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Research Article

Conceptual Understanding of Momentum and Confidence Levels Among Cambodian Pre-service Teachers

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Abstract. The study examined Cambodian pre-service science teachers' understanding of momentum and their confidence levels, providing empirical evidence from the Cambodian context where research on this topic remains limited. The Energy and Momentum Conceptual Survey (EMCS), a well-known diagnostic test in physics education research, was used to collect data online from 94 participants (65 females). We also conducted online informal interviews with a subset of participants (n=15) to understand their reasoning. The Khmer version of the 12-item two-tier EMCS demonstrated acceptable validity and reliability (IOC ≥ 0.80; Cronbach's α = 0.77). The statistical methods used were t-tests, ANOVA, the Friedman test, and Bonferroni post-hoc tests to compare mean scores, and Cohen's *d* to assess effect sizes. The results showed an average EMCS score of 33.0% (SD = 14.5%), and only 38.8% of students who answered correctly selected high confidence. About 36%-53% of students selected medium confidence, whether they answered correctly or incorrectly, across the four momentum sub-concepts. No statistically significant differences emerged between genders in momentum understanding and confidence levels. However, significant differences emerged across the educational levels that the pre-service teachers are trained to teach, with high school pre-service teachers demonstrating higher conceptual understanding than primary and secondary pre-service teachers. Common difficulties found included understanding momentum's vector nature, the impulse-momentum relationship, identifying systems, and distinguishing between momentum and kinetic energy conservation in elastic and inelastic collisions. These findings highlight the need to strengthen both conceptual understanding and confidence levels in Cambodian teacher education programs. The results also support designing instructional approaches that explicitly address momentum-related difficulties while building pre-service teachers' confidence in applying momentum concepts.

Keywords: Momentum; Confidence, Cambodian; Pre-service teachers; Misconceptions

INTRODUCTION

Momentum is a fundamental concept in physics. However, students often struggle to understand and apply it (Singh & Rosengrant, 2003; Denny et al., 2020). This concept is directly connected to Newton's laws of motion, particularly the second and third laws, which describe how forces act on objects and how those objects interact with one another. Momentum is a measure of the motion of a moving object, determined by its mass and velocity. The change in momentum caused by an external force acting for a specific time is called an impulse (Halliday et al., 2021; Serway & Jewett, 2018). Understanding momentum helps explain a wide range of physical phenomena, such as collisions,

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rebounds, and explosions, all of which involve the conservation of momentum within isolated systems. It has practical applications in daily life, from analyzing how vehicles respond during accidents to understanding motion in sports, and even designing safety equipment and transportation systems.

Students enter physics classrooms with knowledge and beliefs shaped by prior learning and everyday experiences, and these conceptual resources influence how they interpret and integrate subsequent physics instruction (Nie et al., 2019; Salehi et al., 2019). Moreover, students' confidence in their ability to learn physics, commonly conceptualized as physics self-efficacy, is strongly associated with conceptual understanding and academic performance (Bailey et al., 2017; Kalender et al., 2020; Marshman et al., 2018). Regarding students' difficulties with impulse and momentum, Saifullah et al. (2017) reported that some stem from a limited ability to apply vector principles. Diyanahesa et al. (2017) found that many students confuse impulse with force, and some ignore mass in the definition of momentum, confusing it with force. Rosa et al. (2018) revealed that students misunderstand momentum changes over time, struggle with graphical representations under force, and have difficulty comparing impulse in one- and two-dimensional collisions. Research by Singh and Rosengrant (2003) showed that students commonly believe that momentum and kinetic energy are the same physical quantities, assume momentum is always conserved even when external forces act, and fail to recognize its vector nature. Many students' misconceptions about momentum come from fragmented knowledge structures, especially weak connections among net force, time, impulse, and change in momentum. Students often memorize equations rather than reasoning from the impulse-momentum theorem. Emphasizing impulse-momentum as a central idea can help reduce misconceptions (Xu et al., 2020).

Momentum misconceptions are found in learners at various educational levels. Among pre-service teachers, weak connections between content knowledge, beliefs about learning physics, and pedagogical content knowledge may contribute to persistent misconceptions and their transfer to future students (Feser & Krumphals, 2022). A study by Métioui and Trudel (2019) reported that a group of pre-service teachers in Quebec believed that force is proportional to speed, as described by the equation $F = mv$. It showed that the teachers failed to distinguish the relationships among force, mass, velocity, and momentum. Martini et al. (2021) examined over 200 pre-service teachers in Italy and found that they believed force and momentum were unrelated. This reflected a fragmented mechanics idea among the teachers, in which force is intuitively connected to motion, but not to momentum. Physically, the net force is related to the rate of change of momentum. Moreover, Sarapak and Kearns (2022) reported that a group of Indonesian pre-service physics teachers struggled to apply momentum conservation consistently, highlighting a gap between knowing $p = mv$ and understanding how mass, velocity, momentum, and interactions during collisions are related. Similarly, Negoro et al. (2020) found that momentum-related critical thinking remained challenging for pre-service teachers.

