TRAINING TEACHERS AS EVALUATORS AND INFORMED USERS OF SIMULATIONS

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Introduction

Interactive simulation environments have been part of the science education scene since the 1980's. Many simulations dealing with a variety of science principles and phenomena are now available to teachers and students worldwide, e.g. [1-10]. Considerable research into the effect of simulations on science learning has been carried out, and it has been shown that given the right conditions, simulations can provide **powerful instructional tools** for addressing conceptual and procedural learning difficulties (e.g. McDermott 1990, Redish 1993, Ronen et al. 1993, White & Fredriksen 1998, De Jong et al. 1999, Edelson et al. 1999, Ronen & Eliahu 1999 and 2000, Goldberg 2000) and for promoting students' motivation (Lepper & Malone, 1987, Keller & Suzuki, 1987). The potential of simulations has been recognized by educational authorities. Since 1994, the physics education authorities in Israel have recognized simulation-based inquiry as a legitimate option for the final practical examination for high school physics majors.

Research has also shown that realizing the learning opportunities simulations can provide depends on specific instructional knowledge, strategy and practice. (e.g. De Jong et al. 1999, Langley 1995, Njoo & De Jong 1993). The abundance and wide accessibility of materials means that teachers can easily increase their stock of collected materials but optimal instructional use of simulations depends on **knowledge about these cognitive tools** and **methods for their evaluation**.

Our extensive experience, gained over more than a decade of training pre-service and in-service physics' teachers to incorporate simulations in their teaching (partially summarized in Ronen et al. 1996), has led to the following characteristics of physics teachers' use of simulations:

- **Perceiving simulations as real experiments**: Simulation developers and marketers often describe their products as "simulated experiments" or "virtual labs" [3, 4]. Teachers tend to interpret this terminology in two contradicting ways: (1) Using simulations threatens the important role of the "real laboratory" in learning physics. (2) The on-screen visual display is identical to physical reality. The first interpretation causes suspicion and unwillingness to use simulations, while the second brings about uncritical use and subsequent frustration.
- **Focus on "traditional teaching needs"**: Teachers often use a simulation "to show" the implementation of formulas. Teachers tend to attribute high value to simulations that technically facilitate the visual display of systems or phenomena that require effort to produce manually on the black/white board or on paper (e.g. trajectories, ray diagrams, electrical circuit diagrams and relational graphs).
- **Limited repertoire of instructional activities and instructional techniques**: Practicing teachers using simulations tend to present students with a limited repertoire of instructional tasks, resembling drill and practice problem types. They rarely utilize the potential of simulations to stimulate discourse or to develop content-related, higher order thinking skills (e.g. making predictions, designing and testing, conducting inquiry).
- **Limited horizon of relevance**: Teachers tend to reject instructional tools that they do not consider relevant to their traditional objectives, dictated by the syllabus or by state exams (e.g. observing and analyzing motion under the effect of an invented force or a complex combination of known forces). Teachers often reject "highly general" simulations dealing with complex environments and prefer easily recognizable applications.

Science teachers have been exposed to instructional simulations for over two decades. For most of this period the focus of teacher training was on acquiring expertise in operating specific programs, a process that required substantial effort (both for trainers and trainees) due to the relatively low level of teachers' computer literacy and operating skills and because simulation programs were less "user friendly". Changes in training foci and methods are indicated owing to advances in computer computation speed and interface technology, increased presence of computers in homes and schools, the abundance of freely available simulations, improved operating skills of the average teacher and most importantly, advances in research-based understanding of learning, instruction and teacher practice (Gil-Perez & Pessoa de Carvalho 1998). We contend that a shift of focus in teacher training is indicated towards general, principled knowledge and skills and away from mere proficiency in operating specific programs and employing them in a non-optimal manner. The current situation presents new challenges for educating teachers to analyze and evaluate available materials and effectively incorporate them into the teaching and learning process.

What teachers need to know about simulations?

"*A simulation is a modeled interactive environment that reflects particular attributes of another system*" (Vivek 2003).
"*A simulation creates or re-creates a phenomenon, environment, or experience; It provides an opportunity for understanding; It is interactive; It is grounded (based on a consistent model of a theory); It is unpredictable: (based on randomness, or an extreme sensitivity to user inputs)*" (Schmuker 1999).
If we view "simulations" as an **area of content** we can associate with it two kinds of teacher knowledge: subject-matter knowledge and pedagogical subject-matter knowledge (Shulman 1986).

