3d-Simulations for Teaching and Learning

Hermann Härtel
Michael Lüdke
PN

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Introduction

At IPN (Institute for Science Education), a simulation program named xyZET has been developed to support teaching and learning in physics. As one of its distinct features the program allows to visualize the movement of interacting particles in 3d. It therefore adds value to the teaching and learning of complex process, where visualisation can help to reduce cognitive load. Most dynamic processes are of this kind. As a distinct example the movement of the gyroscope and its xyZET-representation will be described later in this article.

The program can be used during lectures, where often verbal explanation can be replaced by letting a simulation speak for itself. The program also supports the development of exercise material for individual learning phases. Such material in form of WEB-pages can be combined with xyZET-simulations, controlled by applets. As an example for this use of simulations, a full introductory course for mechanics has been developed. This material has been tested under classroom conditions and proven to be stable, feasible and effective. Further improvements can be expected if students have better access to adequate computers and if in general more support and time is provided to practice exploratory and self-supported learning.

The program xyZET was developed under UNIX and X-windows and runs on PCs under LINUX. For Windows 95/98/NT an additional X-Server is needed.

1. Basic features of xyZET

As already mentioned, the program xyZET allows not only the usual display of time diagrams and the visualization of movements in 2d, but presents itself in starting mode as a three-dimensional cube, where interacting particles can be placed. This cube can be rotated around two vertical axis.

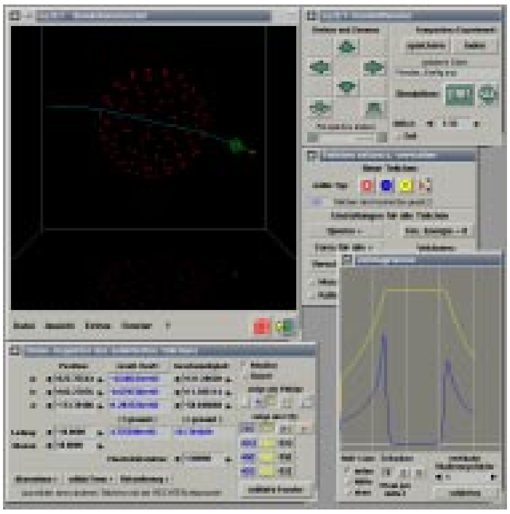

Fig. 1: Simulation window of xyZET with some control panels

As an example fig.1 shows the simulation of an experiment where a positive charge carrier is travelling across a negatively charged shere.

The figure shows the simulation window and some parts of the numerous control panels, for instance a display of the force acting on the charge carrier as function of time.

The implemented algorithm is force based and it has been taken care that by solving numerically Newton’s basic equation (F=ma), energy and momentum are always conserved. Single mass points can be placed at any position within a cube and most of the classical interactions can be activated like contact forces (with variable elasticity factor), spring forces (Hook, van der Waal, Lennard Jones), friction, gravity, Coulomb and Lorentz forces.

In addition to mutual gravity and Coulomb forces, the interaction due to external fields can be studied. Magnetic and electric fields can be oriented in any direction and the electric field strength can be varied in time with variable frequency.

The program allows to represent electric field lines as well as equipotential surfaces of arbitrary arrangements of charge carriers (see figure 2).

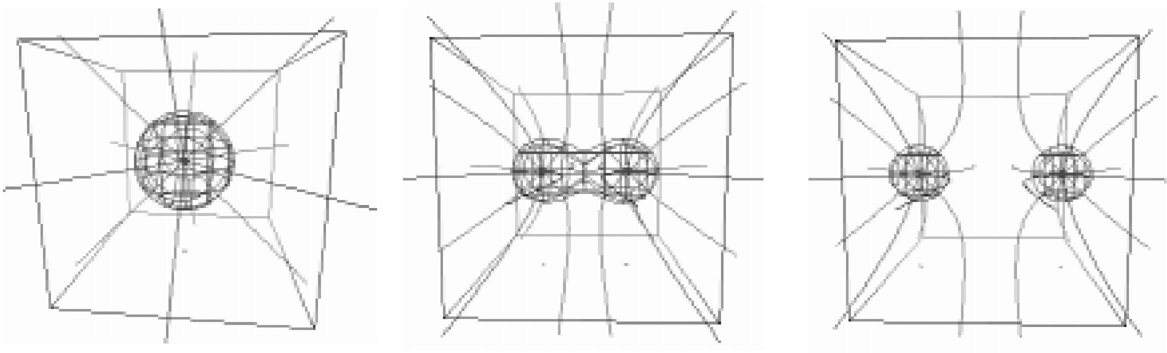

Fig. 2: Field lines and equipotential surfaces for 2 repelling charge carriers (in motion)

As more advanced topics from special relativity the program allows to demonstrate velocity dependence of mass as well as effects based on the theory of retarded potentials.

