

**LABORATORY TASKS WITH MBL AND MBS
IN INTRODUCTORY PHYSICS CLASSES
FOR
PROSPECTIVE HIGH SCHOOL TEACHERS**

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Abstract

An introductory physics course for prospective high school teachers is described, in which modern technology tools for data gathering (MBL) and use of model building systems (MBS) are used together with real world problems and a constructivist teaching strategy ("contrastive teaching"). The idea is to foster the comparison of experimental and theoretical results by using powerful tools for both. Moreover, the MBS tools (like STELLA) are believed to enable students to work actively on their own theoretical models with a graphical structure similar to concept maps, thus also providing a different representation and deeper understanding.

Teacher education in Bremen

Education of prospective high school physics teachers in physics should be different from education of prospective physicists (physics majors). Whereas prospective physicists are expected to be able to use modern physics in a professional way the main task of prospective physics teachers is to guide students in their learning processes. From research about learning processes (1) we know, that this means to guide a process of self development of students' understanding of physics, in which students typically in a "learning pathway" (2) go through a series of different conceptions. This implies, that a teacher should be able to diagnose different states of learning with different conceptions, and this implies that teachers know different conceptions themselves. To train teachers in this direction we have developed special courses in Bremen which we call "theory development" (see Table 1). We have done them in the areas of mechanics (force and motion), electric and magnetic fields, thermodynamics and atomic physics. A course like this typically starts with students' own conceptions, then goes to research results about different conceptions and finally looks at the development of theory in a historical perspective.

Every teacher student in our country from the beginning has two different subjects like physics and mathematics or physics and English. In Bremen every teacher students does two "school projects" (see Table 1) involving him or her in a three semester course, during which he or she will learn something about teaching strategies and planing of instruction, plan and develop their own teaching materials, go to a high school and teach themselves using their own materials, and work on some evaluation.

Sem	Subject 1: Physics	Education	Subject 2
1	Introd. Phys. 1 (mechanics)	Introduction;	Similar to subject 1, same amount of time
2	Introd. Phys. 2 (waves, thermod., rel.)	Courses in education;	
3	Introd. Phys. 3 (electrodynamics)	School project 1	
4	Introd. Phys. 4 (atomic + nuclear)	(subject 1 or 2)	
5	Theoretical physics	Courses in education; School project 2 (subject 2 or 1)	
6	Modern exp. physics		
7	Adv. physics lab		
8	School experiments lab; Theory development		
Masters Thesis			

TABLE 1. Teacher Education at the University of Bremen

Introductory Physics for Prospective High School Teachers

The introductory physics course is similar to the one for physics majors, but separate. We use modern technology tools for lab work (MBL) and theory (MBS), which probably will be used in schools also, now or in the future (Table 2). The constant use of always the same tools for experiment (data gathering) and theory (modeling) reflect the basic structure of physics and help to make these tools available and useful for students' own work. Some MBL tools we use, like Universal Lab Interface (ULI), Motion detector and Mac Motion are widely known from the work of Thornton and Sokoloff (3). In addition we use BremLab, a new interface and software developed in Bremen by Schecker and colleagues (4), (8).

Computer TOOLS	
Experiment	MBL Microcomputer Based Lab e.g. ULI (Thornton) or BremLab (Schecker)
Theory	MBS Dynamic Model Building System e.g. STELLA (High Performance Inc.)

TABLE 2. Constantly Used Computer Tools In Introductory Physics

Table 3 gives an overview of those lab tasks done with modern technology, either with MBL or MBS or both. Each student does 10 to 12 labs each semester, so this list contains only about 30%, the rest is done in a more traditional way.

Overview of laboratory tasks with MBL and/or MBS	M B L	M B S
1. First year, first semester: Mechanics		
- accelerated motion with ultrasonic motion detector and computer interface AND computer aided modeling of accelerated motion with a special model building software (MBS), e.g. STELLA, e.g. spring powered toy car	x	x
- modeling of two-dimensional planetary motion with the computer	Lit	x
- measuring AND modeling of a car crash model experiment	x	Lit
- measuring AND modeling of different damped oscillations	x	x
2. First year, second semester: Optics and Thermodynamics		
- measuring AND modeling standing waves on inhomogeneous strings	TL	x
- measuring AND modeling of Newton's law of cooling	x	x
- quantitative experiments with a stirling motor	x	TT
3. Second year, third semester: Electrodynamics		
- modeling the transient state of electric circuits	TL	x
- measuring AND modeling of charging/discharging a capacitor	x	x
- measuring AND modeling of electric oscillations	x	x
- modeling movement of electrons in electric and magnetic fields	TL	x
4. Second year, fourth semester: Atomic and Nuclear Physics		
- determining states of standing waves on inhomogeneous strings	TL	x
- modeling spherical states in a hydrogen atom with computer	TL	x
- modeling spherical states in a Li-atom with computer	Lit	x
- modeling the H ₂ ⁺ -molecule with computer	Lit	x
- modeling a solid state with computer	Lit	x
- radioactive decay of two Ag isotopes	x	x

TABLE 3. Lab Tasks with Modern Technology in Introductory Physics (TL: Traditional lab work TT: Traditional theory Lit: Measurement from Literature)

In our approach to include modern technology in an introductory course for prospective high school teachers we try to combine the use of these computer tools with three other goals (see Figure 1). The interesting fact is, that the use of these tools contribute to all of the other goals. MBS and MBL help to give teachers and students more power and control to develop and realize their own ideas and questions in open-ended lab work (constructivist teaching), they both contribute to the ability to work on complex real world problems (everyday life world) with good solutions and especially MBS with STELLA

contributes to focus on the "power tools" of physics (such as Newton's second law) and not on "gimmicks" (such as $x=1/2*a*t^2$). All the STELLA models on force and motion e.g. show in their center the kinematic defining relations between distance, speed and acceleration in an icon based representation and Newton's second law in determining acceleration by force and mass at any instant of time.

