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A survey of high school teachers' perspectives on using APOS theory to develop students' problem-solving skills in the context of derivatives

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Abstract: APOS, which Dubinsky developed, is a constructivist learning theory based on Piaget's epistemology. This theory has been adopted all over the world to teach mathematics. Students benefit from a better understanding of mathematical concepts thanks to the application of the APOS theory in mathematics education, which contributes to the overall formation and development of the student's mathematical abilities. This research was carried out to lay the groundwork for subsequent research that will apply APOS theory to instructing high school teachers on derivatives. The research was conducted with forty high school teacher participants to survey their understanding and perspectives on mathematical competencies in general, problem-solving capacity in particular, and APOS theory in teaching the topic of derivatives. According to the research findings, most teachers understood the significance of their role in assisting students in acquiring new skills and appreciate the weight of this responsibility (especially the ability to solve mathematical problems). On the other hand, the majority of the teachers who took part in this survey had only a very basic comprehension of the APOS theory.

Keywords: APOS theory, problem-solving competence, derivation, teacher perspective.

1. Introduction

In order to resolve the tension that exists between the requirements of training new people and the current classical teaching method, which is still ongoing, it is the responsibility of educators to develop novel approaches to the classroom experience. In conjunction with this, the rapid expansion of today's knowledge-based economy has made the problem of elevating the level of education to a higher standard an issue that is more pressing than ever. The development of novel approaches to educational instruction is an essential component in accomplishing this objective.

The General Education Program for 2018 has been published by the Ministry of Education and Training and outlines the requirements for student ability and the program's characteristics and objectives. This program requires teachers to master the innovative perspectives of the program and equip students with the necessary knowledge and skills for competency-oriented teaching methods. In addition, teachers must demonstrate their mastery of these innovative perspectives throughout the program.

According to the general education program for 2018, the requirements to achieve specific competencies in Mathematics are as follows: "Math contributes to the formation and development of students' mathematical competence (the most concentrated expression of computational competence), including includes the following core components: mathematical thinking and reasoning abilities; mathematical modeling ability; ability to solve math problems; mathematical communication competence; ability to use t" (Math contributes to the formation and development of students' mathematical competence (the most concentrated expression of computational competence) including includes the following core components: mathematical thinking and learning should ultimately lead to problem-solving abilities that can be applied in everyday life, as well as the ability to surmount challenges and zero in on the approach that yields the most effective results for issues that crop up as a result of actual use. Therefore, solving problems is considered an important general competency that students must develop early in their education.

Scholars worldwide generally have similar opinions about the concept and components of problem-solving capacity when researching problem-solving capacity. Adapting to societal change is one of the most important roles that capacity plays for individuals. According to Polya, the problem-solving process consists of 4 steps: Understand the problem, plan to complete it, resolve the problem according to the plan, and finally, check all the steps taken [4]. Recent studies on the problem-solving process in teaching mathematics are often developed based on the Polya problem solution process, typically in the mathematics document PISA (international program for student assessment), dividing the problem solution phase by building formulas and forming mathematical models, finally giving solutions [10].

Mathematical problem-solving is one of the most fundamental teaching goals and one of the most difficult for students to achieve. The strategic thinking process of problem-solving necessitates planning.

Students will be able to think critically, logically, and creatively. Evidence suggests that students are more interested in the final result than in the process of arriving at that result and that it is difficult to determine the concepts employed to solve the problem [12].

APOS is a constructivist learning theory originally developed by Dubinsky et al. APOS stands for the words: Action, Process, Object and Schemas; these are the thinking structures that students need to build to understand a new Math concept deeply [6].

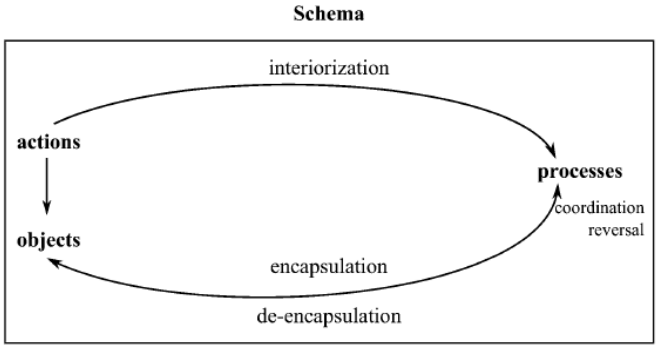

Figure 1: APOS theory (Arnon et al., 2014)

Understanding a mathematical concept begins with manipulating previously constructed mental structures or a physical object to form activities, which are then collected into processes and will continue to be summarized to form new objects. New objects can be de-encapsulated back to the process in which they were formed. Finally, actions, processes, and objects are reorganized to form a schema [8].

