RE-ORDERING KINEMATICS THROUGH SIMPLE COMPUTER-MEDIATED TOOL

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1 STARTING IN A DIFFERENT PLACE

Here I attempt to re-think the order in which kinematics, and so by implication dynamics, can be taught. Considerations include the representation of the subject, both respecting and focussing on the fundamental relationships in a way that emphasises their importance; the ways in which children think; and the researched difficulties in teaching and learning this topic. However the main enabler of change is the application of new technologies to the didactical process. I make the case that the flow of ideas can be smoother, more memorable, and more straightforward if we start with acceleration and end with displacement, rather than the more normal route of starting with calculations of speed as distance / time. There are two issues here - the calculations of the magnitudes: often done in introductory studies and implied by the second statement, and the full vector treatment, implied by the first statement. Since accelerations can be either positive or negative, and both are important, here I will develop a treatment that is consistent with a full vector treatment, although restricting the analyses to one dimension only. This presupposes that the idea of a vector, at least a displacement vector is not so hard for young children, but its expression in terms of Cartesian co-ordinates is less than natural and causes some difficulties, which may be circumvented in the early stages of learning about acceleration by a cunning choice of axis and restricting analyses to one dimension. This reduces the difficulties to dealing with acceleration as a two-way measure, that can be either negative or positive.

2 ACHIEVING A GOOD UNDERSTANDING

To achieve a good understanding of an idea one needs to know what it is capable of: how it can be used; and how it is related to other ideas with which one is familiar. This is a far cry from knowing an idea primarily through the medium of a definition, which is perhaps the most salient facet of acceleration as it is currently met by students of physics. Many students can repeat the declarative definition and have an operational understanding, without having a conceptually secure grip on the idea. Physics education research has shown that this is not unique to acceleration.

The current sequence in kinematics runs like this

$$\Delta x/\Delta t = v;\ \Delta v/\Delta t = a\ .$$

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And, at least in the UK, once cloaked in dynamics the patterns become more disjointed as, one has:

F; m; $\Delta x/\Delta t = v$; $\Delta v/\Delta t = a$: $F = ma$.

In kinematics acceleration is the apogee, or nadir, presented as being furthest from the “ simple”, “fundamental” measurements of position and time. Yet this is far from the everyday experience that children bring to the classroom, for our evolutionary history has equipped us with a set of accelerometers; providing near continuous stimuli. So children have a long-standing experience of acceleration: a useful implicit knowledge; a visceral grasp of the idea that can be built on. This experience introduces acceleration to us as continuously varying quantity which affects other quantities in predictable ways.. If a child experiences an acceleration then it is certain that their motion will change. Acceleration simply tells velocity how to change. This deceptively simple relationship, built into an intelligible and fruitful formalism is at the heart of the possibility of the approach suggested here. It is of course just the inverse of the more conventional definition that acceleration is the rate of change of velocity. The core of the argument in this paper is that the first formulation is a much better basis for building on children’s prior knowledge and everyday experience and so offers a more productive and accessible route into the subject area.

Both difference and differential equations express important and deep connections between acceleration and velocity. Differential and difference equations may seem rather closely connected, yet I suspect that their intelligibility is rather different for those meeting the ideas for the first time. One is about accumulation, the other about finding gradients. This is just the difference between the processes of integration and differentiation. In one the role of time is explicit, in the other it tends to fade towards the implicit, although appearing explicitly in the relationships.

Here are the relationships.

$\Delta v/\Delta t = a$, later to be become $\mathrm{d}a/\mathrm{d}t = v$

and

$\Delta v = a \times \Delta t$.

These are, of course, neat formalisms, idiomatic in interpretation to those who have worked with them for a while. It is however a salutary lesson to try and turn these back into words that explain the series of actions that one is carrying out, represented so neatly and succinctly by the mathematics. It is here that time, ticking remorselessly forward, fades into the background for the difference equation, whilst remaining explicit in the calculations of gradients.

3 REPRESENTING TO ONESELF

The possibility of re-describing what one is doing: of representing to oneself what is done is an important step on the road to full fluency, and may be the core of a tenable general theory of learning. So an evocative means of depicting and describing are pedagogically important. Making a wise choice about how to represent acceleration seems very likely to affect how accessible the idea appears to children, and the effectiveness of their use of the idea. The key location of acceleration, as the link between kinematics and dynamics, makes the effort worthwhile.