Subject-matter knowledge:

1. Simulations are model-driven. Models are essentially mathematical functions (algebraic or logical) that define relationships in the simulation environment and determine its evolution. Simulation related **discourse** has a specific terminology (e.g. model, input, output, time step, sampling, approximation, representations etc.).
2. Simulated events evolve at two levels: the computational (numerical) level and the visual (on-screen animation and graphing) level. Visual elaborateness can range from symbolic/ schematic to rich productions. Not all the visual features are represented in the computational model (e.g. a truck is treated as a point mass).
3. Simulation models may be related to realistic events or to imagined worlds. Simulations vary in their level of generality and the richness of the environments they represent. The model often deals with a selective representation of the environment (e.g. friction with track but not with air).
4. Simulation programs sometimes provide Authoring Tools that allow the teacher to impose content and operational restriction on a general environment (e.g. Ronen & Eliahu 1996).

Pedagogical subject-matter knowledge:

1. Simulations are useful environments for exploring principles, for representing systems and exploring their rule-based behavior (Schwartz, 2003). Simulations can and should be used to explore "other worlds and realities". The explicitness of physical concepts allows control of variables and provides the necessary condition for **interactivity**. Simulations can **provide a bridge between concrete experience and abstract concepts and relations**. The way variables are manipulated, and the spectrum of responses through **multiple representations**, define the simulation's **experiential level**.
   - The fidelity of the simulated environment should be tailored to the level of student expertise and knowledge (Alessi 1988).
   - Simulations are not intended to replace demonstration of real phenomena.
2. Simulations are cognitive tools that offer opportunities to engage students (individually or collaboratively) at different cognitive levels in challenging problem solving tasks (e.g. design and inquiry) in the classroom or away from it.
   - Learners' conceptual and operational difficulties affect their performance of tasks in a simulation environment.
   - The responsiveness of simulations can have a **negative** effect on students' willingness to engage in theory-based predictive reasoning ("What if?" situations). Students tend to "try it and see". Results of several studies have indicated that immediate feedback may be more effective for lower-level knowledge acquisition. Interfaces that are less "user-friendly" may, in some instances, be more conducive to concept learning (Vivek 2003).
   - Learners tend to adopt an "engineering approach" (attempting to achieve a particular end-goal during a simulation), in contrast to a "scientific approach" (theorizing about the model and attempting to uncover model rules and relationships) (Schauble et al. 1995).
   - Fast pace prevents students' from thinking deeply and asking questions. Work in the simulation environment should not be purely technical.
3. Critical, knowledge based, reasoning should be engaged when viewing unexpected "simulated phenomena":
   - Computational "bugs" or the discreteness of the computers time-space sometimes produces scientifically invalid artifacts.
   - Simulations may produce unexpected/surprising patterns of behavior that are scientifically valid.
4. There is a learning curve associated with operating different simulations.

Towards effective teacher training: A proposed Training Model

The preceding discussion reveals the complexity of the knowledge and skills required for effective integration of simulations into physics instruction. It also points to the **potential for professional development** that can be achieved through appropriate training. An effective training model needs to address the complexity of required knowledge and skills and allow for gradual **knowledge integration** through moderating the load of cognitive and practical skills. A suitable training model should have a **progressive** structure that enables the gradual guiding of trainees along such developmental dimensions as: "acting-reflecting", "operator-evaluator", "trainee -instructor", "science focus-instructional focus" and "user-developer". The training model should also have sufficient flexibility to accommodate different training needs of teachers in various stages of their professional development (Fuller 1969, Berliner 1987).
The training model we are proposing is targeted towards:

- Developing a vocabulary and the ability to characterize, analyze and evaluate instructional simulation.
- Relating the use of simulations to learning difficulties documented by research in physics education and to teachers' own experience.
- Training teachers as developers of customized, simulation-based instructional activities.

The training model consists of the following four phases, described in terms of the trainees' intended performance:
Phase 1: Experiencing the student's perspective of simulation-based learning.
Phase 2: Characterizing, analyzing and evaluating instructional simulations.
Phase 3: Defining and addressing specific instructional objectives by simulation based activities.
Phase 4: Testing prepared activities and performing formative evaluation.

