

Teacher Candidates' Understanding of Momentum and Impulse

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Abstract

This study was conducted in a large faculty of education with the participation of teacher candidates from different majors and years. The literature review showed that there is not a significant number of research studies conducted on teacher candidates' learning of impulse and momentum. Hence, the purpose of this research study was two fold: first, to determine how the teacher candidates defined the concepts of momentum and impulse; second, to determine the level of successful application of these concepts to problems. Data were collected through written responses to open-ended questions and four multiple-choice questions that can be solved by using momentum and impulse concepts. Participants were required to give extended responses for all questions. Thus, the raw data were mostly qualitative in nature. They were scored by three researchers first independently and then together. This researcher triangulation ensured reliability of data analysis and the subsequent interpretation of findings. The findings reveal that freshman students, by and large, were not familiar with these concepts, and that during their four-year study the participants majoring in teaching physics developed a substantial gain in defining these concepts. However, the results suggest that there is still room for further development in teaching and learning of these concepts at this level. It was also found that students experienced difficulties in applying the impulse-momentum theorem. The major difficulties were: not drawing limits of the system examined, disregarding internal/external forces, and ignoring that momentum is a vector quantity.

Introduction

Research on science education has gained an impulse since 70's and 80's (Duit, 1993). Especially researchers from Northern America, Europe, and Australia have investigated what students from different age groups and backgrounds think about natural processes (Halloun and Hestenes, 1985; Driver, et.al., 1994; Treagust, Duit, and Fraser, 1996); how science education effects their thinking (McDermott, 1991; Hewson and Hewson, 1983); their learning processes (Niedderer, Goldberg, and Duit, 1992; Fischer, 1993; Niedderer, 1997; Roth, 1998); evaluation and the nature of science subjects from the perspective of teaching and learning. In the light of these research studies new and innovative teaching strategies have been developed.

As the analysis done by Duit shows even by early 90's in about 40 journals the number of papers published on students' conceptions in physics, chemistry, and biology is around 2800. About half of these were published after 1977 mostly of which were about physics subjects (66%). It was also found that mechanics as a research subject area topped all other physics subjects (about one fourth of all papers) and also the percentages of papers belonging to the chemistry and biology categories. This shows how intensely the mechanics subject area was studied. All these research studies on student conceptions and the findings obtained have contributed to the development of teaching techniques and the design of school science curricula (e.g. Camp and Clement, 1994; and Wells, Hestenes and Swackhamer, 1995).

In years researchers also studied how momentum and impulse are understood and learned by students. Camp and Clement gave a list of student misconceptions about collisions. Some of the interesting ones in that list are as follows: During a collision the body with greater speed, mass, or rigidity applies a greater force on the other; on the other hand, if a body is slowing down it applies less force. These authors did not only list the common misconception but also developed and provided a teaching unit with lesson plans based on students' alternative conceptions by utilizing bridging analogies.

Raven's 1965 doctoral dissertation entitled "An investigation into the concept of momentum in primary school children" is one of the first in this line of research (Raven, 1967-1968). In this study the purpose was to determine the order of presentation of concepts in order to meaningfully comprehend momentum. Results showed that pupils from kindergarten through grade 3 (ages 5-8) had from the beginning an intuitive understanding of momentum without understanding how the elements that make up the concept of momentum individually contribute to the whole. At college level it was found that many students' had a lot of difficulty in direct applications of impulse-momentum and the work-energy theorems (Lawson and McDermott, 1987). Authors argue that rote memorization is not sufficient by itself and stress that applications of these concepts to real world situations require deeper understandings. Moreover, they emphasize that those essential aspects of the concepts that cannot easily be visualized can be overlooked if just told orally by the instructor or described verbally in textbooks.

More recently researchers investigated different aspects of teaching and learning of these concepts by using various theoretical frameworks. In this frame students conceptual change processes during learning collisions in relation to conservation laws (Grimellini-Tomasini, Pecori-Balandi, Pacca and Villani, 1993); modeling forces in collisions and Newton's third law (action-reaction forces) (Lattery, unpublished manuscript); computer aided learning of energy, momentum and conservation laws in laboratories (George, Broadstock and Vásquez Abaz, 2000); understanding the concept of momentum and its mathematical expression (Wessel, 1997); a hierarchic developmental modeling of students' understanding of momentum (Graham and Berry, 1996). In addition, conceptual tests of force and motion (i.e. Hestenes, Wells, and Swackhamer, 1992; Hestenes and Wells, 1992; Thornton and Sokoloff, 1998; Mazur, 1997) that were developed for measuring and diagnosing student misconceptions also include related items.