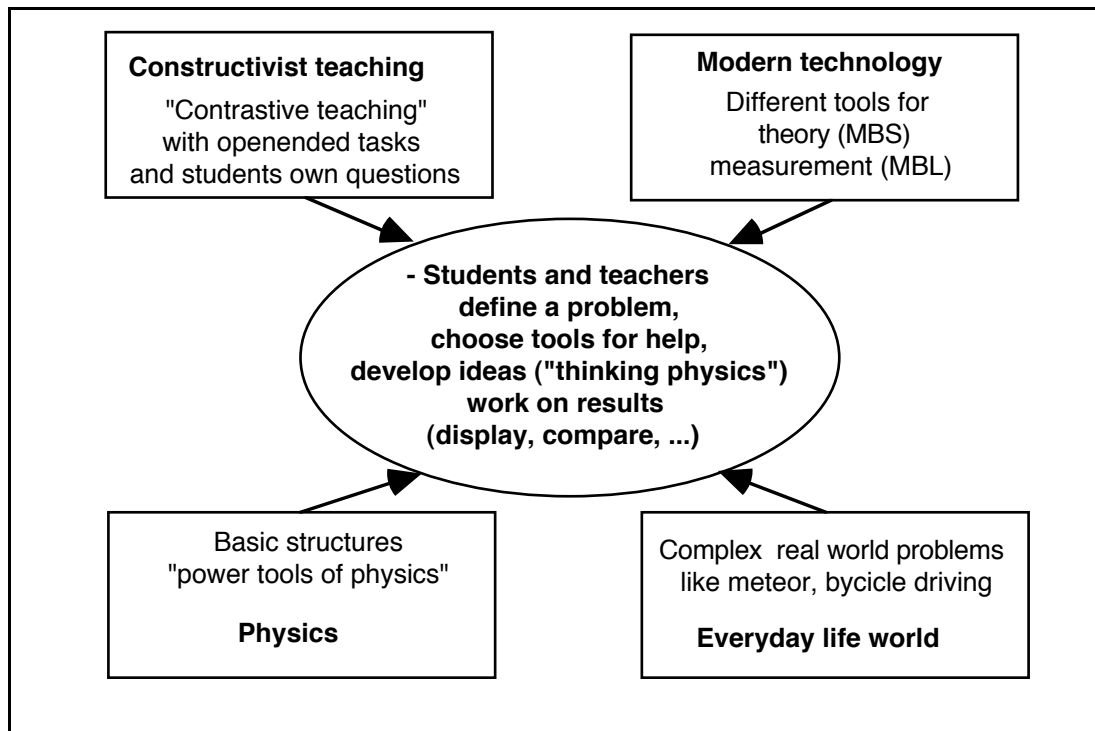


FIGURE 1. Constructivist teaching and modern technology

Different constructivist teaching strategies have been developed, based on research of student understanding and learning (5). They all have one idea in common: to start teaching with some elicitation of students' ideas. In our own constructivist teaching strategy, called "contrastive teaching" (6), we do this explicitly and then come to a point, where the physics idea is introduced by the teacher (or the textbook or whatever) and then contrasted and compared to students' own ideas. The main idea is to let students work on their own predictions, explanations, or models and confront them with the teachers or physics view. This can be done on a short or longer time scale (one minute up to several hours). A short unit can consist of just an open-ended demonstration experiment for which the students write down their observations and questions before any explanations are given by the teacher. Contrastive teaching is not meant to be the overall strategy used in a class. Longer units should take place once or twice a semester in the form of projects. The teachers role there is twofold: he has to understand the students' view and to introduce the physics view. In using this strategy, we try to improve students' active

learning and to show them better teaching strategies for their own teaching later on in school classes. We expect, that teachers often teach as they were taught themselves.

Some specific ways to include those ideas in lectures: I start with a demonstration experiment without explanation (e.g. standing waves on a beaded string). Then each student for him/herself writes predictions (P), observations (O), explanations (E), but also questions, ideas for further experiments, ideas for mathematical treatment. These ideas are gathered at the blackboard, the teacher at this point comments on them reservedly. Students discuss their ideas, After this the teacher starts normal teaching, related to students' contributions. In our lab guides we try to develop more open-ended lab guides. They often give some help to set up a first apparatus and perhaps guide a first measurement in this field. But often later on they have only one open-ended task like: "Try to do an experiment which gives you measurement values which can be compared to a given theory or formula or results of a computer model." Thus students are expected to set up the experiment themselves, plan how and what to measure, and finally come to a comparison of theory and measurement.

Modeling with model building software tools (MBS)

STELLA originally was developed from the system dynamics approach (Forester). It is a model building software tool, which is based on the idea of dynamic modeling as a relation between a variable and its rate of change. This is mathematically equivalent to one or more differential equations. The powerful special feature of STELLA is that it allows students and teachers to work with iconic representations like a concept map, which by the software are translated into difference equations automatically. By this feature STELLA contributes to thinking physics while building a model, to overcome mathematical difficulties, and to gain additional understanding and learning of physics concepts and theoretical structures by providing an additional representation. STELLA focuses on the use of "power tools" of physics, the most general laws like $F=m*a$, not using "gimmicks" like $x=1/2*a*t^2$. We have evidence that thinking physics occurs during the process of building a model, and that specific questions arise for further lab work. So, the ideal situation is building a model while having the experiment nearby.

MBS also reduce restrictions for more complex topics that arise from mathematical boundaries. Quantitative investigations of real world problems, like the motion of a parachutist, can thus be included that are otherwise restrained by the students' insufficient mathematical competence. The students can concentrate on the physical aspects of the description - i.e. conceptualizing and applying principles like Newton's laws - while the computer numerically solves the differential equations.

MBS open up new opportunities for the students to experiment with ideas. Modifying a theory and constructing own approaches is encouraged because MBS based on the system dynamics approach (Forester) present the model in a flow diagram similar to a concept map on the screen .

Structure of the modeling tool STELLA

STELLA is using four main symbols for building models (Figure 2). Two different relations are involved: functional relationship between quantities (algebraic relation) and dynamic relation between "rate of change" and "stock" (calculus based relation, difference equation, see Figure 3).

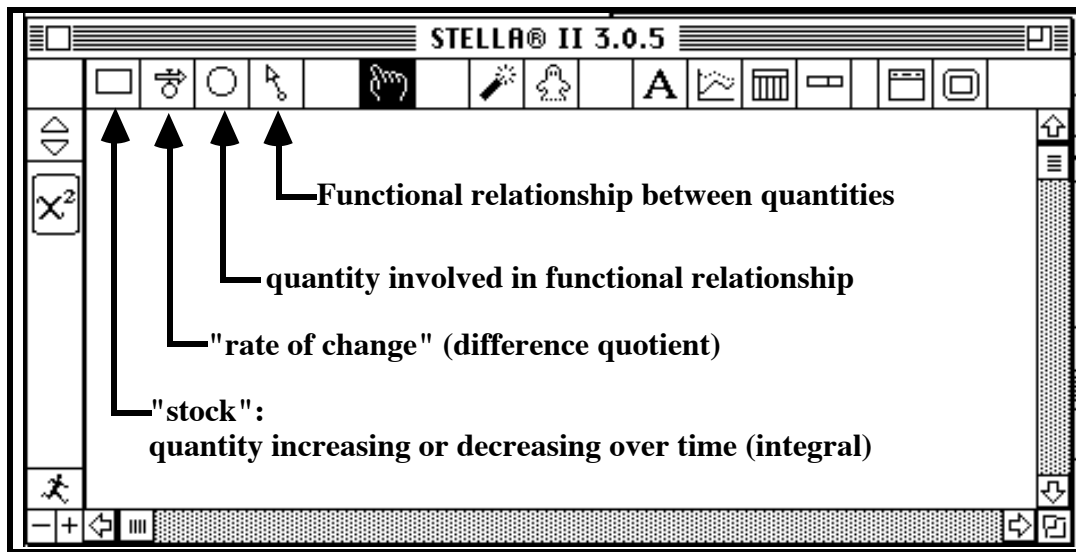


FIGURE 2. The Main Symbols of STELLA for Modeling Physics

Boxes represent so-called "stocks" which are variables to be summed up (integrated) by their "rate of change" (difference quotient), which is represented by the circle beneath the valve. The relation between a "stock" and a "rate of change" is the basic dynamic relation of STELLA models (Figure 3). It can be realized in physics with a great number of relevant variables, like distance and speed, speed and acceleration, energy and power, charge and current and many more (see Appendix).

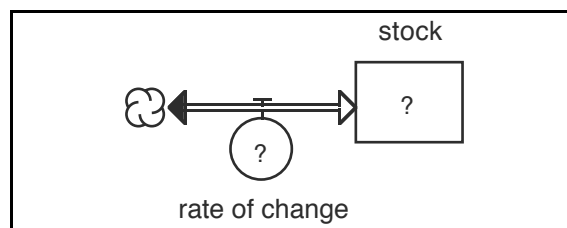


FIGURE 3. The basic structure of dynamic modeling with STELLA

**An example starting with empty screen -
the spring powered toy car.**

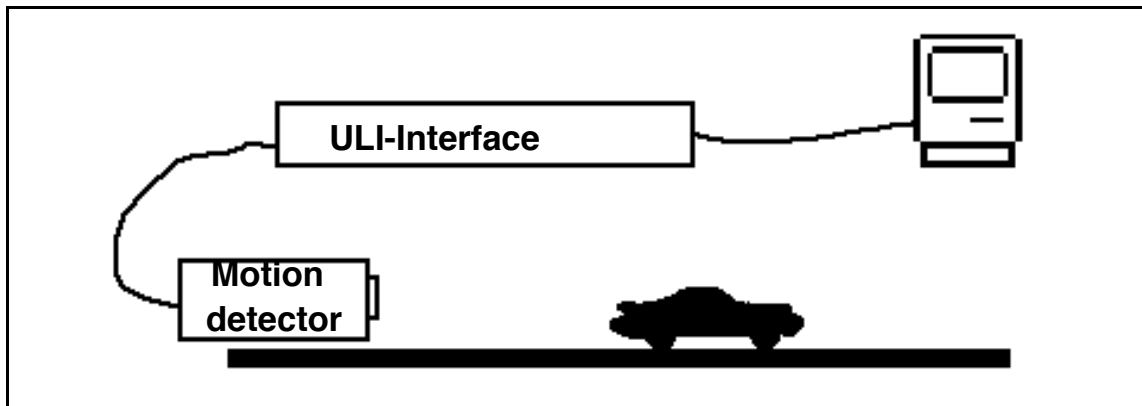


FIGURE 4. Experimental Setup with Spring Powered Toy Car

To show the capacity of iconic model building systems we start with a typical example (7). The situation: In an experiment with a spring-powered toy car and an ultrasonic motion detector connected via interface to a computer, the graphs for position over time, velocity over time and acceleration over time are demonstrated. The task is to explain the graphs by a theoretical model.

