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Multimedia Support of Physics Education

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Contents

Introduction

Multimedia are a phenomenon that has significantly changed our world and especially education in past fifteen years. Multimedia CDs and DVDs, multimedia classrooms, certified multimedia-supporting computers – all those are common things. Teachers create multimedia as educational materials and students are used to them.

The general availability of technology used to create multimedia (shortly called *multimedia technology*), e.g. cameras, camcorders, computers equipped with sound cards and/or FireWire ports etc. offers a great opportunity to physics education and physics teachers. Most of the technology can be used to support teaching physics, especially in relation to school experiments. The potentialities of utilisation of multimedia technology to foster learning physics are the main topic of the doctoral thesis.

The thesis is divided into five parts. First chapter of the thesis contains a short definition of multimedia and a brief summary of the importance of multimedia in general. The main merits of the thesis are the four chapters regarding individual multimedia technologies. Second chapter discusses the utilisation of video records in physics measurements, including a few new experiments. The topic of the third chapter is the slow motion video, its importance, use in physics lessons and description of a series of recorded slow motion video clips. In fourth chapter, the use of a computer sound card as a measurement tool in innovative experiments is discussed. Finally, in the last chapter is characterised a series of newly created computer programs for visualisation of hydrogen atom orbital shapes. All chapters contain a brief summary of the educational use of currently discussed technology, description of created educational objects that take advantage of the technology, and if available, then also experience with applying the created objects in classroom.

1 Multimedia technology and education

1.1 Theory of multimedia learning

Multimedia in a general meaning are media presenting information in both words and pictures [1]. By words we mean spoken words as well as written words, so multimedia are illustrated textbooks as well as a commented series of photographs or an instructional movie, though not all these media are equivalently effective at transmission of the information [1].

Experiments proved that in comparison to text-only or image-only instructions, multimedia instructions improve understanding as well as retention of information [2], especially for a student with low prior knowledge [3]. The mechanism of processing multimedia instruction is described by the *Cognitive theory of multimedia learning* (Fig. 1).

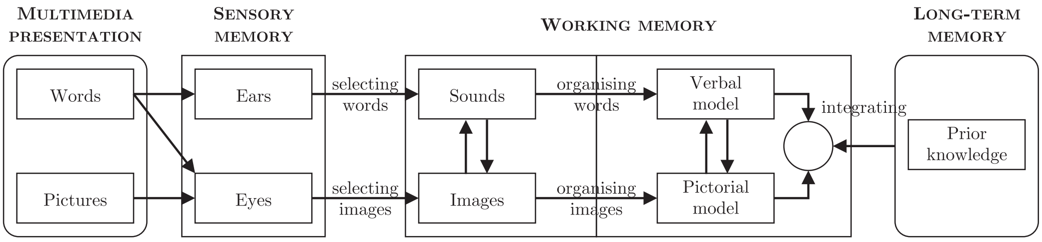

Figure 1: Cognitive theory of multimedia learning (Image taken from [4])

According to this theory we perceive and process information via two channels: the *Auditory/Verbal channel* and the *Visual/Pictorial channel*. The benefit of multimedia consists in parallel processing of information in both channels; though it should be ensured that one of the channels does not become overloaded [5]. From these mechanisms it is possible to derive implications for multimedia design.

1.2 Multimedia technologies

However, the main goal of the thesis is not investigating multimedia themselves but investigating the technologies that are commonly used to create multimedia and are available for physics education support. The discussed technologies are:

- **Video recording** – though multimedia by nature, in physics we mostly use the image track of a video recording to study movement of a body in a process sometimes called "video-analysis".
- **Audio recording** – computer tools enabling visualisation of an audio signal offer us a chance to study sound either in time domain as well as in frequency domain. And, if we connect a phototransistor or some other module to the computer instead of a microphone, the studied signal does not have to be sound at all.
- **Animation** – in simplified meaning, an animation means an image that changes according to commands of the user or creator. In physics we can think of computer models as of animations and also visualisation of functions (especially when having dynamically changing parameters) are a very similar technology.