To demonstrate the spectrum of possible simulations two more advanced topics, one from mechancis and one from electricity will be described next.

2. Examples for the use of simulations

2.1. Movement of a gyroscope

Figure 3 shows a gyroscope as modelled within xyZET. It concists of particles, connected by rather stiff springs.

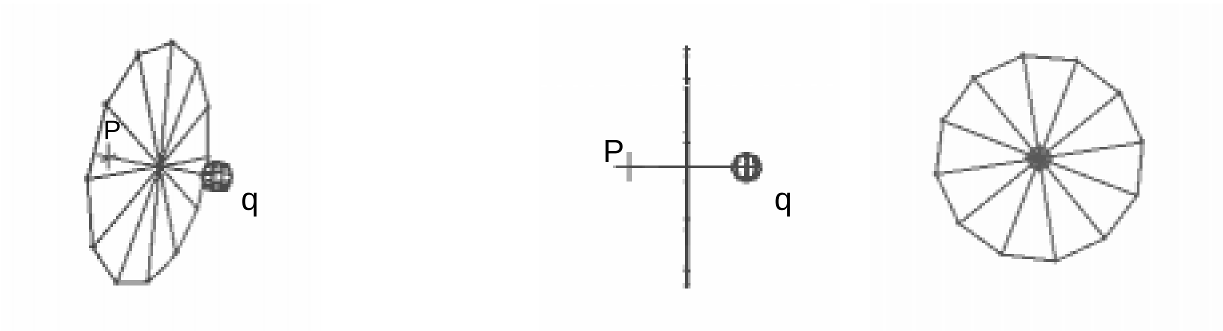

Fig. 3: A gyroscope as modeled in xyZET with front view(middle) and side view(left).
The whole construction is rather stiff. Some springs are hidden for better visibility

The point P is fixed in space and the additional object q is charged and can be pulled downwards by an external electric field. Such a Coulomb interaction was used instead of gravity to overcome a typical learning difficulty with traditional approaches: the interrelation between inertial and gravitational mass. In experimental setups, these two properties of matter, being inert and being heavy, cannot be changed independently. In a simulated world, however, this is possible and facilitates the analysis.

Due to the Coulomb force pulling on q, the whole construction - if not rotating - will swing like a pendulum around its suspension point P (see figure 4).

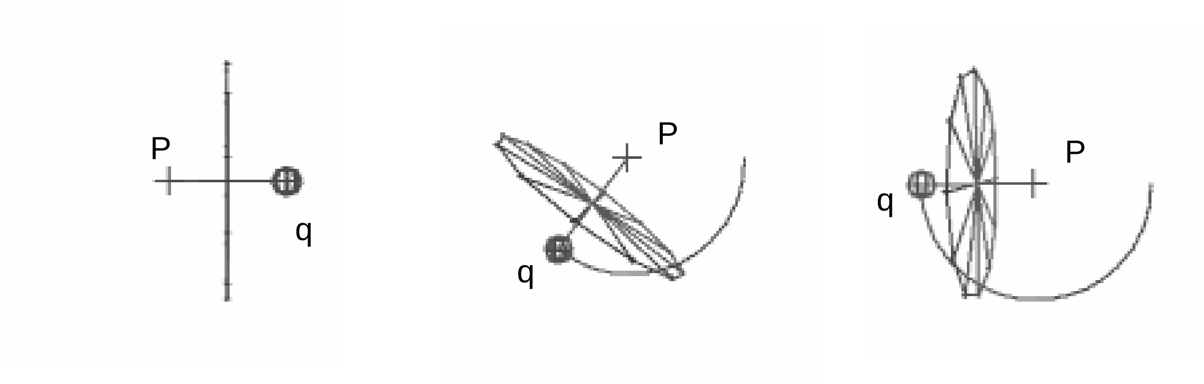

Fig. 4: A force is applied to q, oriented downwards. Point P is fixed. Without rotation the gyroscope is swinging like a pendulum.

Once the gyroscope has started to rotate, it becomes obvious, how the pendulum motion changes to a nutation and precession motion (see figure 5).