In Cambodia, the momentum and impulse concept is first introduced in the Grade 11 high school physics curriculum after Newton's laws of motion. Students learn the basic concepts of momentum, including its definition, the impulse-momentum theorem, and the law of conservation of momentum. At the higher education level, momentum is typically introduced in the first semester of university or college in introductory physics courses required for students enrolled in science and technology programs, including education programs. Science pre-service teachers in teacher education colleges in Cambodia encounter momentum and impulse again in the second semester, where they revisit these fundamental concepts and further study momentum analysis in complex systems, collisions in one and two dimensions, and applications in rocket propulsion. Moreover, physics pre-service teachers were again prepared through mechanics courses, gaining more advanced knowledge of momentum in the second and third years of their study. Concurrently, the pre-service teachers were provided with pedagogical competencies, professional skills, and attitudes needed for effective teaching practice (Pov et al., 2024; Sok & Heng, 2024; Tep, 2024).

In addition, the Ministry of Education, Youth and Sport (MoEYS) introduced updated qualification standards for Cambodian teachers in 2018. These reforms require teachers to complete at least a Grade 12 certificate with 4 years of teacher training (12+4) or a BA/B.Ed+2 for lower secondary teachers, and MA+1 for upper secondary teachers (Sot et al., 2019). Despite these efforts,

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teacher education in Cambodia faces ongoing challenges in quality, curriculum design, training, and resources, with limited empirical research, highlighting a significant gap in understanding its impact on teaching practices and the need for further studies on pre-service teacher preparation and conceptual understanding (Em et al., 2022; Sok & Heng, 2024). Cambodian pre-service teachers often have limited knowledge and practical experience, which shapes their attitudes and may affect their future teaching effectiveness (Pov et al., 2024). Similarly, Bon and Koem (2025) found that Cambodian pre-service teachers demonstrate moderate levels of knowledge, attitudes, and intentions toward STEM education, with positive correlations among these factors, and identified internal, external, and student-related barriers to implementation. While teachers and students in Cambodian physics classrooms value inquiry-based learning, limited training and experience constrain its implementation, highlighting research gaps, particularly at the pre-service teacher level (Mel, 2022). Teacher quality plays a crucial role in shaping students' learning (López-Martín et al., 2023). International assessment results indicated persistent challenges in Cambodian science education. In PISA 2017, Cambodian students achieved a mean science score of 330 points, which increased to 347 points in PISA 2022. Despite this improvement, the 2022 score remained substantially below the OECD average of 485 points. Only 10% of Cambodian students achieved Level 2 or above in science, compared with 76% across OECD countries (MoEYS, 2018; OECD, 2023). This suggests that most Cambodian students struggle to recognize appropriate scientific explanations and use scientific knowledge to interpret evidence and phenomena.

Teacher education in Cambodia still faces significant challenges in improving teacher competence. Existing studies have paid limited attention to subject-specific areas such as physics. To gain deeper insight, this study examines Cambodian pre-service science teachers' understanding of momentum and their confidence level. This study used a modified version of the Energy and Momentum Conceptual Survey (EMCS) developed by Singh and Rosengrant (2003) as a diagnostic instrument, with a three-level confidence scale for each item. We conducted an informal online interview with a group of participants to understand their reasoning. The findings provide empirical evidence in the Cambodian context and support a deeper conceptual understanding of momentum among future students and teachers. This will also help Cambodian curriculum developers, physics educators, and teacher trainers identify pre-service teachers' difficulties with momentum, improve instructional strategies, and support curriculum development.

RESEARCH OBJECTIVES

This work aims to

1) explore Cambodian pre-service science teachers' understanding of momentum and identify possible alternative conceptions,

2) examine confidence levels in their responses, and

3) compare conceptual understanding and confidence across gender and the educational level that the pre-service teachers are trained to teach.

METHODOLOGY

This study used a modified version of the Energy and Momentum Conceptual Survey (EMCS) to assess Cambodian pre-service teachers' conceptual understanding of momentum and their confidence levels. The target sample was science pre-service teachers, who had already completed introductory physics courses at three main teacher education colleges (TECs) in Cambodia: National Institute of Education (NIE), Phnom Penh Teacher Education College (PTEC), and Battambang Teacher Education College (BTEC). The modified Cambodian EMCS was administered online via Google Forms to ensure broader accessibility and efficiency in data collection among pre-service teachers across the three colleges. The researcher then conducted informal online interviews with 15 students with the lowest EMCS scores to explore their reasoning for four EMCS items per student.

Participants

A total of 94 Cambodian pre-service science teachers (CPTs) were from NIE (n = 8), PTEC (n = 31), and BTEC (n = 55). They were science pre-service teachers preparing to teach at different educational levels: 24 at the primary level, 54 at the secondary level, and 16 at the high school level.

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Among them, 52 were in their second year, and 42 were in their fourth year of study. The sample included 28 male and 65 female students (one student preferred not to identify their gender). All participants had learned momentum concepts in high school and again in college.

Research Tools

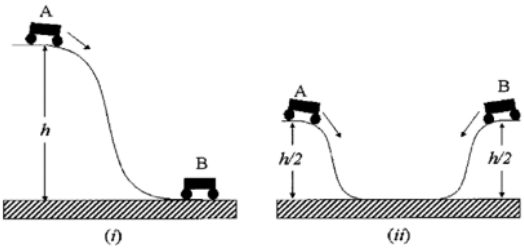
This study modified the original 25 multiple-choice items of the EMCS (Singh & Rosengrant, 2003) to align with our objective. The EMCS is a widely validated tool used in physics education research. Research using the EMCS indicated that students often rely on memorized formulas rather than conceptual reasoning, leading to fragmented and inconsistent understanding (Brundage et al., 2023). Similarly, Yana et al. (2022) used Quizizz with EMCS-based questions and found that high school students demonstrated a moderate understanding of energy and momentum, indicating the need for more effective instruction in these concepts. In addition, Wu et al. (2023) evaluated the EMCS using item response theory with pre-test and post-test data and found it to be a valid, multidimensional instrument that captures different aspects of students' understanding of energy and momentum.

