases of balance. Three classes of students in grades 5 and 6 consisting of 44 gifted students in Korea participated in this study, and their reasoning and perceptions were analyzed. The results of the analysis of students' reasoning indicated that more than 70% of students predicted the phenomenon using mathematical models. Some students (17 out of 44 students) used particular strategies to count all cases of balance. Students perceived that the simulation program helped them to understand the phenomenon, considered that the simulation was not difficult and that the lecture, feedback, and teaching materials were satisfactory. Regarding self-participation, students perceived that they experienced new methods for exploring, were made keenly aware of phenomena and principles, made efforts to engage in creative thinking, and actively communicated with their peers through the simulation program. Through this study, we suggest an example of a gifted student program using a simulation and describe its successful application. Simulation activities, which form the context of this research, can lead to research related to computational thinking, which is crucial for our future society. We hope for more discussions to elaborate on and systematize context and methods of computer simulations.

Keywords: Gifted education; Simulation; Balancing; Elementary science.

1. Introduction

1.1. Gifted Education in Korea

The first governmental policy for gifted education in Korea started with the establishment of the Gyeonggi Science High School in 1983 (Leem, 2014). This school was founded with the special purposes of developing the scientific talent of the gifted and providing superior students with excellent educational programs and opportunities to help them grow into creative humans who will be prepared for the era of advanced science and technology competition (Lee, 2017). For establishment of a legal basis, the Gifted Education Promotion Law enacted by the National Assembly was passed and publicized after its suggestion on January 28, 2000, coming into effect on March 1, 2002 (National Law Information Center, 2017; Woo, 2015) .

According to 'Gifted Education Promotion Law', a "gifted and talented person" is defined as an individual who requires special education to develop their innate potential with outstanding talent in Korea (National Law Information Center, 2017; Tae, 2014). According to the definition in Article 1 of the Gifted Education Promotion Law, the purpose of gifted education is to promote the self-actualization of individuals and have these individuals then contribute to the development of society and the nation, and to search for gifted and talented persons. The identification process of gifted students is composed of four basic steps: teacher recommendation, a giftedness test, a specific academic aptitude test, and a personal interview (Korean Educational Development Institute, n.d.).

There are three types of gifted education units in Korea: gifted classes, gifted education centers, and gifted schools (science academy) (Korean Educational Development Institute, n.d.; Lee and Kim, 2012) ;. Gifted classes

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are operated by elementary, middle and high schools and include extra-curricular activities, discretionary activities and after-school activities during weekends and vacations (National Law Information Center, 2017). Gifted education centers are located at and operated by universities, government-funded research institutions, and public-service corporations (National Law Information Center, 2017). Given that they are not regular schools, students usually use the facilities after school, during vacations, or during school hours (only with the permission of the principal). Gifted schools (science academies) are operated as a full-time system in secondary schools (high school level), targeting the most gifted and talented students with greater potential in professional fields (National Law Information Center, 2017).

1.2. Gifted Education Programs and Computer Simulations

Recent developments in technology have led to the development of teaching and learning materials using various computer simulations. From an educational perspective, a simulation is a teaching and learning tool that provides a realistic learning environment to achieve learning objectives (Thomas, 2014). Scientists construct a model of exemplar phenomena related to a particular aspect of the phenomena in which they are interested (Gilbert, 2005). Students can be given a good exemplar phenomenon for model construction through a computer simulation (Falvo, 2008; Faraco and Gabriele, 2007). They can quickly obtain clear evidence through such as simulation (Wellington, 2002). Unlike traditional experiments, which require much time for the collection of data, students can spend more time in discussions using simulation programs (Barton, 1996).

Simulations have advantages in that inquiry can be focused on a particular phenomenon and can be repeated many times (Merrill *et al.*, 1996). Students can manipulate variables through simulations (Chiappetta and Koballa, 2002). When teaching and learning using simulations, students are provided with a rich learning environment through which they can actively construct, skillfully maintain, and generalize knowledge through learning by doing (Perkins, 1991). Students can control the contents and structure of learning in a simulation. Play, or learning with games (edutainment), is a major motivational factor in simulations (Blissett and Atkins, 1993; Watson and Baggott, 1997).

The teaching and learning styles used to teach science-gifted students at gifted education centers in Korea were highly monotonous and operated by lectures, experiments, and discussions (Yeo and Kang, 2002). Gifted students' learning style preferences are as follows in order of preference: projects, independent study, teaching game simulations, peer teaching, programmed instruction, lectures, drills and recitations, and discussion (Renzulli, 1997). Currently many gifted education centers in Korea are working to develop and apply instruction using methods that are preferred by gifted students, such as projects and simulations Jeong *et al.* (2003); Shin and Lee (2011). In this study, we focus on the development of a simulation program for gifted education centers in Korea. Below we introduce our simulation program to teach the concept of balance in physics and analyze students' reasoning and perceptions.