We start STELLA on the iconic representation level with an empty screen (Figure 5).

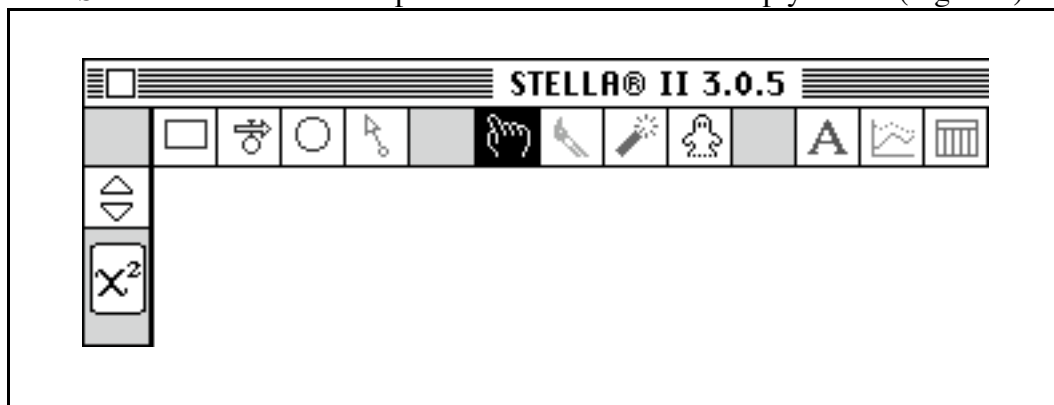
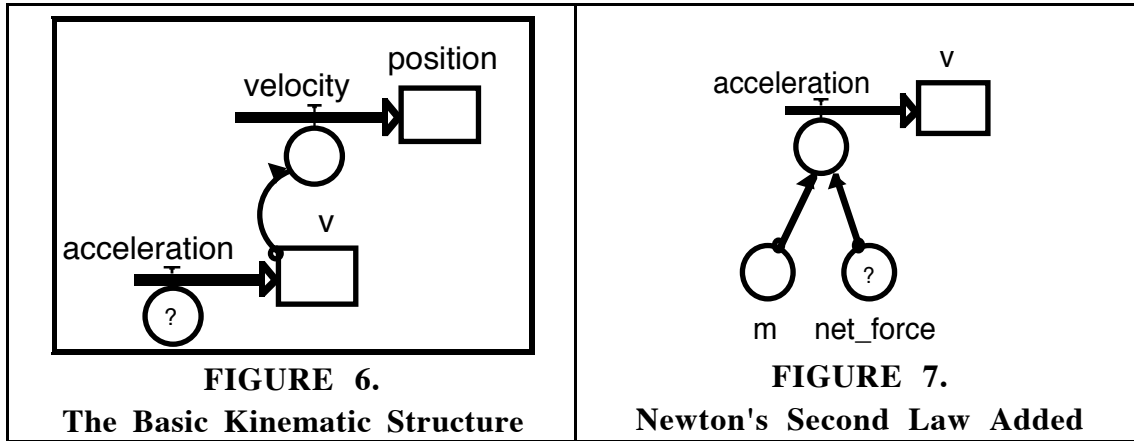
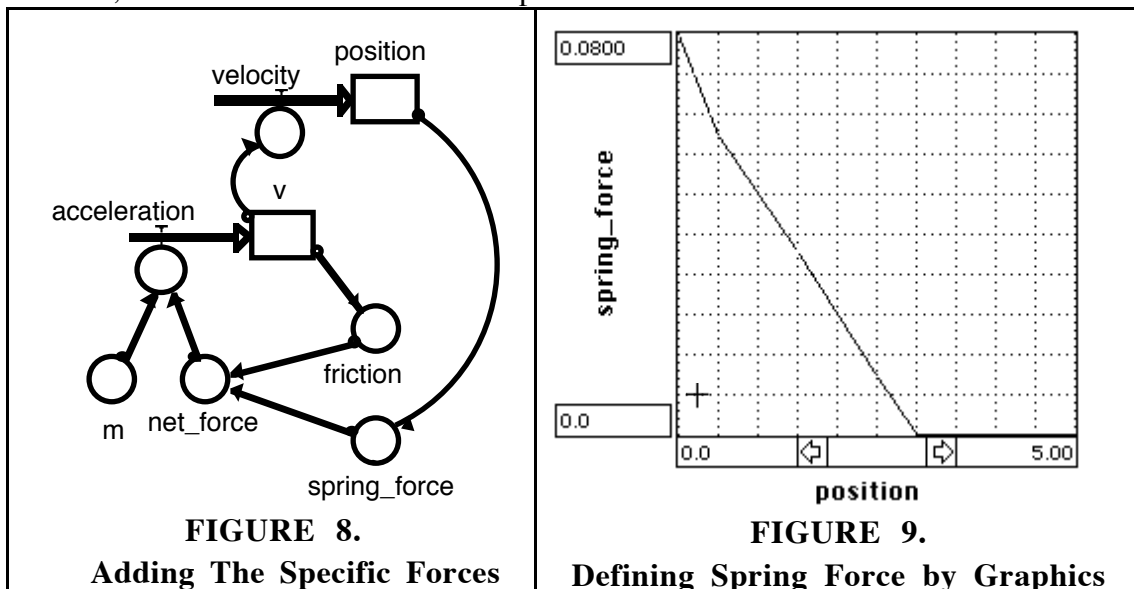


FIGURE 5. Start To Build A New Model With An Empty Screen

Let us assume that we are experienced users of STELLA. Then we already know that velocity v is the rate of change in position d and acceleration a is the rate of change in v . This structure can be represented in STELLA in the form of the $a@v@d$ chain. (Figure 6) Let us further assume that we already know that acceleration depends on mass m and total force net_force (Figure 7)



The now completed $F \rightarrow a \rightarrow v \rightarrow d$ chain forms the core of nearly all the models about the motion of bodies, e.g. cars, rockets, and planets (8). This proto-model has to be adapted to the concrete problem under investigation. At this point we have to analyze the special experiment to be explained by our model more closely. We may conceive that there are two forces, the force of the spring and the friction force. Figure 8 already contains our next qualitative idea that the spring force is not constant but somehow related to position. This idea can be fitted into the model simply by clicking the relation arrow with the mouse and drawing a connection from position to spring. (The question marks in this stadium tell us that initial values and functional relations have yet to be quantified.) Now the iconic model which presents our qualitative assumptions is nearly completed. There is only one feature missing: We have a friction force only if $v > 0$. So we draw an arrow from v to friction, which indicates this relationship.



The conceptual structure of our model, containing the relevant quantities and their principle relationships has been conceived.

We now could do a look to the level of equations by clicking the arrow on the left menu bar. (Table 3) One can see that the equations are prepared using the same names we have chosen. The difference equations showing the relation between integration variables and their rates of change are already formulated.