2 Video analysis

Making a measurement using photographic image or video recording is not a new idea. Wallerstein describes using a camera with repeating shutter to collect data for studying uniform motion as early as in 1939 [6]. As time passed by, the technology was developing, the prices falling and overall knowledge of the technology was rising. Fuller describes video analysis in the 80s [7], later Zollmann in the 90s [8]. Nowadays video measurements (of course in digital video) are a common element of physics education and similar to microcomputer-based laboratories, video-based laboratories (VBLs) are developed and mentioned in literature.

Real expansion of video measurement could be observed about the turn of the century. By this time the digital technology was cheap enough to be affordable by schools and at this price sophisticated enough to record, play and analyse video at a reasonable pace. Since this time, the penetration of technology and knowledge about methods and possibilities of video measurement are really widespread and almost any physics teacher at any school can afford to make vide measurements.

Nowadays, video measurement is a part of future teacher education [9], and in-service teacher training [10, 11, 12], on the web there are video measurement "how-tos" and experiment hints for teachers [13, 14, 15]. Students use these methods in their laboratories [16], in degree theses [17] or in student projects [18].

2.1 Methods of video analysis

There are (in general) two ways of using video recording for physics measurement. The first way is using the video recording as a series of still images and looking for a specific image in the series (usually a breakpoint – "Where does the body leave the surface?", "What is the leaving angle?" etc.). The second method consists of calibrating the image to agree with real world units and then marking position(s) of one or more bodies in every frame. From gained coordinates we can then count accelerations, velocities, angles and so on.

2.2 Typical experiments for video measurement

Not all experiments require analysis using video measurement, some are unsuitable for it at all. Generally we can say that video measurement helps in cases where it is needed to log data that alter quite rapidly, but not so rapidly that it could not be captured by the camcorder. Very good summary of available experiments is given by Chimino and Hoyer [19], later Blume-Kohout et. al. describes the possibilities in more detail [20]. For school purposes are typical analyses of motion in one or two dimensions that enable simple measurement (distance, angle, slope, time, ...) and illustrative interpretation of results. On the other hand, to measure quantities like heat, pressure, magnetic field etc. it is required to use a lot of invention.

2.3 Newly designed experiments

Experiments below and further experiments described in the thesis were presented by the author at GIREP conferences and at the Czech "Physics Teachers' Inventions Fair" conference.

Falling rod

This is a simple experiment concerning the basics of rigid body mechanics where also the mathematical model can be easily made. Just take a homogeneous rod or tube, stand it on one end and let it fall down in a direction perpendicular to the direction of camera view. There are (or at least we found) three main points where to aim interest:

- **Angular velocity of the rod** — the video analysis software is capable to give us positions of a selected point of the rod (usually its end) at certain times. Some programs also export the velocity, otherwise we have to count it ourselves. On the other hand, this is an exercise that can explain how numerical derivatives work.
- **Model to measurement comparison** – The measured velocities can be compared to values predicted by the mathematical model and the correspondence is usually very satisfying.
- **Acceleration of the end of the rod** — the acceleration of the rod's end is higher than gravity acceleration in some part of the motion. This fact might be surprising and it is a good point to let the students think about and explain.
- **The end of the movement** — at the very end of the falling, something strange happens. If we did not somehow fix the axis of rotation, the rod will start moving forward. On first sight this is in conflict with theory because we all know that if the rod did not have fixed the axis and there were no friction, it should just fall down and the centre of mass should not move in horizontal direction. In other words, the bottom end of the rod would slide backwards.

  The explanation is quite simple — the rod did not slide at the beginning because the axis was fixed by frictional force, therefore the mass centre gained momentum. At the end, the friction is not strong enough to fix the axis any more and the rod starts to move in forward direction.

Rolling bodies on a cylinder

Put some kind of round object on top of a cylindrical surface and let it roll down. At some point the object leaves the surface and starts a falling freely. The question is where — at which angle or height — the point of leaving lies. Almost every physicist has once solved this problem during his studies, but most have never seen. We have, and if you take your camera, you and your students can see it too.