2. Method

2.1. Development of the Simulation Program

The concept of balance is included in the Korean curriculum of elementary schools for students in grades 3 and 4. The concept of balance is considered as one of the important inquiry activities in elementary schools. There are various studies focusing on this concept, and most of them attempt to find better inquiry contexts. Some research has suggested the teaching of balance using everyday objects (Yoon *et al.*, 2012). Other research has suggested using smart phone app or computer simulation contexts to offer the ideal exemplar phenomena (Kim and Kim, 2012). McGinn and Roth (1998), Studied students' problem-solving strategies when encountering numerically labelled levers and unlabeled levers. Students used different strategies in different contexts. Therefore, students' explanation should be carefully considered in the different balance contexts.

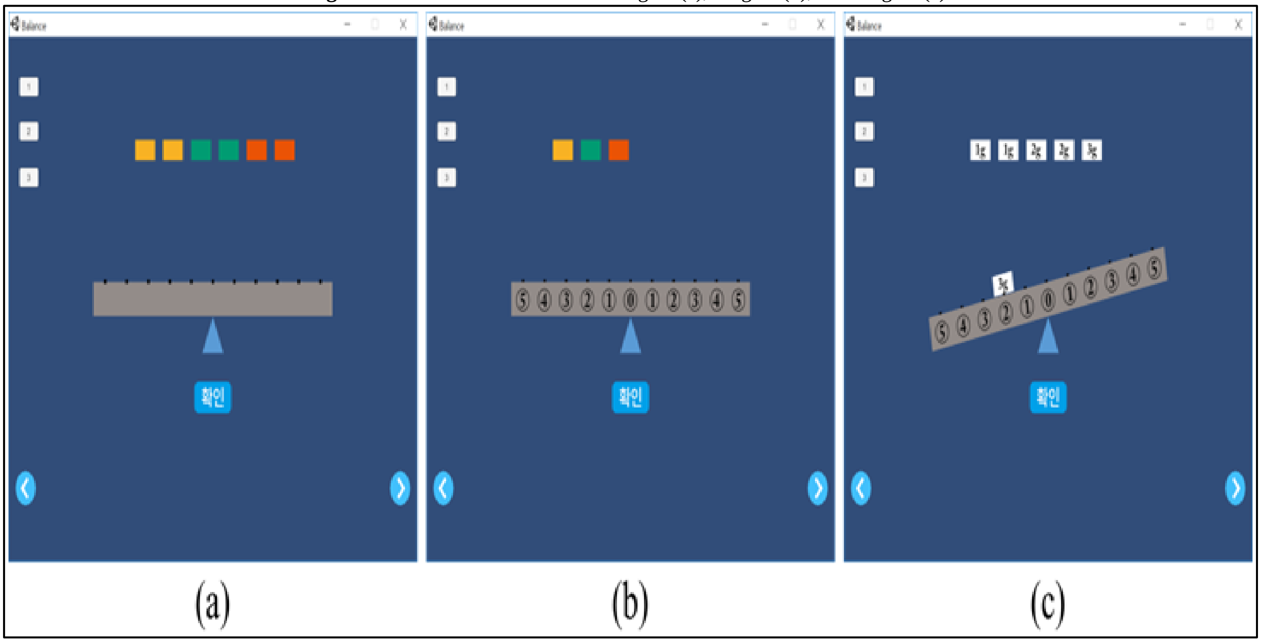
A simulation program was developed based on Brunner's EIS (Enactive, Iconic, and Symbolic Representation) theory (Bruner, 1964). Bruner (1964), argued that students' cognitive abilities and thinking methods develop in the order of enactive representation, visual representation, and symbolic representation. A variety of teaching and learning materials using EIS theory are being developed in the mathematics education field (Ahn and Kim, 2015). In addition, EIS theory is being applied to the development of computer - based learning materials (Lee and Kim, 2012). According to EIS theory, our simulation program is designed to be abstracted gradually from iconic to symbolic. The game-like elements of the simulations increase students' interest (Blissett and Atkins, 1993). Therefore, the goal of the simulation program activity is indirectly presented to perceive all cases of balance in a game-like context rather than directly presenting them to generate an explanatory model by which to explain the examples of balance.

The teaching and learning sequence of the developed simulation program is described in Table-1. The simulation program was developed by the author using the Unity program. In the simulation program, weights and levers are gradually numerical labelled to help students use symbolic representation. Six unlabeled weights and an unlabeled lever were given in Stage 1 (Figure-1 (a)). In this stage, students were asked to determine which is heavier with minimal effort. Three unlabeled weights and a labelled lever were given in Stage 2 (Figure-1 (b)). Students were asked to find examples of balance and to explain them. Five numerically labelled weights (1g, 1g, 2g, 2g, and 3g) and a numerically labelled lever were given in Stage 3 (Figure-1 (c)). Students were asked to find all cases of balance by putting weights on the right side of lever 'when 3g is at position 2 on the left side of the lever' and to explain them. After Stage 3, the students presented their strategies, models, or cases of balance phenomena they used in Stage 3.

