TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC SƯ PHẠM TP HỒ CHÍ MINH

HO CHI MINH CITY UNIVERSITY OF EDUCATION
JOURNAL OF SCIENCE

Tập 16, Số 9 (2019): 369-381

Vol. 16, No. 9 (2019): 369-381

ISSN: 1859-3100

Website: http://journal.hcmue.edu.vn

Research Article

APPLYING STEM EDUCATION IN TEACHING REGISTERS OF REPRESENTATION OF THE FIRST-DEGREE FUNCTION

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Received: July 01, 2019; Revised: July 20, 2019; Accepted: August 10, 2019

ABSTRACT

STEM education is one of the approaches recommended for the new curriculum after 2018 in Vietnam. This article utilizes this approach to construct a teaching situation which allow students to explore and convert among various registers of representation of the first-degree function. The situation was experimented with 9th graders, and the results demonstrated that these students were able to connect mathematic and physics knowledge to create a dynamometer.

Keywords: STEM education, frames and registers of representation, first-degree function.

1. Introduction

Throughout the history of development, functions were not just merely tools, but also research subjects of many scientists and mathematicians. People acknowledged the important role of functions because of their ability to reflect the phenomena of the objective reality and bring out the dialectical features of modern mathematical thinking. However, it has been not easy for teachers to fully understand this concept. Gaudin (2002), Nguyen Thi and Le Van (2003), and Nguyen Thi (2013) pointed out the presentations of this concept in various frames and registers of representation (Table 1).

Table 1. *Frames and registers of representation of the function*

Frames	Registers of representation
Numeral	Table
Algebra	Algebraic expression
Graphics	Graph

To solve mathematical problems, students not only work inside one frame/register of representation but also have to know to convert among different frames/registers (Douady,

Cite this article as: Tang Minh Dung, & Duong Anh Khoa (2019). Applying STEM education in teaching registers of representation of the first-degree function. *Ho Chi Minh City University of Education Journal of Science, 16*(9), 369-381.

1986). The problem is letting the conversion arises from the situation itself rather than from the demands of teachers.

In this article, we will discuss the application of STEM education to solve the problem above. The approach is consistent with the new mathematical curriculum used in Vietnam after 2018, to develop certain competency for students: “The new mathematical curriculum emphasizes the applicability, engaging with practice or other subjects and teaching activities, especially with subjects related to STEM education” (Ministry of Education and Training, 2018, p. 4).

2. Research design

2.1. STEM education

STEM is an acronym for **S**cience, **T**echnology, **E**ngineering, and **M**athematics. Many researchers like Honey et al. (2014), Nguyen Van et al. (2019), Nguyen (2019), these aspects can be explained as follows:

- Science: is a whole subject. They are the insights of the natural world, also a process to achieve these insights through systematic experimenting, combined with observation, indicating objects and phenomenon and explain them to reach a common knowledge which was proven by experimenting.
- Technology: are tools, equipment, and even the process to use these toolsand equipment to create products.
- Engineering: the process to create products which did not exist before.
- Mathematics: is the understanding of structure, order, and relations developed from basic principles of measuring, counting, and describing objects. It also comprises thinking, logic, and measuring calculation. This alway presents, intervening with all other aspects, especially engineering.

Recently, there are many different approaches to STEM education such as search and find, 6**E** (**E**ngage-**E**xplore-**E**xplain-**E**ngineer-**E**nrich-**E**valuate), 4**C** (**C**onnect-**C**onstruct-**C**ontemplate-**C**ontinue), and TRIAL (**T**ask-**R**ecall-**I**deas-**A**pply-**L**earnt). In this research, EDP (Engineering Design Process) will be used to conduct an experiment. It includes eight steps (Jolly, 2017): 1-Define the problem, 2-Research, 3-Image, 4-Plan, 5-Create, 6-Test and evaluate, 7-Redesign, 8-Communicate. It must be noted that these steps do not have to follow a strict procedure but can be modified to fit the purposes of a lesson.

