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Secondary School Students' Conceptions Relating to Motion under Gravity

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ABSTRACT: The study investigated tenth-, eleventh-, and twelfth-grade students' alternative ideas relating to the motion of a body travelling in the field of gravity with an initial horizontal velocity. The sample of the study consisted of 40 tenth-grade students, and 33 and 40 eleventh-grade students that attended different sections of upper secondary school where the time devoted to physics teaching is quite diverse. Open-ended questions related to three different problems were used. The first problem concerned the motion of a metallic ball after reaching the edge of a horizontal surface on which it was moving with constant velocity. The second problem concerned the motion of a ball, which was held in the hands of a runner who was moving on a horizontal surface with constant velocity, after the ball was released by the runner. The third problem concerned the motion of a body that was thrown upwards from a vehicle that was moving horizontally with constant velocity. Students' answers were analyzed qualitatively and were grouped into different categories based on their main conceptual characteristics. Students' conceptions were similar to the pre-Newtonian theories of motion, resembling to Aristotle's ideas about motion and aspects of the theory of "impetus," developed by Buridan during Middle Ages. Comparison of students' answers to the three similar problems indicated students' difficulties to transfer the same conceptual framework from one problem to the other. Differences also existed among the three Groups of students that differed in terms of their educational experiences. Based on the results, suggestions related to curriculum revisions and constructivistic teaching interventions are put forward.

KEYWORDS: Alternative perceptions, constructivism, inertia, independence of motions.

Introduction

Previous research (Watts & Zylbersztajn, 1981; Clement, 1982; McCloskey, 1983; Sadanand & Kess, 1990; Thijs, 1992; Palmer & Flanagan, 1996) indicated that students have their own alternative conceptions which frame the way they interpret natural phenomena. Students' conceptions differ from the acceptable scientific interpretations and are rooted in students' experiences, or are the outcomes of teaching, textbooks, or any combination of these factors. In some cases, these naïve understandings mirror aspects of important 'scientific' interpretations of previous centuries.

Research also indicated that students' conceptions persist even after intensive instruction, especially when teaching does not take them into consideration. Certain conceptions are so well consolidated that they survive after teaching and, in most cases, they co-exist with scientific conceptions that are taught in classrooms (DiSessa, 1982; White, 1983; Beveridge, 1985; Cros, Chastretto, & Fayol, 1988). Sstudents usually apply scientific conceptions in examination problems, but they are unable to recall and connect them with problems of daily life, or to connect them with other applications. Students' conceptions and their influence on learning should however constitute part of teaching, especially when these conceptions are incompatible with the scientifically acceptable knowledge, and conceptual reorganization is required (Posner, 1982; McCloskey, 1983).

The present study attempted to investigate tenth- and eleventh-grade students' conceptions relating to the horizontal motion of a body under gravity and the forces that act on the moving body. The sample consisted of three groups of students having different educational experiences (different curricula and different time devoted to learning physics), while questions referring to three similar problems were used.

Methodology

The Sample

Three different groups of students from the same urban school participated in the study. The first group consisted of 40 tenth-grade students, while the second and third groups consisted of 40 and 33 eleventh-grade students, respectively, who were attending different sections of study with different curricula and different time devoted to learning physics. Thus, the first group of eleventh-grade students were following a more intensive physics program than the second group, whose curriculum did not include Newtonian mechanics. The three student groups are referred here as Group 1 (tenth-grade students), Group 2 (eleventh-grade students with intensive physics program), and Group 3 (eleventh-grade students with general physics program), respectively.

Collection of Data

For the collection of data, open-ended questions relating to three problems were used. The first problem concerned the motion of ball moving with constant velocity on horizontal surface, after reaching the edge of the surface, as indicated in Figure 1. The second problem concerned the motion of a ball held by a runner moving horizontally with constant velocity, after the ball is released free hand, as shown in Figure 2.