Table-1. Teaching and Learning Sequence of the Developed Simulation Program

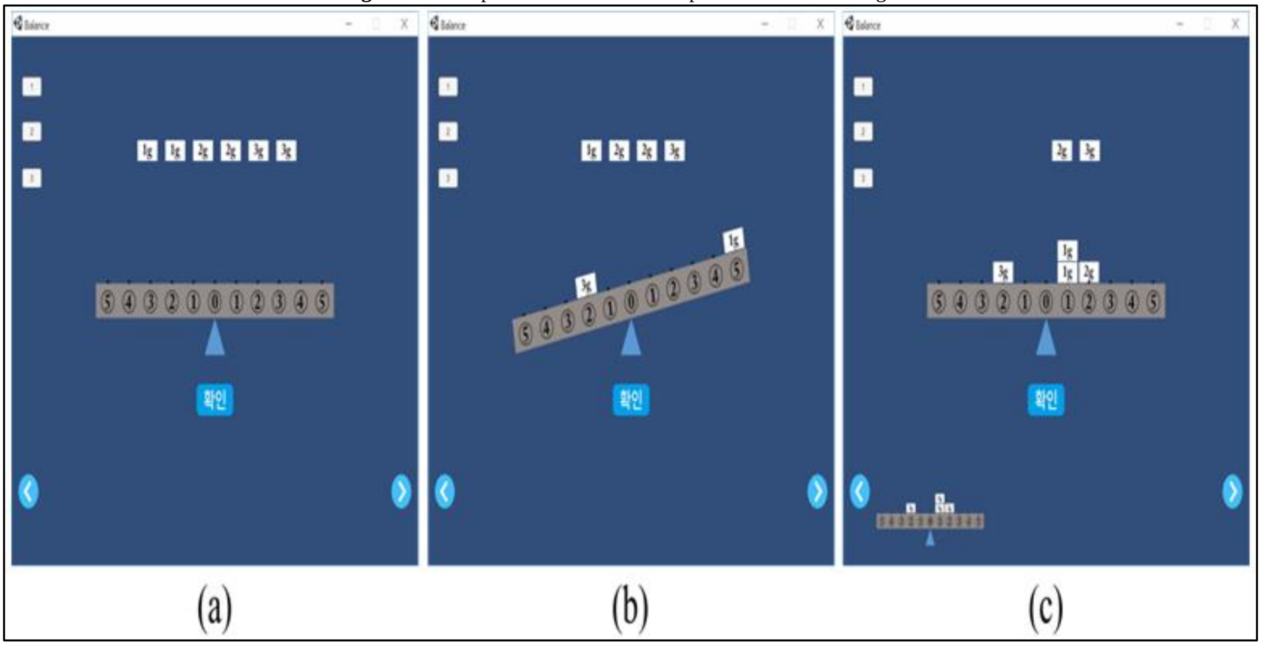
Stage	Activity topics	Numerically labelled	
		Weights	Lever
1	Which is heavier?	X	X
2	When is the lever balanced?	X	O
3	Find all cases of balance when 3g is at position 2 on the left side.	O	O

Figure-1. Screen of Simulations at Stage 1 (a), Stage 2 (b), and Stage 3 (c)



An example of the simulation operation screen in stage 3 is shown in Figure-2. Students can change the steps in the simulation by pressing the button in the upper left corner of the screen (Figure-2(a)). After putting on the weights on the lever, students can check the balance by pressing the blue OK button in the lower middle part of the screen (Figure-2(b)). If students succeed in achieving a balance, this is recorded at the bottom of the screen (Figure-2(c)).

Figure-2. Examples of the Simulation Operation Screen at Stage 3



2.2. Participants

This study was conducted in a mixed grade 5-6 classroom at a gifted education center at, a national university of education in Korea. Three classes consisting of 44 students in total participated in this study, which lasted three hours.

2.3. Data Collection and Analysis

The worksheets and presentation materials of the students, as well as their field notes and a questionnaire on their perceptions were collected and analyzed. The worksheets, presentation materials and field notes for Stage 3 were analyzed to assess students' reasoning. All tables and figures shown in the results were extracted from the students' presentations or worksheets. Students' reasoning were analyzed and categorized by three dimensions of scientific reasoning: phenomenon-based reasoning, related-based reasoning, and model-based reasoning (Tytler and Peterson, 2004). The students' perceptions were investigated through the questionnaire (on a Likert scale ranging from 1 to 5). The questionnaire consisted of items related to their perception of the simulation program and their self-participation.