The complete training model requires a full semester course (14 ninety minute sessions or their equivalent in distance learning methods). Clearly, partial implementation versions are possible with correspondingly reduced outcomes. We shall now describe the content, the foci and the activities included in each phase of our progressive training model.

Phase 1: Experiencing the student's perspective of simulation-based learning.
The main purpose of this phase is to create awareness of a variety of **instructional techniques and approaches** through direct experience. We assume that many of the teachers have not experienced simulation-based learning and that without such experience there is little basis for teachers' ability to design activities or conduct suitable lessons for their own students.
During this phase (2 ninety minute sessions) the Trainee Teachers (TTs) experience simulation-based learning as students, in two forms: (a) Participating in a whole class teacher-directed lesson, (b) Carrying out small-group simulation-based activities.

a. The instructor presents a relatively rich simulation to the TTs in a whole class setting and uses it to address a problematic/challenging issue in some area of basic physics content (e.g.: electricity, optics). The instructor encourages discussion and predictions related to the physics content and contributes to the discussion by demonstrating the simulation's ability to react interactively to user inputs and to produce visual representations. At a crucial point in the controversial discussion the instructor stops the lesson abruptly (without settling the physics content issue) and instructs the TT's to "*Think about his later*". At this point the instructor changes the focus from "physics content" to "instructional content" by stating: "*You have experienced various strategies of using a simulation as a teaching aid. Try to identify and describe them*". The rest of the session is devoted to teacher-led class discussion and reflection on the instructional strategies.
b. The instructor presents the TTs with a printed worksheet containing a set of varied problems designed to reflect researched difficulties in learner understanding (e.g. Eylon & Ronen 1993, Ronen & Eliahu 1997). The problems deal with the same physics content area as in the previous sessions and the same simulation is available on student computers. The TTs work on the problems individually or in pairs, with or without using the simulation. At a certain point the instructor changes the focus from "physics content" to "instructional principles and practice" by requiring trainees to discuss and reflect on: "*How did using the simulation help you deal with the problems you encountered and what are the advantages and difficulties?*"

During this phase, moderation of the cognitive and skills load is achieved by focusing on a single simulation and by the instructor taking responsibility for lesson design, materials and management.

Phase 2: Characterizing and evaluating instructional simulations.
Phase 2 is mainly intended to guide the TTs' development along the "operator-evaluator" dimension.

a. The instructor presents and discusses various characteristics of simulations and establishes a vocabulary. The instructor demonstrates the concepts using the original simulation plus several others. The analysis covers concepts and ideas related to both types of knowledge about simulations teachers should possess:

- Simulation content knowledge: Simulations versus modeling software, simulation versus animation, interactivity, fidelity, controllable inputs (qualitative, quantitative, range) simulation outputs (qualitative/quantitative), computational model (function/iterative, deterministic/probabilistic), representations (iconic/symbolic, qualitative, quantitative, dynamic) and computer artifacts.
- Simulation pedagogical-content knowledge: physics concepts and relations that can be addressed and how (qualitatively/quantitatively), unique potential offered as compared to other instructional tools, limitations, artifacts or confusing aspects.

b. TTs receive a homework assignment that includes selecting a simulation of their choice, analyzing and characterize it using the new terminology, and suggesting possible instructional applications. A template is provided to scaffold this activity.
c. During the following sessions (number depending on class size) a sample of TTs present their work and peers provide feedback, queries and suggestions.

Phase 2 initiates the TTs transformation from naïve to informed use of instructional technology and increases their level of ownership. This is achieved by employing several pedagogical strategies: modeling (by the instructor and eventually by peers), scaffolding (using a template), "writing to learn" (Keys et al., 1999) and feedback (by peers and instructor). The progressive nature of the training model is also manifested during this phase by expanding the world of simulations the TTs encounter.

Phase 3: Addressing specific instructional objectives and Designing related simulation based activities.

a. The instructor presents and discusses various strategies and formats of simulation-based activities focusing on the following aspects: (1) The unique features of simulation-based activities (compared to textbook tasks and laboratory experiments) and (2) Linking activity design to instructional research findings on physics instruction.
b. TTs receive a homework assignment (in pairs or small groups) that includes selecting a physics topic, identifying related instructional problems using resources such as research papers and personal or peer experience, and

developing a series of simulation-based activities to address these problems. This assignment is scaffolded by printed templates and Internet access to examples included in the instructor's presentation.