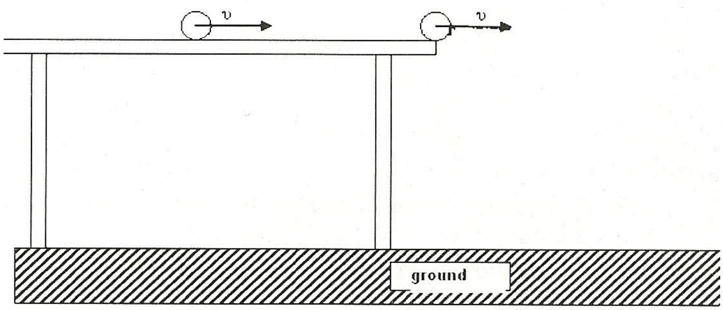

Figure 1. A Ball Moving with Constant Velocity Reaches the Edge of a Horizontal Surface.

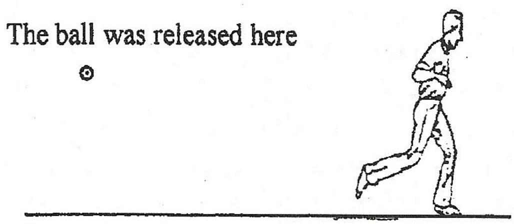

Figure 2. A Runner, Running with Constant Velocity, Releases Free a Ball He Was Holding.

In both problems, students were asked to indicate the path of the ball, after reaching the edge of the horizontal surface or after being released from the hand of the runner, considering that air resistance was negligible. Students were also asked to mention and draw the forces acting on each body prior and after reaching the edge of the horizontal surface, or prior and after being released from the hand of the runner. For the first problem, two different versions, where the mass of the moving ball was different (big and small), were used, and students were asked to compare the horizontal displacement of each ball provided that their velocity was equal.

In the third problem, a man, being on a platform moving horizontally with constant velocity, shoots a ball vertically upwards, while the platform continues to move with the same velocity. Students were asked to draw the path of the ball from the moment it leaves the gun until its return to the same height from which it is shot. The students were also asked to draw the forces acting on the ball during its upward and downward movement, and at the highest point of its path.

The first two problems are similar and thus it was possible to check the consistency of students' answers. The first problem is one of the usual exercises that teachers use in classroom (Group 2), while the second problem is not. The third problem constitutes a more difficult variant of the previous problems and requires the composition of a horizontal motion with constant velocity with a vertical velocity for an object moving under gravity.

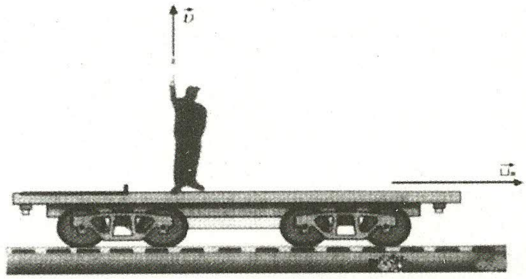

Figure 3. A Man, on a Platform Moving with Constant Velocity, Shoots a Ball Upwards

Students' anonymous answers to questions concerning the three problems constituted the data of the present study. The data were coded and analyzed in an attempt to investigate students' alternative conceptions and whether there were any differences among the three Groups of students.

Results

The method of constant comparative analysis (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was used in qualitatively analyzing students' answers to the questions of the three problems. The aim of this method is to categorize students' answers in appropriate levels. The whole approach constitutes an open coding, because the levels are not determined beforehand. The first answer is initially carefully analyzed and its levels are determined. Then, the levels of each next answer are compared with the levels of previous answers, and, progressively, the final levels of a rubric are decided. For coding the levels of each answer and the development of each rubric, two coders worked independently in order to establish acceptable intercoder reliability (Guba, 1981). Differences between the two coders were discussed and any differences were finally dissolved