3. Results

3.1. Students' Reasoning

Students' reasoning were categorized at four levels (Table-2). Students' reasoning at levels 1-3 were analyzed by referencing the research of Tytler and Peterson (2004). These were phenomenon-based reasoning (level 1), related-based reasoning (level 2), and model-based reasoning (level 3). Some students counted all cases using a particular strategy, as our simulation program provided an activity topic that found all balance cases. We assigned these students to an additional fourth level (level 4).

Six students (13.6%) incidentally discovered cases of balance through the repetitive experience of trial and error (level 1). Seven students (15.9%) discovered empirical rules that were not coherent (level 2). More than 70% of students achieved level 3 or higher, meaning that they predicted the phenomena using mathematical models. Fourteen students (31.8%) discovered or used mathematical models (level 3). Seventeen students (38.6%) used particular strategies to count all balance cases (level 4).

Table-2. Students' Reasoning

Level	Characteristics of reasoning	No. of Students
1	Incidental discovery through the repetitive experience of trial and error	6 (13.6%)
2	Discovery of empirical rules that are not coherent	7 (15.9%)
3	Discovery or use of mathematical models	14 (31.8%)
4	Use of mathematical models and strategies to count all cases	17 (38.6%)

3.1.1. Incidental Discovery Through the Repetitive Experience of Trial and Error

These students solved the problem by trial and error. As a result, they listed only cases of phenomena that were balanced. After finding a case that happened to balance, students looked for a more balanced position by moving the weight to the left when the lever was leaning to the right, and vice versa. Students explained this follows:

> "It was discovered by accident."
>
> "I put on any weight on the lever. I see the slope and then add or subtract weight."

3.1.2. Discovery of Empirical Rules that are not Coherent

These students had no basic knowledge or models of the concept of balance at all beforehand. Like the students at level 1, students in this level moved the weights back and forth and then found a case of balancing. However, in contrast to the students at level 1, these students discovered and explained several rules or patterns. They occasionally generated incoherent rules or patterns that listed partial phenomena or explained only a few phenomenon.

Some students who explained patterns that represented the partial phenomena conducted the following processes. These students explained that balancing occurred when placing 6g at position 1, placing 3g at position 2 and placing 2g at position 3. However, they did not form a model to integrate these findings.

"6g at position 1, 3g at position 2, and 2g at position 3 make a balance."

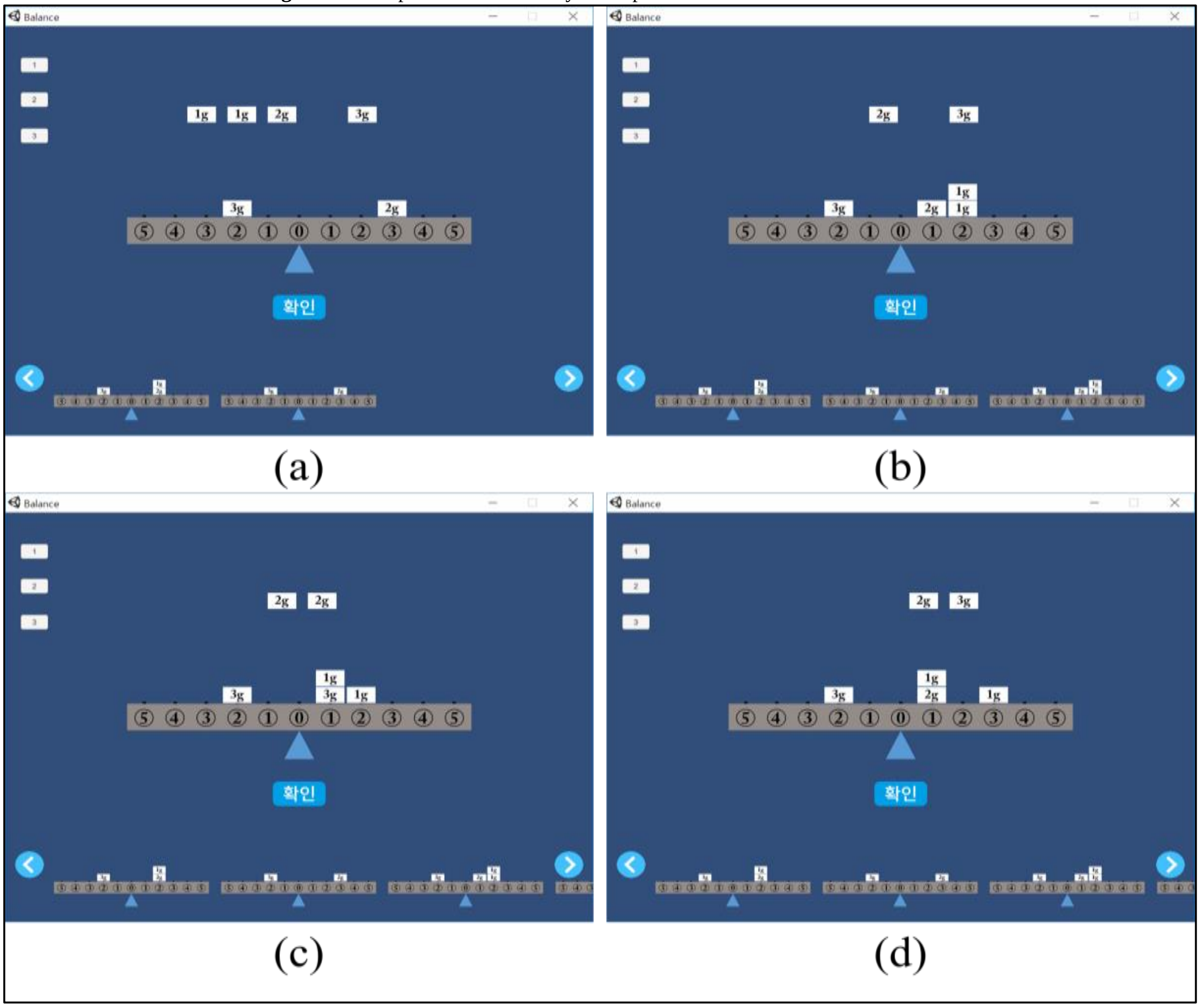
Some of these students attempted to generate rules to incorporate the cases; however, these rules only partially explained the phenomena. In contrast, these students introduced a case of balancing even if they could not explain by using their own rules. As examples, students listed the balancing cases in Figure-2. Figures-2 (a), (b), and (c) were explained by using students' rules. However, Figure-2(d) could not be explained using students' rules. The students explained it as follows:

