FROM SIMPLE TO COMPLEX
BUT WHAT IS SIMPLE AND FOR WHOM?

Hermann Härtel
IPN - Institut for Science Education
Olshausenstr. 62, D-24098 Kiel

Abstract

Most physics textbooks and lectures introduce mass points before rigid bodies, and the treatment of elasticity follows. This sequence correlates with increasing complexity of the underlying mathematics. Translational movements are simpler to describe than rotational motion, and this in turn is simpler than the internal vibrations of elastic bodies. Other examples from the physics curriculum follow a similar sequence. This structure is questioned, and alternative approaches are demonstrated, based on the support of computer technology, particularly in the form of interactive simulations.

1. Point mass, rigid body and elasticity

When preparing learning material for newcomers it should be sequenced in such a way that progression from simple to more complex topics is facilitated. This is one of those rather rare principles on which most educators will agree.

However, what is simple? Here the problem starts. Is Newton‘s point mechanics simpler than the treatment of elastic bodies with internal vibrations? It certainly is simpler mathematically, and this was definitely the case when no computers were available. Conceptually, Newton’s point mechanics may also be simple if we replace the mathematically defined mass point, which by definition has no size or zero dimension, with a little volume, filled with matter, which, however, is so small and compact that internal vibrations can be neglected.

The next step in increasing complexity is the rigid body. This model too is simple, in a mathematical sense, because it can be reduced to Newton’s point mechanics by referring to the concept of center of mass. Conceptually, however, the rigid body is simple only if this reduction is taken for granted and no deeper questions are raised. The model of a rigid body implies some kind of "magic" concept relating to the transmission of force. Whenever a force is applied to a rigid body, the same force is present at all parts of this body at the same moment in time (infinite transmission velocity) and this happens without any change in its internal structure .

Such a process is conceptually rather difficult to understand; we physics teachers would have a difficult time if our students insisted on an explanation. However, the model of the rigid body coincides perfectly with our everyday understanding of how objects move. In physics the movement of an extended object is explained by the movement of its parts. In daily life this concept is exactly reversed: movement of the parts is explained by movement of the whole [1].

A sentient being starts moving because it decides to do so. And if it moves as a whole, all parts must do the same. A car starts moving because the motor starts to apply a force. Again all parts must do the same and no further explanation is needed.

This coincidence of an everyday concept (based on some kind of "magic", unreflected mechanism) and the model of the rigid body (based on force transmission with infinite velocity) makes teaching easy. Students see no problem and the laws of physics, for instance those about the simple mechanical machines and the so-called golden rule of mechanics, can easily be covered. However, a chance is missed to point to problematic aspect of daily life concepts and to argue for a more careful analysis of transmission processes in space and time.

Following the treatment of rigid bodies, elasticity can be introduced. However, this topic implies a major increase in mathematical complexity if closed solutions of the underlying differential equations are of interest. The treatment of elasticity is therefore restricted to advanced studies with special interests in this field.

2. Didactical consequences

This sequence from simple to more complex has some clear advantages, if the focus is on the mathematical methods and closed form solutions of the underying differential equations.

Some didactical problems have already been described in relation to the rigid body. However, there is a more general didactical problem. From the perspective of the learner this sequence has advantages in introducing an unknown field and hopefully leads to early learning success. There is, however, a price to pay. The topics to be learned become more and more difficult and the chances increase that the final experience, which may well be decisive in motivating future learning, may be one of failure.

A second more general aspect is related to the fact that the learner has no choice in the direction of learning, but relies completely on input from the teacher. No aspects of the rigid body are visible when Newton's point mechanics is treated and no elastic behaviour comes to mind when the focus is on rigid bodies.

Ausuebel proclaims the importance of advanced organisers for learning [2] and Wagenschein has focussed on the concept of the exemplary in teaching and learning [3]. The ideas of these authors can be interpreted as an attempt to start with some kind of seed, which already contains some important ingredients of the new and as yet unknown learning field. This seed needs to be unfolded during the learning sessions that follow. The advantage is that during the learning process nothing essentially new need be introduced but any new aspect will be experienced as something which follows logically from what is already known.

The important didactical question is if such a seed can be found which is complex enough to cover a reasonable amount of a learning field and simple enough to be acceptable for newcomers.