This experiment differs from the previous one because it is a good idea to use long shutter times here. If the diameter of the cylinder is small, it is hard to distinguish the point, while if it is big, the movement is too fast for the camcorder. However, we can make use of it: because of long shutter times, we can find one single frame in the clip that contains both movement in contact with the surface and the free fall. On this single image we can measure whatever quantity that interests us.

While doing this experiment, we used three rolling objects: a ball, a tube and a full cylinder. When compared to theory, we can see that the measured angle of the leaving point is slightly bigger than its theoretical value in all three cases, and the difference is quite the same for all three objects (see table 1). This difference may be explained by energy loss due to friction. On the other hand, it is clear that the angle depends on the body's momentum of inertia (a ball of same mass and diameter has lower momentum of inertia than a cylinder or a tube) and the dependence agrees with theory.

body	J	$\cos\varphi$	φ_{theory}	$\varphi_{\text{measurement}}$
ball	$\frac{2}{5}mr^2$	$\frac{10}{17}$	54,0 °	(57,9 ± 1,1)°
cylinder	$\frac{1}{2}mr^2$	$\frac{4}{7}$	55,2 °	(58,2 ± 1,4)°
tube	mr^2	$\frac{1}{2}$	60,0 °	(62,7 ± 1,7)°

Table 1: Example values of leaving angle (Rolling bodies)

2.4 Classroom experience

Two laboratory tasks based on video measurement were included into the physics course of three classes at Gymnázium Pardubice, Dašická (Czech school similar to secondary grammar school or high school) in the year 2010/2011. The tasks were chosen according to students' prior knowledge and abilities: the kinematics of oscillations (a weight on a spring) for two classes of 6th grade students (age ca. 16 years) and the acceleration of ball on an inclined plane for one class of 4th grade students (aged ca. 14 years).

After the laboratory tasks were solved, the students were asked for supplying us their feedback. The selected method of feedback was the Intrinsic Motivation Inventory (IMI) questionnaire, a method that is suitable to measure students' attitudes to an activity [21]. From all the scales that can be examined by the IMI were chosen *Interest/Enjoyment*, *Effort/Importance* and *Value/Usefulness*. The results of students' feedback are summarised in table 2.

6th grade		
scale	*avg. value*	*std. deviation*
Interest/Enjoyment	5,0	1,5
Effort/Importance	4,0	1,8
Value/Usefulness	4,8	1,6

4th grade		
scale	*avg. value*	*std. deviation*
Interest/Enjoyment	4,6	1,4
Effort/Importance	4,7	1,7
Value/Usefulness	4,5	1,5

Table 2: Results of students' feedback on video measurement

We can see, that while in the 6th grade labs were accepted and solved by students without any problem, the 4th grade labs were perceived to be too much demanding and less interesting. This was probably caused by students' low prior experience with school labs at general (students at the school start to do physics labs regularly at 5th grade, before that labs are only occasional) which means that they do not have comparison to "standard" labs which are usually more boring and they are also not as effective in working with data as their older schoolmates. Thus, the labs were probably designed too excessive for the needs of a 4th grade student.

All in all, the labs based on video measurement were successfully included into secondary school physics education and students were able to solve given tasks. Most of them were interested by the method and perceive it to be a method useful for learning physics though not unreasonably demanding. I believe that as such it can be successfully included into other student's education at other schools.

3 Slow motion video

In recent past, say 20 years ago, the technology of slow motion video (video record that takes more than 30 image frames per second) was a technology available only for professional purposes. While it was possible to use standard video recording in analog era and even perform video analysis with TV and transparencies [8], slow motion (or high-speed) cameras were almost unreachable for a common physics teacher. These devices were expensive and usually also quite large. The enormous development of digital imaging technology [22] has resulted in availability of digital cameras able of recording video of up to 1200 FPS frame rates for a reasonable price.