> "(When the weights are on the position 2 on the right side of the lever), If you move the weight forward (to the left) position by one step, its mass is reduced to half. Or, if you move the weight backward (to the right), its mass is increased by 1g."

With this rule, for balancing, the result of the calculation of the mass on the right side should be 3g, which is identical to that on the left side. According to the students' explanation, the mass of 2g of weight in Figure-3(a) is increased to 3g because it is on position 3, which is backwards (on the right side) with regard to the students' reference point (position 2). Here, 2g at the position 2 on the lever becomes 1g, which is half of 2g, because the position with 2g of weight is before (left side) the students' reference point (position 2) in Figure-3(b). This 1g is added to the two 1g weights and the result of this calculation then becomes 3g. In this case, the mass of the two weights of 1g does not change because it is on the reference point, i.e., position 2. This is explained in the same manner in Figure-3(c). However, the result of the calculation in Figure-3(d) is not 3g. According to the students' explanation, 1g and 2g, on position 1, become 0.5g and 1g, respectively. In addition, 1g, on position 3, becomes 2g.

Therefore, the result of the calculation becomes 3.5g (0.5g+1g+2g), which not equal to3g, which is the result on the left side.

Figure-3. Examples of the Discovery of Empirical Rules That Are Not Coherent



3.1.3. Discovery or Use of Mathematical Models

Students at this level generated mathematical models that explained the balancing phenomena. Students explained their models as follows:

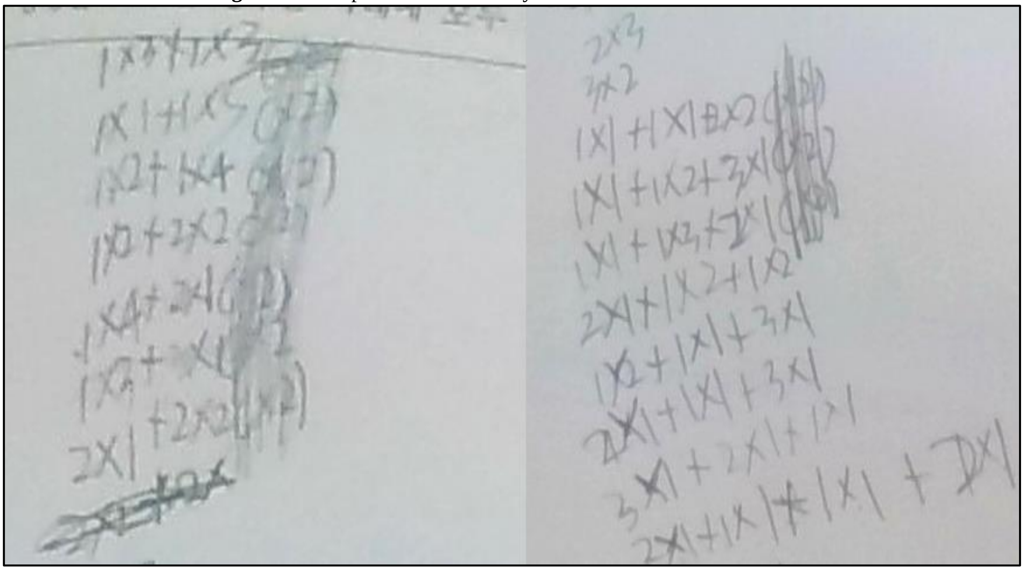
> "There is a rule. If the mass of weight A is twice as heavy as that of B, B should then be placed twice as close to the fulcrum than A."
>
> "The distance of A × the mass of A = the distance of B × the mass of B."
>
> "The sum of the left distance × the mass of the weights = the sum of the right distance × the mass of the weights"