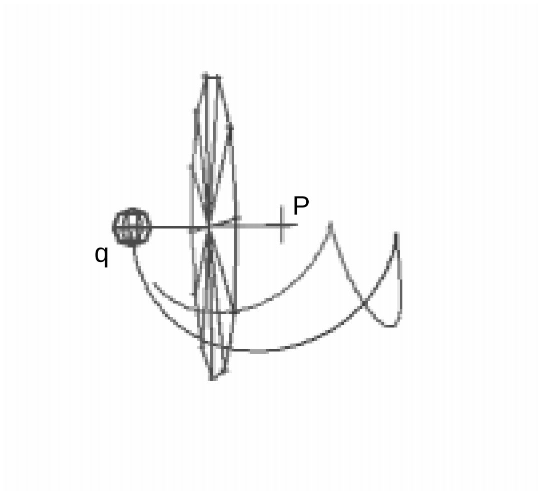

Fig. 5: Nutation and precesion of a rotating gyroscope around point P. The trace shows the path of the object q.

For a non-rotating gyroscope the interactions between q and all other points of the construction are aligned in the direction of the swing. The force acting on q accelerates all other points and these just oppose due to their inertial mass.

With a rotating gyroscope these interactions are no longer oriented in one plane but will spread out in all directions due to the different direction of motion. The sum of all these forces is always directed perpendicular to the actual path of q. Therefore this point can no longer swing through its deepest position like before but is deflected to the side and returns earlier to its original height.

Such an analyis is not straight forward, but needs carefull observation by varying all the different interacting parameters like inertial mass, downward pull and rotational frequency.

Such an analysis serves as a first distinct approach to understand the movement of a gyroscope. This introduction has to be extended by further explanations about the influence of the applied torques and how this can be described in mathematical form.

2.2. Radiation of field - Retarded potentials

In the Berkeley Physics Course[2], it is explicitly described how the field of moving electrons is changed in symmetry as a consequence of special relativity. This leads to an explanation of the magnetic interactions between conductors carrying electric current. Important is the fact that the symmetry of the field changes from a spherical to a cylindrical one.

The same result was found by Leigh Page in his early work[3], where he introduced the electron as source of some “moving elements” radiating out in all directions with the speed of light. The field lines are given by the same principle as the path of a water beam, produced by a moving nozzle (without gravity).

The results which follow from this approach are in quantitative agreement with the classical laws of electro-magnetism. It therefore seemed to be adequate and promising to simulate this model of the electron as source of moving elements and to visualize the resulting field lines on the screen.

Figure 6 shows a charge carrier which has moved from the left and stopped in the middle of the cube. It can be seen that from this acceleration process a sphere like wave of electric field is propagating to the outside. This corresponds to the well-known relation between rot E and dB/dt.

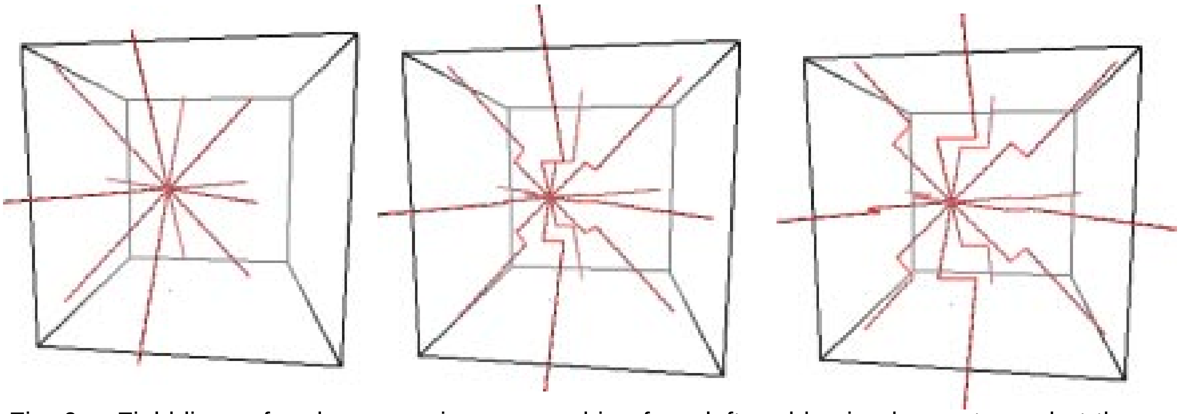

Fig. 6: Field lines of a charge carrier, approaching from left and having been stopped at the center.

