Methodology for Creativity Oriented STEM Education Based on 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 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, motivates students to study further, and inspires their creativity.

Keywords: *STEM Education, Equivalent Transformation Thinking (ETT) Theory, Identification of Equivalence, 3-Dimensional Computer Graphics (3DCG).*

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.

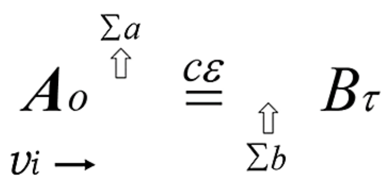
For the STEM education, we propose the methodology based on the viewpoint of Equivalent Transformation Thinking (ETT) theory which was advocated as a principle of creativity by Dr. Kikuya Ichikawa in 1955, after his investigation and analysis of the past discoveries and technological inventions.

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.

Especially, we emphasize that the suitably combined use of dynamic visualization technology based on the viewpoint of ETT 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]).

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 inventions to analyze how creation was done. And he revealed the investigation results that new technology developments and creations were produced along with the ETT process. Then he described the ETT process as a 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 that hold the system, ***vi***: viewpoint at a certain

Fig. 1 Equivalence Equation by Dr. Kikuya Ichikawa in his 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 $\boldsymbol{Ao}$ are discarded, and new elements of property and condition Σb are added to the system $\boldsymbol{B}\tau$.

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 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.

3. Application Examples of ETT Viewpoint

3.1. Cartesian Coordinate System

Looking back on history, it is possible to find out many facts that the act of ETT and/or Identification of Equivalence has made a progress of research in the field of STEAM (Science, Technology, Engineering, Art, and Mathematics), and that it has broadened our horizons and deepened our knowledge. Then, we consider that utilization of the viewpoint of ETT is also effective for STEM education.

For example, René Descartes provided “Cartesian coordinate system” that gives a correspondence between a point P on a plane and a pair of two numbers (x, y), where x and y are quantities based on the distances to two orthogonal axes (x-axis and y-axis), respectively, as shown in Fig. 2.

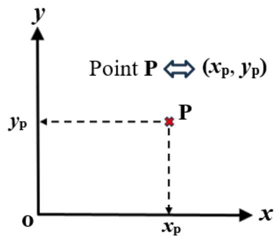


Fig. 2 Cartesian coordinate system.

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 an example that ETT not only opens the new field of mathematics such as Analytic Geometry and Algebraic Geometry, but also brings about the new way of representation such as “Field” into physics, so we consider that it is worth to enhance the idea of ETT. Moreover, we should notice the viewpoint of ETT and appropriately point out the viewpoint of equivalence when teaching the subject of STEM.

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, if we imagine a situation that an object is quietly floating on the water, and if we think of that it is equivalent to the situation where the water in the same volume area of the object under the surface is quietly balanced (Fig. 3(c)), we understand that Archimedes’ principle will be derived.

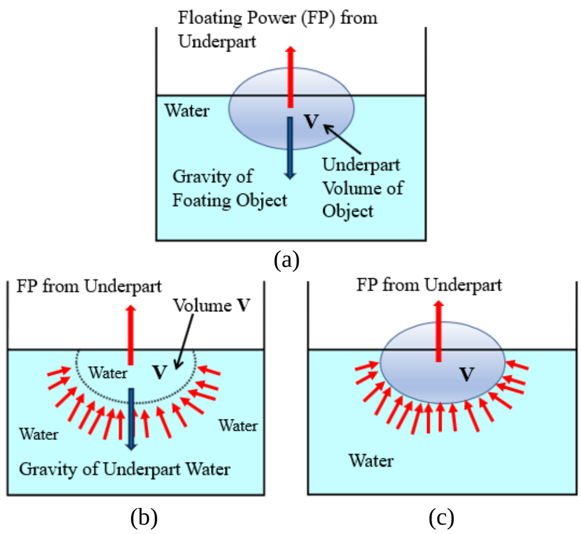


Fig. 3. Floating power (or buoyant force) that operates on a body immersed in a fluid. (a) An object is quietly floating on the water. (b) V means the same volume/area of the object under surface. (c) The water in the same volume area V is quietly balanced.

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.