A typical characteristic of the models is a description and prediction of the phenomena (Gilbert and Boulter, 2000; Gilbert, 2005; Girer, 1991). These types of students not only explained the phenomena but also predicted the phenomena through the model. Examples of students' predictions using a mathematical model are as follows:

> "'The sum of the distance from the fulcrum × the mass of the weight' on the right side should be identical to that on the left side."
>
> "On one side, 3g is fixed in the second place. 3 × 2 = 6; so, if the sum is 6 on the other side, it is balance."
>
> "6 = 2 × 3 = 1 × 4 + 1 × 1 = 1 × 6 = 3 × 2 = 2 × 2 + 2 × 1."

With regard to early predictions, the students confirmed that their prediction cases were balanced using a computer simulation, which is an iconic representation. After checking a few cases, the students no longer used the simulation. These students used a mathematical model, which is a type of symbolic representation, to find the remaining cases of balance. However, they did not have particular strategies to find all cases. They explained that they had no strategies and that they simply wrote down cases, using a type of symbolic representation (Figure-4).

Figure-4. Examples of the Discovery or Use of Mathematical Models



3.1.4. Use of Mathematical Models and Strategies to Count all Cases

Students at this level used a particular strategy to count all cases and to predict which case will balance using a mathematical model. At this level, as with the students of level 3, they used the symbolic representation of a mathematical model to explain discovered cases and to predict other cases. Students used various strategies to count all cases easily. Some of the students at this level could find all of the cases, whereas other students could not. However, all of them strove not to miss cases of balance using particular strategies. They systematically structured and reviewed the list of balanced cases using a strategy. Some used tables, diagrams, or number parity as a strategy. Others classified cases based on whether the heaviest weight was used or on how many weights were used. Examples of students' strategies are given below.

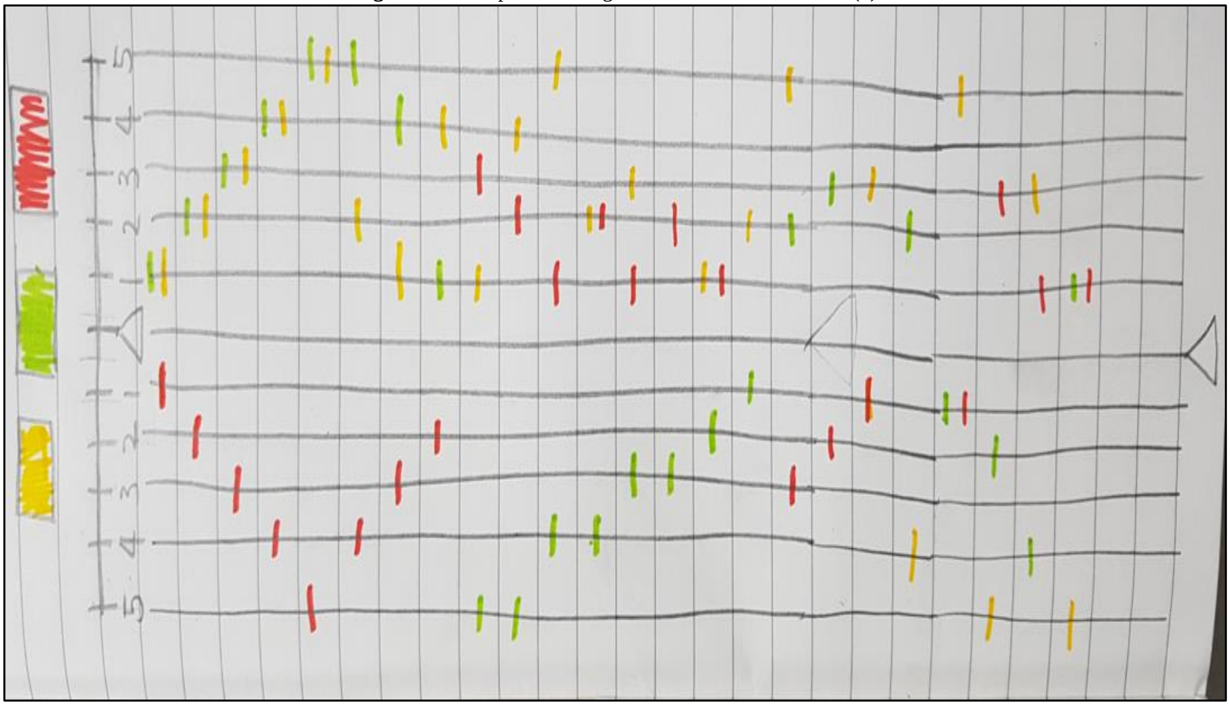
Some of these students created a table (Table-3) with the mass of the weight multiplied by the distance from the fulcrum (a dimension of torque). Students could not select or could only select one number on the horizon. Subsequently, they added these numbers to reach an answer of six. For example, students found that the sum of characters shown in bold text in Table-3 (2 and 4) was six. The bold number 2 indicated that a weight of 2g was placed at position 1, and the bold number 4 meant that a weight of 2g was placed at position 2. Therefore, with this table, they predicted that lever is balance when 2g is at position 1 and another 2g is at position 2.