In Tables 1, 2, and 3, students' conceptions related to the three problems for each Group of students are presented. From the information in Table 1, it appears that the majority of the students (60%) insisted that the ball, irrespectively of its mass, will follow a parabolic path, and 25 students (22%) supported that the ball will move across a linear path following the diagonal of the horizontal and vertical velocity, and ignoring obviously the vertical acceleration due to gravity. A student from Group1 proposed that the ball "initially moves horizontally and then it follows a parabolic course," while another student from Group 3 expressed the opinion that the ball moves initially horizontally and afterwards vertically. These answers seem to result from experience where a body moving horizontally with a high speed does not appear initially to have any vertical displacement. Such a displacement becomes evident only after the body covers a long horizontal distance (i.e., a ball shot by a gun). Four students from Group 3 expressed the idea that the big ball follows "a vertical path" and the small ball "a parabolic path." Nine students supported that the big ball will move only downwards following a vertical path, and four of them insisted that the small ball will follow a parabolic path.

Table 1

Conceptions Related to the First Problem from the Three Groups of Students

Students' Answers	Frequency			
	Group 1	Group 2	Group 3	Total
Orbit of ball of big mass				
Parabolic	21	35	12	68
Diagonal	14	3	8	25
Vertical	1	2	6	9
Initially horizontal and afterwards parabolic	1			
Initially horizontal and afterwards vertical			1	1
They did not give an answer	3		6	9
Total	**40**	**40**	**33**	**113**
Arc of ball of small mass				
Parabolic	21	35	16	72
Diagonal	14	3	8	25
Vertical	1	2	2	5
Initially horizontal and afterwards parabolic	1			1
Initially horizontal and afterwards vertical			1	1
They did not give an answer	3		6	9
Total	**40**	**40**	**33**	**113**
Forces on the horizontal level				
Weight and a vertical force from the level	18	13	2	33
Weight, the vertical force and the friction	5	12		17
Weight, the vertical force and the horizontal speed	7	5		12
Weight, the vertical force, friction and the speed	1	2		3
Weight and the speed	1	1		2
Weight	1	2	3	
Weight and a horizontal force			6	6
Weight, the vertical force and a horizontal force			1	1
Horizontal force		2	2	
They did not give an answer	8	6	20	34
Total	**40**	**40**	**33**	**113**
Forces on the during its fall				
Weight of ball (vertical)	24	12	8	44
Weight and a horizontal force	3	7		10
Weight and vertical force	3	3		6
Weight of ball (diagonal)	6		1	7
The acceleration of gravity	2			2
Weight with horizontal direction			1	1
Weight and gravity			1	1
They did not give an answer	2	18	22	42
Total	**40**	**40**	**33**	**113**
The ball with the biggest horizontal displacement				
Same displacement	8	5	3	16
The biggest mass smallest displacement	26	25	12	63
The smallest mass smallest displacement	1	4	2	7
They did not give an answer	5	6	16	27
Total	**40**	**40**	**33**	**113**

Table 2

Conceptions Related to the Second Problem from the Three Group s of Students

Students' Answers	Frequency per Team			
	Group 1	Group 2	Group 3	Total
Path of the Ball				
Parabolic of same displacement	3	5		8
Parabolic of smaller displacement	6	14	3	23
Vertical	24	11	22	57
Diagonal of smaller displacement	5	4	7	16
Diagonal with same displacement	2	1		3
Initially horizontal afterwards vertical		1		1
Parabolic of bigger displacement		1		1
Diagonal backwards			1	1
They did not give an answer		3		3
Total	40	40	33	113
Forces when the runner holds the ball				
Weight and a vertical force of (equal magnitude)	28	16	3	47
Weight	2	6	3	11
Weight and a horizontal force from runner	1	4	3	8
Weight, vertical and a horizontal force		3		3
Weight and horizontal speed from runner		2		2
Horizontal speed from runner		1		1
Vertical force downwards	1			1
4 vertical forces with resultant zero	1			1
A force from runner			5	5
Force of mass	1		1	2
No force, does not fall			1	1
They did not give an answer	7	8	17	31
Total	40	40	33	113
Forces in ball during its fall				
Weight	26	15	18	59
Weight, and a vertical of smaller value	3	6		9
Weight and a horizontal force	1			1
Weight and the horizontal speed		3		3
Weight, vertical and horizontal speed		1		1
Weight and speed			2	2
No forces are exerted	1			1
They did not give an answer	9	15	13	37
Total	40	40	33	113