APOS theory is applied to teaching mathematics through the ACE learning cycle, which is a pedagogical strategy consisting of three components: (A) Activity; (C) Classroom discussions and (E) Exercises done outside of the classroom. In arranging learning activities, APOS theory requires an assumption about a mathematical concept. The result of this analysis is called genetic decomposition [6].

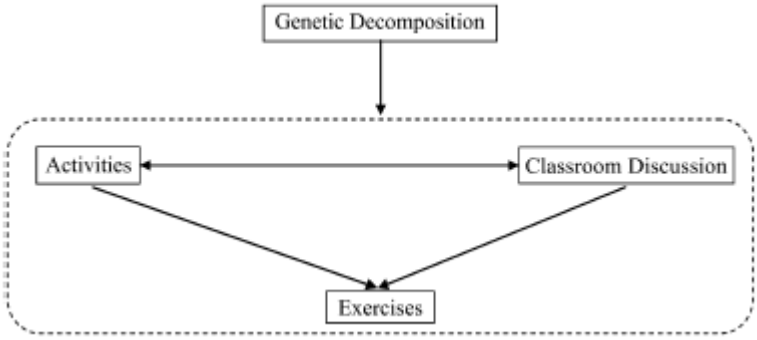

Figure 2: The relationship between genetic decomposition and the ACE cycle (Arnon et al., 2014)

The genetic decomposition of a mathematical concept is a sequence of mental structures to construct a mathematical concept that develops in one's mind. Thus, phylogenetic analysis requires a mental structure of actions, processes, objects, and schemas that describe certain mathematical concepts. Some typical works related to APOS theory in math teaching can be mentioned as follows:

Author Maharaj discussed some measures to improve the student's understanding of two concepts, limit and derivative when using APOS theory to analyze the student's comprehension ability. BIRTH for these two concepts [1,2]. Similarly, APOS theory explores students' thinking mechanisms and structures when they perform demonstration activities to build some measures to support students in building a formal proof [14]. APOS theory has been applied in combination with OSA theory to analyze the understanding of university students about graphs of functions, and its derivatives (sample of 14 students) showed that most of them have difficulty in calculating the derivative at the critical points, the inclination of the tangent lines [15].

Based on the genetic decomposition, Salado & Trigueros designed activities in the ACE learning cycle to teach the concepts of feature values, eigenvectors and vector spaces [5]. In a study examining the impact on student achievement when applying APOS theory to the teaching and learning of Elementary Linear Algebra, Arnawa conducted a study of 65 students from the University of Andalas, which included 35 students in the experimental class and 30 students in the control class. Research results show that the student's understanding

level increases when applying APOS theory to teaching linear algebra [7]. Applying GeoGebra software combined with flexible teaching methods based on APOS theory to clarify the limited "conceptual image" to improve students' ability to understand the concept of limits [9]. This finding opens up an excellent opportunity to propose technology-integrated math curricula.

The concept of the derivative is an important area of knowledge in high school mathematics; it is an important basis of the subject of calculus; however, in general, this is still difficult for students to understand. The following are some examples of typical international works that are related to the method of instruction for derivative subjects:

For an overview investigation of the difficulties when students find the relationship between the graph of a function and its derivative, author Orhun used questionnaires to survey 102 high school students. Information about the graph properties of the derivative in aspects such as slope, increase, decrease, maximum, minimum, and inflection point. The results show that it is difficult for students to make a relationship between the graph of the derivative function and the original functions' graphs [11]. Author Siyepu suggested that it is necessary to improve the visualization when teaching the topic of derivatives when using APOS tools to analyze common errors of chemical engineering students when finding derivatives of exponential functions, logarithmic functions and trigonometric functions in the extended curriculum at the Western Cape University of Technology [13].