Table-3. Example of Strategies to Count all Cases (1)

Distance from the Fulcrum Mess	**1**	**2**	**3**	**4**	**5**
1g	1	2	3	4	5
1g	1	2	3	4	5
2g	**2**	4	6	8	10
2g	2	**4**	6	8	10
3g	3	6	9	12	15

Other students at this level used diagrams as a strategy. To find balanced cases, these students positioned the heaviest weight first and then positioned other weights (Figure-5). They represent the 3g weight in red, 2g weight in green and 1g weight in yellow.

Figure-5. Example of Strategies Used to Count all Cases (2)



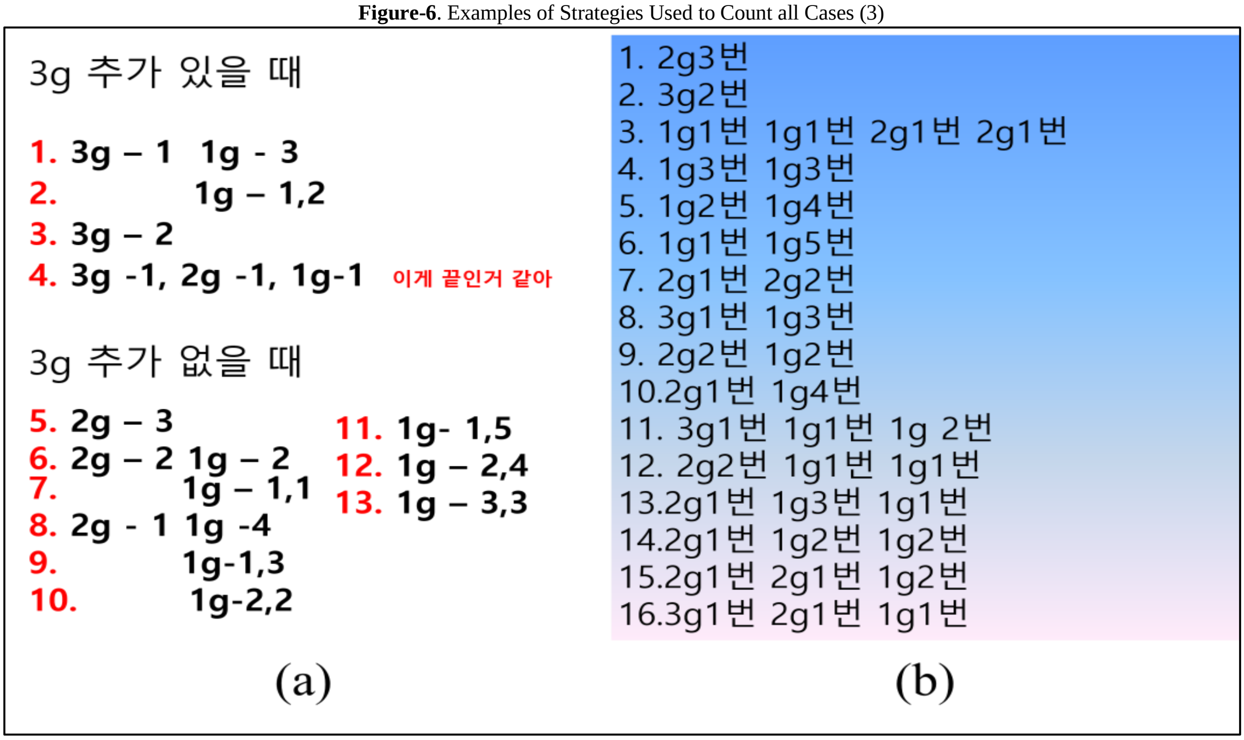
Some students used the parity of numbers, which is a characteristic of even and odd numbers. They eliminated cases that could not be tested using this strategy.

> "The value on the left is six, even. Therefore, on the right, odd + odd = even, even + odd = odd, even + even = even, and odd x odd = odd, even x even = even, odd x even = even."

Some students classified cases according to whether the heaviest weight of 3g was included or not and then counted the number of such cases. Cases 1-4 in Figure-6(a) are representative of these cases when 3g weights were used. Cases 5-10 represent those in which the 3g weights were not used and the 2g weights were used. Cases 11-13 are cases when only the 1g weights were used. These students found all cases strategically, except for the cases in which only the 2g weights were used.

