Diminishing Forces – Implications for Contextual Dependence of a Misconception

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Abstract. Evidence is presented to suggest a misconception concerning motion of an object when acted upon by a force that decreases with distance such as Coulomb's Law. This evidence was collected during interviews of several above average calculus-based physics students. The students stated that the motion of an object would slow, even stop, if the force on it decreased based upon its distance. This may not be surprising until viewed in the light that many of these students didn't reveal this impetus or Aristotelian notion except with diminishing forces.

INTRODUCTION

Over the last 25 years, a large portion of research has focused on the pre-existing mental models that a student brings to the classroom [1]. These have been called preconceptions, alternative conceptions, common sense concepts and misconceptions [2]. Studies have shown that people of all ages hold some type of misconception [3]. And students at all achievement levels have these misconceptions as well [4,5]. Students' misconceptions in mechanics and more specifically Newton's Laws have been of particular interest because Newton's Laws are so often referenced during other topics of instruction in an introductory physics course [6]. One particular misconception, motion implies force, is attributed to Aristotle and widely accepted to exist among introductory physics students [7]. This study has discovered implications that students who use Newtonian reasoning in one context have this Aristotelian misconception triggered when dealing with diminishing forces.

RESEARCH METHOD AND DATA

While conducting a research study on the problem-context dependence of Newton's Second Law [8], I believe that I happened upon a previously undocumented use of a misconception, or at least a complication, regarding forces which decrease in magnitude with distance such as Coulomb's Law.

The longitudinal study allowed me to interview 13 students on the topic of electric charges and fields (as well as a variety of other topics). These students were above average performers in a calculus-based introductory physics course at Kansas State University. The interviews were conducted after instruction. The particular interview discussed here occurred one week after the course exam covering the topics in the interview.

Students were first shown Fig. 1 and were told that the charged spheres were identical. The left one was fixed in place and the right one was set in place and released. There were no other instructions or caveats given such as to ignore friction. The student was then asked to describe what happened. A correct response would include reference to the Coulomb force making the released sphere accelerate to the right. The sphere would continue to accelerate. As it gets farther and farther away its increase in velocity would be smaller and smaller.

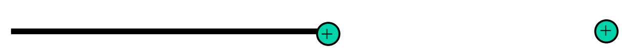

FIGURE 1. Electric Charge Question – Charged Sphere Released from Rest

A majority of student responses included the statement that because the force diminishes as $1/r^2$, the particle would slow as it moves away from the other charge. Most students indicated that a point in space exists where the particle's speed would reach a maximum and then start to return to either a constant velocity or zero.

> "It would accelerate at the beginning until it reached a certain point I suppose where the field isn't so strong on it." (Student 7)

> "So it'll, at first it will probably accelerate and then get to a point when it starts slowing down again..." (Student 18)

These types of responses were given by several students. Some of whom responded to the next question in the interview (which had a larger, more massive sphere in the same scenario) in a Newtonian manner and some who did not. This idea of a maximum speed and then slowing down was quite prevalent. I was only able to eliminate it as a possible reasoning path for one of the 13 students. Yet, a response of this nature might not be indicative of an Aristotelian misconception, but rather the student just neglecting to mention friction or some other intuition from experience in the given response.

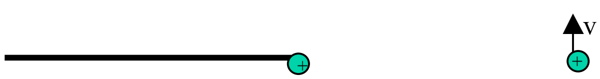

FIGURE 2. Electric Charge Question – Charged Sphere with Initial Velocity

However, the concept came up again when the scenario was changed slightly. The students were shown Fig. 2. Again, the charged spheres are identical and the left one fixed in place. In this scenario, a film has been capturing the sphere's motion and has been stopped when the sphere was moving at a velocity v as shown. The students were then asked to describe what would happen when the film was started again. The correct response would include the moving sphere would turning towards the right due to the Coulomb force between the spheres. Eventually, the sphere would stop turning because as it turns, the force line between the two spheres also changes until the force is in the direction of the moving sphere's motion. This latter detail was beyond the scope of the interviews and was not pursued. Seven of the students drew something similar to Fig. 3.

