“Seeing is believing”: Visual perceptions and the learning of kinematics

Miriam Lemmer

School of Physical and Chemical Sciences, North-West University, Potchefstroom, South Africa

miriam.lemmer@nwu.ac.za

Abstract. The proverb “seeing is believing” is generally applied in science education today. Many of the contemporary teaching strategies engage the learners in activities that guide them in making their own observations. Still, problems regarding the learning of physics, especially the prevalence of alternative conceptions, remain a headache in physics education research. The study reported here investigated learners’ visual perceptions as possible cause for the existence, persistence and transfer of the intuitive conception in kinematics that DiSessa (1993) called changes-take-time. An example of this conception is the assertion that a cannon ball keeps on accelerating after the shell has been launched. A focus group discussion and questionnaire were used in the investigation. Grade 9 and 10 physical science learners participated in the study. The results showed that limitations in visual perceptions (such as differences in real and perceived velocities and changes in velocities) seem to contribute to their intuitive concepts.

1. Motivation and problem statement

Our senses are the only means to obtain information about the world around us. Every second a multitude of stimuli reaches the sensory register of the brain. According to the information processing model [1], selective perception takes place in the sensory register and only the selected stimuli are transformed to neural information. In the working memory the new information is combined with existing knowledge that has been extracted from the long-term memory. If the information is found to be useful and also consolidated through repeated use, stable knowledge structures are formed in the long-term memory.

Learning of concepts consequently depends on the new information that is attended to, as well as the existing knowledge that is cued. While physics education research paid much attention to existing knowledge (especially misconceptions), perceptions formed from new information has not often been studied. In chemistry education visual perception is of utmost importance due to the problem that macroscopic observations are explained in terms of microscopic entities [2]. For example, a table does not look or feel as consisting out of very small vibrating particles with spaces in between. Visual perceptions can also account for the finding that learners often attribute macroscopic properties to microscopic particles, e.g. they think that the particles of solids are hard while liquid particles are soft and fluid.

This study focused on the role of visual perceptions in the learning of kinematics. In the teaching of kinematics at school and first year university level, the motion of well-known everyday life objects such as balls and cars is often used in examples and problems. As long as the mass of an object is perceived to be concentrated in the centre of mass, the basic concepts and laws can be applied. Still, misconceptions regarding force and motion are amongst the most reported ones [3]. These misconceptions seem to be independent of culture [4] and are very resistant to change [5], even with contemporary teaching strategies. One of the misconceptions found in kinematics is the so-called changes-take-time perception [6]. Accordingly, learners assume that an object maintains its acceleration or velocity after it has been launched. This perception seems to be related to the well-known misconception force-as-mover according to which learners always attribute a force in the direction of motion. Another well-documented problem in the learning of kinematics is that learners tend to confuse related concepts such as position, velocity and acceleration [7]. Since learners daily observe the motion of rolling balls, projectiles, etc. the question arises as to whether their visual perceptions can cause the formation of these misconceptions and oppose their understanding of the scientific interpretation of motion. The following research questions were investigated:

(1) What reasons do learners give for having the changes-take-time perception?
(2) What role does visual perception play in the formation of this perception?
(3) What are consequences for the teaching and learning of physics?

2. Theoretical framework

A variety of causes may be ascribed to the occurrence of alternative conceptions, e.g. that textbooks contain them [8], teachers themselves hold them [9] or do not attend to learners' intuitive ideas. Learners may also focus on contextual features of an event and do not observe what educators intend them to [3]. For example, when a force is applied to an object, the learners may attend to features of the person performing the action (e.g. a strong male exerts a large force) while, for the scientist, the actor is of no importance since the force is related to the acceleration of the object's motion. Furthermore, in kinematics scientists differentiate between constant velocity and accelerated motion, while everyday observations is usually just concerned with whether the object moves or stands still.

Apart from the effect of selective perception on the formation of conceptions, limitations of our sensual perceptions can also influence what new information reaches the working memory. For example, we cannot see very small particles such as atoms or molecules with an unaided eye. There are also limitations to the sounds that the human ear can detect (namely between 20 Hz and 20 kHz). Furthermore, two sounds in the hearing range cannot be distinguished when their frequencies are too near [10]. In his standard work on visual perception, Brown [11] reported factors that cause differences in perceived (phenomenal) and real velocities of objects, which include:

1. Perceived velocity decreases with increase in distance from the observer.
2. Increase in the size of the moving object decreases the perceived velocity.
3. The direction of the movement relative to the observer affects the perceived velocity, e.g. vertical movements are phenomenally faster than horizontal movements, while movements diagonally between horizontal and vertical fall phenomenally between these two.
4. Movements observed while fixating a stationary point are phenomenally faster then when the eye follows the moving object.

