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Research Article

Proposal of Integrated Methodology for Creativity Oriented STEM Education Using the View Point of ETT Theory

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ABSTRACT

Recently, the necessity of integrated and comprehensive methodology for STEM (Science, Technology, Engineering and Mathematics) education is growing. In this paper, we propose an educational methodology utilizing the viewpoint of Equivalent Transformation Thinking (ETT) theory which has been proposed by Dr. Kikuya Ichikawa in 1955 as a principle of creativity. Especially, we show that the viewpoint of ETT is very useful not only for new technology invention but also for STEM Education in the sense that it deepens insights of the contents to be learned. Moreover, we suggest that the appropriate combination of the ETT viewpoint and the visual presentation such as animation and simulation by 3-Dimensional Computer Graphics (3DCG) will be more effective in motivating students to study further.

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1. Introduction

Recently, the necessity of integrated and comprehensive methodology for Science, Technology, Engineering and Mathematics (STEM) education seems to be growing [1], [2], because the content of the STEM field is becoming increasingly sophisticated.

For the STEM education, we propose the methodology based on the viewpoint of Equivalent Transformation Thinking (ETT) theory which was advocated as a principle of creativity by Dr. Kikuya Ichikawa in 1955, after his investigation and analysis of the past discoveries and technological inventions.

In this paper, we briefly explain the ETT theory ([3], [4], [5], [6], [7], [8]) and describe that the viewpoint of ETT is very useful not only for new technology invention but also for STEM education. This is because the past inventions, discoveries and academic developments in STEM field can be explained according to the ETT theory.

Also in this paper, we emphasize that the suitable presentation of the ETT viewpoint using visualization technology will be very effective for the students to deeply understand the learning contents, to promote their motivation, and to stimulate their creativity ([9], [10], [11]).

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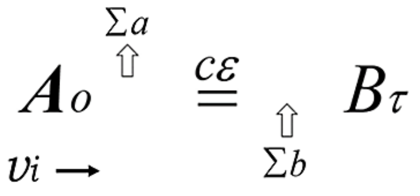
2. ETT Theory

As aforementioned, the ETT theory has been proposed as a principle of creativity by late Dr. Kikuya Ichikawa in 1955, after his investigation of the past discoveries and original inventions to analyze how creation was done. And, he clarified the investigation results that new technology developments and creations were produced along with the ETT process based on "Analogical Thinking and its Abstraction". Then he represented the ETT process as a simple form of symbolic logical expression which is called "Equivalence Equation" as shown in Fig. 1.



Ao: original system, ***Bτ***: transformed (or arrival) system, **Σ*a***: a set of special/peculiar properties and conditions that holds the system *Ao*, ***cε***: core essence or essential meaning that reasons the equivalence under some conditions, **Σ*b***: a set of necessary properties and conditions, ***vi***: viewpoint at a certain meta level.

Fig. 1 Equivalence Equation of ETT Theory.

The description of "Equivalence Equation" means that, from a certain viewpoint ***vi***, the original system *Ao* can be transformed to the system ***Bτ*** according to the conditionalized essence *cε*, where some properties and conditions *Σa* in *Ao* are discarded, and new elements of property and condition *Σb* are added to the system ***Bτ***.

When Dr. Ichikawa presented "Equivalence Equation", he also showed the schematic flowchart of ETT. And he insisted that, if we make effort to develop something to be desired according to the ETT flowchart, creative achievement will be possible more efficiently.

As for the ETT theory, he mainly published the papers at the Creativity Research Workshop that was held by Dr. Hideki Yukawa, the winner of 1949 Nobel Prize in Physics. Dr. Yukawa called this Dr. Ichikawa's theory as "Identification Theory" in his own words and highly praised it [5].

For example of application of ETT theory, the new invention process of basketball shoes which can stop suddenly by Mr. Kihachiro Onitsuka can be explained according to the theory [6]. Mr. Onitsuka got the idea from the octopus foot suckers when he looked at cooked vinegared octopus as shown in Fig. 2.