The frame rate about 1000 FPS and higher brings a new quality into the recorded video clip. As a usual video recording of an experiment it can of course be used to motivate students to study certain phenomenon, to explain it and to measure values inside the recording, however these facts do not fully cover the potentialities of slow motion video. Author's experience shows that the motivational effect of slow motion video clips is significantly higher. Not only the students can see things they would not be able to observe with their eyes or in a standard video recording, they watch the videos fascinated by the simplest things like falling object or moving pendulum. Watching a slow motion video makes them feel looking through different eyes.

Even though the availability of slow motion recording technology is good and the benefit it can have on physics education is great, the penetration of the technology is probably very low. Thus only we can explain that there are only a few articles concerning slow motion video to be found in professional journals – the study of a bungee jump [23] and the study of shuttlecock movement (including air resistance) [24].

3.1 Limitations of the technology

Not all phenomena can be recorded with a high speed video offered by a digital camera (the one used by author of the thesis has 1200 FPS frame rate and resolution of 336×96 px). The most problematic is recording of small objects or objects that do not stay at one spot (these are the limitations of low resolution). Also, many processes are to fast to be recorded (e.g. airgun pellet movement or transfer of momentum on Newton's cradle). Also the propagation of a discharge between Ruhmkorff inductor poles is too fast, however the camera captures at least single frames containing the shape of the discharge.

Also there are two factors that degrade the image quality: high video compression (otherwise the camera would not be able to store numerous video frames) and improper lighting of the scene. The source of light has to be steady, a standard light bulb lowers and raises its brightness 100 times per second, and incandescent tube darkens at all with the same frequency. This results in flickering of the image that can be avoided only by using an accumulator powered lamp.

3.2 Slow motion experiments

The video clips described in the thesis were presented at the conference "Physics Teachers' Inventions Fair" [25], published in Physics Education journal [26] and as a series of texts on the FyzWeb server [27]. A selection of all the clips is described below.

Two weights on a spring

Take a pair of weights connected by a spring, hold one of them and let the other hang down. Then start your camera and release the weights. The recorded clip shows us the top weight accelerating down while the bottom one hangs freely in space. This phenomenon usually fascinates students and might be a good start for discussing weightlessness. The smarter of your students will probably soon discover the explanation.

Before release, the top weight is affected by three forces: the force of gravity mg and the force of the spring, both pointing downwards, and the force of the holding hand pointing upwards. The bottom weight is affected only by gravity and by the force of the spring pointing upwards. The resultant forces are zero for both weights and therefore the weights do not move. After release, the weights are affected only by gravity and the spring. Just after release the spring force is given by mg (it held the bottom weight still) and decreases as the weights fall down. Thus, at the beginning of the fall, the top weight falls with an acceleration of approximately $2g$ and the bottom one does not accelerate at all.

From video analysis we can obtain the parameters of the weights movement: The top weight accelerates with $a = 18.4\,\mathrm{m\,s^{-2}}$. The bottom weight does not accelerate measurably.

The forming of a drop

The process of formation and detachment of a water drop is usually viewed and described on a thin tube such as a syringe or burette. However, a droplet on a larger surface like a water faucet gives us a surprising view. First of all, the process of drop creation is finished by the formation of an unexpectedly long thin "stalk" with the drop at its end. The length of the stalk is usually two or three times longer than the diameter of the drop.

Furthermore, in slow motion video clips we can observe the shape of the drop which turns out to be almost spherical, not having the "drop shape" that usually occurs in drawings or cartoons. The drop is elastic due to surface tension, and after its detachment from the stalk, it oscillates.

The so-called "water hammer"

The experiment sometimes called the "water hammer" [28] is usually well remembered by students. Pour about 0.3 l of water into a wine bottle, plug it with a cork plug and cut the plug at the level of the bottleneck. Then hit the bottleneck with a rubber mallet from the top in a sharp blow. If the hit is successful, the bottom of the bottle falls off.

This experiment is usually explained by inertia and low atmospheric pressure. When hit, the bottle almost immediately starts moving down. However, since it is not fixed to the bottle, the water inside stays for a while in its former position due to its inertia. This results in the creation of a space of very low pressure between the bottle bottom and the water. After a short time, the atmospheric pressure above "hits" the water and presses it to the bottom of the now motionless bottle. The impact of the water mass then knocks off the bottle bottom.