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

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

(a)

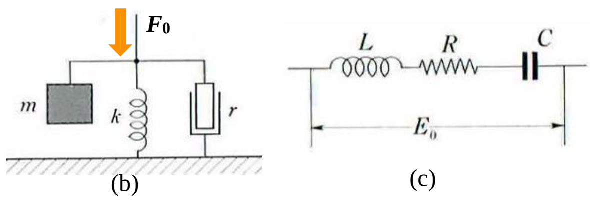
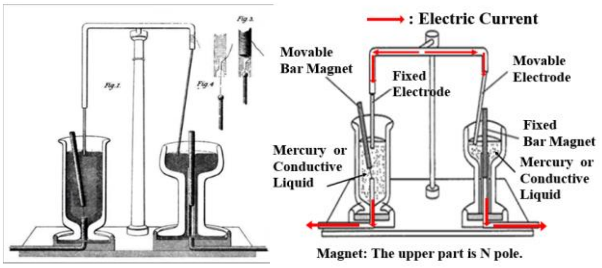


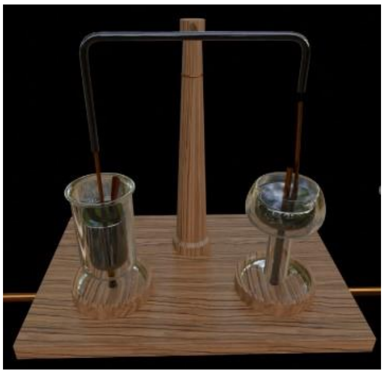
Fig. 4. (a) Differential equations and their corresponding elements in MDS and ECS. (b) Conceptual image of MDS. (c) Conceptual image of ECS.

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. Viewing from the above, when the current flows, both of bar magnet and electrode (or conductor) rotate clockwise.



(a) (b)



(c)

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

As for the force that causes rotation, there are different explanations (or lectures) for the left and right sides. For the left side, the current flowing through conductor rotates the movable bar magnet by creating magnetic according to Ampere's law. On the contrary, for the right side, the the current in conductor rotates because it receives Lorentz force from the magnetic field made by the fixed bar magnet.

However, there is a unified explanation from law of action and reaction. In the left side, like the left side, the magnetic field caused by the current in conductor exerts a force on the fixed bar magnet, but since the bar magnet is fixed and the conductor is floating, then the the conductor rotates itself by the reaction force.

This unified explanation can be easily provided by 3-DCG video, referring 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

Recursive programming is useful, but it is not so easy to suitably write down. Taking the problem of "Tower of Hanoi" for example (Fig. 6), the problem is to move the tower consisting of n disks, from the place at pillar A (or start place) at the left end to the pillar C (or destination) at the right end, using the pillar B in the middle (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 sections, (iii) Do not put a disk over a smaller disk.

(a) (b)

Fig. 6. The "Tower of Hanoi" problem. (a) Initial state when the number of disks n=5. From the left end, we call three 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.

For making the recursive program in the general case of n disks, we note a pattern of disk moving, that will appear clearly when the number of disks n=2. That is, the pattern is equivalent to what can be seen if we divide n disks into two parts: upper parts (n-1 disks) and lowest part (the bottom largest disk).

Imagine when the largest disk can be moved from A (start) to C (destination) under the constraints. Firstly, we must move the upper parts (n-1 disks) from the place A to B (workplace), after that, the largest disk (=lowest part) can be moved from A to C. As the next step, the upper parts (n-1 disks) are to be moved from B to C. This is the important turning point (Fig. 7).

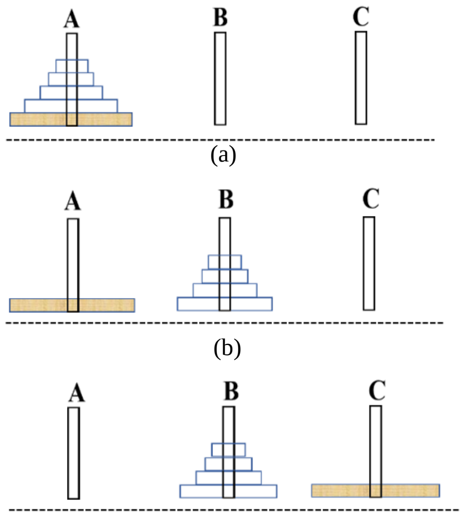


Fig.7. The turning point procedure of "Tower of Hanoi" problem in moving n disks from the place A to C using the place B. (a)Initial state. (b) and (c). The turning point when the top n-1 disks are moved from A to B, after that, largest disk left at A is moved to C.

Then, if we let TOH(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.

TOH(n, A, B, C) =TOH(n-1, A, C, B) + Move the largest of n disks from A to C+ TOH(n-1, B, A, C).