$\text{position} = \text{position} + dt * (\text{velocity})$ $\text{INIT}(\text{position}) = 0 \text{ \{m\}}$ $v = v + dt * (\text{acceleration})$ $\text{INIT}(v) = 0 \text{ \{m/s\}}$	$\text{friction_force} =$ $\text{IF } v \geq 0 \text{ THEN } 0.035 \text{ \{N\}} \text{ ELSE } 0$ $\text{spring_force} = \text{graph}(\text{position})$
$\text{acceleration} = \text{net_force} / m$ $\text{net_force} = \text{spring_force} + \text{friction_force}$	$m = 0.04 \text{ \{kg\}}$

TABLE 3: Model Equations for Spring Powered Toy Car

Now we proceed to complete the model on the icon level by double-clicking one question mark after the other. Concerning the first equation we have to fill in an initial position, let us say 0 m. The same goes with the second equation: initial value of velocity 0 m/s. In the equation with friction_force we can use the logical variables IF .. THEN .. ELSE to express that there is a friction force only for $v > 0$. The value of 0,035 Newton for the friction force was measured. The mass (0.04 kg) was also taken from measurement. In the force equation we simply say that net force is the sum of spring force and friction force.

A crucial point of physical analysis comes in at the last equation: We have to make a reasonable assumption about the relationship between spring force and position. Instead of formulating a functional equation this can be done in STELLA more easily by using an graphical converter. Let us assume to have the idea that spring force is decreasing linear with position (Hooke's law). In the graphical converter's diagram we can then simply draw a straight line between the initial value 0.08 N - which is given from a measurement of the spring force at the beginning of the motion - and 0 N after three meters which also was given from the experiment. (Figure 9)

This step finished up the second step of model formation: All the relationships are quantified.

The third step is to explore the model. Does the model predict acceleration, velocity, and position in accordance with the experimental data? Proper values for time span and time step have to be chosen as well as the numerical method (Euler, Runge-Kutta). After scaling the axes the model's data can be displayed (Figure 10).

Comparative results "spring powered toy car"

The measurement of model parameters like friction force and spring force are only possible with limited accuracy. In a first calculation we get already the correct shape of all three diagrams. The STELLA model also gives very good quantitative results for the final distance traveled and the maximum speed reached, after the model parameters are fitted to meet the measurements. This is object to a final discussion.

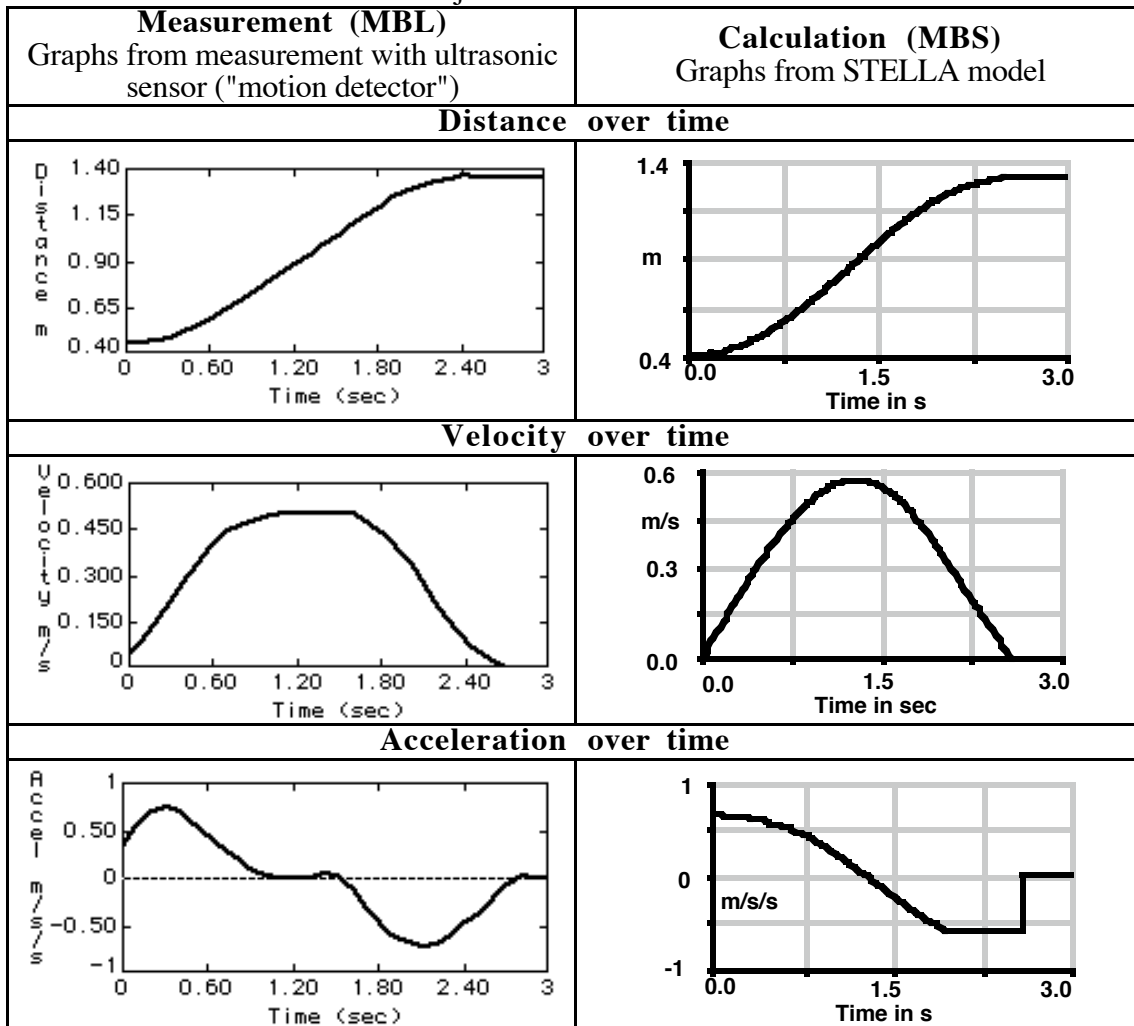


FIGURE 10. Results of MBL and MBS with Spring Powered Toy Car

These results show very good agreement between measurement with MBL and the calculated results from STELLA. To build the model requires good thinking about forces and their dependency on speed and distance. It also requires good measurement of some crucial parameters of friction force and spring force. The model itself displays the main equations like a concept map, helping to understand their relation in a qualitative way.

Crash of a model car

A model car with some simulation of a bumper was used on a car track. Different shapes of sheet metal as a energy absorbing device were inquired. The resulting curve of acceleration over distance (not time!) shows a similar shape as in a professional car crash experiment and can be interpreted as properties of the special construction of the front part of the car or model car correspondingly.