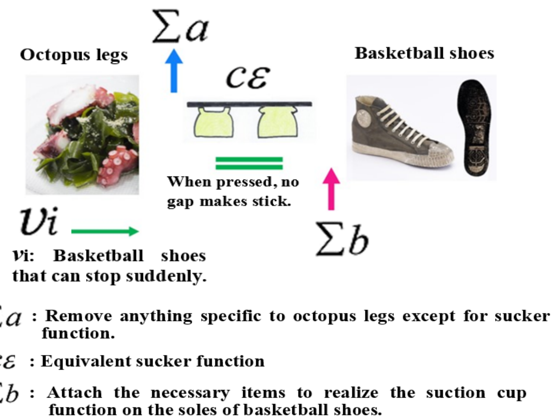


Fig. 2 Example of invention of basketball shoes where the inventing process can be explained by ETT Theory

3. ETT Viewpoint for Education

3.1. From Construction Geometry to Analytical Geometry by Cartesian Coordinate System

Looking back on history, we can find out many facts that the progress of research in the field of STEM has been made due to the actions of ETT (or Identification of Equivalence or Analogical Thinking and its Abstraction), and that the results have broadened our horizons and deepened our knowledge. Then, we consider that clear presentation and utilization of the viewpoint of ETT is also effective for STEM education.

For an example, the "Cartesian coordinate system" produced by René Descartes which gives a one-to-one correspondence between a point P on a plane and a pair of two numbers (x,y), i.e., P ⇔ (x,y) where x and y are quantities based on the distances along to the direction of two orthogonal axes (x-axis and y-axis), respectively.

As a result, taking a parabolic curve C for an example, it can be simply represented by a set of coordinates and algebra, without showing the procedure of geometric drawing, such as

$C = \{P(x, y) \mid y = ax^2,\ a\text{: constant number}\}$.

This is one of examples that ETT not only opens the new field of mathematics such as Analytic Geometry and Algebraic Geometry from Construction Geometry, but also brings about the new concept such as "Field" into physics.

So, we consider that it is worth to enhance the idea of ETT, and that, in the education of the STEM subjects, to clearly show the viewpoint due to ETT when teaching will be effective.

3.2. Archimedes' Principle of Buoyancy

According to Archimedes' principle, floating power (or buoyant force) that operates on a body immersed in a fluid, is equal to the weight of the fluid in the same volume as the volume of body in the fluid (Fig. 3).

As shown in Fig. 3. suppose that an object is quietly floating on the water while the underwater volume area V is receiving the floating power from surrounding water. Then if we think of that the situation is equivalent to another one where the water part in the same volume area V is receiving the floating power from surrounding water and quietly balanced (Fig. 3(c)), we understand that Archimedes' principle holds. This is also an example of the viewpoint of ETT.

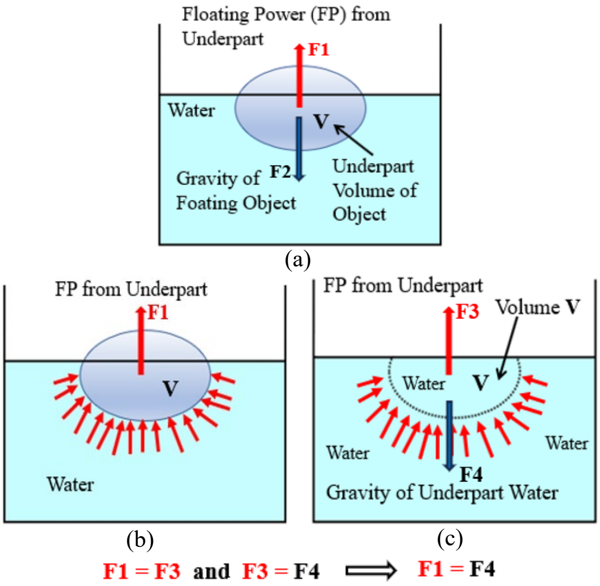


Fig. 3 Floating power (or buoyant force) that operates on a body immersed in a fluid (water). (a) An object is quietly floating on the water. (b) F1 is the power that receives at the underpart volume V of object. (c) The situation where water in the same volume area V is quietly balanced.