In order to evaluate a STEM lesson, Jolly (2017) suggested five characteristics:

- STEM lessons focus on real-world issues and problems;
- STEM lessons are guided by the EDP;
- STEM lessons immerse students in hands-on inquiry and open-ended exploration;
- STEM lessons involve students in productive teamwork;
- STEM lessons allow for multiple right answers.

2.2. Theory of Didactical Situations in Mathematics

The Theory of Didactical Situations in Mathematics was proposed by Guy Brousseau in the 60s in France. This theory has been adopted and developed by many researchers in the world. This theory provides us a necessary framework to analyse teaching situations by selecting pedagogical options in order to offer learning strategies for students, allowing teachers to establish an environment in which students can study by adapting similar strategies to an unfamiliar environment (Bessot et al., 2009).

3. Methods

This research focuses on creating and experimenting a STEM lesson for middle school students to create a chance for them to work and convert different registers of representation of first-degree function.

This situation was adapted and renovated from "Stretching It" situation (Benken et al., 2019) to fit the research's context.

3.1. Participants

We conducted an experiment with 32 9th graders in Nguyen Van Ba Middle school (Ho Chi Minh City).

The experiment took place after students had finished the lesson "First-degree function." So they had been provided with enough insights and skills to meet the expectations of our situation: first-degree function and graph, coordinates axis. In physics, they had known about force and weight.

Students worked in groups of four.

3.2. Research Phases

Table 2 illustrates experimental questions guided by EDP.

Table 2. *Phases and experimental questions*

Phases	EDP steps	Experimental sheets	Experimental questions	Content
Phase 1	Define the problem	Sheet 1	Question 1	Information about dynamometer
Phase 2	Research, Image, Redesign	Sheet 2	Question 2.1	Given weight (P), determine the length of the spring (l)
			Question 2.2	Determine the formula between weight (P) and the length of the spring (l)
Phase 3	Create, Test and evaluate, Redesign	Sheet 3	Question 3	Build, create a dynamometer from given items
	Communicate	Game challenge		Using the dynamometer to measure the weight of the given item.

Phase 1 (15 minutes)*:* The teacher discusses the purposes of the course, that is to build a dynamometer which can be used to measure objects whose weight is smaller than 3N. The students will work in groups to answer three questions in Sheet 1.

Question 1.1. Define a dynamometer

Question 1.2. Describe the design of a dynamometer. Draw an image of the dynamometer

Question 1.3. Can an elastic string be a replacement for the spring in a dynamometer? Explain why

Phase 2 (45 minutes): Teacher distributes to each group the following items: heavy objects with known weight (0,1N; 0,2N; 0,5N; 1N) and can be connected to create various combinations of weight, spring which is attached on a metal hanging, ruler, pen, caculator, graph paper (with the smallest unit of 1 milimeter). Teacher prepares a 2N-heavy object which will be used in question 2.2e.

Students still work in the previous group to answer questions in Sheet 2.

Question 2.1. One by one, attach the heavy objects into the spring as shown in the following picture

Measure the length of the spring corresponding to the weight and fill those values in the following table.

Weight of heavy objects (unit: *N*)	0,1	0,2	0,5	0,7	0,8	1,0	1,1	1,5
Length of spring (unit: *mm*)								

Question 2.2. Find the formula representing the relationship between the weight of the objects (P) and the length of the spring (l). Use these following suggestions:

a) Demonstrate the pair (P,l) as dots onto the coordinates axis.

b) Draw a line (d) closest to the dots (in the previous question) as possible.

c) Determine a function representing (d) in question b.

d) Conjecture the length of the spring (l_o) if attached with a 2N-object.

e) Attach an object of $2N$, measure the length of the spring and compare with your prediction in question d.

f) If there is a big difference in the result, adjust your function (d) by using SCATTER in Microsoft Excel software.

Students can consult about the SCATTER function in "Learning document Maths 7," p. 102.

Phase 3 (30 minutes): Teacher distributes Sheet 3 with question 3: With these given items: spring (in phase 2), plastic tube (used for attach the spring), tape, graph paper in question 2.2, build and create a dynamometer. Then, with your dynamometer, proceed to measure the weight of the objects which will be given by the teacher.