The results in Table 1 indicate that the students from Group 3 gave different and more incorrect answers, in comparison with the students from the other two groups, about the forces acting on the body as it moves horizontally with constant velocity. In terms of the question "which forces act on the ball during its fall," 24 students (60%) from Group 1, and only 12 students (30%) from Group 2 gave a correct answer, although students from the latter group (Group 2) had been studying the respective topics more extensively than the other two groups of students. It seems that when students are involved in solving complicated mathematical problems related to two simultaneous motions of a body, they do not necessarily have a conceptual understanding of the respective material. For example, 10 students from Group 1 and 7 from Group 2 supported that gravity and a horizontal force act on the moving body, while another student from Group 3 insisted that only gravity (the weight) acts on the body, and thus he insisted that the direction of gravity was along the tangent of the parabolic path of the body. Another student from Group 3, in his effort to interpret the horizontal motion of the ball, depicted the weight as a horizontal force.

Table 3

Conceptions Related to the Third Problem from the Three Groups of Students

	Frequency			
Students' Conceptions	Group 1	Group 2	Group 3	Total
Path of the Ball				
It returns above the man	8	11	2	21
It returns behind the man	8	13	12	33
It returns to the point of shot	17	12	16	45
It returns behind the place of shot	4		1	5
It returns in front of the man		1		1
They did not give an answer	3	3	2	8
Total	40	40	33	113
Forces during the rise of the ball				
Weight	1	5	1	7
Weight and vertical force from gun	18	15	5	38
Weight and vertical speed		5	2	7
Vertical force from the gun	8		12	20
Vertical speed of ball			1	1
Weight and vertical force (reaction)	1	6		7
Weight ,force from gun and horizontal speed		1		1
They did not give an answer	12	8	12	32
Total	40	40	33	113
Forces at highest point				
Weight	10	7	2	19
Weight and opposite force by gun	10	2	1	13
Weight and vertical force (reaction)	7	8	10	25
No forces are exerted	1			1
Weight and horizontal speed		3		3
They did not give an answer	12	20	20	52
Total	40	40	33	113
Forces on the ball during its fall				
Weight	25	16	21	62
Weight and a smaller vertical force	4	8	12	24
Weight and a horizontal force		8		8
They did not give an answer	11	8		19
Total	40	40	33	113

The results in Tables 1 and 2 indicate that more than half of the students from all Groups, who proposed that the path in the first problem was a parabolic one, did not accept that the path was the same for the second problem as well. Thus, 64% and 60%, of the students from Group 3 and Group 1, respectively, suggested that the ball after being released by the runner will move vertically and downwards. Students from Group 2, who studied intensively the respective phenomena, also continued to express a variety of alternative conceptions. A high percentage of them (35%) suggested that the ball after being released from the hand of the runner will follow a parabolic path, but that its horizontal displacement will be smaller than the runner, and 27,5% of them suggested that the ball will move only vertically and downwards. The results of the present study corroborate the results from previous studies where the first problem was used (McCloskey, 1983), or where the movement of a body released from an aeroplane moving horizontally with constant velocity was investigated (McCloskey, Caramazza, & Green, 1980).

Similarly, students expressed conceptions about the forces acting on the ball that were different from those expressed to the same question of the first problem. Thus, a smaller number of students suggested that there was horizontal force acting on the ball, as indicated in Tables 1 and 2. A student from Group 3 proposed that that no force was exerted on the ball, and another student suggested that there were "4 vertical forces with a resultant force equalling zero." Students' answers to the question, "Which forces are exerted on the ball during its fall," were also different than in the first problem. Actually, 44 students (39%) selected the correct answer in the first problem and 59 students (52%) in the second problem, as indicated in Tables 1 and 2. This could be attributed to the fact that students' answers might be influenced by the first problem that was the first to be answered.