3.3. Mechanical Dynamic System (MDS) and Electric Circuit System (ECS)

For taking the relation between MDS and ECS as an example, we can deal with the equations of two systems (see Fig. 4) as equivalent equation from both meaning of mathematics and physics. We consider that this kind of clear presentation on what is equivalent in what meaning is useful for integrated education for STEM.

$$\begin{cases} \boldsymbol{m}\dfrac{d^2x}{dt^2}+\boldsymbol{r}\dfrac{dx}{dt}+\dfrac{x}{\boldsymbol{k}}=\boldsymbol{F}_0 \quad \left(v=\dfrac{dx}{dt}\right) \\ \boldsymbol{L}\dfrac{d^2q}{dt^2}+\boldsymbol{R}\dfrac{dq}{dt}+\dfrac{q}{\boldsymbol{C}}=\boldsymbol{E}_0 \quad \left(I=\dfrac{dq}{dt}\right) \end{cases}$$

Mass $\boldsymbol{m}$ ⇔Inductance $\boldsymbol{L}$, Responsiveness $\boldsymbol{r}$ ⇔Resistance $\boldsymbol{R}$, Compliance $\boldsymbol{k}$ (the inverse of spring constant) ⇔Capacitance $\boldsymbol{C}$

(a)

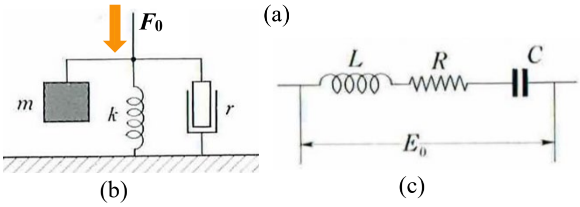


Fig. 4 (a) Differential equations and their corresponding elements in MDS and ECS. (b) Conceptual image of MDS. (c) Conceptual image of ECS

3.4. Explanation of Faraday's World First Motor

Faraday's world first electromagnetic rotating device is shown in Fig. 5, where the current flows from top to bottom into the left and right mercury containers.

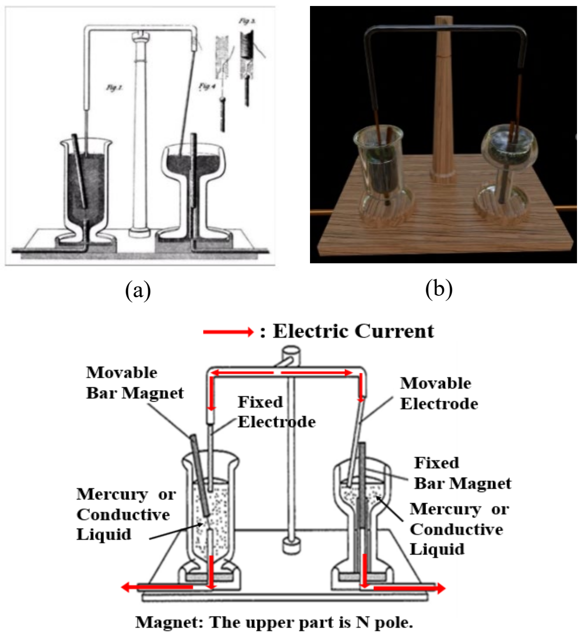


Fig. 5 Faraday's World's First Motor. (a) Documents left at the Royal Institution. (b) Motion video made by 3-DCG "Blender" ([9], [10]). (c) Explanation of each part and direction of electric current

Viewing from the above, when the current flows, both of bar magnet and electrode (or conductor) rotate clockwise. For the each of forces causing rotation, there are different explanations (or lectures) in the left and right sides.

According to the general explanation, for the left side, the electric current flowing through conductor makes magnetic field according to Ampere's law, and the field rotates the movable bar magnet. On the contrary for the right side, the current in conductor of the movable electrode receives Lorentz force from the magnetic field caused by the fixed bar magnet.

On the other hand, we consider that there is a unified explanation based on law of action and reaction. In the right side, like the left side, the current in conductor of the movable electrode is making the magnetic field according to Ampere's law. And the current is going to rotate the fixed bar magnet through the magnetic field caused by the current. However, the bar magnet is fixed and the conductor is floating, so the conductor rotates while receiving the reaction force.

This unified explanation will be further understandable by presenting the 3-DCG video and illustrating that an electric current generates a magnetic field around it and receives a reaction force from the bar magnet via the magnetic field.

3.5. Recursive Programming Education

As for the education of programming, the recursive programming tends to be difficult depending on the problem to be solved.

Taking the programming of “Tower of Hanoi” for an example of difficult problem (Fig. 6), the problem is to find out the optimal procedure to move the tower of n disks, from the place at pillar A (or start place) to the pillar C (or destination), using the pillar B (as work place), under the constraints as below.

(i) Only one disk must be moved at a time, (ii) Do not go outside the three pillar places of A, B, and C, (iii) Do not put a disk over a smaller disk.