3.3. STEM aspects in the study

This teaching situation is designed to bring out the following STEM aspects:

- Science (S): Knowledge in physics such as force and dynamometer;
- Technology (T): Spring, more specifically, the elasticity of the spring which can be expressed by the stiffness;
- Engineering (E): Determine the relationship between the elasticity of the spring and a force-scale measurement;
- Mathematics (M): Various registers of representation (table, algebraic expression, graph) of first-degree function.

Comparing all the characteristics presented in Section 2.1, we believe that these aspects help student with hands-on activities in creating a dynamometer. These activities were organized in a way that students can work in groups, allowing students to develop diverse skills such as communication, presentation, and persuasion. It should be noted that the measurement process, calculation, and assemble can generate some computing errors, or even students can propose different designs for the dynamometer; eventually, because of this diversity, the products of this activity will also be different (all will be acceptable as long as the operating principle is based on physics fundamental), student's creativity is also encouraged.

3.4. Pedagogical options in the experiment

a) Sheet 1

The purpose of question 1.1 and 1.2 is to remind students the knowledge related to dynamometer which has been introduced since Grade 6. It also reminisces the image of a dynamometer which contributes to the creation of the dynamometer in phase 2 and 3.

Question 1.3 addresses the properties and advantages of the spring compared to the elastic band as a material in creating a dynamometer. This allows the students to approach the Technology (T) aspect in STEM. The anticipated answer is: "Elastic band is an easily worn material, more ephemeral than a spring. After using it for a period of time, it tends to wear down and is no longer effective and accurate as it used to be. This will lead to the inaccuracy in measuring." If for some reasons, students are not able to answer this question, the teacher will clarify the answer at the end of the activity.

b) Sheet 2

In question 2.1, student proceeds to gather data from the experiment, assembles a data table between two variables "weight" (P) and "length" (l) in order to resolve the request of the following answer about this relationship. We take into consideration these following pedagogical options:

Varible V1: Number of data in table.

If there are only two data, the situation becomes a regular requirement about finding the equation of a straight line through two points. So in order to avoid that, we create a table with many data points; therefore, student must consider the relationship between (P) and (l) from the statistical point of view.

Variable V2: Measurement subject

There are two options that we consider: either measure the whole length of the spring or only the difference in length of the spring. In order the avoid the ratio strategy, we have to choose the method that is to measure the whole length of the spring. This option requires the students to solve the problem with function $y=ax+b$ ($b \neq 0$).

In question 2.2 (a-c), the students must convert among different registers of function: table → graph→ algebraic expression to determine the relationship between two variables P and l by the stiffness of the spring (hidden meaning). Afterward, questions (d) and (e) will create a situation for students to realize whether the computing error is acceptable or not by comparing the data through prediction with the data from conducting experiment. The observation from physics enviroment will be the feedback for students to adjust their coefficients a and b in the first-degree function. Question (f) is a guide for students to recreate and adjust with the SCATTER feature in Microsoft Excel software.

Also in question 2.2, the variable V3 related to the weight of the objects (2N) will be used to verify the function. The number (2N) is chosen based on the difference of the data in question 2.1. This will ensure that the computing error when using the function is significant enough to make the students realize they need to adjust.

c) Sheet 3

By determining the relationship between weight (P) and length of spring (l) at Sheet 2, students will design and build a dynamometer. This will not be the first time students are requested to build a dynamometer, as a matter of fact, building a dynamometer has been mentioned in physics curriculum since Grade 6:

- Step 1: One by one, hang two heavy objects with the given weight (1N and 2N).

- Step 2: Use a ruler to measure the difference in length $\triangle l$ between the two measurements. Use that difference as a distance between two notches in the dynamometer measurement scale.
- Step 3: Divide those $\triangle l$ length into ten smaller equal units. The distance between those units will be the smallest unit measurement.