Here, we selected 12 momentum-related items from the original EMCS and redesigned them into a two-tier format to assess Cambodian pre-service teachers' understanding of momentum (tier 1) and their level of confidence (tier 2). The modified 12-item two-tier EMCS was translated into Khmer. An example item in English is shown in Figure 1, and the cluster of items by momentum sub-concepts is presented in Table 1. Five experts from TECs evaluated the Khmer version of the EMCS using the index of item-objective congruence (IOC) to assess validity. All items achieved values of 0.80 or higher. Reliability was assessed using Cronbach's Alpha, which yielded 0.77, indicating acceptable internal consistency.

Setup for questions (6): Carts A and B are identical in all respects before the collision.

Diagram (i): Cart A starts from rest on a hill at a height h above the ground. It rolls down and collides "head-on" with cart B which is initially at rest on the ground. The two carts stick together.

Diagram (ii): Carts A and B are at rest on opposite hills at heights $h/2$ above the ground. They roll down, collide "head-on" with each other on the ground and stick together.



6.1 Which one of the following statements is true about the two-cart system just before the carts collide in the two cases?

Just before the collision on the ground,

a) The kinetic energy of the system is zero in case (ii).
b) The kinetic energy of the system is greater in case (i) than in case (ii).
c) The kinetic energy of the system is the same in both cases.
d) The momentum of the system is greater in case (ii) than in case (i).
e) The momentum of the system is the same in both cases.

6.2 How sure are you about your answer to the previous question?

1) Not sure
2) Somewhat sure
3) Sure

Figure 1: An example item of the modified version of the 12-item two-tier EMCS. Tier 1 is a momentum question with five choices, and tier 2 is a three-level confidence scale.

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Table 1: Four sub-concepts of momentum measured by the modified version of the 12-item two-tier EMCS.

Sub-concepts	*Item number*
S1: Definition of Momentum	3, 9
S2: Impulse and Momentum Theorem	2, 10, 12
S3: Conservation of Momentum	4, 11
S4: Momentum and Kinetic Energy	1, 5, 6, 7, 8

Data Collection and Analysis

Data were collected online via Google Forms from Cambodian pre-service science teachers in 2025. To ensure data quality, lecturers at Teacher Education Colleges (TECs) supervised the test administration. The researcher coordinated with lecturers to obtain class timetables and scheduled the test accordingly. The researcher sought permission to collect data from participating students and obtained their signatures. The researcher briefed them on the testing procedure and shared the test link through the Telegram group. Students were given 45 minutes to complete the test in a computer room, with one or two lecturers serving as proctors and providing assistance when needed.

We used responses from the 94 Cambodian participants to calculate average scores, identify common alternative conceptions about momentum in tier 1, and assess confidence levels in tier 2. Data were analyzed overall, across four sub-concepts, by gender and by the educational level that the pre-service teachers are trained to teach. Statistical analyses included independent-samples t-tests ($\alpha = 0.05$) to compare mean scores by gender and one-way ANOVA with Bonferroni post-hoc tests ($\alpha = 0.05/3$) to compare mean scores across educational levels. We used the Friedman test ($\alpha = 0.05$) to compare scores across the four momentum sub-concepts, followed by Wilcoxon signed-rank tests with Bonferroni correction ($\alpha = 0.05/6$) for pairwise comparisons. Cohen's d was used to assess effect sizes for the group comparisons, and Kendall's W was used as the effect size for the Friedman test. Cohen's d was interpreted as very small ($d < 0.20$), small ($d = 0.20$-0.49), medium ($d = 0.50$-0.79), and large ($d \geq 0.80$) categories (Cohen, 1988). Moreover, we selected 15 students with the lowest EMCS scores to conduct informal online interviews to explore their reasoning. To obtain five responses per question, we distributed the 12 EMCS questions among 15 students, with each student answering four questions. One researcher interviewed each student in Khmer for approximately 8-10 minutes via Zoom and audio-recorded the interviews. The researcher began the interview by describing the objective and time, and asked for permission to collect data and audio recordings. Then, the researcher summarized the information, questions, and answers to confirm the participants' responses earlier. The researcher asked participants to explain further why they selected those choices, question by question. Because most participants were not comfortable turning on the video camera during the interview, the researcher noted only tone of voice and atmosphere. The researcher translated all interview conversations and contexts into English. Three researchers grouped participants' interview responses by common concepts and used them alongside the multiple-choice responses.