(a) (b)

Fig. 6 The images of “Tower of Hanoi” problem that are parts of the motion video made by Blender. (a) Initial state when the number of disks n=5. From the left end, we call three pillar places as A, B, and C. (b) The smallest disk at A is moved from A to C, and the next small disk is on the way to move out from A

For making the recursive program to solve the problem in the general case of n disks, based on the ETT viewpoint, we note that there is a consistent pattern of disk moving that appears clearly when the number of disks n=2.

That is, the moving pattern when the number of disks n=2 is equivalent to that one in the case if we divide n disks into two parts: upper part (n-1 disks) and the lowest part (the bottom largest disk).

Suppose when the largest disk can be moved from A (start place) to C (destination) under the abovementioned constraints (Fig. 7). Firstly, we must move the upper part (n-1 disks) from the place A to B (workplace).

Secondary, the largest disk (=lowest part) can be moved from A to C. This movement is the most important turning point. After that, we can move the upper part (n-1 disks) from B to C.

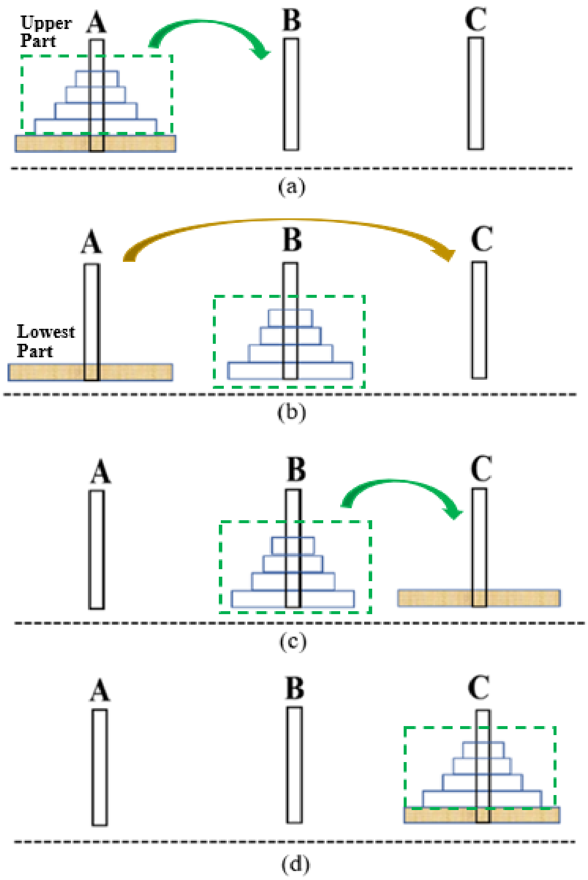


Fig.7 Equivalent moving pattern between the case of n disks and the case of two disks in Tower of Hanoi problem to optimally move n disks (n ≧3) from the place A to C using the place B, where the set of n disks is divided into two parts: upper part (n-1 disks) and the lowest part (the bottom largest disk). (a)Initial state. (b) and (c) The turning point when the upper part (a set of n-1 disks) is moved from A to B, and then largest disk left at A can be moved to C. (d) After the upper part is moved from B to C, the problem is solved

Then, if we let T(n, S, W, D) represent a procedure of the “Tower of Hanoi” problem to move n disks from the start place S to destination D using workplace W, we obtain the following symbolic formulation as a recursive procedure, based on the equivalent moving pattern.

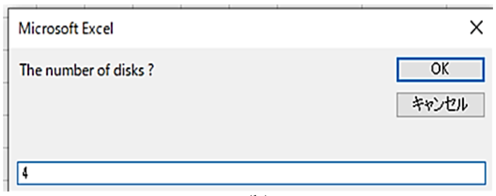
T(n, S, W, D) =T(n-1, S, D, W) + Move the largest of n disks from S to D+ T(n-1, W, S, D).

The procedure T(n, S, W, D) is concretely described as Hanoi_Tower(n As Integer, S As String, W As String, D As String) by Excel VBA. Fig. 8 shows the program and the execution results, where the disks are numbered in ascending order of diameter.