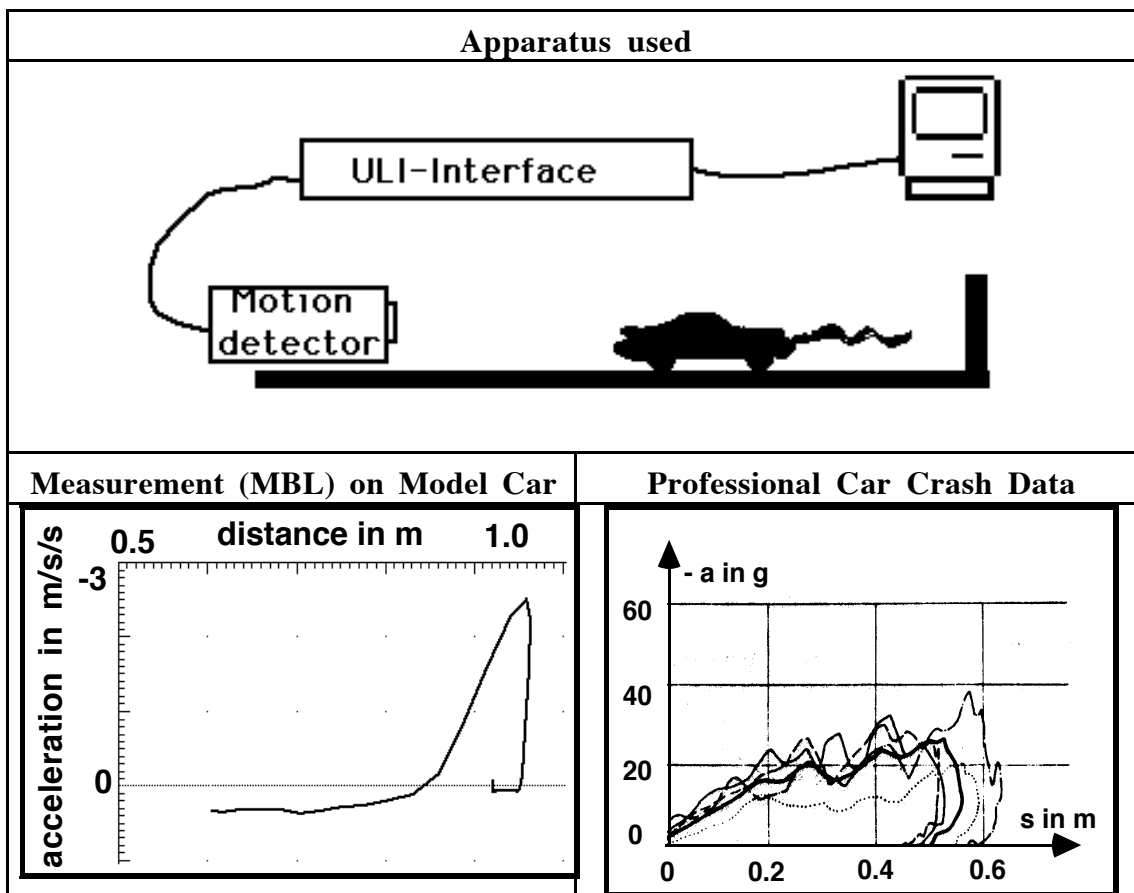


FIGURE 12.
Comparing Results for Car Crash Experiment

From Figure 12, we can see that the acceleration and force increase during the collision in a nonlinear way, both in our model and in reality. The task technically would be to construct the front part of the car such that acceleration and force are more constant, because then it has the least impact on injury.

Oscillations (Free, Damped, Forced)

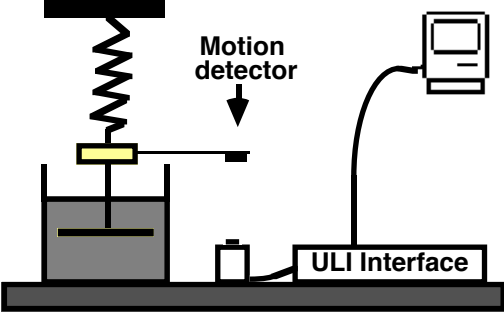
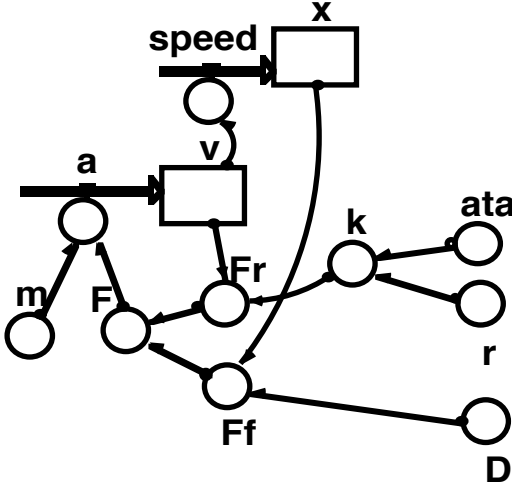
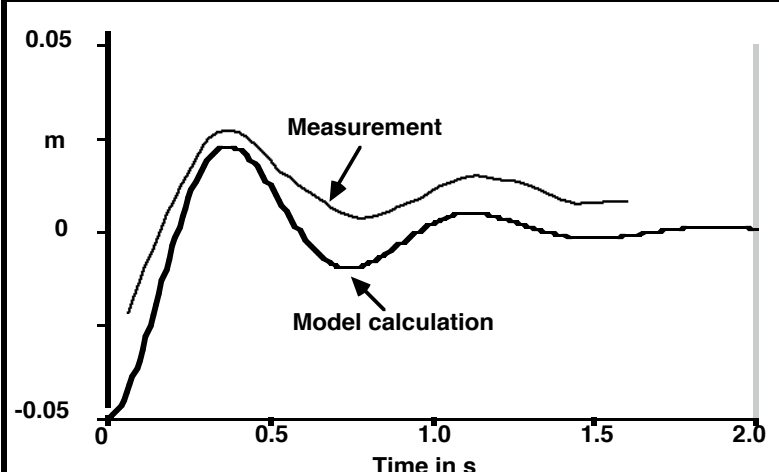
Apparatus used	
	<p>A mass is hanging on a spring. Below the mass, a plate with radius r is connected to the mass and moving in water. The movement is measured with an ultrasonic motion detector together with the ULI interface.</p> <p>The STELLA model is done with a linear equation between friction force F_r and speed v.</p>
STELLA model "damped oscillations"	Equations
	$x(t) = x(t - dt) + (\text{speed}) * dt$ <p>INIT $x = -0.05 \{m\}$ $\text{speed} = v$</p> $v(t) = v(t - dt) + (a) * dt$ <p>INIT $v = 0 \{m/s\}$</p> $a = F/m$ $F = F_f + F_r$ $F_f = -D * x; F_r = -k * v$ $k = 6 * \text{PI} * \text{ata} * r$ $\text{ata} = 4 \{Ns/m/m\}$ $D = 80 \{N/m\}$ $m = 1.062 \{kg\}$ $r = 0.06 \{m\}$
	

FIGURE 13. Damped oscillation.

Measurement with ultrasonic motion detector (ULI) Result of STELLA-Model. Comparison between measurement and theory