This phase presents a **major step** in the development of trainees along the dimensions of "user-developer" and "trainee-instructor" and requires integration of pedagogical content knowledge related to both physics and simulations. TTs now apply the knowledge, ideas and skills they acquired in the previous phases with the focus on **specific instructional impact**. The progressive design of our training model is manifested by expanding the horizon of relevance to include research in science education. During this phase TTs gain experience and confidence in preparing their own instructional materials which they will be able to use and test during the next phase.

Phase 4: Testing prepared activities and performing formative evaluation.
TTs test, evaluate and revise their prepared simulation-based activities in one of the following settings:
- Testing on peers followed by peer evaluation and feedback (mainly for pre-service trainees).
- Classroom implementation and reflection through action research (mainly for in-service trainees).

The evaluation process includes discussion and summary of the results. Later, the activities are revised according to the evaluation findings.

This phase provides the TTs with opportunities to implement and integrate the knowledge and skills developed during the previous phases. This phase places the TT in the roles of "instructor" and "evaluator". The progressive structure of the training model is manifested by including the ultimate subjects of instruction – school students.
This phase promotes teachers' professional development along the "acting-reflecting" dimension by providing tools for, and emphasizing the importance of, formative evaluation. In addition, TTs continue to improve their knowledge and skills concerning giving and receiving peer feedback.

Some features of trainee teachers' response to the training model

We have implemented variants of this training model with different trainee populations, and we have found some typical response features for in-service and pre-service participants, which the following examples will illustrate:

Phase 2: The assignment requires trainees to select a simulation, analyze and characterize it using the new terminology in a prescribed format and to conclude by suggesting possible instructional applications. The first part requires application of explicitly taught terminology within a provided template and TTs perform quite well, regardless of their teaching experience. The second part (relating the identified characteristics to pedagogical subject-matter knowledge) is expectedly problematic for TTs, especially those lacking teaching experience:

Limor (a pre-service student) was excited about a simulation she found on "Young's Double Slit Interference" [6] (fig 1). She used the given template and correctly characterized all the aspects of this simulation. Her original suggestion for possible applications included quantitative activities regarding the relations between the properties of the interference pattern (distance between the fringes) and the input variables (light wavelength, slits' spacing and the distance between the slits and the screen). Only during her presentation to peers did she realize that her suggestions were not feasible with this environment since the **simulation output** is **only qualitative** and no numerical data is provided about the distance between the fringes.

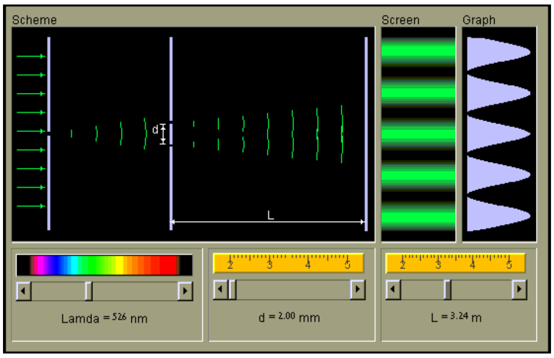

Figure 1

Anna is a highly motivated novice teacher in her 3rd year. After phase 1 she enthusiastically used the instructor's simulation based activities in her own class. For phase 2 she selected a pendulum simulation [8]. She was excited about the richness and multiple representations, the quantitative data provided by this program and by its friendly interface. Anna suggested potential use of this simulation for: "*demonstrating and exploring the difference between large and small oscillations*". When trying to demonstrate her idea to the class Anna was dismayed to find that input of initial angles was limited to 20 degrees. This limit was imposed by the developers who based the computational model on the small angle deviation approximation. Anna did not interpret correctly the instructional significance of the limited range of the relevant input variable. This instance represents a common tendency of novices to associate a given simulation with a visually similar real physical set up and to expect identical behavior.