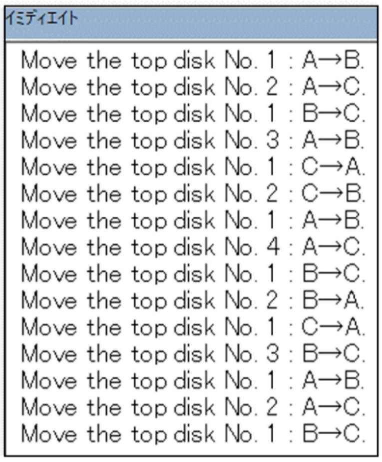
```
'***********************************
Sub main_Tower_of_Hanoi()
Dim n As Integer, Input_n As String
Input_n = InputBox("The number of disks ?")
n = Val(Input_n)   '数字文字列を数値に変換
Call Hanoi_Tower(n, "A", "B", "C")
End Sub
'***********************************
Sub Hanoi_Tower(n As Integer, S As String, W As String, D As String)

  '/*Move n-1 disks from "S" to "W" via "D."*/
 If n >= 2 Then
        Call Hanoi_Tower(n - 1, S, D, W)
 End If
 Debug.Print "Move the top disk No. " & n & " : " & S & "→" & D & "."
  '/*Move n-1 disks from "W" to "D" via "S."*/
 If n >= 2 Then
        Call Hanoi_Tower(n - 1, W, S, D)
 End If
End Sub     '******************************
```

(a)



(b)



(c)

Fig. 8 Excel VBA program and its execution results for the Tower of Hanoi. (a) The program lists. (b) Inputbox where n=4 is input. (c) The output at immediate window in the case n=4

The number of necessary steps $a(n)$ to move n disks is decided from the above algorithm in the followings.

$a(n)=a(n-1)+1+a(n-1)=2a(n-1)+1$ $(n \geqq 2)$, $(a(1)=1)$.
Let $b(n)=a(n)+1$, then $b(1)=2$ and $b(n)=2b(n-1)$. Then,

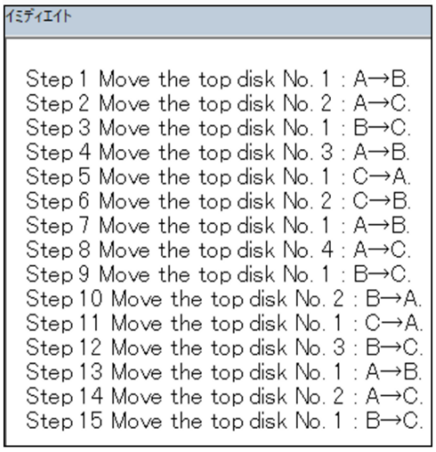
$$b(n)=\frac{b(n)}{b(n-1)}\cdot\frac{b(n-1)}{b(n-2)}\cdots\frac{b(3)}{b(2)}\cdot\frac{b(2)}{b(1)}\cdot b(1)=2^n$$

Therefore, $a(n)=b(n)-1=2^n-1$.
Then when n=4 and n=5, the numbers of steps are 15, and 31, respectively.
The program that outputs the step number at each step can be obtained by modifying the program in Fig. 8, as shown in Fig. 9.

```
'****************************************
Sub modified_Tower_of_Hanoi()
Dim n As Integer, Input_n As String, step As Integer
step = 0
Input_n = InputBox("The number of disks ?")
n = Val(Input_n)
Call Hanoi_Tower_m(n, "A", "B", "C", step)
End Sub
'****************************************
Sub Hanoi_Tower_m(n As Integer, S As String, W As String, D As String, step As Integer)

  'Move n-1 disks from "S" to "W" via "D."
If n >= 2 Then
     Call Hanoi_Tower_m(n - 1, S, D, W, step)
End If
step = step + 1
Debug.Print " Step " & step & " Move the top disk No. " & n & " : " & S & "→" & D & "."
  'Move n-1 disks from "W" to "D" via "S."
If n >= 2 Then
     Call Hanoi_Tower_m(n - 1, W, S, D, step)
End If
End Sub
'****************************************
```

(a)



(b)

Fig.9. Modified Excel VBA program and its execution results for Tower of Hanoi problem. (a) The modified program lists. (b) The output at immediate window in the case n=4.

4. Conclusion

In this paper, we have proposed a methodology for integrated and comprehensive STEM education, based on the viewpoint of ETT. Moreover, we have presented some application examples of teaching way from the ETT viewpoint, in order to show the usefulness.

We consider that the suitably combined presentation of ETT viewpoint and visualization such as 3-DCG will be more effective in the STEM education.

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