Other students classified the cases according to the number of weights used and then counted the number of each case. Cases 1-2 in Figure-6(b) are cases in which only one weight was used. Cases 3, 4-10, and 11-16 indicate when four weights, two weights, and three weights were used. These students succeeded in finding all possible cases.

Figure-6. Examples of Strategies Used to Count all Cases (3)



3.2. Students' Perceptions

3.2.1. Perceptions of the Simulation Program

Table-4 shows the students' perceptions of the simulation program. The questionnaire about their perceptions of the simulation program consisted of five items (ranked on Likert scale of 1 to 5). Students perceived that this simulation program greatly helped them gain knowledge and information in this field (Item 1, 4.80). Moreover, they perceived that the lecture (Item 3, 4.94), feedback (Item 4, 4.94), and teaching materials (Item 5, 4.63) were excellent. The simulation program for these gifted students was deemed not overly difficult (item 2, 2.38).

Table-4. Perceptions of the Simulation Program (N= 44)

Items		Mean	Standard Deviation
1.	It helped me gain knowledge and information in the field.	4.80	0.56
2.	The contents of the class were difficult.	2.38	1.78
3.	The professor lectured in an easy-to-understand manner.	4.88	0.34
4.	The professor appropriately answered questions about the contents of the class.	4.94	2.35
5.	The teaching materials and teaching aids used in the classroom were excellent.	4.63	0.89

3.2.2. Perceptions of Self-Participation

Table-5 shows the students' perceptions of their self-participation. The questionnaire for their perceptions of self-participation consisted of ten items (on Likert scale 1 to 5). Students perceived that they did not ask many questions (Item 1, 3.69). However, they perceived their self-participation as high on other items (Items 2 to 10, more than 4.00). Some of the high scores (exceeding 4.50) regarding their perceptions of their self-participation are as follows: students experienced new ways of exploring (Item 10, 4.63), were keenly aware of the phenomena and principles (Item 2, 4.56), made efforts to engage in creative thinking (Item 3, 4.56), and actively communicated with their peers (Item 5, 4.50).

Table-5. Perceptions of Self-participation (N=44)

		Mean	Standard Deviation
1.	I asked many questions.	3.69	1.30
2.	I was worried about the phenomenon or principle more sensitively.	4.56	0.73
3.	I made efforts to think creatively.	4.56	0.73
4.	I had patience to solve the problem to the end.	4.44	0.81
5.	I communicated my opinions effectively to my peers through discussions.	4.50	0.82
6.	I had an effective presentation experience.	4.31	0.79
7.	I gained new knowledge and experience.	4.31	0.79
8.	I came up with broader ideas about all studies.	4.19	0.91
9.	I stimulated and developed curiosity about my studies.	4.38	0.72
10.	I expanded my experience about with new inquiry methods.	4.63	0.72

4. Discussion

In this study, we focused on the development of a simulation program for a gifted education center in South Korea. We introduced our simulation program for the concept of balance in physics and analyzed students' reasoning and perceptions. According to Brunner's EIS theory, the simulation program was designed to be abstracted gradually from iconic to symbolic. The simulation program was developed by the author using the Unity program. Weights and levers were gradually numerical labelled to help students use symbolic representation in the simulation program.

Students' reasoning were analyzed at four levels: incidental discovery through the repetitive experience of trial and error (6, 13.6%), the discovery of empirical rules that were not coherent (7, 15.9%), the discovery or use of mathematical models (14, 31.8%), and the use of mathematical models and strategies to count all cases (17, 38.6%). According to the result of this study, the level of representation was found to be related to the level of students' reasoning. Students at levels 1 and 2 used iconic representation to explain. Students at levels 3 and 4 mainly used symbolic representation to explain and predict.

More than 70% of the students predicted the phenomenon using mathematical models. Students at level 4 attempted not to miss balanced cases by using particular strategies. They systematically structured and reviewed the list of balanced cases using strategies. Students used tables, diagrams, the parity of numbers, or classified cases (with whether the heaviest weights were used, or how many weights were used) as a strategy.

According to a questionnaire on the student's perceptions of the simulation program, it was founded that the simulation program helped them to understand the phenomenon; that the simulation was not difficult; and that the lecture, feedback, and teaching materials were satisfactory. According to the student's perceptions of their self-participation, it was founded that students felt that they experienced new ways of exploring, were more keenly aware of phenomena and principles, made efforts to conduct creative thinking, and actively communicated with their peers.

5. Conclusion

In this study, we suggested an example of a gifted student program using a simulation and described its successful application. Most students as participants explained and predicted the phenomenon in their own way, while some adopted strategies for effective predictions. Simulation activities, which are the context of this research, can lead to research related to computational thinking, which will be crucial for our future society. We hope that more discussions elaborate and systematize the context and methods of computer simulations will arise.

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