GeoGebra software and the ACODESA method were used to explore how University of Education students relate the concept of derivative and differential with the concept of integral. Based on empirical descriptive analysis, combined with the Toulmin model, Author Zengin concludes that: The students draw that Δx and dx are two different symbols for the same variable [17].

The concepts in the topic of derivatives are quite abstract, so two authors, Lan & Zhou, proposed a model of six questions: "From where", "what", "why", "how", "what if it changed" and "think about it" in one study. Research results show that this model helps students have a deeper understanding of the concept of derivatives [16].

The derivative is an important concept and has many applications in mathematics and physics: Finding the tangent's slope to a curve and the instantaneous velocity of a motion. The following is a list of minimum requirements for students on the topic of high school derivatives in Vietnam:

Table 1: Requirements for knowledge and skills of derivative topics in grade 11

Derivative	Level to be achieved	
	Knowledge	Skills
Derivative concept	Know the definition of derivative (at a point, on an interval). Know the mechanical and geometrical meanings of derivatives	Calculate the derivative of a power function, a polynomial function of the second or third degree according to the definition. Write the equation of the tangent to the function's graph at a point on the graph. Know how to find the instantaneous velocity at a time of a motion with the equation S = f(t).
Rules for calculating derivatives	Know the rules for calculating the derivative of the sum, difference, product, and quotient of functions; composite function and derivative of a composite function.	Calculate the derivative of the function given in the above forms.
Derivatives of trigonometric functions	Know the limit (no proof required) $\lim_{x\to 0}\frac{\sin x}{x}=1.$ Know the derivative of a trigonometric function.	Calculate the derivative of some trigonometric functions.
The second derivative of functions	Know the definition of the second derivative.	Calculate the second derivative of some functions. Calculate the instantaneous acceleration of a motion with the equation S = f(t) given.

It is difficult for students to learn directly the concepts related to this topic because the concepts related to the topic of derivatives are very abstract and complex for high school students. Students' mathematical

abilities will benefit greatly from the investigation and application of APOS theory in mathematics education, especially when teaching.

2. Method

This study is a qualitative study conducted to survey the views of teachers, the current situation of teaching in the direction of capacity development in general and the ability to solve math problems in particular, as well as the ability to APOS application in teaching mathematics (especially for the topic of derivatives). Specifically, the study included surveys:

1) The level of teachers' interest in teaching in the direction of capacity development in general and math problem-solving capacity in particular.
2) Teachers face difficulties and challenges when teaching mathematics in the direction of competency development.
3) Teachers understand APOS theory in teaching mathematics and the feasibility of applying APOS theory to teaching derivative topics.

The research process is depicted in the diagram below (see Figure 3):

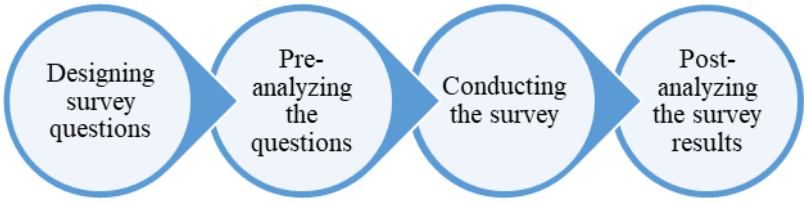

Figure 3: The process of research

A survey was conducted with 40 high school teachers teaching mathematics in Vietnam, including high schools in Can Tho city, Hau Giang province, An Giang province, Soc Trang province, and Vinh Long province. The survey consists of 10 questions to collect information about teachers' opinions on teaching to develop mathematical competence in the topic of derivatives (especially the ability to solve mathematical problems) and other information related to APOS theory.