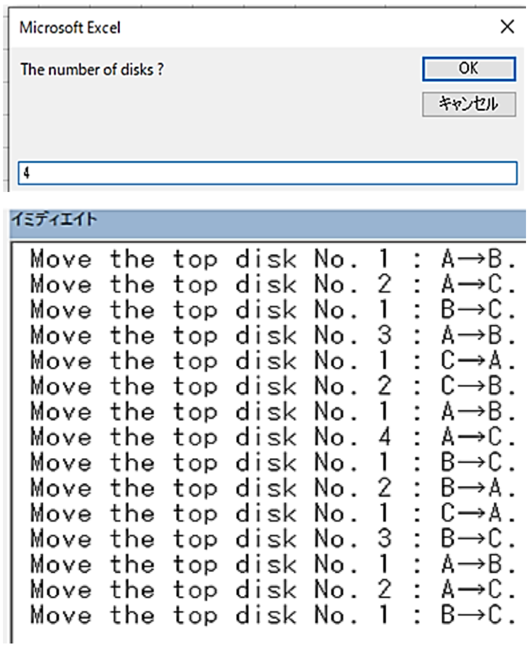
The procedure TOH(n, S, W, D) is concretely, described by Excel VBA, as shown in the Fig. 8.

```
Sub main_Tower_of_Hanoi()
Dim n As Integer, Input_n As String
Input_n = InputBox("The number of disks ?")
n = Val(Input_n)
Call Hanoi_Tower(n, "A", "B", "C")
End Sub
'**********************************
```

(a)

```
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
'****************************************
```

(b)



(c)

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

The necessary number of steps $a(n)$ to solve the problem of n disks is decided from the above algorithm.

$a(n)=a(n-1)+1+a(n-1)=2a(n-1)+1 \ (n\geqq 2),\ (a(1)=1)$.

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, $a(n)=b(n)-1=2^n-1$.

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 use of visualization tool such as 3-DCG will be more effective.

As a further study, we are considering that the solution algorithm for the Tower of Hanoi problem can be represented as the tree generation in tree language notation. Then, we find out that the recursive algorithm may be described as an iterative algorithm equivalent to the recursive one, and that a fast solution algorithm can be obtained. We would like to report this on another opportunity.

References

1. Yeping Li, Ke Wang, Yu Xiao & Jeffrey E. Froyd, Research and trends in STEM education: a systematic review of journal publications, International Journal of STEM Education, Springer Open, Vol.7, No.11, https://doi.org/10.1186/s40594-020-00207-6G (2020)
2. Fitzgerald, M. S., & Palincsar, A. S., Teaching practices that support student sensemaking across grades and disciplines: A conceptual review, Review of Research in Education, Vol.43, pp.227–248(2019)
3. Kikuya Ichikawa, Science of Creativity, NHK Publishing (1970) (in Japanese)
4. Kikuya Ichikawa, Creative Engineering, Lattice Co., Ltd. (1977) (in Japanese)
5. Hideki Yukawa, Leap to Creation, Kodansha (1968) (in Japanese)
6. Equivalent Transformation Creativity Society ed., Equivalent transformation theory that can be understood graphically, NIKKAN KOGYO SHINBUNSHA (2005) (in Japanese)
7. Hikaru Matsuki, Hideaki Ogawa, Yasuaki Kajisha, A New Movement on the Theory of Equivalent Transformal Thinking, The Japanese Society for Artificial Intelligence, Vol.22, No.3, pp.392-398 (2007) (in Japanese).
8. Takeo HARUYAM, A Study on the Technology and Skill Transfer from the Creative Engineering Point of View, Journal of Japan Society for Production Management, Vol.15, No.1, pp.1-6 (2008) (in Japanese)
9. Tetsuo Hattori, Rikiya Masuda, Yoshio Moritoh, Yoshiro Imai, Yusuke Kawakami, Takeshi Tanaka, Utilization of Both Free 3DCG Software "Blender" and 3D Printing for Early STEM Education, Proc. of IEEE TALE2020 (An International Conference on Engineering, Technology and Education), ISBN 978-1-7281-6942-2, pp.971-974 (2020)
10. Tetsuo Hattori, Rikiya Masuda, Toshihiro Hayashi, Yoshiro Imai, Yoshio Moritoh, Yusuke Kawakami, Takeshi Tanaka, A STEM Education Method Utilizing 3DCG Software Blender, Proc. of the Sixth International

Conference on Electronics and Software Science (ICESS2020), ISBN978-1-941968-62-8, The Society of Digital Information and Wireless Communications (SDIWC), pp.38-43 (2020)

11. Tetsuo Hattori, Asako Ohno, Yoshiro Imai, Yusuke Kawakami, Katsunori Shimohara, Takeshi Tanaka: "Creativity Oriented STEM Education Utilizing Equivalent Transformation Thinking Theory and Dynamic Visualization Technology", Proc. on 2022 Annual Conference of Electronics, Information and Systems Society, IEE of Japan, GS3-6, pp.1058-1062 (2022) (in Japanese)

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