With this method, students acknowledge the ratio relationship between the two variables P and $\triangle l$. In other words, $\triangle l=k.P$. The quantity "k" represents the stiffness of the spring. However, with our purpose in mind to guide students towards the first-degree function, we consider variable V4 related to the equipments provided for students. More specifically, we do not give out ruler with measuring notches and heavy objects in this phase. This will contribute to the fact that student must use the graph paper and the graph of the function in phase 2.

Moreover, in the game challenge activity, we use objects with which the weight is known to the teacher, with that weight not exceeding the elasticity limit of the spring (a key for example).

3.5. Possible strategies used by students

In this section, we will clarify the mathematics knowledge used by the students in Question 2.2 by analyzing all the possible strategies which might have been utilized and observed during the experiment. Specifically, we turn our attention to the methods the students used to determine the function (graph, algebraic expression) from the data from the table.

a) "Visualization-graph" strategy

After demonstrating all the data points as dots in the coordinates axis, students is then expected to use a ruler to draw a line as close as possible to all the dots (Phan, 2012). The algebraic expression of function can be determined by choosing two points on the graph and writing the equation of a straight line through these two points.

b) "Approximate" strategy

Students is projected to determine the coefficients a and b by using the arithmetic mean of coefficients a_i, b_i of function (d_i) which can be found through two points A_i and A_{i+1}.

c) "Technology tool" strategy

Students will use the scatterplot features in technology tools (calculator, software).

4. Results

a) Sheet 1

In question 1.1, to define the dynamometer, the answer we received from all groups were all related to the operation of the dynamometer: "a tool which is used to measure force".

In question 1.2, seven out of eight groups were able to introduce the basic materials in a dynamometer such as the spring, the measurement scale, a hook (Figure 1). Only group 6 did not mention the spring in the structure of the dynamometer.

In question 1.3, related to the Technology aspect (T), except for group 8, all other groups disagreed with the replacement of spring over the elastic band. They also indicated various disadvantages associated with the elastic band such as "poor elasticity", "easily deformed", "worse durability than spring", "unstable", "unreliable under high temperature", or "fracture".

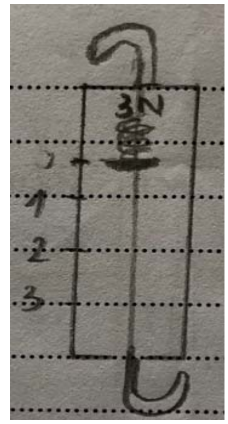
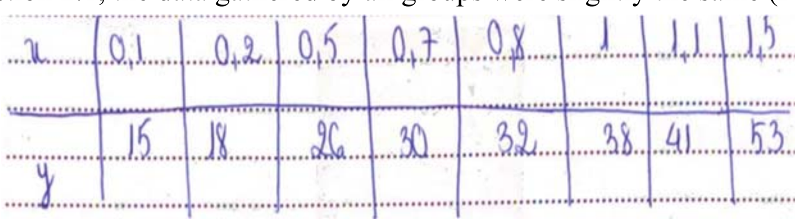


Figure 1. *Image of a dynamometer from group 5*

b) Sheet 2

In question 2.1, the data gathered by all groups were slightly the same (Figure 2).



x	0,1	0,2	0,5	0,7	0,8	1	1,1	1,5
y	15	18	26	30	32	38	41	53

Figure 2. *The data of group 8*

In Question 2.2a, all groups understood and indicated all the dots in graph paper corresponding to the data points in the table.

In Question 2.2b, the "Visualization-graph" strategy turned out to prevail over other strategies with seven out of eight groups drawing a line as close as possible to the dots in question 2.2a (Figure 3). However, the graph of group 3 showed a significant difference from the rest by having the graph going through the origin of the coordinates axis (Figure 4). This can be viewed as a trail of influence from grade 7 with the commonly encountered function $y=ax+b$ ($b \neq 0$). When being questioned about how the graph seems "odd" because the distance from the line to the dots seem a little bit remote, the students in this group assumed the data which they gathered had some miscalculation at the few first numbers. However, the students were fairly confident about the final numbers of the data (equivalent to the 1N; 1,1N and 1,5N). Therefore, according to this group, the line only needs to be close to the few final dots.