Newton's law of cooling

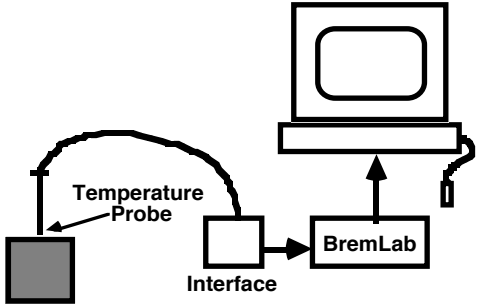
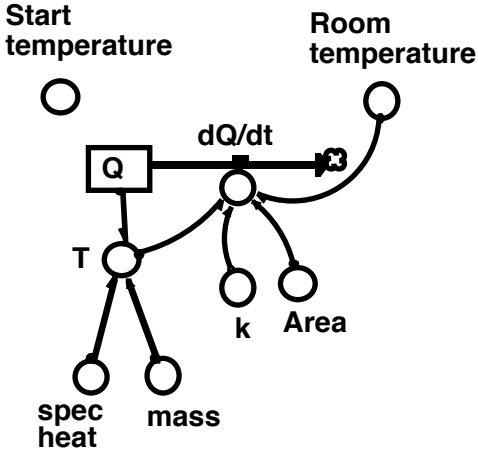
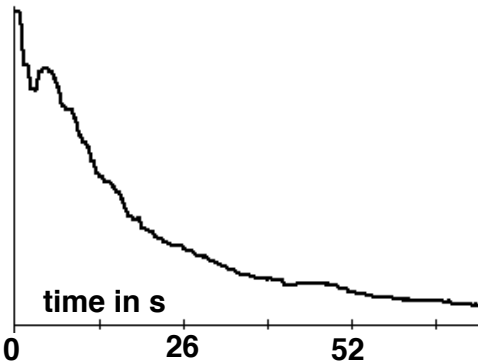
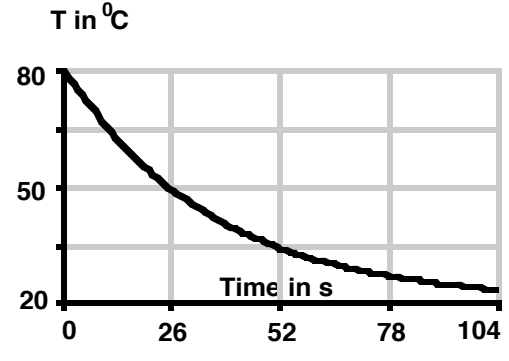
Apparatus used	
	<p>Hot water in a glass tube was connected to temperature probe. In the STELLA model realistic values of surface area and estimates of constants from literature for the cooling constant k (composed of different factors for the different layers) were used. The factor 2 of different half times from experiment and model tells, that these estimates can be improved by fitting the model.</p>
STELLA model of cooling process	Equations
	$Q(t) = Q(t - dt) + (- dQ) * dt$ $\text{INIT } Q = \text{spec_heat} * \text{mass} * \text{Start_temperature}$ $\frac{dQ}{dt} = k * \text{Area} * (T - \text{Room_temperature})$ <p> $\text{Area} = 35e-4 \{ \text{sqm} \}$ $k = 300 \{ \text{J/sqcm/grd} \}$ $\text{mass} = .009 \{ \text{kg} \}$ $\text{spec_heat} = 4182 \{ \text{J/kg/grd} \}$ $T = Q / \text{spec_heat} / \text{mass}$ $\text{Room_temperature} = 20 \{ \text{celsius} \}$ $\text{Start_temperature} = 80 \{ \text{celsius} \}$ </p>
Results from Measurement (MBL)	Result from STELLA model
 <p style="text-align: center;">Half time ≈ 13 s</p>	 <p style="text-align: center;">Half time ≈ 25 s</p>

FIGURE 14. MBL and MBS with Cooling Process

Stirling engine

A Stirling engine from Leybold was used with sensors for transforming p and V to voltage. This voltage was measured with the computer and interface BremLab. Afterwards, the data were imported into MatheLab and analyzed. Especially the area of the curve covering one circle was determined by a special tool of MatheLab, which allows you by simply clicking inside the area to determine its area size in corresponding units, here Joule.

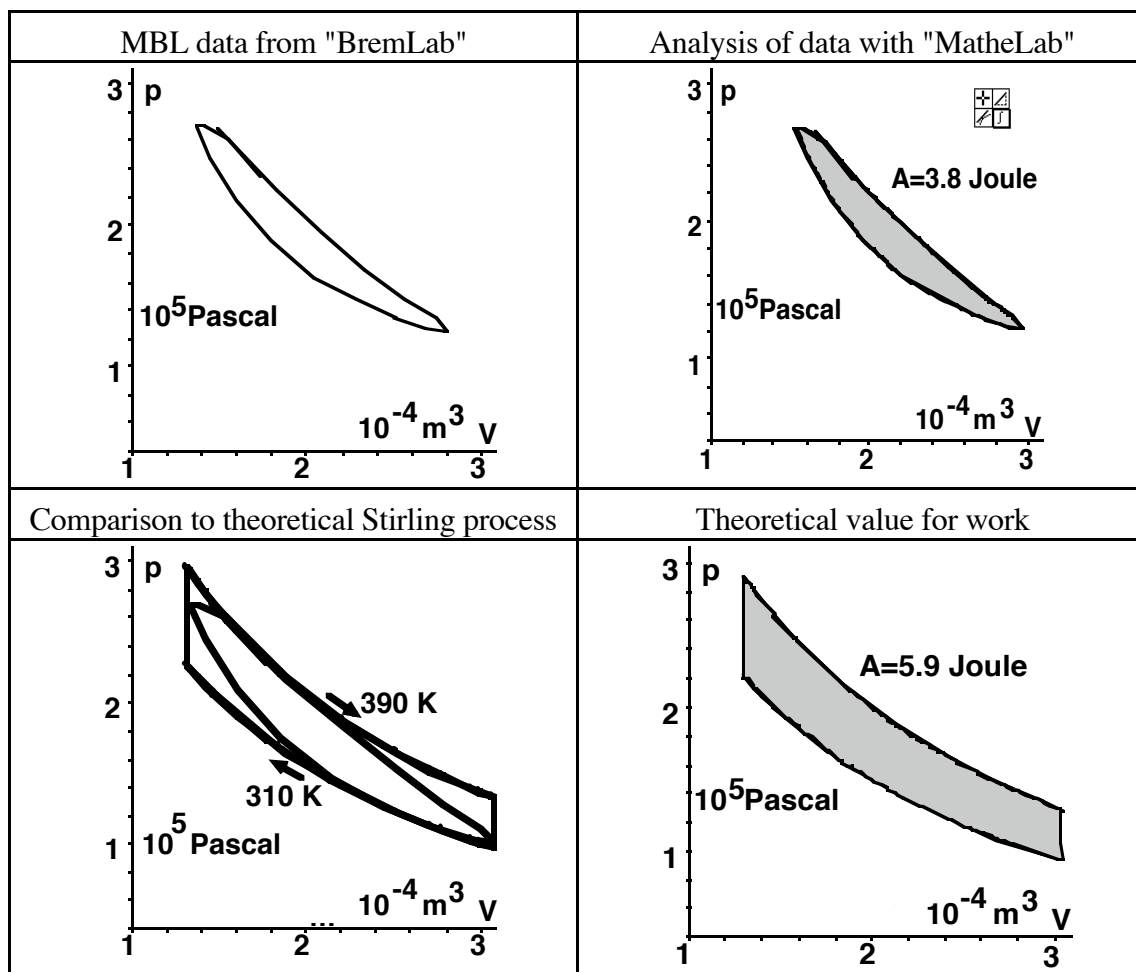


FIGURE 15. Experimental and theoretical results for p-V-diagram

From the measurements, theoretical and real efficiency values can be calculated:

$$\eta_{\text{theor}} = \frac{T_{\text{hot}} - T_{\text{cool}}}{T_{\text{hot}}} = \frac{390 - 310}{390} = 0.21; \quad \eta_{\text{meas,p-V}} = 0.21 \cdot \frac{3.8}{5.9} = 0.13$$

They can be compared to other values from direct measurement of energy input and output:

$$\eta_{\text{meas,work}} = \frac{\text{energy - output}}{\text{energy - input}} \approx 0.05$$