In order to model hierarchically the steps taken while learning momentum and impulse the 20-item "momentum hierarchy survey" was developed (Graham and Berry). In an administration of this survey to a large group of students (N=549) of ages 17-18 it was found that grossly they can be grouped into four categories: those who are confused with the concepts (ignoring mass and largely depending on speed when thinking about momentum); those who can understand the basic ideas, recognize relevant situations, and make calculations without knowing the relationships between momentum and impulse and the law of conservation of momentum (still have difficulty in perceiving momentum as a vector quantity); those who are progressed in the hierarchy further and can understand momentum as a vector quantity and apply impulse-momentum theorem and the law of conservation of momentum in one dimensional problems; lastly the fourth group who completely comprehend the concept of momentum (together with the nature of momentum can also show in one way or another that they understand the situations in two dimensions).

Hasweh (1988) divides research studies methodologically into three groups: descriptive studies, explanatory studies, and those testing conceptual change. In the first group of studies students' preconceptions need to be determined and described. Methodologically, no suggestions, conclusions or inferences are made in this group of studies as to how learning takes place or how an educational model supports conceptual change since no findings are obtained towards how conceptual change occurs and only diagnosis formed. Hence, descriptive studies do not have direct educational implications. It can only be established which methods and techniques are more beneficial within what kind of strategies, after conducting explanatory studies and studies test them.

By using the interviews about instances technique Jones (1983), Watts (1983), and Osborn (1985) have investigated students alternative and pre-conceptions. In this technique students are presented certain situations, preferably from daily life, containing a problem and their views and ideas are extracted by open ended questions. In this way responses are analyzed to see if they form a pattern. In such studies qualitative analysis of participant responses is needed. It is often tricky if only one researcher evaluates the responses since there exists a threat of subjective scoring. One of the important tools is, thus, utilizing researcher triangulation in order to eliminate interpretation mistakes stemming from subjective evaluation of individual scorers. Researcher triangulation has great importance for maintaining objectivity in forming categories based on participant responses (Denzin, 1970). When done correctly and carefully it provides an opportunity to minimize mistakes and portray what is in the data more accurately.

By conducting interviews or obtaining responses to open ended questions there is an opportunity to uncover interviewees ideas as they exist within their minds and more authentically since participants are not forced to choose among a limited set of predetermined options. Although qualitative data analysis is time consuming and messy, it is very useful in determining the richness in students ideas. In such studies it is essential to determine especially what exists in the field about a chosen issue about which only little or non is known (such as teacher candidates' ideas about momentum) rather than to observe how a certain case will come about in a certain field of observation (Strauss and Corbin, 1998, pp. 10-14).

Rationale and Purpose

When the relevant literature is reviewed and examined it is seen that i) the number of research studies specifically conducted on momentum and impulse is limited as compared to other physics subjects; and ii) there exists no research study on teacher candidates' understanding of these concepts (defining, describing, and conceptualizing). Therefore, new studies are needed that will detect and diagnose difficulties in teaching and learning of these concepts. In addition, it is also needed to investigate how and to what degree teacher candidates learn and understand these concepts at the beginning and throughout their university education.

The purpose of this study was to investigate teacher candidates' background and current state of knowledge of the concepts of momentum and impulse and how they apply what they know in different situations. The aim was to contribute to the existing body of literature by obtaining data and subsequent rigorous analysis. The conclusions of this study are expected to reveal teacher candidates' conceptual difficulties together with other relevant learning difficulties regarding momentum and impulse.

Data Collection

The data in this study were collected during the first two weeks of fall semester in several sessions since the participants constituted of different majors and years. A total of 192 teacher candidates participated in the study. The majors, years, and the respective numbers of participants are given in table 1.

Table 1. The majors, years, and the respective numbers of participants.

Major and Year		Number of students (<i>N</i>)	Percentage
High School Physics Teaching – I	(HSPT-I)	39	20%
High School Physics Teaching – II	(HSPT-II)	32	17%
High School Physics Teaching – III	(HSPT-III)	22	11%
High School Physics Teaching – IV	(HSPT-IV)	42	22%
Middle School Science Teaching – I	(MSST-I)	17	9%
Middle School Maths Teaching – II	(MSMT-II)	40	21%

It should be noted that MSST and HSPT majors take introductory mechanics courses in fall semester of their freshman year, MSMT majors take it in their sophomore years. That is the reason for including MSMT-II group in the sample.