RESULTS AND DISCUSSION

The results showed an average EMCS score ± standard deviation of 33.0% ± 14.5% among Cambodian pre-service science teachers (n = 94) who learned the concept at the high school and university levels. This study applied the Certainty of Response Index (CRI) approach (Hasan et al., 1999) in conjunction with answers to EMCS multiple-choice questions. In our test, students indicated their confidence levels when selecting each choice in tier 2. Responses of confidence levels were scored on a three-point scale: 1 = not sure (low confidence), 2 = somewhat sure (medium confidence), and 3 = sure (high confidence). Figure 2 shows the response distribution for both tier 1 and tier 2 questions. It displays five sets of bar graphs, where the first bar graph in each set illustrates the average EMCS score and the average scores for sub-concept 1 (S1), sub-concept 2 (S2), sub-concept 3 (S3), and sub-concept 4 (S4), respectively. The second bar graph in each set shows the proportion of confidence levels (high, medium, low) among students who answered the EMCS correctly (conf.cor.).

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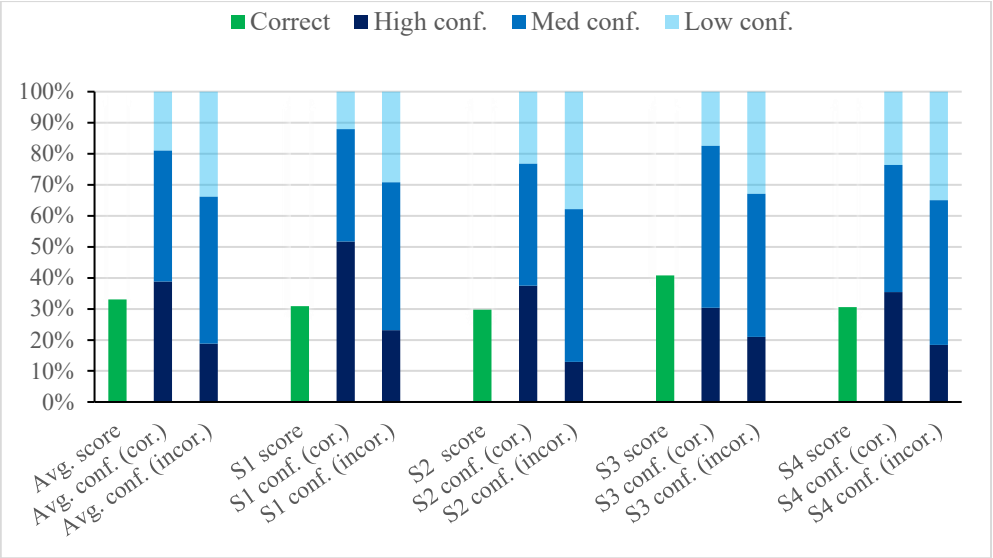

Figure 2: The average EMCS score and the proportion of confidence levels (high, medium, low) among students who answered the EMCS correctly (conf. cor.) and incorrectly (conf. incor.) for overall and across the four momentum sub-concepts (S1-S4).

The third bar graph in each set shows the proportion of confidence levels among students who answered the EMCS incorrectly (conf.incor.). For each bar graph, we calculated the proportion of responses at each confidence level (high, medium, low) by summing the number of responses at that level, dividing by the total number of responses in that group, and converting to a percentage. As shown in Figure 2, among students who answered the EMCS correctly, 38.8% selected high confidence, 42.2% selected medium confidence, and 19.0% selected low confidence. Although they chose the correct answer, only 38.8% were sure about their knowledge of the correct concept. As shown in the second bar graph of each set, 12%-23% of the correct group selected low confidence across the four sub-concepts. Based on the CRI interpretation, a correct answer with low confidence may indicate a lucky guess. Moreover, 33.8% of the incorrect group selected low confidence, as shown in the third bar graph of the first set, suggesting a lack of knowledge. Another 18.8% selected high confidence, indicating a misconception (Hasan et al., 1999). We also found that 36%-53% of participants selected medium confidence whether their responses were correct or incorrect across the four sub-concepts.

Table 2 presents the EMCS mean and median scores and mean rank across the four momentum sub-concepts. The Friedman test revealed a statistically significant overall difference in score distribution across the four momentum sub-concepts, $\chi^2(3) = 11.435$, $p = .010$, with a small effect size (Kendall's $W = .041$). As shown in Table 2, conservation of momentum (S3) had the highest mean score (40.8%±28.1%), median score (30.0%), and mean rank (2.9). In contrast, the other three sub-concepts had mean scores ranging from 29.8% to 30.9%, with mean ranks of approximately 2.4. However, post-hoc Wilcoxon signed-rank tests with a Bonferroni-adjusted alpha ($\alpha = 0.05/6$) revealed no statistically significant differences for the six pairwise comparisons. Thus, although conservation of momentum had the highest descriptive scores, the post-hoc analyses did not identify statistically significant differences between any specific pair of sub-concepts.

Table 2: EMCS mean and median scores and mean rank across the four momentum sub-concepts.