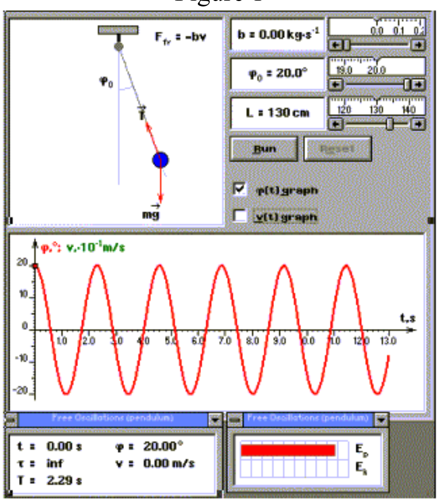

Figure 2

Phase 3: This phase is very demanding and requires learning and integrating different kinds of new knowledge and skills. The assignment requires trainees to identify specific instructional problems and to design and prepare simulation-based activities to effectively address these problems. Although this activity is scaffolded by resources, examples and templates, trainee performance shows the following characteristic faults:

- Failing to identify a meaningful instructional problem: This aspect is especially problematic for pre-service trainee. Lacking relevant experience to draw upon, these TTs are unable to make use of the research references the instructor provides. Getting pre-service trainees started on their project often requires personal guidance for identifying and defining a meaningful instructional problem. A prepared list of identified instructional problems in various domains would be a useful scaffolding tool for these teachers.
- Poor or unsuitable selection of the simulation environment and lack of awareness of necessary "tradeoffs" that may be imposed by the limitations of the tools: TTs tend to select simulations they already know or the first ones they find rather than continue searching for one most suitable for their purposes. Trainees sometimes select simulations that prove to be unsuitable for dealing with the instructional problem they are trying to address and remain unaware of this because they write activities without actually trying them out, naively assuming that the simulation would work the way they want it to.
- Employing limited instructional strategies: Both in-service and pre-service trainees manifest a strong "resistance" to change. In spite of the many examples presented, the first version of the prepared activities often resembles "familiar" materials (textbook exercises).
- Difficulties in producing instructional materials: The first version of activity worksheets is poorly written and designed, lacking attention to detail.

These issues surface during the formative evaluation in **phase 4**, when peers try the materials, suggest improvements and reflect on the activities. Feedback provided by peers and by the instructor may result in some improvement in the design of the activity (student worksheet), in revised instructional strategies and in better matching between instructional tools and goals (selecting a more suitable simulation or changing the instructional goals so that they can be addressed with the existing simulation).

The following example illustrates a successful design process that included "tradeoff" between the instructional goals and the available simulation:

Rafi, an experienced teacher, became aware that his 10th grade students confuse the concept of "short circuit" with "disconnected circuit". "*Since it is not advisable to explore short circuits in the lab*", Rafi designed a set of simulation based student activities to help students understand these concepts and the possible sources of confusion.

Rafi tested his draft version in the "EWB - Electronic Workbench" simulation environment that that was available at his school. His first circuit (fig. 3a) included a battery, a light bulb and an open switch connected in parallel. Rafi used a **Predict, Observe, Explain** strategy: "*What will happen to the light bulb and to the battery if you close the switch? Explain your reasoning*". Rafi expected students to see that the bulb goes out and the current becomes very high, then the battery "dies".

When he closed the switch, an error massage appeared explaining that the simulation model accounts only for ideal batteries, and suggesting that a resistor be added to the circuit. Rafi thought that since he had to add a component he would use an Ammeter with internal resistance so that students would be able to see the values of the current. Now he got the expected behavior of the bulb and the high current but the battery in this simulation continued functioning indefinitely regardless of the high current (fig. 3b).

At this point Rafi could either change his original activities (and alter some of his original instructional goals) or find another simulation program (for modeling the limited capacity of batteries). He decided to continue using "EWB" but to present the battery as a "*DC voltage source like the one used in the Lab*" and to present a **Design and Test** type activity that challenged students to create a circuit so the wires should be protected from currents exceeding 1A (fig. 3c).