Standing waves on inhomogeneous strings

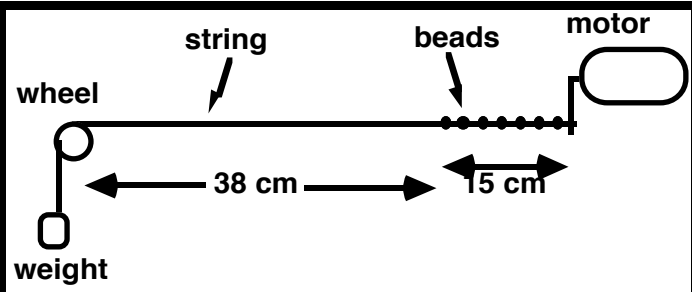
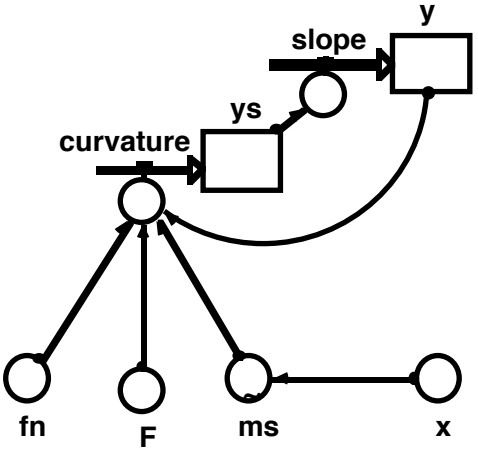
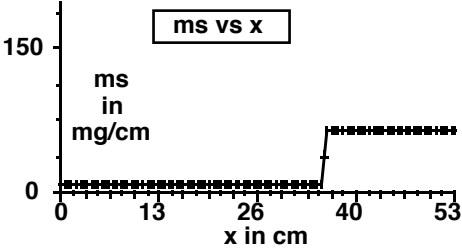
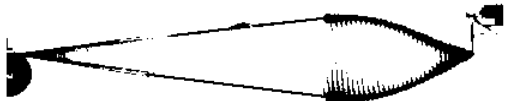
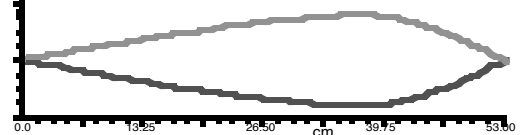
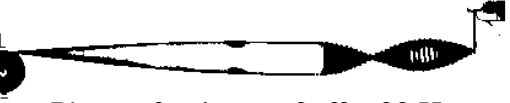
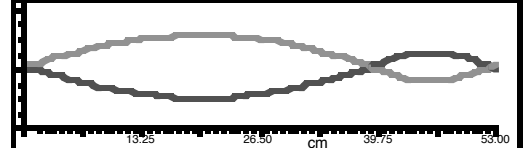

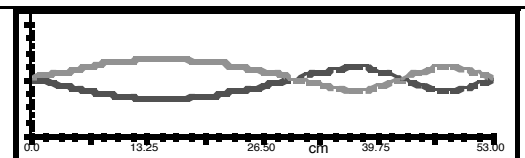
Apparatus used	
	<p>A string consists from 0 to 38 cm of a nylon filament, between 38 and 53 cm yellow beads of a mass of 80 mg/cm are mounted on the string. This string is put in tension by a weight of 0.2 N and is oscillated by a DC-motor and an electric oscillation generator.</p>
STELLA model	Model equations
	$y = y + dt * (\text{slope}) \quad x = \text{time}$ $\text{INIT}(y) = 0$ $ys = ys + dt * (\text{curvature})$ $\text{INIT}(ys) = 1$ $\text{curvature} = -4 * \text{PI} * \text{PI} * 1\text{E-}8 * f * f * (\text{ms}/F_s) * y$ $f = 8.9 \text{ \{Hz\}} \quad F_s = .2 \text{ \{N\}}$ $\text{ms} = \text{Diagram}(x)$ 
Experiment	Calculation (MBS)
 <p>Photo of string: $n=1, f_1= 8.6 \text{ Hz}$</p>	 <p>STELLA model: $n=1, f_1= 8.9 \text{ Hz}$</p>
 <p>Photo of string: $n=2, f_2= 20 \text{ Hz}$</p>	 <p>STELLA model: $n=2, f_2= 22.3 \text{ Hz}$</p>
 <p>Photo of string: $n=3, f_3= 27 \text{ Hz}$</p>	 <p>STELLA model: $n=3, f_3= 28.5 \text{ Hz}$</p>

FIGURE 16.
Comparative Results For A "Two-Step-String"

Radioactive decay of activated silver Ag

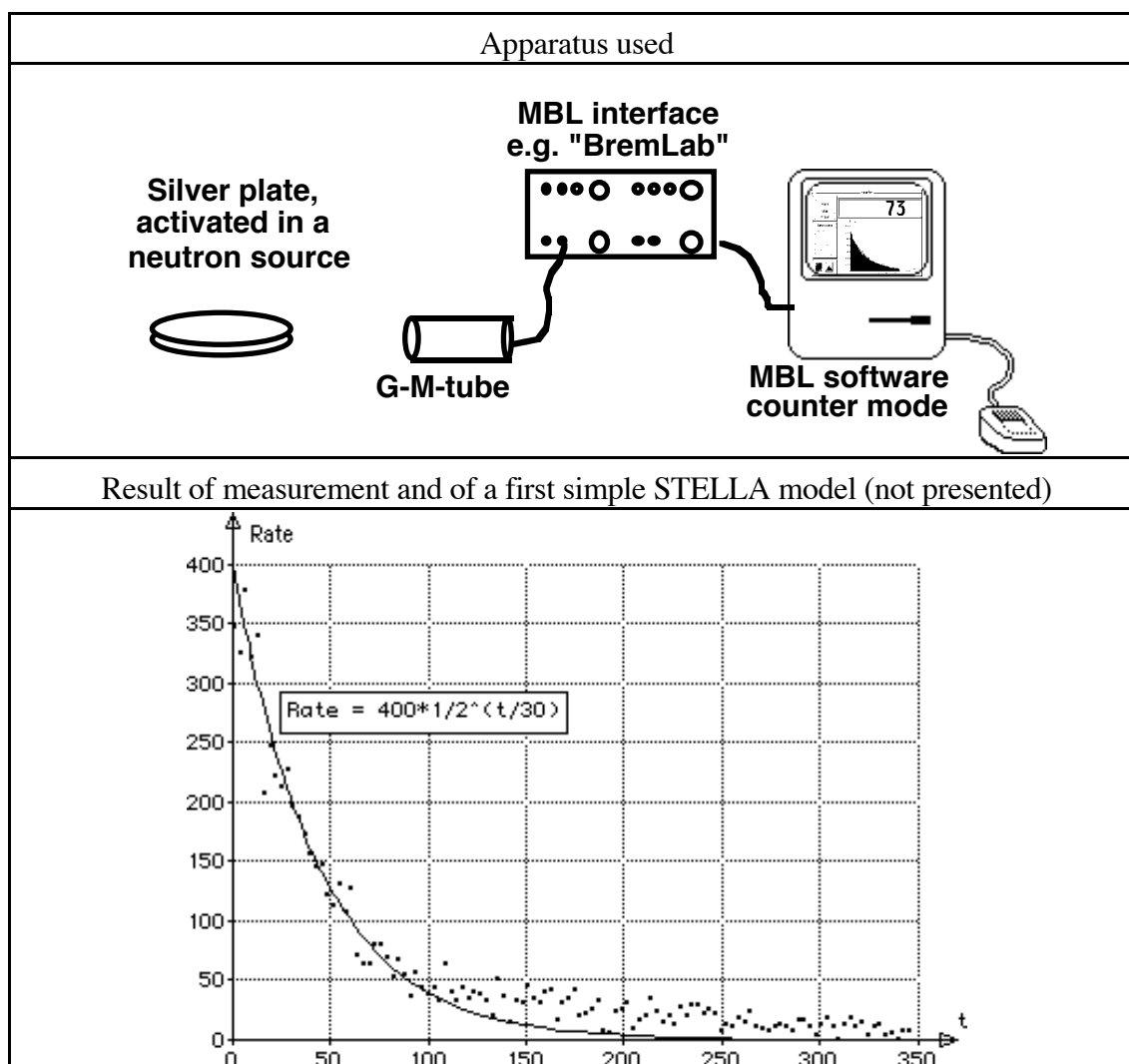


FIGURE 17. MBL data and first model

Here the students have done a simple model first, in fact using a simple equation like

$$\text{rate} = 400 \cdot \left(\frac{1}{2}\right)^{\frac{t}{30}}.$$

From Figure 17 it was obvious, that this theoretical model was not really fitting the data. After this, they started to use STELLA to come to a revised theoretical model, taking the idea of two different nuclei Ag 110 and Ag 108, sending out b-rays to the G-M-tube.

