Teach to learn

In his article ‘Having faith in sound knowledge’ [1], Keith Taber raises the issue of one of the difficulties that we face regularly in teaching. It is the question of how much detail to teach—what depth we should go to. The problem is, of course, that we wish to encourage the student to ask probing questions, to find out more, to further their understanding, but in indulging those pupils we always run the risk of losing others. We have to manage this process in such a way as to help all pupils to further their understanding.

I certainly agree with the aphorism that you only really learn something when you teach it to others, although that statement makes it appear to be an endpoint rather than part of a journey. But this is part of the point. Learning is a continual process. We learn from our interactions and discussions with others, especially when we are trying to teach, to explain our thoughts to others. This applies as much to pupils as it does to teachers. Therefore we need to make the most of it. Models are valuable for helping us to understand the physical world. But their power in learning is paradoxically partly in their limitations.

There are problems with every model. Personally, I have a difficulty with picturing curvature of space, the propagation of light and how on Earth gravity works. I too share Taber’s concern about gas behaving elastically. But this is its power. We need to teach pupils to question models. Classroom discussions can raise all manner of problems with models, but also suggest ways in which the model can throw light on physical phenomena.

The point is that a model is just that—a representation of the world, not the world itself. It is the map, not the territory. Pupils need to be reminded that models help us to visualize a process, they bring complicated ideas within our sensual framework, but their limitations should be debated. As practitioners in the classroom, a vital role we play is to tackle this head-on, to encourage this debate.

Pupils must challenge the model, identify the problems that they have with it. Explaining these ideas to the others in the class is the teaching part. In my experience this usually leads to another member of the class putting forward their view. Challenging the model, explaining to others, listening to others, re-evaluating. It is the same process in principle that we go through internally as teachers when, through experience, we adapt and improve our explanations.

Science depends on evidence, it needs to be backed up with reasoned argument. Even where there are holes in the model and we have trouble picturing what is going on, faith has no role to play. The model may not be perfect. If it were, then it wouldn’t provide the simplification required of a model, but it is still backed by a large body of evidence. Our challenge, as teachers, is to present that reasoned argument and to encourage questioning of that argument.

References

[1] Taber K S 2009 Having faith in sound knowledge Phys. Educ. 44 450

Daryl Phillips Welshpool High School, UK

Roll or slide?

In an otherwise very interesting article by S Straulino [1] I noticed a quotation from an English translation of Galileo Galilei’s Dialogues Concerning Two New Sciences, containing the description of his famous experiment with an incline [2]. I read, for example, that ‘we rolled along it a hard, smooth and very round bronze ball etc’. The verb ‘roll’ is used several times in this extensive quotation describing the behaviour of the ball descending along the incline. Thus an inexperienced reader may get the impression that in the original experiment, the ball rotated around its instantaneous axis while descending along the incline. If so, then why did Galileo cover the incline with ‘parchment also as smooth and polished as possible’? Every historian knows that the parchment on which old books were written by hand is slippery.

The same excerpt from the same book translated into Russian states that ‘we forced the ball to slide along the channel’. There is an Italian proverb: ‘traduttore, traditore’ meaning ‘a translator is a traitor’. So I had my suspicions regarding the original text.

A web search readily provided me with the original quote in Italian [3]. To my satisfaction, I found that in this excerpt Galileo five times used the Italian verb scendere meaning ‘to come down’ or ‘to descend’ and nowhere did he
use the verb *rotolare* meaning ‘to roll’. Moreover, the original description of the behaviour of the ball moving down the full length of the incline—‘il tempo che consumava nello scorrerlo tutto’—has the direct English translation ‘the time that it consumed in sliding it all’.

To my sorrow, Straulino (much like the translator of [2] and numerous sources in English) described his own reconstruction in terms of ‘rolling’. And he was right because in his reconstruction experiment the ball was actually rotating during its descent along the incline, consuming more time to come down, whereas the sliding motion might dominate in the original experiment performed by Galileo, consuming less time in comparison with the former. Thus the reconstruction in question seems to be incomplete because the path of the ball down the incline was not slippery. Today we perform these experiments in lecture rooms with an incline equipped with an air track and they raise none of these questions.

This incomplete reconstruction presents a nice experiment in itself and can be used for establishing the acceleration of the free fall quantitatively. One only needs to add to the known tilt value those for the width of the groove and the radius of the ball (not given in [1]).

Let us consider a ball of radius \( r \) rolling along a groove of width \( d \) in the incline tilted at an angle \( \alpha \) to the horizontal plane. From the equation of motion for the ball’s angular momentum under the action of the torque due to the force of gravity (e.g., eq. 11.13 in [4]) one may find for the linear acceleration \( a \) of the ball’s centre of mass the formula in figure 1.