FIGURE 3. Written Response to Electric Charge Question (Student 2)

> "It'll look like a trajectory plot. It'll still accelerate this way identical to the first one. [Drawing arrow and labeling it a] In the x-direction it's going to do the same thing. However in the y direction it's going to continue to stay at this velocity. So for the most part it's going to be like that [Draws arc]." (Student 2 – while drawing Fig. 3)

One of the students drew a straight line with no change in trajectory. Two of the students drew diagonal lines angled to the right. Three of the 13 students drew responses similar to that drawn in Fig. 4 below:

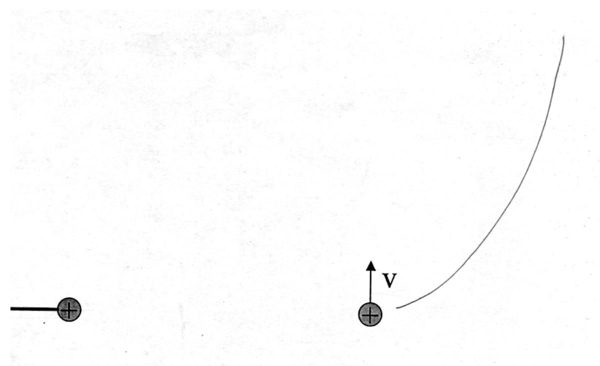

FIGURE 4. Written Response to Electric Charge Question (Student 17)

> "I would say that it should be accelerated in that direction but it will slow down as it gets farther away. So it should move [draws concave up arc]" (Student 17 while drawing Fig. 4)

Neither friction nor previous experience can account for such a trajectory shape. In fact, two of these students drew more intuitive trajectories initially then changed their minds as they discussed how they would include the $1/r^2$ factor of the force. An example is shown in Fig. 5.

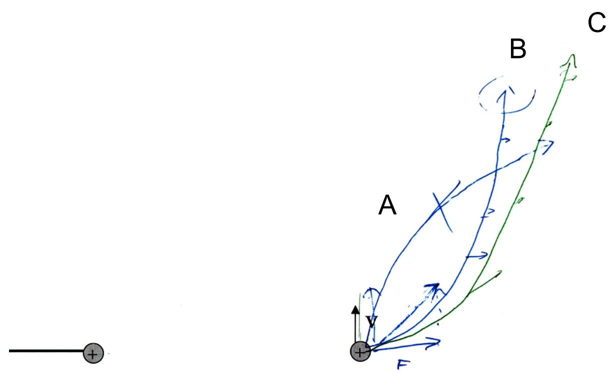

FIGURE 5. Written Response to Electric Charge Question (Student 15)

"Maybe like that [drawing concave down arc A]…I'm thinking….since…only I'm going to change my mind…because as you get farther away this force is less so maybe it'll go like that instead [draws concave up arc B] since that is going to dominate the direction it goes since as you get farther away this force is going to be less. It's just a guess though. [Interviewer: So which are you going with?] This one, not that one [Crosses out arc A] It would be in this direction since as it's getting farther away the force vector is becoming less and less [draws arrows on arc B] but you still have this original velocity..." (Student 15 while drawing Fig. 5)

The student-drawn arrows pointing to the right represent the electrical force diminishing as the sphere gets farther away. This truly supports a diminishing forces causing diminishing velocity misconception regarding Newton's laws of motion.

Both the above students earned an A grade in BOTH semesters of the course. Student 17 received the highest score on the exam covering electrical charges which had been given in the week prior to the interview. In addition, both students used Newtonian reasoning in answering the next interview question when the mass of the moving sphere was doubled. By traditional measures and from previous and subsequent interview data, these students were exceptional. So just what is going on here? To find out, I had time available in one interview to request a comparison of nearly equivalent situations.

Later in the same interview the students were asked a similar question with a particle entering an electric field at a velocity v – See Fig. 6.