Sub-concepts	*(Mean ± SD) (%)*	*%Median*	*Mean Rank*
S1: Definition of Momentum	30.9±37.5	0.0 (50)	2.4
S2: Impulse and Momentum Theorem	29.8±33.1	25.0 (50)	2.4
S3: Conservation of Momentum	40.8±28.1	30.0 (40)	2.9
S4: Momentum and Kinetic Energy	30.6±22.1	20.0 (20)	2.4

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Results by Gender and by Education Levels

Male participants (n = 28) obtained an average EMCS score of 30.8% ± 10.8% and an average confidence score of 64.6% ± 19.7%, while female participants (n = 65) obtained an average EMCS score of 34.2% ± 15.8% and an average confidence score of 65.3% ± 19.5%. The average confidence score is the weighted average calculated by assigning a numerical weight to each response level: high confidence = 3, medium confidence = 2, and low confidence = 1, as mentioned earlier. The number of respondents selecting each level was multiplied by its corresponding weight. The weighted scores were then summed and divided by the total number of respondents. The weighted scores can also be converted to a percentage by dividing by the full score of 3 and multiplying by 100. Independent-samples t-test results indicated no significant gender differences in either conceptual understanding or confidence at the $\alpha = 0.05$ significance level. Similarly, we found no significant gender differences across the four momentum sub-concepts.

However, significant differences emerged across the educational levels that the pre-service teachers are trained to teach, as shown in Table 3. High school CPTs had the highest EMCS scores of all groups. This group may have a stronger background and experience in physics. One-way ANOVA and Bonferroni post-hoc tests ($\alpha = 0.05/3$) showed significant differences in EMCS scores between high school CPTs and both primary and secondary school CPTs, with large effect sizes. Confidence levels differed significantly between secondary and primary school CPTs (medium effect size) and between high and primary school CPTs (large effect size). In contrast, no significant (ns) difference was observed between high and secondary school CPTs. The findings suggest that educational background and prior academic preparation influence physics conceptual understanding and confidence more than gender. Consistent with several studies, which reported no significant gender differences in physics conceptual understanding (Afifa et al., 2024; Balta & Asikainen, 2019). Although Nti et al. (2023) found that male students demonstrated higher conceptual understanding of linear momentum, both genders exhibited similar difficulties. Similarly, Stylos et al. (2023) found no significant gender differences in personal physics teaching efficacy beliefs or physics teaching outcome expectancy among pre-service primary teachers, suggesting that male and female teacher candidates may demonstrate comparable levels of physics teaching self-efficacy. Furthermore, Kaltakci-Gurel (2023) showed that prior achievement was a stronger predictor of conceptual understanding and confidence than gender. These findings suggest that conceptual understanding and confidence are not strongly gender-dependent and that observed differences across studies may reflect variations in educational context, participant characteristics, and learning experiences. Bailey et al. (2017), Marshman et al. (2018), and Kalender et al. (2020) identified self-efficacy as the strongest predictor of physics conceptual understanding for both male and female students.

Table 3: EMCS and confidence scores by education levels and pairwise comparison results using the Bonferroni post-hoc test ($\alpha = 0.05/3$).

Scores	*Group*	*Mean± SD (%)*	*Comparison*	*p-value*	*Cohen's d*
EMCS	Primary	25.7±10.4	Secondary vs Primary	.045 (ns)	-
	Secondary	32.3±14.1	High vs Primary	< .001	1.87
	High	46.9±12.5	High vs Secondary	< .001	1.06
Confidence	Primary	54.2±13.6	Secondary vs Primary	.008	0.66
	Secondary	66.0±19.4	High vs Primary	< .001	1.57
	High	78.5±17.8	High vs Secondary	.025 (ns)	-

Common Alternative Conceptions Found in this Study

Table 4 summarizes the common alternative conceptions identified among Cambodian pre-service science teachers participating in this study and categorizes them according to the four momentum sub-concepts assessed by the EMCS. The last column also includes previous studies that reported similar difficulties. Details for each sub-concept are described below.

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Table 4: Common alternative conceptions of the four sub-concepts of momentum found in this study.

Alternative conceptions about momentum and related physics	
Common alternative conceptions found in this study *(% selection)*	**Other references**
S1: Definition of Momentum	
- Momentum is a scalar quantity *(24.5%)*.	(Saifullah et al., 2017; Triyani et al., 2019)
- Momentum solely depends on mass, while velocity is underestimated *(27.7%)*.	(Diyanahesa et al., 2017; Nti et al., 2023; Triyani et al., 2019)
S2: Impulse–Momentum Theorem	
- In a completely inelastic collision, the object transfers all of its kinetic energy to the other object, causing the combined system to move faster *(19.1%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)
- Impulse, or a change in momentum, depends only on force *(34.1%)*.	(Brundage et al., 2023; Rosa et al., 2018)
- Average force is determined only by mass, initial velocity, and interaction time, regardless of final velocity and impulse *(30.9%)*.	(Brundage et al., 2023; Diyanahesa et al., 2017; Singh & Rosengrant, 2003)
S3: Conservation of Momentum	
- Kinetic energy is always conserved in explosions, as is momentum *(34.0%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)
- Momentum conservation can be component-specific, and vertical-object parameters cannot affect horizontal-object parameters *(35.1%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)
S4: Momentum and Kinetic Energy	
-In an elastic collision, the kinetic energy and momentum of each object are conserved *(38.3%)*.	(Saifullah et al., 2017; Singh & Rosengrant, 2003)
- A ball bounces back in an elastic collision, meaning it does not transfer momentum or kinetic energy *(50.0%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)
- Before the collision, the system's kinetic energy can be determined only from an individual object's potential energy *(31.9%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)
- The system's kinetic energy is conserved in an inelastic collision *(27.7%)*.	(Brundage et al., 2023; Singh & Rosengrant, 2003)

