EURASIA Journal of Mathematics, Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
OPEN ACCESS
2018 14(4):1407-1413
DOI: 10.29333/ejmste/83678

Incline Height and Object Weight: Examining the Fluidity of Children's Commonsense Theories of Motion

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Received 12 November 2017 ▪ Revised 30 December 2017 ▪ Accepted 31 December 2017

ABSTRACT

144 children aged 5 to 12 years made initial predictions about the speeds of a heavy and a light ball rolling down a slope. They were then asked to consider how changing the incline height would impact the initial predictions. The findings illustrate a shift from rigid differentiation to more flexible knowledge structures. While perceptions changed with increasing age from light-as-faster to heavy-as-faster, younger children were also less likely to believe that any other incline steepness could conceivably lead to a different outcome. Older children, on the other hand, showed a heightened awareness of how changing incline heights could allow for alternative motion patterns. The study adds to current understanding of conceptual development. It expands on the debate between knowledge-in-pieces and knowledge-as-theory, concluding within its constrained scope that development of scientific knowledge about object motion possibly occurs in a transition from pieces to theory. Consequentially, the paper also considers implications for early science education.

Keywords: commonsense theories of motion, conceptual development, conceptual change, science education

INTRODUCTION

When trying to interpret the physical world, mental modelling can assist in the reasoning process. Mental models act as prototypical representations of the world, often as a result of experiences with that world, and these representations allow the simulating of new events or of behaviours of new objects (Jonassen, 2003; Nersessian, 2008, 2013). But what do the knowledge structures in these mental models that enable the prediction of future events look like? The current literature, at large, offers two views on this matter. In diSessa's (2006, 2013) opinion, scientific knowledge exists in pieces. These are loosely connected to each other within unstructured conceptual networks. Relevant pieces and their connections are accessed depending on the reasoning demands of a particular task. The other key viewpoint considers that knowledge exists as theory (Vosniadou, 2007, 2013). Scientific conceptions exist within coherent belief structures underpinned by ontological and epistemological presuppositions.

Recent research has attempted to evaluate the representations of knowledge in the particular development of children's commonsense theories of motion (Hast, 2014; Hast & Howe, 2012, 2013a). There seems to be a fairly clear picture as far as horizontal and vertical motion are concerned, and that these two aspects are clearly differentiated in children's reasoning. Regardless of age, children were shown to consistently believe that heavy objects fall faster than lighter ones, but that the lighter ones would roll faster along a horizontal surface than the heavy ones. Concurrently, the same children would make varying predictions about the same objects rolling down slopes – younger children assumed the light one to be faster, and with increasing age the predictions shifted towards a heavy-faster conception. A key question, as a result, was whether this shift was because of a third theoretical structure or changes in how children integrated information across the horizontal and vertical knowledge fragments.

In relation to this question, diSessa (2006, 2013) has argued that knowledge fragments are an abstraction of individual experiences and predictions about events are, as a result, often seen as self-explanatory and only at best

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Contribution of this paper to the literature

- The study highlights the development of commonsense theories of motion throughout middle childhood, with specific interest in differentiation and integration of horizontal and vertical dimensions in the context of motion down inclines.
- The study makes claim that throughout middle childhood understanding of object motion down inclines develops from rigid differentiated understanding towards fluid integrated conception.
- The study argues against delineation between views of knowledge-in-pieces and knowledge-as-theory but instead – in the context of commonsense theories of motion – for a transition from the former to the latter.

systematic in merely a broader sense. In the context of motion this might be reflected in the common statement that heavy objects fall faster, or that light objects roll faster along horizontals – something that, on the surface of individual experiences, often seems to be true. On the other hand, Vosniadou's (2007, 2013) framework theory approach might argue that object motion is explained through more coherent and consistent knowledge structures. Such structures, in the present context, would, for instance, elicit a common conceptual understanding of force as being the property of an object rather than a process. This would mean that a statement cannot be reduced to a light object rolling faster because it is the interaction of various variables such as surface or object texture that determines outcomes.