Filming the experiment confirms this general explanation. However, it also reveals more detail. (Use a thick glass bottle and hit it with a really powerful blow to make the phenomenon more visible.) When stepping through the filmed video, we might see the appearance of tiny bubbles (separated bubbles, not a contiguous space) near the bottle bottom for about 5 ms. These bubbles disappear immediately and the bottom is knocked off. We believe that we are observing the phenomena called cavitation. The very low pressure creates areas of vacuum (or water vapour at extremely low pressure) that disappear in an implosion followed by impulse waves. These impulse waves knock off the bottle bottom just as well as they are able to disrupt the steel vanes of a turbine or a pump.

3.3 Classroom experience

Short clips of slow motion video were used as small educational elements during physics lessons in three classrooms at Gymnázium Pardubice, Dašická in years 2009–2011. The purpose of use was usually explanation of a fast experiment that had been performed live just before the clip or measurement inside the clip. The students were then asked to supply their feedback concerning the use of slow motion video clips via the IMI questionnaire [21]. The scales *Interest/Enjoyment* and *Value/Usefulness* were selected as relevant to the topic and method of use.

scale	*avg. value*	*std. deviation*
Interest/Enjoyment	5,7	1,3
Value/Usefulness	5,4	1,4

Table 3: Results of IMI questionnaire responses for slow motion video

79 students responded to the anonymous questionnaire. The feedback analysis results are summarised in table 3. We can see that this technique has been accepted in a positive manner, 81 % of respondents feel that slow the motion clips are an interesting and amusing element in physics lessons and 73 % perceive it to be beneficial for learning physics.

From these data as well as from further student comments we can conclude that using slow motion video clips is a positive point of physics lessons and can foster learning physics, however the clips have to be accompanied by appropriate comment and real live experiments.

4 Sound card measurements

The sound card of a computer is most commonly used (in terms of teaching physics) for the topic of wave mechanics – acoustics. Usual are visualisations of an audio signal (as an oscilloscope), its frequency analysis [29], speed of sound measurements [30], Doppler effect demonstrations and measurements [31] and as a tone or sound generator. A lot of freeware programs suitable to perform these tasks in classroom are available on the web, e.g. Winscope [32] or Soundcard Oscilloscope [33].

However, if we think of the sound card as of an A/D converter there is a more general way of using a sound card – as a data logger [34]. This way we can measure gravitational acceleration [34], speed of a bullet [35] etc.

4.1 Measuring with a phototransistor

It is possible to study motion of a body with just a sound card and a phototransistor connected directly into the sound card input. Such experiment setup results in computer measuring the curve corresponding to illumination of the phototransistor. We can now take a round body (ball, cylinder or tube), dye one half of it black and the other white, put it onto an inclined plane and follow its motion with the phototransistor. The computer will measure a curve of an “alternating illumination” and from the shortening period of this curve we can count the acceleration of the body.

4.2 Electro-optical tone generator

To generate a signal of given parameters we can use a few freeware programs like Soundcard Oscilloscope [33]. As a toy that can help us discussing oscillations, alternating current etc. we can use also a simple toy generator made from a phototransistor (as in previous experiment) that is placed over a turning disc of differing levels of grey. To create such discs, the author of the thesis has written a computer tool that can produce a bitmap of given pattern (square pulses, sawtooth, sine oscillation or mathematic formula).

When the disc turns, the phototransistor measures the amount of light reflected by the disc. The resulting waveforms are similar to input patterns but not identical. Identifying the main reasons for the differences (inaccuracy of transfer of grey level from number/screen to paper, finite width of the phototransistor etc.) can be a beneficial task for students.

4.3 Characteristics of a communication channel

Another interesting point is to find out how exactly does a communication channel (telephone, optical channel, etc.) transfer different frequencies. A hard way could be to record "beeps" of defined frequencies and read the transferred amplitude values. The process can be quickened by transmitting a complicated sound containing many frequencies, preferably white noise, then converting both input and output signal into frequency domain and finally subtracting frequency magnitudes.