Simulating an oscillating charge carrier results in field line images as shown in figure 7, left. This explains qualitatively, why the strength of the field is different along a circular wire (as indicated in figure 7, left) and why, according to the law of induction, a current will be induced.

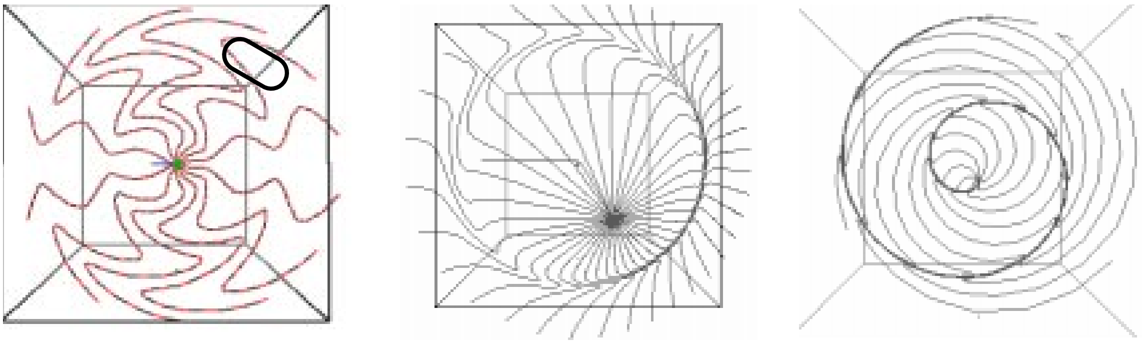

Fig. 7: Oscillating charge carrier and retarded field

“Bremsstrahlung” of a scattered charge carrier

Cyclotron radiation of a circulating charge carrier

Figure 7, middle shows the result of a simulation, were a charge carrier at “half the speed of light” has been accelerated towards a scattering centre and is deviated while passing. The resulting pattern of field lines corresponds to the “Bremsstrahlung” as found in high energy scattering experiments. On the right, the radiation pattern of a circulating charge carrier is shown.

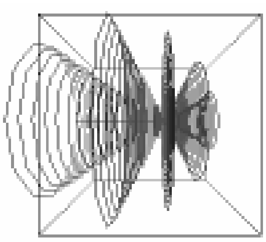

Fig. 8: Magnetic field lines of an accelerating charge

In this emission theory, field lines are defined as lines connecting all moving elements, which are emitted under the same angle. Magnetic field lines are defined as lines connecting all moving elements, which are emitted at the same moment in time. The latter, when visualized on the screen, tends to result in rather complex and confusing images. They can be useful to demonstrate symmetric features for some not too complicated arrangements.

Experience in classroom will show how profitable this kind of representation can be for teachers and students to support the learning process in respect to these rather basic and demanding topics.

3. Combination of simulations and WEB-pages

A so-called learner-mode for xyZET has been developed where all control elements are hidden with the exception of controlling the rotation of the cube and the start and stop of simulations. All further control elements are provided as active buttons, integrated in WEB-pages (see figure 9). The communication between these active buttons and the simulation is provided by an applet, using the TCP/IP-protocol to send the prepared commands to the simulation. From a prepared list any specific commands can be entered by using standard editors.

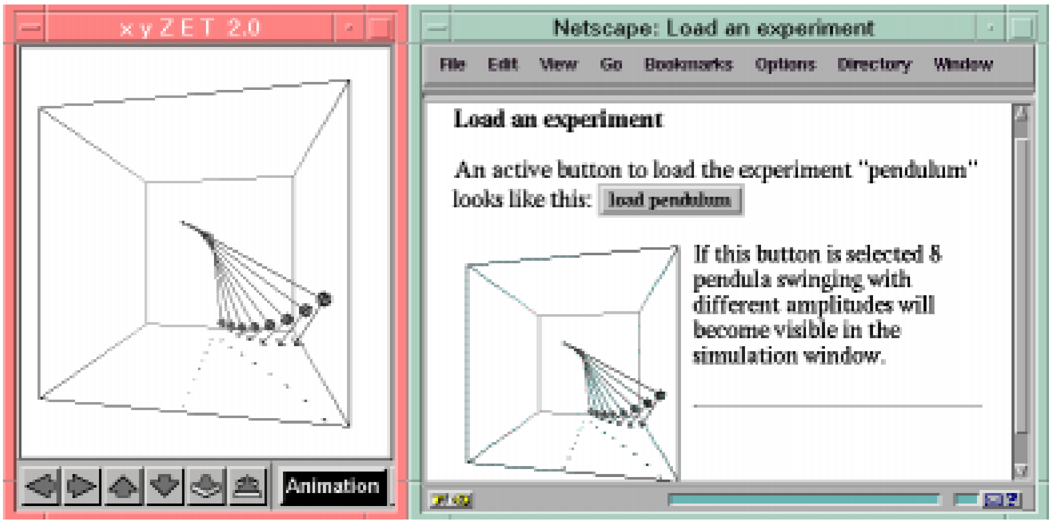

Fig. 9: Simulation window and a WEB browser with active buttons to control the simulation

This method of combining WEB-pages with simulations was mainly used to develope the mechanics course[4], mentioned above.