As far as a scientifically accurate understanding of motion in the various dimensions is concerned, different variable constellations are necessary to appreciate. When falling, a ball's mass and its acceleration due to gravity have to be considered, as well as – sometimes negligible – resistance of the medium through which it is falling. The ball will fall until some form of support is obtained. When rolling along horizontals, friction also needs to be incorporated. Different from fall, motion occurs even though support exists and a ball can stop rolling even if no obstacle is in its path. Motion down slopes is an integration of both of these, and the height or angle of incline can determine how much each plays a role. A knowledge-in-pieces view on this might suggest a differentiated understanding of fall and horizontal based on the particular requirements, and might associate motion down slopes with either of the two. A framework theory, on the other hand, would be more likely to show some understanding – accurate or not – of the interplay of all three, since the underpinning laws relate.

Within the context of the theoretical discussion, some progress has been made. Hast (2016), for instance, concluded that children's understanding of curvilinear downward motion is likely to be guided by knowledge-as-pieces rather than knowledge-as-theory. However, the outcomes were not entirely conclusive and there was also acknowledgement of the possibility of an interaction of both pieces and theory (cf. Brown & Hammer, 2013). As a result, some progress has been provided, but not enough. There seemed to be indications that, within commonsense motion theory structures, representations of falling objects are distinct from representations of objects rolling along horizontals, and that both are taken into consideration when reasoning about objects rolling down inclines. Yet no clarity could be provided on how with increasing age the knowledge representations change in their structure, only in content. However, if knowledge in the context of commonsense theories of motion does exist in pieces, then over time a reinforcement of the connections between pieces may result in more systematic forms of reasoning (Wagner, 2010). Further to this, within the particular processes of fragmentation and integration of knowledge, the magnitudes of influence of individual pieces may change over time (Clark & Linn, 2013).

To attempt to examine this issue, the present study evaluated the particular role of incline height in the development of children's commonsense theories of motion. Previous work has already evaluated children's understanding of the impact that incline changes have on the distance objects travel after rolling down and leaving the slope (Ferretti, Butterfield, Cahn, & Kerkman, 1985; Inhelder & Piaget, 1958) or the impact of changes on object speed along the slope (Hast & Howe, 2013a; Howe, Tolmie, & Rodgers, 1992). The study adds to this by looking at how children's predictions of incline height changes link to knowledge-in-pieces or knowledge-as-theory. Specifically, it examines the rigidity and fluidity of children's expectations of heavy and light objects rolling down slopes.

METHOD

Participants

Participants were recruited from state primary schools located in the Greater London area. A total sample of 144 children (73 boys, 71 girls) aged 5 to 12 (*M* = 8.50 years) was selected. An equal number of children with similar average age and distributions took part in each of the conditions outlined below.

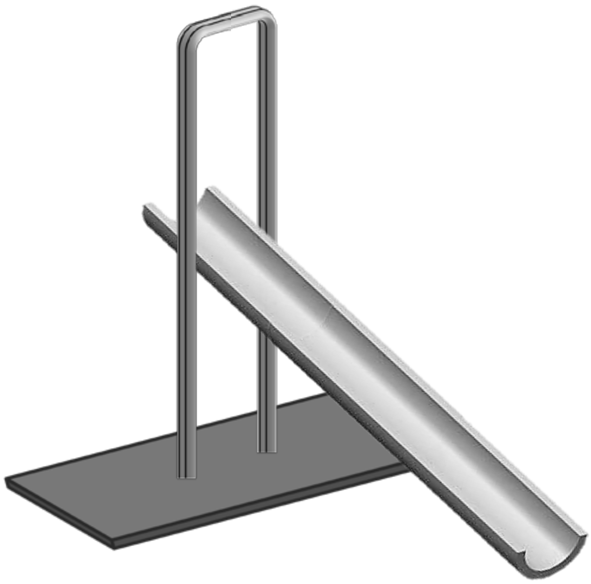

Figure 1. Diagram of apparatus setup

Design and Materials

A metal frame of 125 cm height was fixed to a wooden base of 70 cm length and 30 cm width. Attached to the metal frame was a plastic channel of 100 cm length, 5 cm height and 10.5 cm width (see **Figure 1**). The channel was attached in such a way that it could be moved along the metal frame to modify the height of its incline. The height ranged from practically horizontal at 5 cm height to practically vertical at 99 cm height. A white table tennis ball (4 cm diameter, 3 g) and a dark glass marble (4 cm diameter, 75 g) were used as test balls. In addition, a squash ball similar in size to the two test balls was used as a practice ball. To examine the particular findings presented in Hast and Howe's (2013a) research, the channel's starting height was set at 15 cm (Condition 1) or at 30 cm (Condition 2).