Nowadays can such task be performed with freeware programs [33], however in time of presenting this measurement there was not any suitable tool available, therefore the author of the thesis has written such program called FFTLevelScope.

As a verification measurement we chose an RC element that, in agreement with theory, shows 6 dB decrease per octave. An "optical telephone" made from LED with amplitude-modulated light intensity and phototransistor has an almost "flat" characteristics, meaning that all frequencies are transferred equally.

5 Visualisation of hydrogen atom orbitals

Quantum mechanics is a very abstract part of physics that is hard to imagine. On the other hand there are many practical applications in nowadays world that originate in quantum mechanics and therefore it is desirable to introduce at least the basics ideas of quantum mechanics to high school students. However, the complexity of this topic demands not only proper approach, but also suitable tools for visualisation. For example, the polar and spherical plots (quite usual in textbooks) are difficult for students to understand.

There are a lot of set of tools (Java-based, Flash-based) that help students understand these coordinates and visualise hydrogen atom eigenstates [36, 37, 38], however, most of these tools are too complex for demands of a common high school student (in terms of displaying complex functions, mixed states etc.). Therefore we designed our own set of interactive tools (fig. 2) that visualise the radial and angular part of wave functions and probability density plots of hydrogen atom eigenstates in various types of graphs. These tools allow very good and precise visualisation of functions, better than common printed images.

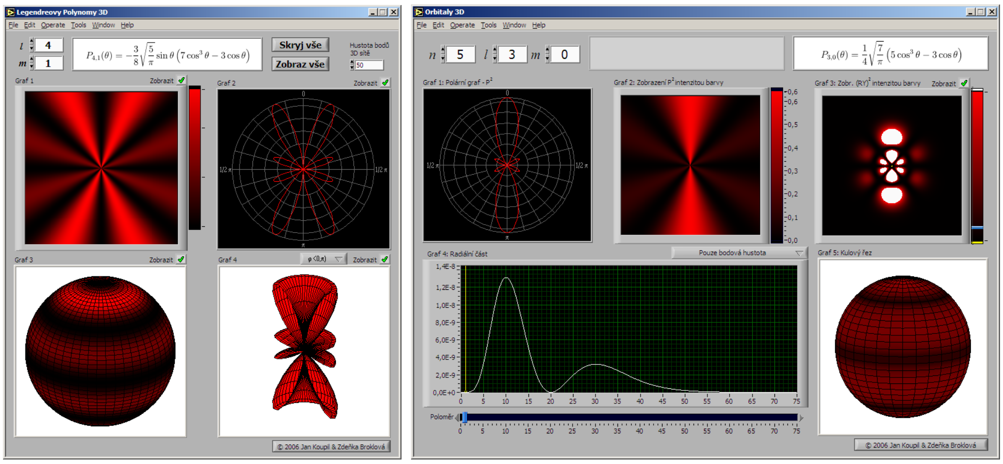

Figure 2: Screens of two programs for visualisation of hydrogen atom eigenstates

Based on students' experience we assume that attractive images and interactivity (e.g. zoom and rotation of 3D graphs) increase their interest and help them understand the abstract topic.

Conclusions

This thesis deals with possibilities of use of multimedia technology in physics education. Four different multimedia technologies (video recording, slow motion video, sound card recording and animation) are discussed and a few innovative educational units are proposed. Most of the technologies were also tested with students and classroom experience is contained in corresponding chapters. Appendices to the thesis contain author's how-to for performing successful video measurement and English texts that were published in professional journals or conference proceedings.

The world of digital multimedia is continuously changing. The thesis summarises possibilities that are nowadays offered by multimedia technology. It is certain that today technologies will be superseded by tomorrow ones and what was fresh and innovative by the time the theses had been written would become old and obsolete. Hopefully, the methods and objects proposed in the theses will help nowadays teachers and their students in their voyage of teaching and learning physics and maybe will serve as an inspiration to form new ideas, technologies and educational objects.

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