To a great extent the difficulties in learning about acceleration are to do with its role in changing velocity: it is a quantity that has essential relationships with another as a rate (Although not with all - it has a "follows" relationship with force for example: acceleration is proportional to force). Thinking with rates is known to be hard.

4 EXPRESSIVE TOOLS

So besides looking for a means of measuring it continuously, one ought to think of exploiting expressive tools that are designed to work with rate relationships as well as proportional relationships. A real part of an understanding of acceleration is appreciating that it tells velocity how to change, or, more precisely, how to accumulate. This idea of accumulation is central to an understanding based on difference equations: as time ticks on in the background, so one quantity is incremented or decremented by a fixed or variable amount each second. This relies on addition, accumulating a total by adding to what is there already. Mathematically this is arguably one of the simplest steps possible, so a sound basis for constructing an understanding. This line of thought has a further advantage, for younger users, in that it is possible to interpret the relationship as an action: that is the child can act out the relationship, so understanding how one quantity is acting on another. To make the principal links for acceleration, one needs only two kinds of links: one where the enactive command is "follow-me", the second where the command is now "grow-like-me". One is an accumulation, the first a statement of proportionality. With these one can capture the two primary relationships for acceleration:

$F \rightarrow a$: F "tells" a what to be. A follow-me (as in mimics) relationship. The value of F dictates the values of a from moment to moment. they have no shared history, only a current constraint.

$a \rightarrow v$: a tells v how to change. A grow-like-me relationship. The value of a tells v how to accumulate. A shared history determines the value of v.

These arrows are of course, not the best representations of such relationships. One tool designed to support thinking about variables and relationships is VnR. This was developed with children aged 11-4 years old in mind, so one might expect clean expressions here. The whole of kinematics looks almost too simple.

But it really is that simple: acceleration tells velocity how to change and velocity tells displacement how to change. Nothing is hidden: save the implicit clock ticking away in the background.

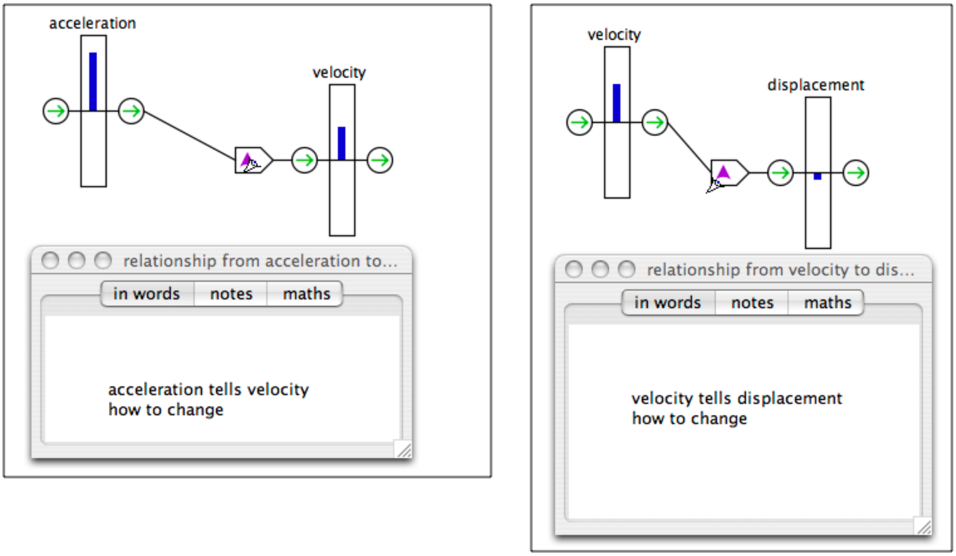

Figure 1 Kinematics summarised in VnR.