The acceleration manifestly depends on the ratio of the groove width to the ball radius. The dimensionless factor \( f \) varies between unity for wide grooves \( (d \gg r) \) and 5/7 for narrow grooves \( (d << r) \). From the slope of the line in figure 7 of [1] it is easy to infer the linear acceleration of the ball \( a \) and then to apply the above formula to find the acceleration of the freefall \( g \).

**Figure 1.** A = \( g \sin \alpha \left( \frac{d}{r} \right) \), \[ f \left( \frac{d}{r} \right) = 5 \frac{1 - \left( \frac{d}{r} \right)^2}{7 - 5 \left( \frac{d}{r} \right)^2} \]

**References**

[1] Straulino S 2008 Reconstruction of Galileo Galilei’s experiment: the inclined plane Phys. Educ. 43 316

[2] Galileo G 1914 *Dialogues Concerning Two New Sciences* (translated from Italian into English by Henry Crew and Alfonso de Salvio) (New York: Macmillan)

[3] [www.liberliber.it/biblioteca/g/galilei/discorsi_e_dimostrazioni_matematiche_intorno_a_due_nuove/etc/html/index.html](http://www.liberliber.it/biblioteca/g/galilei/discorsi_e_dimostrazioni_matematiche_intorno_a_due_nuove/etc/html/index.html)

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**Vladimir D Yegorenkov**

Kharkiv Karazin National University,

Ukraine

*Reply to the above letter by the author of ‘Reconstruction of Galileo Galilei’s experiment: the inclined plane’* [1]

Vladimir D Yegorenkov states that in Galileo’s experiment on the inclined plane the ball was not rolling but sliding on the guide. He bases his consideration on some details in the original passage in Galileo’s book *Dialogues Concerning Two New Sciences* and reads the English translation by Crew and de Salvo [2] in the light of the original text written in Italian, first published in 1638.

First of all it has to be considered that modern Italian is different from the language of the 17th century and the usage of some words may have changed. It is true that in the well known excerpt in which the inclined plane is depicted Galileo never used the verb *rotolare* (to roll), but repeatedly *scendere* (to descend) and once *scorrere* to describe the motion of the ball. According to Yegorenkov these verbs represent a first indication that the ball was sliding on the guide. In particular he finds confirmation of his theory in this sentence:

‘Si lasciava (come dico) scendere per il detto canale la palla, notando, nel modo che appresso dirò, il tempo che consumava nello scorrerlo tutto.’

‘We rolled the ball, as I was just saying, along the channel, noting, in a manner presently to be described, the time required to make the descent.’

In the original text ‘make the descent’ corresponds to *scorrere* and the most frequent meaning of this word is ‘to slide’. For Yegorenkov this is proof of the
translational motion of the ball. I do not agree with that because *scorrere* can be also used in a different way. Another sentence from Galileo’s original text can be given as a counter-example.

The point of the matter can be explained with reference to figure 2. When the big circle rotates to the right, it moves along the line $BF$, whose length corresponds to its circumference. In the meantime, the centre moves on the segment $AD$ and the small circle on $CE$. Because the distance $CE$ is equal to $BF$, a question arises:

‘...tiratolo drittissimo, e, per averlo ben pulito e liscio, incollatovi dentro una carta pecora zannata e lustrata al possibile...' ‘...having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible...' Actually, such devices were not intended, in my opinion, to reduce the friction so as to obtain a translation of the ball instead of a rolling, but to make the movement regular and straight, as required to obtain good measurements. We experienced that even a tiny roughness of the groove made the ball skip. Moreover, it is reasonable that Galileo would have expressly mentioned such unnatural motion of the ball (sliding without rolling) if he was able to obtain it. Finally, it is not of minor importance that all the Galilean tradition agrees on the study of the accelerated motion of balls rolling on inclined planes.

Yegorenkov also wonders in his letter why we did not give an estimation of the acceleration of gravity, $g$, which is directly obtainable from our results, provided one knows the radius of the ball and the width of the groove. There are several reasons for this choice.

First, this is not a measurement inspired by Galileo’s work and students may be confused about the historical development of the subject. Second, this procedure is somewhat difficult for secondary school students because the moment of inertia is usually taught a long time after the study of uniformly accelerated motion. Finally, the results of this method have poor precision because many parameters are involved. For instance, the measurement of the slope of the inclined plane is not as simple as one might expect (the precision of $g$ is not better than 10% with our instrument). As an alternative, the measurement of $g$ using a long (2–3 m) simple pendulum is straightforward for students and gives very good results (the precision can be about 0.5%).

References
[1] Straulino S 2008 Reconstruction of Galileo Galilei’s experiment: the inclined plane Phys. Educ. 43 316
[2] Galileo G 1914 Dialogues Concerning Two New Sciences (New York: Macmillan) (translated from Italian into English by Henry Crew and Alfonso de Salvio) (New York: Macmillan)
[3] LiberLiber digital library: www.liberliber.it

S Straulino Dipartimento di Fisica dell’Università di Firenze, Italy