3. Research design

A qualitative and a quantitative research strategy were combined in the investigation. In a focus group discussion with five Grade 9 learners of a local school, it was qualitatively determined whether they hold the changes-take-time perception or not, and what reasons they give for or against it. This was followed by a questionnaire that quantitatively determined the occurrence of and reasons for the changes-take-time perception amongst 208 Grade 10 learners from 14 local schools.

4. Results and discussion of results

4.1. Focus group discussion

In the focus group discussion the learners' perceptions of the change in speed in different contexts were investigated. Three out of the five learners (A, B and C) showed the changes-take-time perception, while the other two learners (D and E) held more scientific ideas.

The interviewer (I) started by pushing and releasing a small ball to roll on a long table.

I: (demonstrates while talking): When I am pushing the ball, how does its speed change?
A & B (together): It accelerates
I: And after I've removed my hand?
E: It slows down
D: And then stops

B: No, it will keep on accelerating

D: Ma'am … (laughs) … You pushed it. Then it's on its own and moving and then slows down because you're not pushing it anymore.

The learners were then asked to roll balls on the floor and observe the changes in speed.

I to learners A, B & C: Do you still have the idea that it goes faster after release?

A: Yes

B: No, it's constant

A: Yes, it stays constant … until it stops.

I: Why do you think will it stay constant?

A: I think that the surface that we use right now is flat, so there's nothing interrupting it. It just goes.

I: Why does it stop later?

B: (Thinking) … Ma'am …

(The three learners discuss the problem with each other but cannot provide any answer.)

The flat surface of the floor was used as explanation for the constant velocity motion of the ball, but it could not account for the observation that the ball eventually stops. Still, learners A, B and C did not alter their intuitive perception. They were also not sure whether the ball accelerates or moves with constant velocity. The changes-take-time perception as well as confusion of the concepts acceleration and velocity may thus be due to limitations in visual perceptions. From own experiences one cannot clearly see if and how the velocity of a moving object changes after it has been accelerated by some force. For example, a deceleration of -2 $m.s^{-2}$ cannot be observed if the velocity decreases in 1 s from 24 to 22 $m.s^{-1}$, but it can be clearly detected when the velocity decreases from 4 $m.s^{-1}$ to 2 $m.s^{-1}$ in 1 s, i.e. with the same deceleration at a lower velocity.

The learners treated vertical motion differently from horizontal motion. This is in agreement with the finding of Brown [11] that the direction of movement relative to the observer affects the perceived velocity. Learner A differentiated between the up- and downwards motions of a ball that was thrown vertically upwards:

A: In think that when you throw the ball up, say it goes with 50 km/h, then when it comes down, it may be 70 km/h, because gravity is pulling it down and gravity is going to be a larger force than for throwing it up.

For the first time in the discussion, a learner referred to a "force for throwing it up" which may indicate the force-as-mover perception. Later on learners B and C also reasoned than something inside the ball is pushing it:

C: There cannot be only gravity. There must be something inside the ball.

I: What is inside the ball?

C: Potential energy

B: Air – there is air inside this ball. It is pushing the ball. A force is something that pushes – It's a push or a pull.

The learners with the changes-take-time perception easily adapted the force-as-mover conception when they needed it. Learner B cued existing physics knowledge to validate this conception. Later in the discussion learners D and E combined the idea of an inside force with the retarding force to explain why an object slows down after it has been released. This result is in accord with the finding of Hammer [12] that learners initially reasoned phenomenologically, e.g. "moving objects slow down and stop". Only when asked to explain the motion, the learners begin to look for causes and activate a force-as-mover conception.

After discussions regarding a ball rolling along the table and in free-fall, the motion of a ball on a ramp that was inclined upwards, downwards and horizontal was used to further probe the learners' reasoning. Upon the question of the interviewer of why the ball rolls down the ramp, learner E immediate said "the slope" and learner D added "the steepness of the slope." The other learners agreed and no one referred to the force of gravity. For the ball rolling on a horizontal ramp the learners maintained their ideas of the previous discussions. The changes-take-time learners added a new explanation for their assertion that the ball will move with a constant speed on the ramp, which was expressed by learner A as follows:

A: The ball doesn't stop on the ramp; therefore it will be constant all the way. If it rolls from here to there (shows to the other side of the classroom), it is going to stop. But if you give us

10 cm (shows a distance of about 30 cm between her hands), it will move with the same speed.

Learners A and B agreed, but D and E reacted as follows:

D: But the speed of the ball in the beginning and end of the 10 cm won't be the same. At the end of the ramp it will be slower than at the beginning

I: Why do you say so?

D: Because it can't move on its own.