The participants were given a two-part questionnaire (see box 1). The first part contained several questions aiming to measure conceptual understanding regarding momentum and impulse. And the second part contained questions requiring providing descriptions. Participants were asked to provide extended responses to all of the questions.

Box 1. The questionnaire. Figures were provided for questions 2 and 3 (not shown here).

1. Consider that you have a ball in your hand. Is momentum conserved when you release it and after hitting the ground if it returns back to where it was released? Explain why you think so.

2. Choose one of the options and explain your answer.

As shown in figure consider that you are standing on a cart with ignorable friction with the surface. You are throwing balls onto a panel fixed firmly to the cart. If the balls bounce directly back as shown will the cart move? (Mazur, 1997, p. 134).

- a) Yes, moves toward right.
- b) Yes, moves toward left.
- c) No, stands still.

3. Two objects with mass m and $2m$ are at rest on a frictionless surface. If these two objects are pushed for 3 seconds with equal forces, how many times more will be the momentum of the lighter object as compared to the heavier one? (Mazur, 1997, p. 129).

- a) 4 times
- b) 2 times
- c) equal
- d) half
- e) a quarter

4. Three astronauts Joe, Bob, and Tom who weigh equal on earth. While they are at rest in outer space Joe pushes Bob towards Tom with a velocity v and Tom catches Bob. Describe the motions of these three astronauts at these instances by also describing the direction and magnitude of their velocities (Hewitt, Suchocki & Hewitt, 1999, p.74).

- 5. What is momentum?
- 6. What kind of a quantity is momentum? Why?
- 7. What is the unit of momentum?
- 8. What is impulse?

Data Analysis and Findings

Response sheets were scored according to a rubric by each of the researchers individually and then together in order to ensure reliability of interpretations and avoid subjective evaluation mistakes. Indeed, it was seen during data analysis that this way of researcher triangulation considerably reduced such mistakes.

According to the rubric one of three codes were assigned to each response:

[0] : denotes scientifically unacceptable or no response cases,

[1] : denotes scientifically complete and acceptable responses,

[2] : denotes responses that contain acceptable or nearly acceptable expressions.

Analysis of responses to the first question:

Two sorts of answers are considered in category [1]:

A) When the ball's momentum considered alone it will not be conserved, since momentum is a vector quantity. Even though the magnitude of momentums just before and after collision they are in opposite directions. When the ball is considered alone it under the influence of an external force (earth's gravity). Momentum is not conserved under the influence of an external force.

B) When the earth and ball system is considered together momentum is conserved. This is like the case of colliding two objects. Since the earth's mass is too large as compared to the ball's mass it will not, practically, gain an acceleration. There is no external force for the earth-ball system and the total momentum is conserved.

It is noteworthy that only two responses out of 192 are in category [1]. Seventeen responses are considered in category [2], and the remaining bulk of the responses, 173, are in category [0].

Analysis of responses to the second question:

A response is considered as [1] if it states and explains that the cart will move towards left and shows that impulse is equal to the change in colliding balls' momentum. If the correct choice is signed but an explanation is not provided it is included in category [2]. Analysis of responses are given in Table 2. It is seen that participants are in real confusion when they are required to respond to a problem that can also be answered intuitively.

Table 2. The number of codes and students in each category for question 2.

Major and Year	Categories						Percentages in categories
	Number of codes			Number of responses			
	[1]	[2]	[0]	[1]	[2]	[0]	
HSPT-I	4	11	8	7	17	15	[1] 17.9% [2] 43.6% [0] 38.5%
HSPT-II	4	4	8	16	5	11	[1] 50% [2] 15.6% [0] 34.4%
HSPT-III	2	1	12	6	1	15	[1] 27.3% [2] 4.5% [0] %68.2%
HSPT-IV	3	3	13	15	4	23	[1] 35.7% [2] 9.5% [0] 54.8%
MSST-I	1	2	6	3	3	11	[1] 17.7% [2] 17.7% [0] %64.6
MSMT-II	2	7	14	3	15	22	[1] 2.5% [2] 37.5% [0] 55%
TOTAL	16	28	61	50	45	97	

Analysis of responses to the third question:

A response is considered as [1] if it states and explains that according to the impulse-momentum theorem the changes in momentum of the two masses will be equal or that according to Newton's second law mass and acceleration are inversely proportional if forces are equal for two different masses. Since momentum is the product of mass and velocity both bodies will have equal change of momentum. Analysis of responses are given in Table 3. It is seen that physics teaching majors are gaining more accurate understandings as they progress through the years.