S1: Definition of Momentum

Momentum is a vector quantity that measures how much motion an object carries, which depends on its mass and velocity. Results from EMCS items showed common alternative conceptions among Cambodian pre-service science teachers (CPTs): 24.5% believed momentum is a scalar quantity, 27.7% believed that a moving object with greater mass has greater momentum regardless of velocity, and 17% selected the wrong SI unit of momentum. The interview results found that students believed mass, not velocity, is the only factor affecting momentum. Some believed mass and velocity are always positive to make an object move forward, so momentum is a scalar quantity. Examples of students' explanations are *"The truck is heavier and hard to stop, so it must have larger momentum than a motorcycle.", "I know that p =mv, but this term cannot be negative because of the positive mass and velocity to make the object move forward, so I think momentum is a scalar term, which cannot be a negative value."* These findings suggest that CPTs focused primarily on mass and failed to recognize that momentum depends on both mass and velocity and is a vector quantity. Similar difficulties have been reported by Diyanahesa et al. (2017), Saifullah et al. (2017), and Triyani et al. (2019), who found that students often neglect the role of velocity and misunderstand momentum as a non-directional quantity. These difficulties may arise from everyday experiences in which heavier

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objects appear harder to stop, leading students to overemphasize mass when reasoning about momentum.

Results of EMCS sub-concept 1 (definition of momentum) did not differ significantly among educational-level groups at $\alpha = 0.05/3$. However, confidence levels differed significantly between primary and high school CPTs, with a large effect size ($d = 0.86$). High school CPTs showed higher confidence than primary school CPTs, likely due to greater exposure to physics content. Prior academic preparation is an important factor affecting both conceptual understanding and confidence (Kaltakci-Gurel, 2023).

S2: Impulse–Momentum Theorem

In the impulse-momentum theorem, the impulse of the net force acting on an object equals the change in its linear momentum. For a given change in momentum, increasing the interaction time reduces the average force. Our EMCS results revealed common alternative conceptions among CPTs; for example, 19.1% believed that if a fired bullet becomes embedded in a wood block, it would move faster because the bullet transfers all of its kinetic energy to the block. Moreover, 16% believed the wood block would move faster because the bullet transfers all momentum to the block. From the interview, a student explained with a medium confidence level that "*The wood block moves faster because the bullet embeds inside it and there was no kinetic energy loss, while another bullet split kinetic energy to bounce back."* The responses suggest confusion between momentum transfer and kinetic energy transfer in a completely inelastic collision. However, 50% of them correctly answered that a fired bullet bouncing off the steel block will make the steel block move faster.

In addition, 34.1% of CPTs believed that a bicycle experiences a smaller change in momentum (or a smaller impulse) when it was stopped by hitting a haystack than by hitting a concrete wall. One student explained that *"When a bicycle hits a soft haystack, a smaller force existed, so it produces a small impulse."* Another student said, with low confidence, *"I am not sure, but I think hitting a haystack can reduce force, and then reduce impulse following $F\Delta t = \Delta p$."* This reflects the belief that impulse (or a change in momentum) depends only on force, whereas it depends on both force and interaction time. In the item's situation, a bicycle stopped by hitting a haystack or hitting a concrete wall gives the same impulse because both have zero final velocity and have the same initial momentum. Therefore, increasing the interaction time by hitting a haystack produces a smaller force for the same impulse.

Furthermore, 30.9% of the CPTs believed that when dropping a rubber ball and a putty ball from the same height, both exert the same average force on a surface because of equal mass, initial velocity, and contact time. A student explained, "*Have the same force because both balls have the same mass and were dropped from the same height, then experience the same $F = mg$.*" These responses indicate that CPTs tended to focus on collision time and initial conditions while overlooking the magnitude and direction of momentum change, particularly the larger change in momentum that occurs when a ball rebounds and reverses direction. In the item's situation, a rubber ball and a putty ball have the same initial conditions and contact time when hitting a surface. The rubber ball bounces up, producing a larger change in momentum, so the force is larger. The putty ball comes to rest (zero final velocity) and produces a smaller change in momentum. The misconceptions were also reported by Diyanahesa et al. (2017), Rosa et al. (2018), and Brundage et al. (2023), who found that students believed softer impacts produce smaller momentum changes and considered bouncing and sticking collisions to involve the same force. Likewise, Singh and Rosengrant (2003) and Xu et al. (2020) showed that students often confuse momentum with momentum change, impulse with force, ignore the vector nature of momentum, and struggle to relate force, time, and momentum during collisions.

In this sub-concept, we found significant differences among educational-level groups in both conceptual understanding and confidence ($\alpha = 0.05/3$). High school CPTs demonstrated significantly higher conceptual understanding than secondary school CPTs ($d = 0.84$) and primary school CPTs ($d = 1.35$), corresponding to a large effect size. Similarly, high school CPTs showed significantly higher confidence levels than primary school CPTs ($d = 1.56$), with a large effect size. Students with stronger learning beliefs achieved higher conceptual understanding and better physics performance (Kim & Im, 2021; Ogodo, 2019).