Procedure

The apparatus was set up in a quiet but open area in each of the participating schools. Children were worked with individually. After invitation to the area, each child was told by the researcher that they would be working on a science experiment. The child was first familiarised with the apparatus, including how the channel's height could be adjusted. The researcher then presented the practice ball and asked the child to explain what would happen if the ball were let go from the top of the channel. The practice ball was then released down the channel. If children had initially given an incorrect explanation or one that did not sufficiently explain the process, they were asked to explain again what would happen if the ball were let go.

The practice ball was then removed and the researcher presented the two test balls. Both balls were given to the child who was then asked to state whether one ball would be faster or whether they would be as fast as each other if released down the channel. If one ball was predicted to be faster than the other, the child was asked to give reasons for this. The child was then further asked whether the incline could be adjusted in such a way that the two balls would be as fast as each other. If this was deemed to be the case the child was asked to adjust the channel to that position. If the child had initially stated that the two balls would be as fast as each other, the child was asked whether there was a height when one of the balls would be faster than the other. If so, the child was invited to indicate this height as well as explain which of the two balls would then be faster and why. Incline heights were recorded by the researcher after completion of the task. The task took around 10 minutes.

Data Analysis

All children passed the control question about the practice ball so all data were included for analysis. Children were first given a score of 1 according to which prediction was made (heavy-faster, light-faster, or same speed). Children were then given a score of 1 or 0 according to whether they thought the incline height could be changed or not. Where they had been invited to adjust the incline, the new height was recorded in cm. Comparisons between

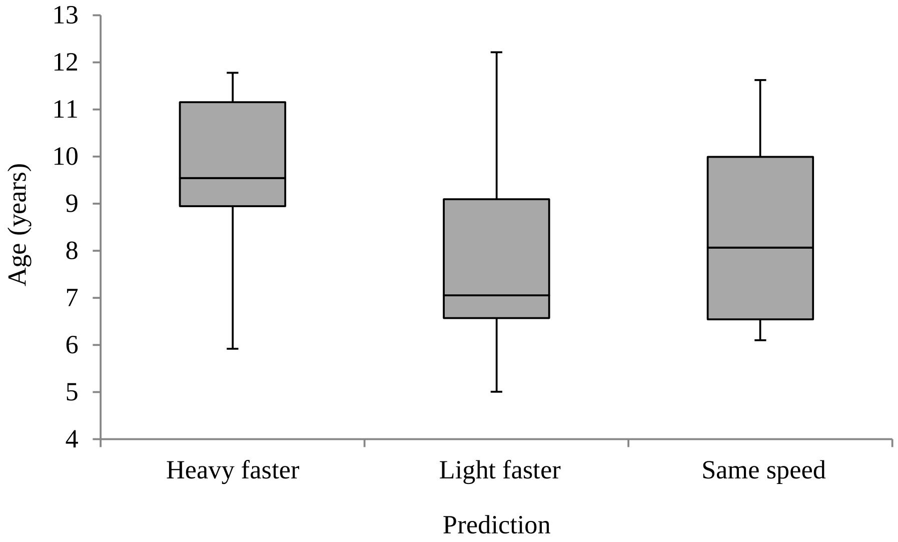

Figure 2. Box plots showing age distributions for predicted outcomes

gender and condition were also carried out but showed no significant differences and are therefore not discussed further. All data reported below were analysed using SPSS Statistics 21.

RESULTS

Children varied significantly in their predictions of whether the heavy ball or the light ball would be faster, or whether the two balls would have the same speed, $\chi^2(2, 144) = 68.67$, $p < 0.001$. Post-hoc pairwise comparisons showed that a significantly larger proportion of children predicted that the light ball would be faster in comparison to those who thought the heavy ball would be faster, $z = 3$, $p < 0.02$, $r = 0.24$, which in turn was predicted significantly more often than same speed, $z = 5$, $p < 0.001$, $r = 0.69$. No significant differences were noted between the two conditions, suggesting the initial incline height did not have any particular impact on children's reasoning. Looking at age related changes (see **Figure 2**), mean age varied significantly across prediction types, $H(2) = 30.83$, $p < 0.001$. Post-hoc pairwise comparisons showed that children who predicted the heavy ball to be faster ($M = 9.64$ years, $SD = 1.66$) were, on average, significantly older than those who predicted the light ball to be faster ($M = 7.74$ years, $SD = 1.67$), $z = 6$, $p < 0.001$, $r = 0.47$. This is comparable to the shift in predictions across age that noted in previous research, where younger children were more likely to associate lightness with faster motion down inclines but with increasing age were more likely to associate it with heaviness (e.g. Hast, 2014; Hast & Howe, 2013a, 2017).