Table 3. The number of codes and students in each category for question 3.

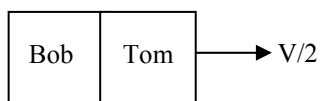
Major and Year	Categories						Percentages in categories
	Number of codes			Number of responses			
	[1]	[2]	[0]	[1]	[2]	[0]	
HSPT-I	2	4	11	13	5	21	[1] 33.4% [2] 12.8% [0] 53.8%
HSPT-II	3	2	6	24	6	2	[1] 75% [2] 18.8% [0] 6.2%
HSPT-III	2	0	6	15	0	7	[1] 68.2% [2] -0.0% [0] 31.8%
HSPT-IV	3	2	3	36	3	3	[1] 85.8% [2] 7.1% [0] 7.1%
MSST-I	1	2	7	2	4	11	[1] 11.8% [2] 23.5% [0] 64.7%
MSMT-II	2	4	11	13	5	21	[1] 0.0% [2] 30.0% [0] 70.0%
TOTAL	13	14	44	103	23	65	

Analysis of responses to the fourth question:

In this question there is no external force acting on any of the bodies involved. Also there is no friction since the astronauts are not on a surface. So, it needs some abstract thinking. However, the question can be solved easily by applying the law of conservation of momentum. In the first part Bob should move with velocity v towards Tom and Joe should move backwards with the same speed.



In the second part Tom, while at rest, catches Bob. Afterwards, they move together (with the same speed). Their speed should therefore be half the speed of Bob.



Most participants responded to this question (85%). One fourth of all students correctly answered this question. One third of the responses were counted in category [2]. These contained correct responses to either part of the question. It is noted that overwhelming majority of participants in this group correctly answered the first part of the question. Considering that students are more familiar with collision problems, this finding represents a perplexing situation.

As a result, more than 40% of the responses were counted in category [0] 15% of which were no response cases. It was also noted that too many codes emerged for this question. (see table 4). Therefore only the most frequent ones are presented in table 5.

Table 4. The number of codes and students in each category for question 4.

Major and Year	Categories						Percentages in categories
	Number of codes			Number of responses			
	[1]	[2]	[0]	[1]	[2]	[0]	
HSPT-I	1	6	19	2	10	27	[1] 5.1% [2] 25.6% [0] 69.2%
HSPT-II	1	7	4	13	11	8	[1] 40.6% [2] 34.4% [0] 25%
HSPT-III	1	4	5	10	5	7	[1] 45.5% [2] 22.7% [0] 31.8%
HSPT-IV	1	10	4	19	15	8	[1] 45.2% [2] 35.7% [0] 19%
MSST-I	1	2	10	2	5	10	[1] 11.8% [2] 29.4% [0] 58.8%
MSMT-II	1	10	11	2	18	20	[1] 5% [2] 45% [0] 50%
TOTAL	6	39	53	48	64	80	

Table 5. The most frequently seen response patterns for question 4.

Category	Number of responses	Percentages	1st Part		2nd Part	
			Joe	Bob	Bob	Tom
[2]	21	10.9 %	$\leftarrow V$	$V \rightarrow$	-	$V \rightarrow$
[2]	9	4.7 %	$\leftarrow V$	$V \rightarrow$	$V \rightarrow$	$V \rightarrow$
[2]	67	34.9 %	$\leftarrow V$	$V \rightarrow$	-	$2V \rightarrow$
[0]	5	2.6 %	\leftarrow	\rightarrow	-	\rightarrow
[0]	4	2.0 %	0	$V \rightarrow$	-	0
[0]	3	1.6 %	$\leftarrow V/2$	$V/2 \rightarrow$	-	$V/2 \rightarrow$
Total	109	55.7 %				

Analysis of responses to the fifth question:

Besides responding to problem situations it is also important to be able to formally define concepts as they are accepted in the scientifically. When participants' responses about definition of momentum are analyzed and coded it is seen that only one third of them were in category [1]. However, it is also seen that physics teaching majors achieved considerable gain in defining this concept as years passed (30.8%, 31.2%, 59.1%, and 71.4% respectively for years 1-4).


