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S3: Conservation of Momentum

Conservation of momentum is a special case of the impulse-momentum theorem. When the net external impulse on the system is zero, the total linear momentum of a system remains constant. Related EMCS results showed that 34.0% of CPTs believed the total kinetic energy of bomb fragments remains constant before and after an explosion. A student explained that "*Kinetic energy is always conserved because it's an isolated system and no friction.*" Another student said, "*Momentum conserved means kinetic energy is also conserved.*" These responses reflect a misunderstanding of the distinction between conservation of momentum and conservation of kinetic energy. They also believed that no friction means no change in kinetic energy, but in an explosion, the bomb's internal energy converts to kinetic energy. In this item's situation, the system's total momentum before and after the explosion is the same and equals zero. The bomb is at rest at the beginning, then explodes and breaks into three pieces, but its center of mass remains constant.

Moreover, 35.1% of CPTs believed that when raindrops vertically fall into a horizontally constant-velocity moving cart and accumulate, the cart continues moving at a constant velocity because the vertical raindrops did not affect the horizontal motion. Some students from the interview confirmed that "*Because raindrops fall vertically, no momentum changed of the cart in the horizontal direction.*" This reflects a disconnect between the component-specific nature of momentum conservation. The students failed to recognize that the total mass moving with the cart increases as the rain accumulates, so the cart slows down because the cart-raindrop system conserves horizontal momentum. However, the system's vertical momentum is not conserved because of gravity and the normal force.

No significant differences were found in EMCS sub-concept 3 among the educational-level groups ($\alpha = 0.05/3$). However, confidence levels differed significantly. Secondary school CPTs demonstrated significantly higher confidence than primary school CPTs ($d = 0.73$), while high school CPTs showed significantly higher confidence than primary school CPTs ($d = 1.66$), corresponding to medium and large effect sizes, respectively. The results indicate that CPTs at higher educational levels demonstrated greater confidence, consistent with a report that stronger content knowledge and specialized training enhance conceptual understanding and self-efficacy (Ogodo, 2019).

S4: Momentum and Kinetic Energy

Momentum is a vector quantity conserved for an isolated system of elastic and inelastic collisions. In contrast, kinetic energy is a scalar quantity conserved only in elastic collisions. Results from the Cambodian pre-service science teachers showed that 38.3% believed that, in an elastic collision, the kinetic energy and momentum of each object are conserved. Interview results from a group of students confirmed that "*No external force, so momentum of each object conserved, individual kinetic energy is conserved as well."* Some students explained that if the individual object is conserved, the whole system is conserved too, or vice versa. They said there was no difference. This reflects an alternative conception that, in an elastic collision, each object's kinetic energy and momentum are conserved, and that if momentum is conserved, kinetic energy is conserved. In fact, in this case, the system's momentum and kinetic energy are conserved, not the individual object. This is a key concept in the conservation of momentum and kinetic energy.

An EMCS item asks what happens when you throw a ball at your friend, and the ball bounces elastically back, while both of you stand on a frictionless surface. We found that 55.3% of the CPTs selected that your friend will remain stationary, in which 27.7% of them believed that because the ball does not impart momentum to your friend, and 22.3% of them believed that because kinetic energy is conserved. The interviewed students gave more details that "*The ball elastically bounced back; it means that it did not transfer momentum or kinetic energy to a person. When momentum and kinetic energy are conserved (do not change), the person will not move."* This misunderstanding concerns a ball bouncing back in an elastic collision, meaning it does not transfer momentum or kinetic energy, so the person cannot move. In fact, you and your friend will move. When you throw a ball forward, you move back to conserve the system's linear momentum. The ball bounces elastically off your friend, produces the impulse, and makes your friend move following Newton's

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third law. The results reflect difficulties with momentum transfer, the vector nature of momentum, and Newton's third law (Saifullah et al., 2017; Singh & Rosengrant, 2003).

In addition, two EMCS items on the two-cart collision with different initial conditions were used to explore students' understanding of momentum and kinetic energy. Figure 1 shows the mentioned items. Results showed that 31.9% of CPTs believed that, before the collision, the kinetic energy of the system is greater in case(i) than in case (ii). Some students explained that *"The height in case (i) is double, more potential energy, which can be converted to more kinetic energy."* This difficulty involves using an individual object's energy to determine the system's kinetic energy. In fact, before the collision, the system's kinetic energy is the same in both cases. The cart A in case (i) is double the height, but both cart A and cart B in case (ii) are moving. A subsequent item asked about this situation, but after the collision. We found that 27.7% of the CPTs believed that after the collision, the system's kinetic energy is the same in both cases. Some students explained that " *because both systems have equal kinetic energy before the collision, their kinetic energy remains equal afterward due to conservation of momentum and kinetic energy*." In the item's situation, the two carts collide and stick together, representing an inelastic collision in which the system's momentum is conserved, but not kinetic energy. Therefore, the momentum of the system is non-zero in case (i) while it is zero in case (ii). The students' responses indicate a confusion between conservation of momentum and conservation of kinetic energy, particularly in inelastic collisions where kinetic energy is not conserved (Brundage et al., 2023; Singh & Rosengrant, 2003).

Significant differences were found among educational-level groups in both conceptual understanding and confidence at $\alpha = 0.05/3$. In conceptual understanding, secondary school CPTs outperformed primary school CPTs ($d = 0.68$), while high school CPTs scored significantly higher than both secondary school CPTs ($d = 0.75$) and primary school CPTs ($d = 1.40$). For confidence levels, a significant difference was found only between primary and high school CPTs, with high school CPTs showing higher confidence and a large effect size ($d = 1.42$). High school CPTs likely have greater exposure to physics content and problem-solving experiences than primary and secondary CPTs, contributing to their higher conceptual understanding and confidence. Self-efficacy is a significant predictor of students' conceptual understanding and achievement in physics (Bailey et al., 2017; Kalender et al., 2020; Marshman et al., 2018).