Only four children thought that the two speeds would be the same from the beginning, and that the two balls' speeds would not diverge through any subsequent incline height changes. All remaining children ($N = 140$) assumed that speeds for the two balls would be different. Where this was the case, approximately equal numbers of children believed that the incline could ($N = 64$) and that it could not ($N = 76$) be adjusted so that the two balls would, at some point, have the same speed. However, these two groups differed according to which of the two balls had been predicted to be faster. Those children who had predicted that the light ball would be faster were significantly more likely than those who had predicted that the heavy ball would be faster to assume that the incline could be changed to achieve same speeds, $z = 5$, $p < 0.001$, $r = 0.67$. The two groups also differed in their mean age. Those children who predicted that same speed could be achieved were, on average, significantly younger ($M = 7.95$ years, $SD = 1.73$) than those who thought it was not possible ($M = 8.97$ years, $SD = 1.94$), $z = 3$, $p < 0.05$, $r = 0.27$. This suggests that, alongside the shift from light-as-faster to heavy-as-faster, with increasing age there is increasing stability in such predictions.

Where an incline change was deemed possible to achieve same speeds for the two balls, children's height adjustments showed no significant difference in average height between the two starting height conditions. However, there was a significant difference between the adjusted incline height for children who had initially predicted the light ball to be faster ($M = 61.3$ cm) and the height for those who had predicted the heavy ball to be faster ($M = 16.0$ cm), $z = 8$, $p < 0.001$, $r = 0.73$. For those children who had made an initial heavy-faster prediction, there was no significant correlation between age and height. On the other hand, for those children who had predicted the light ball to be faster, there was a strong significant negative correlation between the two variables, $r = -0.67$, $p < 0.001$, indicating that the height at which the two balls were considered to have the same speed decreased with increasing age (see **Figure 3**).

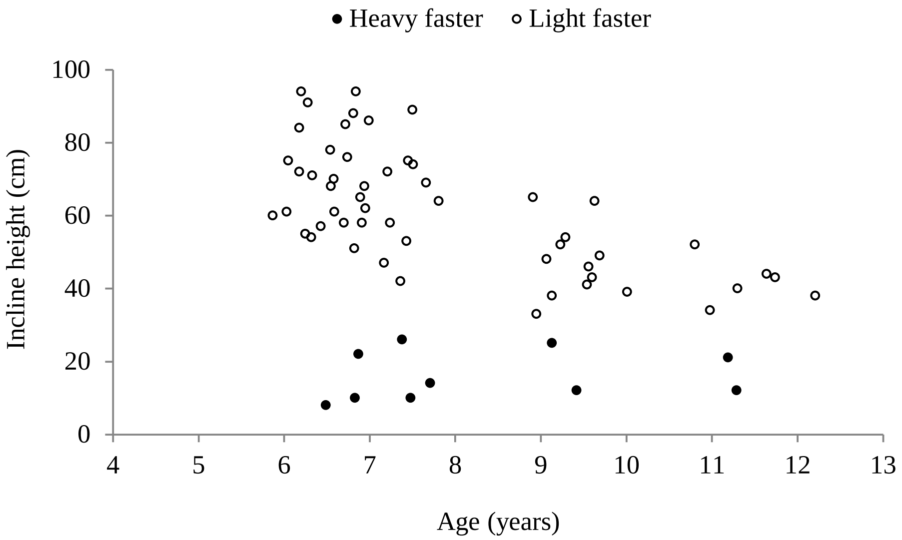

Figure 3. Distribution of adjusted incline heights by age and initial speed predictions

DISCUSSION

The present findings, in sum, indicate that in the context of processing information about object motion down inclines, children appear to develop from a rigid prediction style towards a more fluid understanding. For younger children, lightness seems to be of advantage as far as faster speed is concerned. With increasing age, heaviness is seen as more crucial in this regard. In the first instance, this is in agreement with other studies demonstrating the same shift in perceptions (Hast, 2014; Hast & Howe, 2013a, 2017). But not only does the vertical element of inclines seem to increasingly gain salience over the horizontal element, the predictions also appear to be increasingly embedded in more flexible knowledge structures. First, younger children were less likely to consider that different incline heights could lead to different outcomes. Older children, on the other hand appeared to see this as possible. And second, with increasing age the point of same speed came closer to a 45 degree angle; arguably the point where horizontality and verticality should be given equal consideration in evaluation motion down inclines.