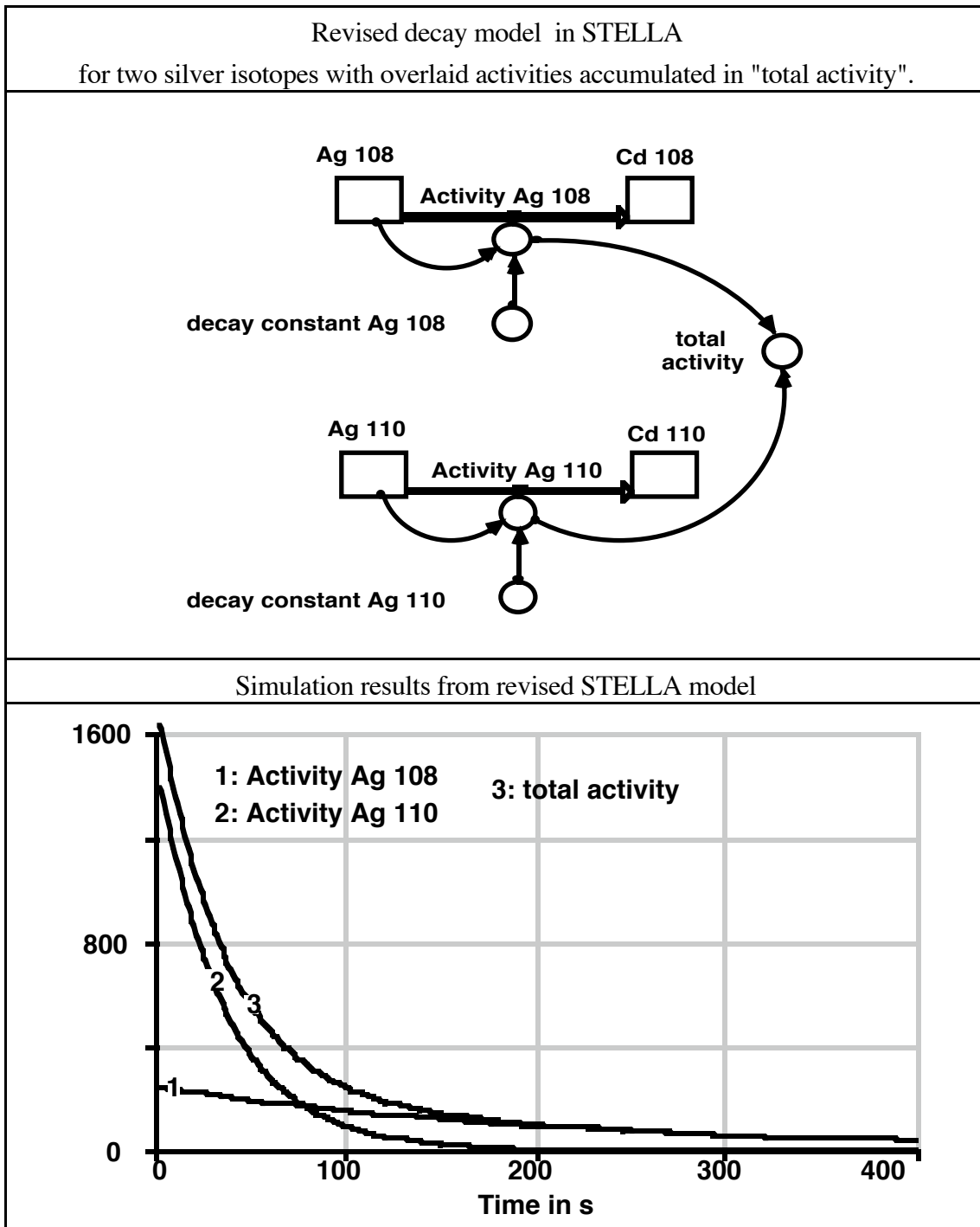


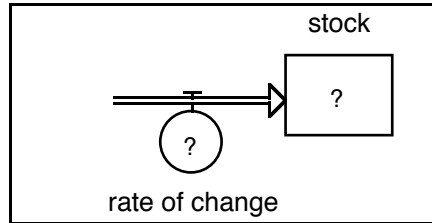
FIGURE 18. Revised STELLA model and resulting graphs

These results are in perfect agreement with measurement, and the STELLA model moreover gives a graphic representation of a conceptual understanding: two different nuclei with different half times contribute to the radiation, one being more intensive at the beginning and one taking over at the end.

Modeling physics with STELLA.

Overview of some basic structural elements

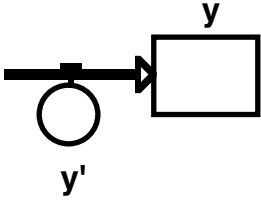
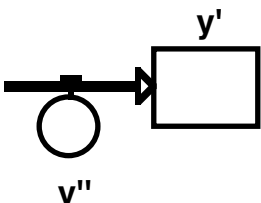
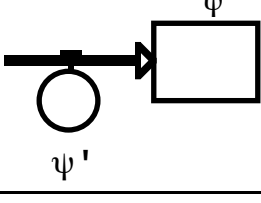
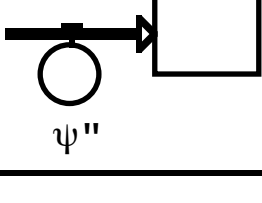
The basic structure used in STELLA is the dynamical relation between a stock, e.g. distance, and its rate of change, e.g. velocity. As this is crucial for all work with STELLA we give a list of examples from physics.



Rate of change	Symbol	Stock	Equations	Examples
velocity or speed v	 d v	distance or position d	$v = \frac{\Delta d}{\Delta t}$ $d(t) = d(t - dt) + (v) * dt$	Any linear or curved movement, e.g. oscillations
acceleration a	 v a	velocity or speed v	$a = \frac{\Delta v}{\Delta t}$ $v(t) = v(t - dt) + (a) * dt$	Any linear or curved movement, e.g. oscillations
power P	 W P	energy W	$P = \frac{\Delta W}{\Delta t}$ $W(t) = W(t - dt) + (P) * dt$	Any time changes of energy in mechanics or electricity or else where
electric current I	 Q I	electric charge Q	$I = \frac{\Delta Q}{\Delta t}$ $Q(t) = Q(t - dt) + (I) * dt$	Any time changes of a charge, e.g. charging a capacitor
activity A of a radioact. subst.	 N A	total number N of active nuclei	$A = \frac{\Delta N}{\Delta t}$ $N(t) = N(t - dt) - (A) * dt$	Any radioactive decay of one or more substances

All examples above were related to changes **in time**. STELLA is primarily used in that way. But of course you can have changes along other dimension, e.g. in space. This has become an important tool in our approach to model standing waves and atomic orbitals in

a similar way. So below we continue the table with two examples of a change **in space** along a x-axis.

Rate of change	Symbol	Stock	Equations	Examples
First deriv. y' , also called slope or gradient		Function $y(x)$, e.g. amplitude of a standing wave	$y' = \frac{\Delta y}{\Delta x}$ $y(x) = y(x - dx) + (y') * dx$	Standing waves on strings, membranes or in cavities
Second deriv. y'' , also called curvat.		First derivative $y'(x)$, e.g. slope	$y'' = \frac{\Delta y'}{\Delta x}$ $y'(x) = y'(x - dx) + (y'') * dx$	Standing waves on strings, membranes or in cavities
First deriv. y' slope or gradient		Function $y(r)$ e.g. the amplitude	$\psi' = \frac{\Delta \psi}{\Delta r}$ $y(r) = y(r - dr) + (y') * dr$	Wave functions in atoms, molecules, and solids
Second deriv. y'' , also called curvat.		First deriv. $y'(r)$, e.g. slope	$\psi'' = \frac{\Delta \psi'}{\Delta r}$ $y'(r) = y'(r - dr) + (y'') * dr$	Wave functions in quantum physics, e.g. in atoms, molecules and solids

This overview already by its qualitative iconic representation produces a new understanding. It shows that from this perspective the relations distance- speed, speed- acceleration, charge-current and energy-power are of the same kind. Because some of these relations are more intuitive than others, this already can be a help by some kind of learning from analogies.

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