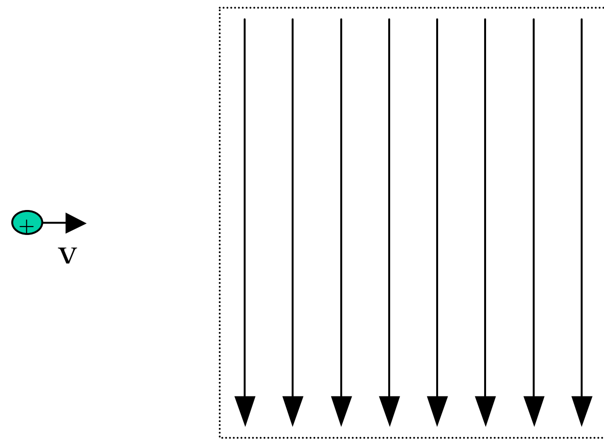

FIGURE 6. Electric Field Question – Charge Sphere with Initial Velocity

The students were asked to describe and draw what would happen. All three students who drew concave up arcs for the two charged spheres question, drew concave down arcs in response to the electric field question as shown in Fig. 7.

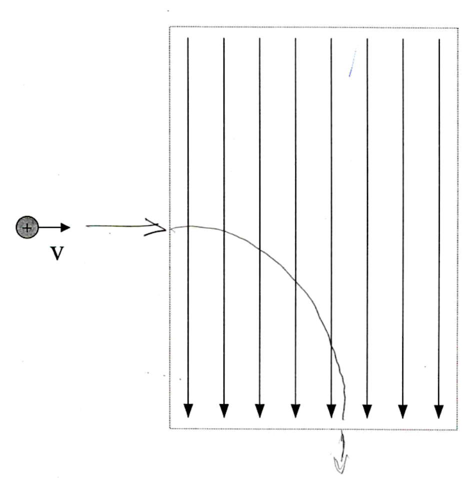

FIGURE 7. Electric Field Question – Charge Sphere with Initial Velocity

"Well it's going to look the same as, like you know, a projectile. Since it's accelerating in one direction and its velocity is in the other. Like when you throw something horizontally and it drops. So it'd pull one of these numbers right there [draws arc]" (Student 17 while drawing Fig. 7)

Student 17 was asked to compare the two responses shown in Fig. 4 and Fig. 7. The question posed was whether the arcs should be the same.

> "Yeah…this is a really good question. Yes. Yes they should. I have no idea why it's drawn that way. [Interviewer: Really. Ok.] Huh. Cause it would seem like the force is going this way in both things. Accelerates. But this one [Fig. 4 – charge at v] acclerates it's DEcelerating as it goes this way. …So maybe it should be that way. Cause in that one [Fig. 7 - charge at v entering E-Field] it's ACCelerating as it goes that way should …should….should be …sure…I'm going to say yes they should be that way. Because this one [Fig. 4 - charge at v] is DEcelerating and this one [Fig. 7 - charge at v entering E-field] is ACCelerating in this direction. Hence it would go [gestures along the arc in Fig. 4 - charge at v] instead of going [gestures a different arc shape] you know…" [Student 17, with student's emphasis included as capitalization]

To summarize, the student stated the two paths should be dissimilar because one is accelerated by a constant field and the other is decelerating as it moves away. This student is associating the $1/r^2$ nature of the force with a sphere's deceleration and according to the student, while in the E-field the sphere continues to accelerate. This is clearly an Aristotelian misconception triggered by the diminishing nature of the force

CONCLUDING DISCUSSION

Evidence has been presented to suggest a contextual dependence of the use of a misconception concerning motion of an object when acted upon by a force which changes with distance. This evidence was collected while pursuing a different research goal which limits its thoroughness and amount. It is also important to note that forces of the $1/r^2$ form were first introduced in the course in addressing electrical charges. Gravitation was not covered although some students admitted to having learned it in high school

Despite these caveats, I believe the evidence suggests a contextual dependence or triggering of the use of an Aristotelian misconception when regarding diminishing forces that is possibly shared by many of the students I interviewed. These students were above average and quite possibly over thought the problem to the point of neglecting parameters they know to be true – like the continuity of the trajectory. This path to using misconceptions is likely triggered by some contextual feature, as in this case with diminishing forces.

FUTURE RESEARCH

As mentioned previously, this was a discovery made on the way to answering a different research question. The student interviews were not structured to investigate this particular situation and as such, useful follow-on questions were not pursued at the time. A future research investigation should be more thorough and include forces that diminish over time as well as distance and include as many differing physical contexts as possible. This would tease out the particulars of the issue and possibly help to discover what triggers the Aristotelian concept in students who otherwise have shown they understand Newtonian concepts.

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