Previous work has shown that even at younger ages, children appropriately understand how changing an incline's height can fundamentally impact a single object's speed (Ferretti et al., 1985; Hast & Howe, 2013a; Howe et al., 1992; Inhelder & Piaget, 1958), and even that objects rolling down slopes should generally accelerate as in fall, rather than decelerate as along horizontals (Hast & Howe, 2013b). So the issue arising in the present study does not appear to be with comprehending the concept of motion down slopes per se. However, the more complex interaction of height changes and of consideration of weight of two different objects seems to be more challenging. As a result, initial conceptions seem to follow a pattern of extremes. Either the light ball is seen as the faster one at all times regardless of incline steepness, or if a point of same speed is seen to exist then it is either at a very shallow or a very steep level, as seen in **Figure 3**. It is plausible that this is supportive of a lack of ability to systematically incorporate multiple variables, and that this competency only emerges at some point during middle childhood (cf. Baroody, Lai, Li, & Baroody, 2009; Hast, 2014; Howe, Nunes, & Bryant, 2010; Wilkening, 1981).

The insight afforded by the present research can also be considered in the wider context of scientific theory formation. To take sides between the two main perspectives of knowledge in pieces (diSessa, 2006, 2013) and knowledge as theory (Vosniadou, 2007, 2013) is a formidable task based on such a small study. However, both are seen as possible explanations here. The outcomes evident in the younger children seem to lean towards diSessa's interpretations of conceptualisation. Knowledge about motion down slopes is not fully consolidated within a broader theoretical construct and so children are instead drawing on fragmented knowledge where horizontality as the visible element plays a more salient role (cf. Mou, Zhu, & Chen, 2015). As a result, perceptions of light-as-faster are more prevalent and persistent, as might be expected from their predictions about motion along horizontals (Hast, 2014; Hast & Howe, 2012, 2013a; Inhelder & Piaget, 1958). On the other hand, older children's predictions show a more intricate consideration of different pieces of information, quite possibly within more complex theoretical structures akin to Vosniadou's interpretation. In fact, it appears to correspond with the notion of theoretical coherence as result of hybridisation from two different meanings (cf. Ioannides & Vosinadou, 2002). Taken as a whole, then, fragmented ideas are interlinked and coordinated within larger configurations of knowledge and the reinforcement of these connections over time results in more systematic forms of reasoning (Wagner, 2010).

What, then, does this mean for science education in practice? The findings strengthen previous calls to organise science curricula in such a way that children first learn the differentiation between horizontal and vertical motion, and then the integration of these two dimensions in understanding slopes (Hast, 2016; Hast & Howe, 2012, 2013a). The second step would also provide opportunities to reinforce previously learnt materials about object motion in the individual dimensions by returning to them and then evaluating not their distinction but how they can also interact; an approach much akin to Bruner's (1960) spiral curriculum. Importantly, these need to occur at age levels where children begin to show scientifically inadequate conceptions but are still open to conceptual change of the individual knowledge pieces before fuller theoretical constructs emerge. The present study cannot provide sufficient rationale for such organisation but indicates that throughout the primary school age range, the individual dimensions should be considered at the earlier end and the interaction at a later point in time.

This study only provides a small window into the topic, particularly constrained by its quantitative approach. As it does not include qualitative data the scope of insight is limited, particularly on the subjective interpretation of motion events as well as the extent to which knowledge is present. In particular, there may be variables beyond object weight that play a role in the outcomes – although weight is a predominant variable in children's judgement (cf. Hast & Howe, 2012) and other variables such as size and shape were kept the same between the two balls, because questioning did not include any detailed discussions into why predictions were made the way they were. Despite being able to deduce these from other studies (e.g. Hast & Howe, 2013a), further research would nonetheless do well to examine the qualitative nature of children's scientific reasoning. Similarly, the study limits itself to only two weights. A wider range of weights and perhaps also combinations with other variables, such as small but heavy or large but light, would also provide a fuller picture around the development of commonsense theories of motion throughout childhood.

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