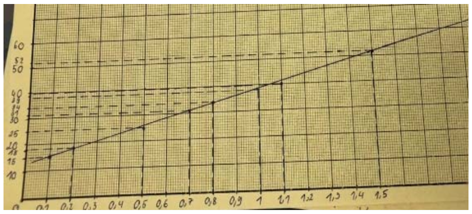


Figure 3. *The graph image of group 5*

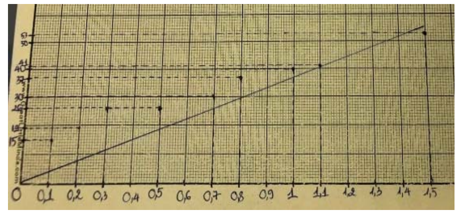


Figure 4. *The graph image of group 3*

In Question 2.2c, we compiled all the strategies and answers of eight groups into Table 3.

Table 3. *The strategies and answers of eight groups for Question 2.2c*

Strategy	Group	Algebraic Expression
Visualization-graph	2	*y=27,86x+11,21*
	4	*y=28x+11*
	5	*y=185/7 x + 173/14*
	6	*y=26,43x+13,355*
	7	*y=30x+11*
Approximate	1	*y=32x+13*
Technology tools	8	*y=26,46x+12,11*
Ratio	3	*y=42,3x*

Five out of eight groups used the "Visualization-graph" strategy. In detail, to find the algebraic expression, the method used by groups 2, 4, 5, and 6 was to choose two points and find a first-degree function with two given points (Figure 5). In addition to this strategy, group 7 used another method to arrive at a solution. The *Y*-intercept *b* was determined by the intersection between the line and the *y*-axis (*OP*); the slope a was determined by using *tan* of the angle formed by the line and the *x*-axis (*Ol*) (Figure 6).

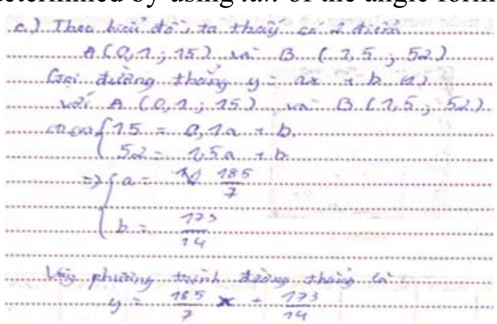


Figure 5. *The 2.2c answer of group 5*

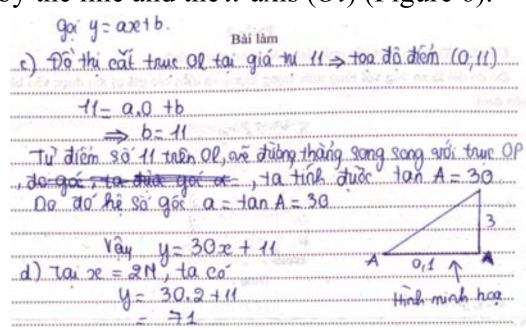
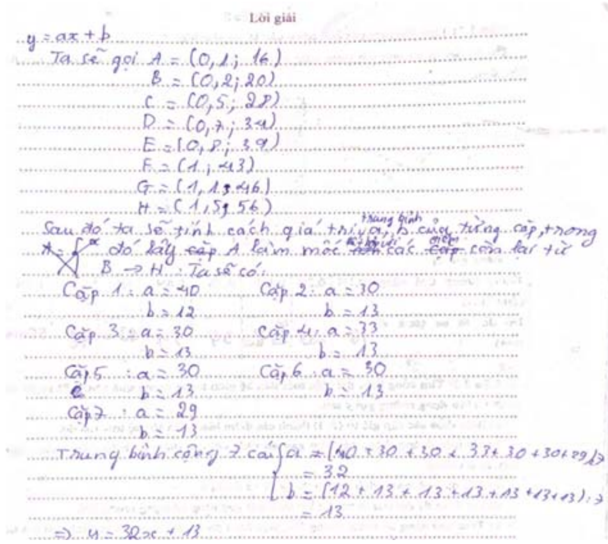


Figure 6. *The 2.2c answer of group 7*

The "Approximate" strategy was used by group 1 with the arithmetic mean of 6 first-degree function continuously equivalent to 2 points in 8 points of datas in question 2.1 (Figure 7).