Overall, the findings indicate that Cambodian pre-service science teachers hold several alternative conceptions across the four momentum sub-concepts. No significant gender differences were found in conceptual understanding or confidence. However, significant differences emerged across the educational levels that the pre-service teachers are trained to teach, with high school CPTs demonstrating higher conceptual understanding and confidence than primary and secondary school CPTs. Academic preparation and exposure to physics content, rather than gender, influence conceptual understanding and confidence (Eaton, 2021; Kaltakci-Gurel, 2023; Kim & Im, 2021). These preliminarily identified alternative conceptions will guide the design of a learning management approach for Cambodian pre-service science teachers in the next phase of this study. In general, we cannot directly and accurately measure the system's momentum and kinetic energy from offline experiments, but recorded videos and video analysis can support this management. Moreover, these preliminary results show that target students have different knowledge backgrounds, so they should study earlier at their own pace and on their own time before joining regular classes with instructors and peers. To support this, the researchers planned to use the flipped classroom approach to facilitate learning. The identified alternative conceptions will be embedded in instructional videos for students to watch early and answer follow-up questions, activating conceptual change and reorganizing students' ideas. Since some students still believed that momentum was a scalar and used the wrong SI unit, students need to review the fundamental physics concepts of vector and scalar quantities, dimensional analysis, and potential energy and kinetic energy before learning about momentum. In class, instructors should design probing questions related to these basic concepts to diagnose students' progress after watching the provided videos and clarify that their difficulties with momentum do not stem from misunderstandings of other concepts. The alternative conception relates to the idea that the kinetic energy and momentum of each object are conserved in an elastic collision; students can revise this by recording a two-object elastic collision and using Tracker video analysis to examine each object's momentum and kinetic energy. They will see that each object's momentum

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and kinetic energy change, but the system's momentum and kinetic energy are conserved. In addition, we aim to incorporate multiple representations, demonstrations, experiments, and popular physics tools such as Tracker video analysis and the PhET simulations to help students visualize momentum transfer, impulse, energy changes, and conservation of momentum and kinetic energy. These learning media can support learners' conceptual understanding and reduce difficulties in momentum-related concepts (Alonzo & Mistades, 2021; Erol et al., 2020; Rosa et al., 2018; Triyani et al., 2019).

CONCLUSION AND IMPLICATIONS

This study investigated Cambodian pre-service science teachers' conceptual understanding of momentum and their confidence levels using a modified 12-item two-tier EMCS. The results revealed low conceptual understanding (average score: 33.0% ± 14.5%). Of the incorrect group, 33.8% selected low confidence, suggesting a lack of knowledge, and another 18.8% had misconceptions (incorrect answers with high confidence). We also found that 36%-53% of participants selected medium confidence whether their responses were correct or incorrect across the four momentum sub-concepts: definition of momentum, impulse-momentum theorem, conservation of momentum, and momentum and kinetic energy. Comparison across the 12 items and the four sub-concepts revealed no significant gender differences in either conceptual understanding or confidence. The post-hoc analyses did not identify statistically significant differences between any specific pair of sub-concepts. However, significant differences emerged across the educational levels that pre-service teachers are trained to teach, with high school pre-service teachers outperforming primary and secondary school pre-service teachers on the momentum concept. Common alternative conceptions indicated that many Cambodian pre-service teachers struggle to understand the vector nature of momentum, the impulse-momentum relationship, system identification, and the distinctions between momentum and kinetic energy conservation in elastic and inelastic collisions.

The findings highlight the need to strengthen conceptual instruction in teacher education programs. Because pre-service teachers will become future science educators, unresolved difficulties can transfer to their students (Feser & Krumphals, 2022). Therefore, teacher educators in Cambodia should place greater emphasis on developing pre-service teachers' conceptual understanding, scientific reasoning, and self-efficacy during teacher preparation. The results also inform curriculum planners and physics educators in improving the teaching of momentum concepts by incorporating interactive teaching methods that explicitly target common alternative conceptions and promote deeper conceptual understanding. Furthermore, the modified Khmer-version two-tier EMCS developed in this study may serve as a useful diagnostic instrument for Cambodian physics educators to identify students' learning difficulties, assess conceptual understanding, and monitor conceptual development.

However, this study has some limitations. For example, the sample was drawn from three Cambodian teacher education institutions. It may not represent all pre-service teachers in Cambodia. The study collected multiple-choice items from EMCS online and interviewed a group of students for reasoning; the reported results may not fully reflect students' views. In the interview process, selecting only the 15 lowest scorers may introduce selection bias. Furthermore, institution, year of study, and educational level may confound interpretations of group differences. Future research should use larger, more diverse samples and incorporate other qualitative procedures to gather broader, deeper information in the Cambodian context.

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USE OF ARTIFICIAL INTELLIGENCE TOOLS

The authors used Grammarly and Claude AI solely for grammar checking, phrasing suggestions, and reference formatting. All research data and findings were from the authors' original ideas. The

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