Analysis of responses to the sixth question:

Defining momentum as a vector quantity is essential in understanding the concept fully. Therefore, participants' responses are important in relation to their definitions of the concept. It is seen that participants who had not yet taken introductory physics courses yet, are in great difficulty in giving appropriate and acceptable responses (15.4%, 0%, and 7.5% respectively for HSPT-I, MSST-I, MSMT-II). But in subsequent years HSPT majors had better results (59.4%, 31.8%, and 64.3% respectively for HSPT-II, HSPT-III, HSPT-IV). It is noted that there is a jump right after taking the introductory physics course).

Analysis of responses to the seventh question:

Units of physical quantities are important to recognize while learning concepts, but students often fail to do so. The data shows that HSPT majors attained a better level of success in their responses to this question as compared to the fifth question (see table 6). Again it is seen that upper level participants are far better in responding to this question than lower levels.

Tablo 6. The number of codes and students in each category for question 7.

Major and Year	Categories						Percentages in categories
	Number of codes			Number of responses			
	[1]	[2]	[0]	[1]	[2]	[0]	
HSPT-I	3	3	10	13	5	21	[1]  %33,3 [2]  %12,8 [0]  %53,9
HSPT-II	4	3	4	24	3	5	[1]  %75 [2]  %9,4 [0]  %15,6
HSPT-III	6	2	1	19	2	1	[1]  %86,4 [2]  %9 [0]  %4,7
HSPT-IV	8	1	2	39	1	2	[1]  %92,9 [2]  %2,4 [0]  %4,8
MSST-I	1	0	7	1	0	16	[1]  %5,9 [2] - %0 [0]  %94,1
MSMT-II	2	1	8	3	1	36	[1]  %7,5 [2]  %2,5 [0]  %90
TOTAL	24	10	32	99	12	81	

Analysis of responses to the eighth question:

Impulse is a very closely related concept to momentum. Lastly, participants definitions of impulse were probed by directly asking to define the concept. Here a similar pattern like in the sixth question is observed in participants' responses to defining impulse. Also, it is noted that participants who had not yet taken the course virtually were not aware of the concept. This time much so for the HSPT majors also (only 7.7% of this group of participants' responses were counted in category [1]).

Some participants tended to define the concept as "momentum=impulse" rather than "change in momentum=impulse". This tendency was also observed in a small group in responses to defining momentum. This finding shows that some students had heard about these concepts and their relation to each other but they were not accurately remembering and/or explaining them.

Results and Discussion

The purpose of this study was to investigate teacher candidates' background and current state of knowledge about momentum and impulse and how they apply what they know in different problem situations. The data obtained in this study revealed eye opening results in order to determine the current state of affairs regarding the above stated research problem. The first and far most important finding is that participants' initial knowledge state is not adequate. They virtually do not know even the basics such as definitions and have considerable difficulty in applying their existing knowledge to problems. One example of this was seen when participants' responses to questions 1 and 6 are evaluated together. Although, about half of the participants knew that momentum is a vector quantity they failed to apply this piece of knowledge when responding to question 1 and the majority stated that (56%) the mass and speed of the ball is the same while falling down and climbing up and therefore the momentum is conserved.

Another important finding, when considered upper level HSPT majors also participated in this study, is that almost all of the students do not distinguish the role and importance of internal/external forces in collisions and conservation of momentum. Therefore, emphasis must be given and attention must be paid during instruction, if students come to an understanding of this sort as a result of learning the concepts. Another study (Grimellini-Tomasini, Pecori-Balandi, Pacca, and Villani, 1993) also presented similar findings with regards to isolation of the system in hand from the surrounding and considering momentum as a vector quantity in dealing with conservation of momentum. Current study also revealed such difficulties students' have and confirmed agreement with the above mentioned study.

One implication that can be drawn from this study is that in teaching conservation of momentum the role and importance of internal/external forces in collisions should be sufficiently stressed and examples should be given for both cases where momentum is conserved or not conserved.

It is also seen as a result of this study that although HSPT majors showed a considerable positive gain in learning as years progressed there still a lot to do in defining the concepts of momentum and impulse and solving related problem situations.

When it is considered that in this study the participants were actually teacher candidates, it should also be mentioned that in this open-ended extensive response survey participants had difficulty in explaining and expressing their own views and ideas. The importance of this finding becomes obvious since teachers are not educated for themselves only and training and educating future teachers also demand fluent individuals in expressing themselves.

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