In the light of modern computers, a new question can be posed: can modern media help to develop such seeds and can it facilitate the learning process?

3. Examples

Before such questions will be considered with possible answers, some more examples from the physics curriculum will be given, where the sequence "from simple to complex" seems to be dominated more by mathematical than by didactical arguments.

In electricity, the topics "dc-current", "Ohm's law" and "Kirchhoff's laws" are covered before ac-currents and high frequency phenomena are introduced. This relates to the increasing complexity of the related mathematics, moving from simple algebraic equations to trigonometric functions and then to wave equations.

When teaching dc-current and the so-called simple electric circuit, the elements of "current", "resistance"and "voltage" are treated in sequence before any system aspect is considered [4].

In electrostatics we first introduce charge and the Coulomb force as acting at a distance. Later the field is introduced, sometimes by claiming that the latter is caused or produced by the charge. Since a charge without a field does not exist, this sequence in not only questionable didactically but also in terms of correct physics.

If vector terms like velocity, acceleration or force are treated they are discussed first as scalars and later, if at all, as vectors.

Elementary particles like electrons are first introduced as particles, later as waves and finally as "wavicles" in the light of the particle/wave dualism.

When covering the topic "oscillation and waves" the simple harmonic oscillator is treated first, then the coupling between two oscillators is introduced, which is then expanded to a system of coupled oscillators to describe the phenomena of waves.

When waves in one dimension are studied, sinusoidal solutions of the wave equation are taken as basic building blocks, and only via Fourrier analysis and Fourrier integrals, do other forms of waves and pulses come into reach.

In each case the order of presentation is determined mainly by the underlying mathematics, moving from simpler methods to more complex ones.

This link between the structure of the discipline and the structure of learning has its drawbacks, principally because it limits activity on the part of the learner. New knowledge can hardly ever be developed independently by the learner, who instead relies on external input.

Further, it is questionable whether simple mathematical objects, such as point masses, really are simple to understand, and whether mathematical derivations, when applied to physics, have much explanatory power.

With computers available the definition of mathematical simplicity must be completely revised. A new mathematical "language" is provided by computer displays and this opens up a new dimension for explanation and understanding.

4. Computer supported solutions

This new language has been used to develop a new approach for all the examples mentioned above. In nearly every case the traditional sequence is changed, starting from a more complex construct, similar to a seed. It contains in elementary form the major aspects of the topic to be covered and should be unfolded during the learning cycle.

xyZET

In our simulation program xyZET we represent all objects in 3d and when ever feasable we start from there. Two and one dimensional movements can be introduced later.

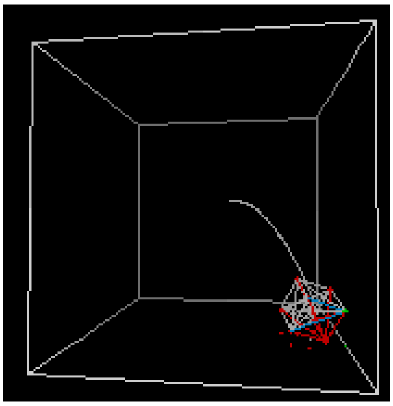

Figure 1: Elastic object,dropping to the ground with a trace of it centre of mass

All connections between mass points are elastic and the behaviour of elastic objects can easily be shown. The rigid body has to be introduced as a simple but unrealistic model.

Charge and field can be shown from the very beginning as two sides of the same phenomenon. For any arrangement of charge carriers, field lines and an equipotential surface can be shown in animation.

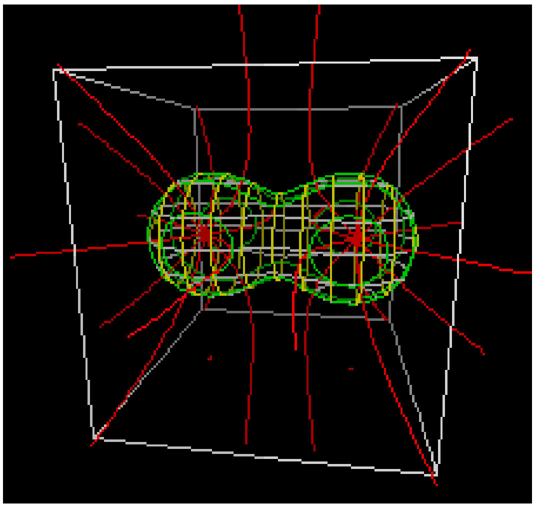

Figure 2: Two equally charged particles with fieldl ines and an equipotential surface in animation

Microcosm

In our program Microcosm we can visualize atomic particle in different forms and even with dynamic features.