Lời giải

y = ax + b

Ta sẽ gọi A = (0,1; 16)
B = (0,2; 20)
C = (0,5; 28)
D = (0,7; 34)
E = (0,8; 39)
F = (1; 43)
G = (1,1; 46)
H = (1,5; 56)

Sau đó ta sẽ tính cách giá trị trung bình của a, b của từng cặp, trong đó lấy ~~cặp~~ A làm mốc kết hợp với các ~~cặp~~ điểm còn lại từ B → H. Ta sẽ có:

Cặp 1: a = 40, b = 12 — Cặp 2: a = 30, b = 13
Cặp 3: a = 30, b = 13 — Cặp 4: a = 33, b = 13
Cặp 5: a = 30, b = 13 — Cặp 6: a = 30, b = 13
Cặp 7: a = 29, b = 13

Trung bình cộng 7 cái: a = (40 + 30 + 30 + 33 + 30 + 30 + 29) : 7 = 32; b = (12 + 13 + 13 + 13 + 13 + 13 + 13) : 7 = 13

⇒ y = 32x + 13

Figure 7. *The 2.2c answer of group 1*

Group 8 had a very fast conclusion with the result of *y=26,46x+12,11* though they did not clarify the answer. When being asked about the solution, the students explained that they realized the graph was a straight line, they then used a calculator to find the algebraic expression. They described the method as these following steps:

- Step 1: Choose MODE > STAT. Then choose A+BX.
- Step 2: Proceed to import the value of X and Y corresponding to the datas in the table.
- Step 3: Choose command SHIFT+STAT. Then choose Reg>A or Reg>B to access the value of A and B.

This technique did not get a proper introduction in the current curriculum system. When being asked about the origin of this technique, the students informed that they were taught by a Physics teacher while they encountered similar exercises about drawing graph between the amperage (*I*) and voltage (*U*).

In Question 2.2d, all groups chose the method of substitution by replacing the value of *x=2* into the algebraic expression to predict the length of the spring attached with a 2N-object. (Table 4).

Table 4. *The result by eight groups for Question 2.2d*

Group	1	2	3	4	5	6	7	8
Prediction (Unit: mm)	77	66,93	84,6	67	65,2	66,215	71	65,03

In Question 2.2e, the result of the experiment was a feedback for students to realize whether their prediction was an acceptable outcome or not. There were three groups (1, 3, 7) who recognized their prediction in question 2.2d is too different from the actual result.

Afterwards, in Question 2.2f, these three groups (1, 3, 7) used the Microsoft Excel software and gathered a new algebraic expression (Table 5).

Table 5. *The result of three groups 1, 3, 7 for Question 2.2f*

Group	1	3	7
Result	$y=28{,}74x+14{,}05$	$y=26{,}65x+12{,}97$	$y=27{,}26x+12{,}39$

After re-evaluating $x=2$ with the new function, group 3 and group 7 found the results slightly the same with the result from the experiment. However, with group 1, there was still a significant difference in numbers between the two results. Therefore, these students decided to collect the data again and realized the data from Question 2.1 were not accurate. This group then asked for permission to do the experiment again.