3. Results And Discussion

3.1 Question 1: What is your understanding of the general education program in Mathematics issued in 2018?

Table 2: Statistics of teachers' opinions on question 1

Levels	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
Number	0	2	10	19	9
%	0	5	25	47.5	22.5

This question was designed to investigate the level of understanding middle school teachers have regarding the Mathematical General Education Program 2018 (MGEP 2018), which was considered a guideline for new teaching methods that would be implemented shortly. According to Table 2, the vast majority of educators were aware of the curriculum for the 2018 general education year (72.5 percent). According to this result, the educators at the high schools (described above) had the necessary knowledge regarding the program's objectives, content, teaching methods, and assessment criteria. A small number of educators were unaware of the general education program for the 2018 school year (accounting for 5 percent). In general, this offers a benefit for the process of implementing new pedagogical approaches, which the Ministry of Education and Training supervises

3.2 Question 2: When teachers participate in teacher training/retraining sessions, how often is the teaching content in the direction of developing students' mathematical ability?

Table 3: Statistics of teachers' opinions on question 2

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	0	2	11	22	5
%	0	5	27.5	55	12.5

Question 2 was designed as a survey to investigate teachers' access to content for teaching, with the goal of capacity development. According to the findings presented in Table 3, 67.5% of educators have participated in professional development opportunities in which the subject matter of teaching focused on capacity development in line with the objectives of the general education program for 2018 was discussed on multiple occasions. The survey also reveals that five percent of educators believe competency-oriented teaching content is only occasionally mentioned. As a result, the findings of this survey indicate that the vast majority of educators have been presented with instructional strategies geared toward enhancing students' mathematical capabilities. The fact that this result was obtained demonstrates that the majority of the provinces that participated in the survey were interested in teaching content geared toward capacity development.

3.3 Question 3: How do you see the importance of the goal of forming and developing students' mathematical competence?

Table 4: Statistics of teachers' opinions on question 3

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	0	1	15	13	11
%	0	2.5	37.5	32.5	27.5

Table 4 of question 3 illustrates the teachers' interest in fostering students' mathematical competence to their best. The percentage of educators who understood how significant it was to achieve this objective could be accounted for by more than one. There were a total of teachers, but only half of them participated in the survey (60 percent). The findings also indicate that one educator did not comprehend the significance of the overarching objective of shaping and cultivating the mathematical capability of students (accounting for 2.5 percent). Nevertheless, there was a possibility that this was an exception. The responses to this question in the survey indicate that most teachers had a high consensus regarding the importance of forming and developing mathematical competence for students. This result created a positive environment for the implementation of innovative pedagogical practices.

3.4 Question 4: Do you think developing students' ability to solve math problems is important?

Table 5: Statistics of teachers' opinions on question 4

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	1	1	16	17	5
%	2.5	2.5	40	42.5	12.5

The objective of the fourth question was to determine the level of interest teachers have in assisting students in becoming proficient problem solvers in mathematics. A conclusion was analogous to the one reached in response to question 3 could be drawn from the data presented in Table 5. The total number of teachers who took part in the survey was greater than the number of teachers who believed it was important to cultivate students' capabilities to solve mathematical problems (22 teachers, 55 percent). Two teachers, or five percent of the total, believe that there was little or no necessity for students to develop the ability to solve problems. Because of this result, it is clear that the research on using APOS theory to develop students' ability to solve mathematical problems would be simple enough for most high school teachers to comprehend and implement.

3.5 Question 5: Teachers often encounter the following difficulties when teaching in the direction of developing competence in general and the ability to solve math problems in particular for students? (can choose more than one answer).

Table 6: Statistics of teachers' opinions on question 5

Difficulties	Number	%
Capturing the characteristics, manifestations, and requirements of math problem-solving ability	2	5
Building situations to develop math problem-solving capacity	8	20
Class time does not guarantee the organization of activities to develop math problem-solving capacity	20	50
Unequal knowledge among students in class	13	32.5
Assessment of the development of mathematical problem-solving abilities	10	25

The purpose of question 5 was to learn more about the challenges that teachers frequently face when attempting to develop mathematical competence in their students, specifically the ability to solve mathematical problems for students. According to Table 6, the most challenging obstacle for teachers was the time required to plan and execute activities designed to strengthen students' ability to solve problems (with 20 teachers having difficulties, a rate of 50 percent). A significant barrier for teachers was the disparity in students' levels of knowledge among their classes (with 13 teachers having difficulty, a rate of 32.5 percent). Next on the list were the challenges associated with assessing the development of the capacity to solve mathematical problems (which together account for 25 percent of the total), as well as the challenges associated with the construction of learning situations to develop the capacity to solve mathematical problems. (8 out of the 40 educators who took part in the survey were having difficulties, which was 20 percent). Only two out of every forty teachers who took part in the survey had trouble understanding the characteristics, manifestations, and requirements for mathematics solutions. This result was supported by the fact that only two of the forty educators who took part in the survey reported having difficulty with the topic above. Most teachers who participated in the survey learned a lot about capacity in the new general education program, so they had little trouble grasping the competency's characteristics, manifestations, and requirements for mathematics solutions (Rate 5 percent).