E: Something that goes uninterrupted until it stops shows that it was decreasing. It doesn't go constant and ...gup… it stops (moves her hand horizontally in the air and suddenly drops it). It goe-e-es (hand gradually slows down) and then it stops.

In this discussion both learners A and E referred to observations of the ball moving on the horizontal ramp. For learner A the speed of the ball is determined by whether you observe that it stops or not, while learner E referred to her observation that the ball's speed does not change suddenly. The different observations that they focused on therefore supported their perceptions. Learners with intuitive conceptions seem to use contextual features as explanations, while the more science-orientated learners tend to use logical reasoning.

Second questionnaire:

From the focus group discussion different reasons for the perception changes-take-time emerged, namely some "inside" force and situational features such as the "flatness" of the floor or the short length of the ramp. The learners who did not show the changes-take-time perception, argued against the idea that the external force causing the motion maintains it, but later in the discussion accepted an "inside" force. A short questionnaire was used to investigate which reasons occurred more frequently among a larger number of learners.

The questionnaire comprised of three questions and was answered by 208 Grade 10 learners from 14 schools in the district of the researcher. The first question was a multiple choice item on the change in speed of a ball after a hockey player hit it from rest. Then the learners had to choose reasons for their responses from a given list to which they were urged to add more reasons. They also had to indicate which of the chosen reasons they felt most sure about. In the third question they were asked to draw force vectors at four positions of a ball that rolls over a hockey field after it has been hit.

The result of item 1 of the questionnaire showed that the largest percentage of learners believed that the hockey ball either accelerates or moves at a constant velocity after it has been hit, i.e. they displayed the changes-take-time perception. The reasons for their responses (item 2) were categorized as in table 1 with examples of each category given in table 2.

Table 1. Results of item 2: Number and percentages of learners who gave certain reasons for their perceptions regarding the speed of a hockey ball after it has been hit.

Reasons for answers to item 1	Number	Percentage
Visual perception	132	25.3
Force-as-mover	135	25.9
Energy	188	36.1
Situational features	50	9.6
Opposing forces	16	3.1

Approximately 25 % of the reasons given by the learners were based on their visual perceptions and a similar percentage on the force-as-mover misconception. The largest percentage (36 %) was obtained for the idea of energy transfer. This can be understood in terms of the emphasis that is laid on the concepts of energy and change in the preceding years of study in the South African schools. About 10 % of answers referred to situational features such as the smoothness (or grassiness) of the field, while only 3 % of learners referred to forces that oppose the forward motion of the ball. Since the learners could chose as many of the reasons as they wanted, they were also asked which one they were most sure of. Their responses yielded very much the same percentages as the percentages for the different options in table 1. They were thus most sure about the transfer of energy, followed by the changes-take-time and force-as-mover intuitive conceptions.

Table 2. Examples of reasons given by learners.

Reason	Examples
Visual perception	I can see the different velocities of the ball I play hockey and knows how the ball moves after being hit You can see how hard the ball is hit.
Force-as-mover	The force of the hockey stick helps the ball's velocity to be constant The ball has been hit with a large force The force of the stick still acts on the ball after it has been hit
Energy	The hockey stick transferred energy to the ball The ball uses the energy transferred to it which is eventually used up and the ball stops Energy gets lost after a while and you cannot transfer any more energy.
Situational features	The ball moves away fast / rolls far The ball is in motion The surface is smooth / There is grass on the hockey field
Opposing force	It stops because of the wind Friction and/or gravity oppose the ball's force. When the ball touches the ground the speed decreases

In the third question of the questionnaire, the vast majority of learners (88%) included a force vector in the direction of motion. Only about 20 % of learners showed an opposing force which was in many cases only used towards the end of the motion. It is interesting to note that less than a quarter of the 88% of learners that used a force vector in the direction of motion indicated the force-as-mover misconception in their reasons in item 2. It seems that they did not initially connect the force-as-mover misconception to their perceptions of the change in speed of the ball, but that it was brought forward when they were prompted to draw the force vectors.

5. Conclusions

The results indicate that the proverb "seeing is believing" is relevant in the learning and teaching of kinematics. Visual perceptions seem to play a significant role in the formation of the changes-take-time intuitive perception. This perception is probably established by repeated observations of moving objects, attention to situational features and limitations in seeing changes in the speed of fast-moving objects. When unattended, syncretism with science concepts may occur and robust misconceptions such as the force-as-mover conception may be formed.

In the science classroom limitations in visual perceptions regarding the speed of moving objects can be compensated for by technology such as stroboscopic photos, ticker-timer experiments and computer simulations. By focusing learners' attention and providing repeated experiences in a variety of contexts the kinematics concepts can be formed and established.

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