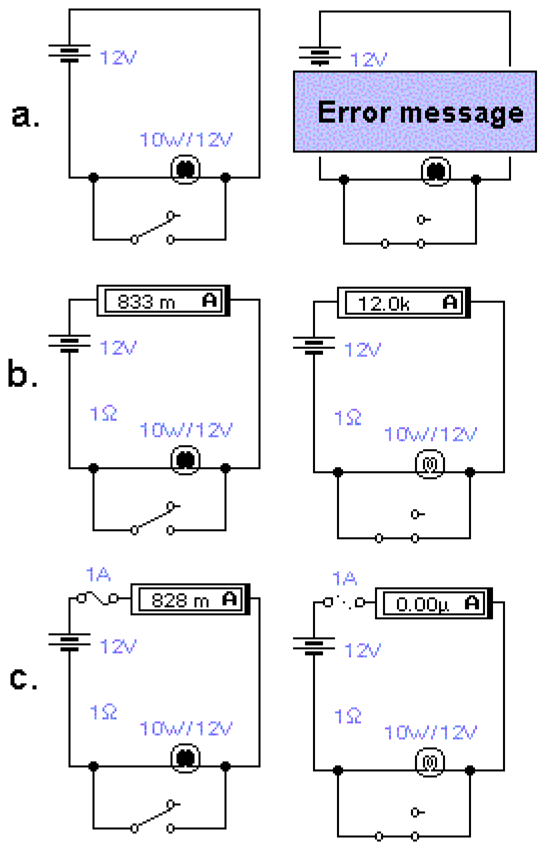

Figure 3

Summary, implications and future trends

The training model we have described includes three progressively complex iterations of a basic cycle: Modeling, Practice, Evaluation and Reflection. The training model provides opportunities for teachers to master methods and strategies for increasing instructional impact, improve ability and gain confidence in adapting existing materials to suit their specific needs and in designing their own instructional materials. This training can contribute to teachers' professional development by improving knowledge about physics content, students' conceptual difficulties, syllabus requirements and sources of simulations and activities. TTs respond to the model in ways reflecting their current professional development. Aided by instructor and peer modeling and by scaffolding tools, trainees gradually progress from naïve and intuitive description and use of simulations to characterization and analysis using concept-based terminology and to research-based knowledge and skill for evaluating and implementing these cognitive tools. Our course is a starting point of a long process that should continue through further field experience and advanced training courses.

The 2003 Girep seminar is concerned with preparing professional physics teachers for the demands of the 21st century. The "Teacher Education and New Technologies" workshop theme states that *"Educating teachers in this context is not only a matter of training them to use the new technologies, it also implies helping them to adopt new working patterns."* The training model we have described clearly mirrors this perspective. It responds to the challenge facing teacher educators to help teachers towards becoming life-long learners: reflecting on their own knowledge, defining their needs and designing a path of development.

We have recently started exploring ways of producing and implementing a web-based version of the training model. Phases 2-4 of the training model can be presented and conducted as a long term WebQuest (Dodge 2000): Teams of three trainees (playing roles of "technology", "research" and "pedagogy" experts) develop a set of simulation-based activities on a selected topic. Each of the group members conducts an independent research in his "domain of expertise" and presents a report to the team. The rest of the development is conducted as teamwork, products are uploaded to the course web site and peer evaluation is provided online.

It is interesting to note that the trend away from intuitive, "seat of pants", attitude, and towards principled, theory- based knowledge and practice is not limited to training teachers to use and evaluate simulations but also to training and informing designers and programmers of instructional software (Design Principles Database 2003).

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Sample online, downloadable and licensed physics simulations:

[1] Physics Simulations: http://webphysics.ph.msstate.edu/javamirror/
[2] Physics applets, Educational Object Economy: http://www.eoe.org/FMPro?-db=Categories.fp3&-token=library&-format=/library/JavaApplets.htm&class=Branch&-max=all&-find
[3] Virtual Labs and Simulations: http://www.hazelwood.k12.mo.us/~grichert/sciweb/applets.html
[4] Virtual Physics Laboratory: http://www.phy.ntnu.edu.tw/java/
[5] Java Applets on Physics: http://www.walter-fendt.de/ph14e/
[6] General Physics Java Applets: http://surendranath.tripod.com/
[7] Crocodile Physics: http://www.crocodile-clips.com/crocodile/physics/index.htm
[8] Open teach Simulations: http://www.openteach.com/download.html
[9] Interactive Physics simulations: http://www.interactivephysics.com/simulations.html
[10] The CPU project: http://cpucips.sdsu.edu/web/CPU/default.html