With the survey results on difficulties such as those related to teaching in the direction of capacity development in general and the ability to solve math problems in particular for students as stated above, the application of APOS theory to teaching and learning to develop student's problem solution capacity becomes urgent; the ACE learning cycle was simple (consisting of only three phases: Activities, Classroom discussion, Exercises) would contribute to the teacher's ability to overcome the difficulties described above, would assist students in developing a profound understanding of the concepts, and would ultimately result in an improvement in the students' ability to solve mathematical problems.

3.6 Question 6: What typical teaching situations do you find necessary to design and feasible when applying such designs to develop students' ability to solve math problems? (You can choose more than one answer).

Table 7: Statistics of teachers' opinions on question 6

Typical teaching situations	Number	%
Teaching concepts	5	12.5
Teaching theorems, rules, formulas	15	37.5
Teaching math problem-solving methods	16	40
Teaching and solving exercises	18	45

The purpose of the question was to investigate the teacher's conception of constructing situations to develop mathematics students' ability to solve mathematical problems. In the findings in Table 7, most teachers believe that the design of situations in teaching problem-solving (which accounted for 40% of the responses), methodological teaching situations such as problem-solving (which accounted for 16%), teaching theorems and rules (which accounted for 37% of the responses), and teaching concepts (which accounted for 3% of the responses) are the most important aspects of teaching problem-solving (Rate 12.5 percent). Because choosing solutions based on relevant mathematical knowledge is the most important aspect of solving problems, one must have a strong understanding of mathematical concepts and theorems to be effective at problem-solving. The ACE Learning Cycle, a learning model, built on APOS theory, will assist mathematics students in developing a better understanding of mathematical concepts by constructing activities that encourage the construction of mental structures of a concept.

3.7 Question 7: How is your understanding of APOS theory in teaching Mathematics?

Table 8: Statistics of teachers' opinions on question 7

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	37	2	1	0	0
%	92.5	5	2.5	0	0

This question aimed to understand the teacher's initial understanding of APOS. Table 8 shows that only a small percentage of teachers heard of this concept. Most teachers who participated in the survey had no prior knowledge of the APOS theory of math instruction (39 teachers did not understand and did not learn, a 97.5 percent). This was a surprise given APOS's widespread acceptance as a learning theory. As a result of these findings, it is believed that math teacher training programs should include APOS theory content. The Departments of Education and Training should include this content in the training course for general teachers and administrators of public education institutions. Teachers' perspectives on teaching, developing mathematical competency in derivatives, and whether or not APOS theory could be applied to classroom instruction were explored in further detail in the survey's follow-up questions.

3.8 Question 8: How is the teacher's interest in developing math problem-solving capacity for students in teaching the topic of derivatives?

Table 9: Statistics of teachers' opinions on question 8

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	0	1	7	20	12
%	0	2.5	17.5	50	30

Math problem-solving ability was shown by question 8, and the purpose of question 8 was to find the teacher's interest in developing problem-solving capacity in the topic of derivation. The survey results in Table 9 found that 32 teachers (80 percent) focused on developing students' problem-solving abilities on this topic. Some teachers (2.5 percent) were not interested in developing students' problem-solving abilities on derivations. This result shows that teaching and research-oriented toward developing problem-solving capacity on derivatives was practical and would receive the attention and support of most high school teachers.

3.9 Question 9: When teaching situations about derivatives (especially teaching concepts), how is the teacher's interest in issues related to the origin of that concept?