5 TOOLS FOR ACCUMULATION

In thinking of doing this kind of simple accumulation with a spreadsheet like tool, there is a subtlety that is missing from the standard array of regularly arranged boxes. One want to show the value of a quantity at particular times and then the increment between that snapshot and the next. That is the increments come between the snapshots. Such a line of thinking is much easier to follow if one has an offset grid. This kind of numerical accumulator could be used in addition to VnR to present very concrete examples of accumulation, for both constant and varying accumulation. The gain in each increment is, of course, just the acceleration.

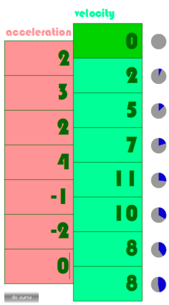

Figure 2 Using a numerical tool to explore accumulation.

Since the value to be added can be represented in a number of ways one could use a bar or arrow to represent the number, so introducing the increments and resultant changes as vectors.

This small set of tools could be elaborated on, but I think that are enough here, when combined with the possibility of making direct measurements of acceleration as a continuous quantity, to support appropriate explorations in a classroom.

6 A TEACHING APPROACH

Start with an large acceleration gauge on a computer screen, connected to an accelerometer in the hand of a willing volunteer. Work might be complemented with rather simpler accelerometers - of tethered corks floating in viscous fluids, non-zero values of the acceleration again indicating how the the motion is to change. Force and mass determine acceleration. So the schema has a causal chain from force, though acceleration to velocity. But of course it does not stop there; velocity tells displacement how to change, just as acceleration did for velocity. For a given velocity, the displacement just grows and grows and grows. The schema can then be represented dynamically in a modelling package, which uses the "grow like me" and "follow me" relationships to connect variables. This gives a particularly clean modifiable and theoretically tractable representation of the connections between these quantities.

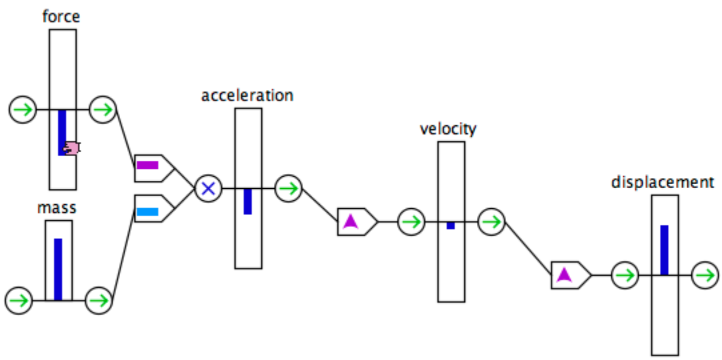

Figure 3 Dynamics and kinematics in VnR.

The central place of acceleration, as linking forces and masses with changes in velocity is here evident, emphasising Newton's central insight, that force caused a change in velocity, rather than a velocity, as the consensus prior to his work held. As this is a central difficulty in the teaching of mechanics, a clear and frequently represented connection of these kinds keeps the issue to the fore and encourages discussion and reflection on the meaning of the terms. It seems likely that this teaching arrangement, depending on carefully chosen representations, can strengthen and and complement the other strategies for promoting the desired conceptual change.

As the idea of acceleration is developed one is likely to deal with only a small range of situations: constant acceleration; acceleration depending on velocity; acceleration depending on position.

A firm conceptual grasp of acceleration as set by forces and masses, and as that which changes velocity makes the understanding of these more complex situations relatively straightforward to develop, because one has the central pattern of reasoning well represented.

7 LOOKING FORWARDS TO EXPRESSING THINKING

I have tried to do this by making acceleration feel like a measure that is directly accessible, so traversing the links from force to acceleration to velocity to displacement, rather than taking any other route.

A telling comparison might be made with another physical quantity, temperature. This is something of which we have direct experience, being able to give an ordering of temperatures based on experience unmediated by measuring instruments, and therefore treat the physical temperature as a semi-quantitative variable. The introduction of a measuring instrument (whatever kind of thermometer we use) allows the community to agree on an inter-subjective scale, so rendering the variable fully quantitative. Yet, in spite of the increased ability to manipulate the idea children do not gain a real understanding of temperature until very much later on; and in many cases not at all, if they decide not to take their studies of physics to a rather high level. Thus temperature has been used as a primitive, or basic building block, in much the same way as I propose to use acceleration. It might just make the route into Newtonian mechanics more accessible.

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