4. Evaluation results and further activities

4.1. Objectives for evaluation

Since September 1997 the developed material - xyZET and the mechanics course - has been tested under classroom conditions with two different classes of grade 11 (German Gymnasium)

The main objective of this tryout was to test the feasibility and robustness of the material. Furthermore some major didactical questions had to be answered.

- How much control and guidance has to be transmitted by the material to stimulate and support self-sustained learning phases for the majority of students, while the teacher can be involved in helping individual students or sub-groups?
- How can the students be motivated to use the interactivity of the prepared simulations for exploratory learning activities?
- To work with information in form of text is an essential part of learning. Is there an added or reduced value if this text is presented on the screen? How can this work be best supported?
- Finally the learning result of the students in normal paper and pencil test should be measured to prove that at least normal learning progress can be achieved, when using the developed material.

4.2. Evaluation results

The results can be summarised as follows:

- The developed material has proven to be robust and applicable and was used by students without significant problem.

- Due to the different reading habits of students it seems to be necessary to offer information on both screen and hardcopy.
- Individualized classroom activities lead to a wide variation in the rate of student progress. This points out the need for balancing measures such as additional assignments for the fast learners and additional teacher support for the slow learners.
- Most students are very strongly oriented towards assignments. They follow instructions closely and rarely develop their own questions as a starting point for exploratory learning activities. No correlation was found between the time spent on assignments and test results.
- Exploratory learning activities cannot be expected to be developed spontaneously by students, simply because they are using interactive material; such activities need to be specially stimulated and trained.
- Results in paper and pencil tests corresponded to the average gain in knowledge known from other studies. The results shown by classes from other high schools were comparable or lower.

These results show some similarity with other findings[5] about advantages and shortcomings when technology is introduced and students are asked to take on more responsibility for their own learning process. Insufficient technology in the hands of students is one source of trouble, which will probably vanish with time. The main obstacle, however, lies in the fact that only a few of the stronger students can live up to these expectations. For the vast majority, however, it is not enough to offer a rich, interactive interface and expect them to engage in exploratory learning activities. They definitely need support to learn this kind of learning.

More work has to be invested to develop ideas and material for the right kind of scaffolding that will support this kind of qualified learning.

We have started to work on this problem. We help students to install our material on their private computers or offer access to school computers and we will grade any qualified extra work. We offer a list of interesting problems with an open solution to be reproduced as simulation and/or carried out as hand-on experiment. We use part of the time in class to guide our students through the complex interface of xyZET and to construct new simulations. We develop a CD with a series of short video sequences showing an experiment with an open end, asking for additional work to find the correct solution.

A sequence of tryouts under controlled conditions will be carried out to study the influence of these different measures on motivation and learning results.

5. Technical remarks and downloads

The program xyZET was developed under UNIX and X-Windows and runs on a PC platform under the free operating system Linux and under Windows95/8 together with an X-Server.

StarNet (http:// www.starnet.com) has given permission to IPN to distribute the demo version of their X-server X-Win32 together with the demo-version of xyZET.

Demo-version download: http://www.ipn.uni-kiel.de/english/projekte/a7/a7.1/xyzet/mainpage_e.html

Hardware requirements

- Processor: Pentium or comparable
- RAM: 32 MB
- screen resolution: minimum 800*600 with 256 colours
- needed harddisc space: 10 MB for X-Win32, 12 MB for xyZET and components

References

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2 Purcell, E.M., “Berkeley Physics Course, Vol. 2, Electricity and Magnetism”, mc-graw-hill (1965) pp 147-181.

3 Page, L., “The Emission Theory of Electromagnetism”, Transactions ot the Academy of Arts and Sciences, Vol. 26, pp. 213-243, New Haven (1924)

4 H. Härtel, “Classical Mechanics”, 1998, http://www.ipn.uni-kiel.de/english/produkte/programme/programme.html

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