c) Sheet 3

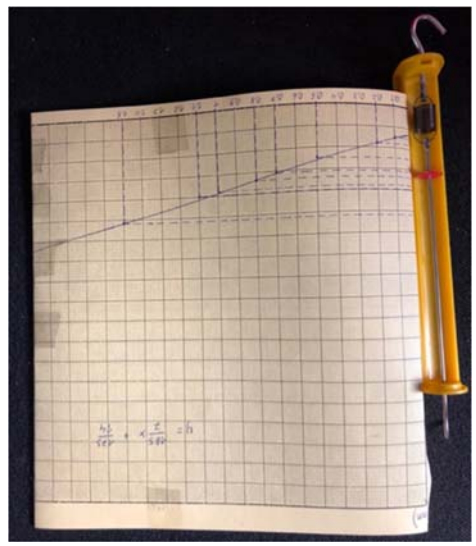


Figure 8. *The product of group 5*

With those items provided by the teacher, students no long had the ruler with notches and heavy object. An obstacle was met on the path to create a measurement scale for the dynamometer. However, more and more students realized the role of the paper graph with the graph in question 2.2b. It could possibly be the measurement scale (Figure 8). More specifically, students strapped the spring in vertical position of the axis (l), the start-point of the spring stayed at the origin of the coordinates axis. At the end-point of the spring, students drew a horizontal line which intersects with the graph of the first-degree function, from the intersection, drew a line vertically intersected with the OP axis. The value determined on the (P) axis is the weight of the object.

5. Discussion

At the begining of this research, a teaching situation was chosen from a foreign curriculum (American): "Stretching It". Then this situation was developed, adapted and guided into an EDP in STEM education. By carefully taking into consideration those pedagogical options, we allowed the appearance of all three expression forms of the first-degree function (table, algebraic function, and graph) and the conversion among those three. It is neccesary to look at a function from many perspectives. However, Vietnamese students tend to favor the algebraic expression more than any other forms. This conclusion can somehow be reflected in our experiment because none of these groups explored the idea of the graph to solve the Question 2.2d. This phenomenon, once again, reaffirmed the results from the research by Nguyen Thi and Le Van (2003). They are still valuable, eventhough the research was published in the re-adjusted curriculum before 2006. Organizing a STEM lesson can create an enviroment which allows students to synthesize the insights of many different educational subjects, in this case, Physics and Mathematics. Those operations based on mathematics fundamental (function) are spontaneously integrated in real-world situation: creating a dynamometer. Furthermore, the measurement scale designed by the students clearly shows that a first-degree function - relationship between two quantities: the length of the spring and the weight of object by recreating the graph (on graph paper) of the function in Question 2.2. Meanwhile, it is easy to find a measurement scale on the market, but they only display the value of the weight. In other words, only the value of the function is presented but the relationship between two quantities is concealed by their neat design.

This research prompts a dilemma about developing an educational curriculum. For instance, Question 2.2 in our experiment is a linear regression problem. It is a commonly known situation and a technique used to solve and discover the principle of the natural world from experiment data. However, this knowledge is not even mentioned in our current mathematics system. So, in developing a curriculum, educators should praise the connection and integration among many subjects so as to enhance the integrated education.

In addition, as mentioned above, the origin of our experiment is from a foreign education system. This raised a discussion about the exploitation and adaptation of foreign STEM lessons into the Vietnamese education system. If the proccess can be done, our nation's education system will have access to enriched, qualified resources to be able to carry on this path of teaching.

❖ ***Conflict of Interest:*** *Authors have no conflict of interest to declare.*

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VẬN DỤNG ĐỊNH HƯỚNG GIÁO DỤC STEM TRONG DẠY HỌC CÁC HỆ BIỂU ĐẠT CỦA HÀM SỐ BẬC NHẤT

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Ngày nhận bài: 01-7-2019; ngày nhận bài sửa: 20-7-2019; ngày duyệt đăng: 10-8-2019

TÓM TẮT

Giáo dục STEM là một định hướng được khuyến khích trong chương trình mới sau năm 2018. Bài viết vận dụng định hướng này để xây dựng một tình huống dạy học giúp học sinh khai thác và chuyển đổi các hệ biểu đạt của hàm số bậc nhất. Tình huống đã được đưa ra thực nghiệm trên đối tượng học sinh lớp 9 và kết quả thực nghiệm cho thấy học sinh đã liên kết các kiến thức toán và vật lí để giải quyết yêu cầu chế tạo một lực kế.

Từ khóa: giáo dục STEM, khung và hệ biểu đạt, hàm số bậc nhất.