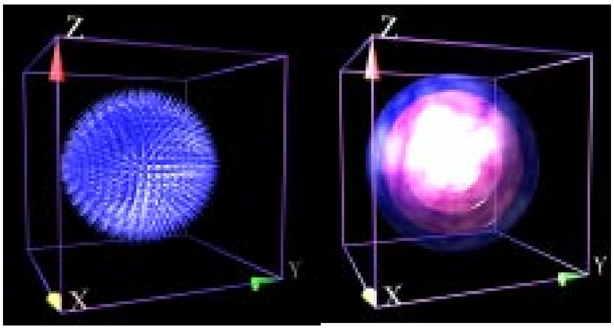

Figure 3: Atomic particles with forms to be discussed

Transport in Circular Systems - TICS

In our simulation program TICS - Transport in Circular Systems - we can edit any kind of simple circuit and visualize how current and voltage is reaching equilibrium. The potential is visualised as a quantity in the dimension perpendicular to the circuit.

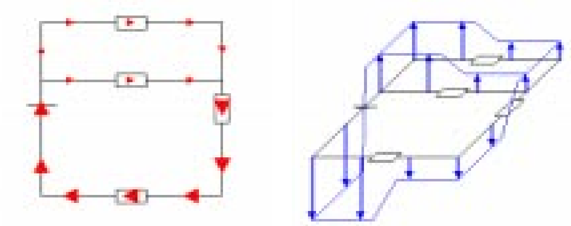

Figure 4: An electric circuit program, visualizing how current (left) and potential (right) are approaching equilibrium.

Transmission line - TeEl

In our simulation program TeEl- Transmission line - the transmission process of single pulses can be studied in detail, including reflection, change of impedence and losses. Ohm's law follows as the equilibrium state, after all reflections have died out.

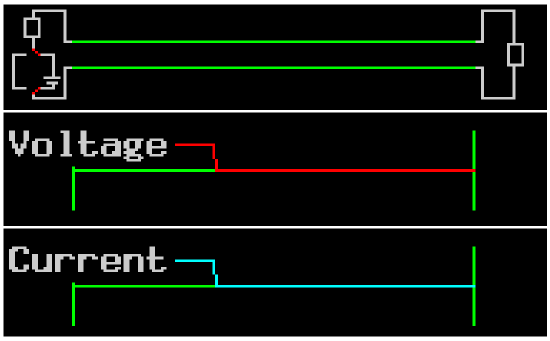

Figure 5: A pulse along a transmission line

In all these programs an attempt has been made to use the flexibility of computer displays to visualize some basic features of the topic under study to serve as guide line or advanced organiser for the unfolding learning process.

The price to pay is higher complexity initially, which may act as a barrier and which the newcomers have to overcome. Research will be needed to determine if this approach favours only strong learners and those who have acquired some pre-knowledge, or if the interactivity and flexibility of computer displays as the new language can help to improve learning and understanding for a broader spectrum of students.

5. References

[1] Ogborn, J. (1987). Newton and common sense. Physics education 321

[2] Ausubel, D. (1960). The use of advance organizers in the learning and retention of meaningful verbal material. Journal of Educational Psychology, 51, 267-272.

[3] Wagenschein, M. (1989), Verstehen lehren, Weinheim und Basel

[4] Härtel, H. (1982). The Electric Circuit as a System: A New Approach. European Journal of Science Education, 4, 1, 45-55.

[5] Härtel H., Martin E., (1993). New path for teaching electricity. Prodeedings of the “International Conference on Computer Based Learning” CBLIS 93, Wien, 275 - 284

[6] Härtel H., (1994) TICS - Transport in Cirkularen Systemen, IPN-Materialien, IPN