Table 10: Statistics of teachers' opinions on question 9

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	8	9	19	4	0
%	20	22.5	47.5	10	0

The results from Table 10 show that the teacher's interest in the origin of a concept in the topic of derivation was relatively low, with only four teachers (10%). The teacher who cares little and does not care is 17 (42.5%). Warm-up activities in learning situations in the ACE teaching cycle (a teaching model built from APOS theory) would be a hint to help teachers realize the importance of this issue and help students learn new math content more actively.

3.10 Question 10: When teaching situations on the topic of derivatives (especially teaching concepts), what is the level of interest of the teacher/teacher in the student's homework?

Table 11: Statistics of teachers' opinions on question 10

Levels	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Number	0	1	9	25	5
%	0	2.5	22.5	62.5	12.5

The results from Table 11 show that the number of teachers interested in using homework to help students review and deepen their knowledge accounts for a large number (30 teachers, a rate of 75%). Hence the third phase (homework) of the ACE teaching cycle will be accessible to most teachers.

4. Conclusion

According to the survey findings, most high school teachers had access to the general education program released in 2018. One of the essential components of this program was competency-based instruction, particularly the capacity to solve mathematical problems. Most teachers were aware of this novel instructional approach; the favorable responses evidence this in response to sentences associated with student competency growth. The survey findings also highlighted teachers' challenges when implementing instructional strategies to enhance students' mathematical problem-solving skills. In a context in which the most significant difficulty that a teacher encounter was the difficulty of organizing time (which accounts for fifty percent), a relatively low percentage (five percent) of teachers had difficulties related to grasping the characteristics, manifestations, and requirements of the ability to solve mathematical problems. As a result, this section also demonstrated the positive impact of training courses provided by the Ministry of Education and Training.

Another surprising result from this study is that almost all teachers participating in the survey were unfamiliar with APOS theory in teaching Mathematics, despite its popularity when applied. There is a high level of involvement in the construction of math teaching situations, from high school to university levels, such as the studies applying APOS theory to teaching different topics by Salado & Trigueros. 2015), Syamasuri (2017), and Arnawa et al. (2021) all demonstrate a positive effect on students when applying APOS theory.

As for the topic of derivatives, the survey results also show that teachers have recognized this as an important topic and paid great attention to the development of students' ability to solve math problems (with 80% of teachers answering that they were interested and very interested). However, in teaching this topic, teachers often pay special attention to the construction of problem-solving situations (ratio of 45%) and are less interested in conceptual teaching situations (Proportion: 45%). The interest rate is only 12.5%. Showing that this is a topic with many abstract and complex concepts, the results are consistent with the studies on teaching derivatives of Orhun (2012) and Loc & Nu (2015). Teachers often stop at just helping students know the concepts and using the exercise as an example to help students create a solution process, as shown by the teacher giving special attention to the problem student's home (75% rate). However, this can also be seen as an advantage for applying APOS theory to teaching content on the topic of derivatives because the third phase of the ACE learning cycle focuses on using homework to synthesize knowledge for students.

In addition to the findings, a few limitations to the study need to be considered. It is safe to say that this research's findings are local, as only forty teachers from neighboring provinces in the same region participated in the survey. The findings reflect only the teachers' perspectives on how students in this region can develop their mathematical capabilities, so it is safe to say that the findings of this research are local.

5. Suggestions

Numerous pieces of research have pointed to the importance of ongoing professional development for those who work in education. As a consequence of this, the program that prepares teachers ought to incorporate APOS theory subjects as well as teaching strategies that are oriented toward capacity development. It is possible to conduct new studies with larger samples, which will enable the scope of the survey to be expanded geographically or according to grade level. Because it is not physically impossible, this is a possibility. It is important, both conceptually and practically, to survey the current state of research and application of APOS in teaching mathematics to prospective teachers at schools that specialize in the education of teachers. The investigation and implementation of APOS theory in teaching students about the topic of derivatives is entirely doable and will unquestionably contribute to enhancing the student's ability to develop mathematical problem-solving skills. This is a feasible option that should be considered.

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In addition to his roles as associate professor and senior lecturer at the School of Education at Can Tho University in Can Tho City, Vietnam, **Duong Huu Tong** also works as a consultant in the field of education. Over 17 years, he has gained expertise in a wide range of fields, some of which include the education of mathematics, the evaluation of educational programs, and the creation of an educational curriculum.