In the third problem, 45 students (40%) supported that the ball will finally return to the point from which it was shot, as if it had no horizontal velocity due to the movement of the platform from which it had been shot. Other 33 students (29%) suggested that the ball will return to a position behind the man, either because the ball did not have a horizontal speed or because its speed was smaller than the speed of the platform. The results in Table 3 indicate that 65 students (57, 5%) expressed the idea that during the upward motion of the ball, apart from gravity, there was bigger force acting on the ball upwards. This force was however progressively consumed and diminishing up to zero at the maximum point of its path. Other 13 students (11, 5%) suggested that, at the maximum point of its path, the resultant force is zero or that no forces are acting on the ball (one student from Group 1). As for the downwards movement of the ball, 64%, 62,5% and 40% of students from Group 3, Group 1, and Group 2, respectively, provided correct answers, as it is indicated in Table 3. Eight students from Group 2 suggested that on ball, apart from its weight, a horizontal force acts on it that contributes to its parabolic path.

In most of these answers, there exist elements of "the theory of impetus," proposed in the middle Ages mainly by Buridan (1300-1358). This theory proposes, for example, that, when a body is thrown upwards, a force is inserted in the body, but the force (impetus), because of body's weight and the resistance of air, is progressively consumed (exhausted), and, as a result, the body begins its return under the effect of its weight. Similar ideas have been identified in other studies from various countries (Clement, 1982; McCloskey, 1983; Osborne & Freyberg, 1985; Watts & Zylbersztajn, 1981).

Discussion

The overall results of the study clearly indicate that many students face enough difficulties in comprehending the laws of Newtonian mechanics. Certain ideas from Newtonian mechanics are not easily conceptualized even after intensive teaching, and certain persistent alternative conceptions seem to dominate secondary school students' way of thinking. Students from Group 2 expressed almost similar alternative conceptions as students from the other groups, despite the fact that they devoted much more time in learning the respective topics. Other studies also indicated that many students, even after a series of courses targeting conceptual understanding of Newtonian mechanics, maintained their initial conceptions or they only slightly modified them (Thijs, 1992; Gunstone, Champagne & Klopfer, 1981). The role of education is `to fill' the gap between students' ideas and the scientific interpretation of certain phenomena. According to Posner et al. (1982), the learning should be the result of interaction of what the students are taught at school and what they already know. Obviously, students' alternative ideas should not be ignored, but should be an important part of the content of teaching.

Studying students' answers from Group 2 also revealed that the students fail to transfer the conceptual framework of familiar problems to other similar problems from everyday life activities. A common alternative conception that was identified relates to Aristotle's idea that every motion of a body presupposes force acting on it in the direction of its motion. The same conception was also adopted by Buridan during the fourteenth century, and it seems to dominate students' understanding at the university level as well (Watts & Zylbersztajn, 1981; Clement, 1982; McCloskey 1983; Sadanand & Kess ,1990). The existence of an internal force in a moving body that is progressively consumed is not only related to Buridan, but it was also identified in many other studies (Clement, 1982; McCloskey, 1983; Watts & Zylbersztajn,1981). According to Viennot (1979), this is a consequence of students' conception that the force is proportional to the velocity of the moving body, rather than the force being proportional to the change of velocity.

The results indicate that observations and their common sense explanations constitute "reality" for many people. Conceptual change can only be achieved only if individual learners recognize that their observations and their previous explanations are inaccurate. Real teaching should provide opportunities to individual learners "to live" phenomena that are incompatible with their existing conceptions and create for them a kind of discomfort and cognitive disequilibrium. The simple recognition of discrepancy between one's cognitive structures and real phenomena can not always alone lead to conceptual change. It consists however an important aspect of teaching for any consequent conceptual reorganization of the existing cognitive structrures of any individual learner. Finally, the acceptance of any new idea is not automatic, but depends on the clarity, the verisimilitude and its inquiring value (Posner et al., 1982; Gunstone, Gray, & Searle 1992). It seems as a one-way approach to always follow constructivistic teaching techniques including a historical approach of the explanation of certain phenomenon. These approaches favour the use of conceptual questions, analogies, Socratic dialogues, and computer models or simulations that may facilitate learners' conceptual understanding and reorganization.

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