Simulating Technology Processes to Foster Learning

Nira Krumholtz

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A view of technology processes in human endeavors has guided me and my colleagues to produce a model of these processes. In turn, the model combined with learning and instruction theory has influenced decisions on how students should be taught science and technology subject matter.

This article discusses the model and its underlying rationale. Then a brief review of learning theory and teacher instructional support needs is offered. Finally, the workings of the simulation learning system that resulted from the preceding considerations are described.

Technology is one of the main characteristics of today's world, and it accounts for most of the development and changes in society. In their everyday activities people encounter technology and technological products. The educational system that aims to prepare the student for life in such a society has to adapt its curriculum to include technology as a vital field of knowledge.

TOWARD A MODEL

We use the term *technology* as human knowledge that is utilized to answer both material and spiritual needs. Knowledge, skills, and resources are combined to help solve various existential and practical problems. Toffler (1970) stated that the metaphor that relates technology to machine has always been unsuitable and even erroneous, since technology was always more than factories and machines. Technology can be seen as human competence and talent utilized to overcome its biological restrictions by extending its abilities (Hiedegger, 1969; Simon, 1990).

The Spiral Model

In order to study the interrelations between technology and mankind and to realize its influence on the development of society, we have conceived a model that describes the evolution of technology (see Figure 1).

This spiral model describes the interrelations of four factors: human needs, physical

Figure 1. **The "spiral model" of technology evolution.**

Dr. Krumholtz is the head of IDEA Center at the Department of Education in Technology and Science, Technion—Israel Institute of Technology, Haifa, Israel.

phenomena, technological constraints, and technological solutions.

Human needs are the driving force of technological evolution and are the initiators of technological development and innovation. Technological solutions that respond to these needs are developed under two categories of external constraints: *natural physical phenomena* (such as gravitation force, friction, and velocity) and *technological constraints* (such as budget, time, existing knowledge, and social and environmental demands).

This model describes a continuously evolving process of technology. Technological solutions influence the environment and change the quality of life. These changes evoke *new human needs* which, in turn, lead to research and development of new or improved technologies. Follow the process of development in communications as an example. From the use of the radio that transmits sounds only, the demand for both sound and picture was answered in the development of television technology. The television, in its turn, evoked new requirements for more realistic broadcasting and that was satisfied by the color TV. Because this process is ongoing, new features such as interactivity and virtual reality are already in use or on the near horizon to modify television.

Two features of this evolutionary concept suggest the use of the spiral to depict it. The first is the enormous increases in the rate of change over recent years. The time intervals between the appearance of a new development and the subsequent changes in human needs that follow it seem to be shortening. The second feature is that this process never ends. The fulfillment of one need immediately evokes a new need that requires more advanced technology. And so the process of technology evolution continues.

THE EDUCATIONAL APPROACH TO TECHNOLOGY EDUCATION

Understanding the nature of technology and its influence on human life is essential in technology education curriculum development. One of the main goals of the educational system, in all grades, is to prepare children to be able to adapt to a rapidly changing technological world (Black, 1996). The qualifications of students to live in a technological world will be evident in their ability to efficiently utilize technology, use existing technology to plan and manufacture new products, and think of directions to develop new technologies. This way suggests two primary technology education learning activities: using technology and developing new technologies.

We suggest an approach to teaching technology that allows the learner to experience technological activities and technological processes. A technological process includes the ability to distinguish all four factors in the spiral model. It starts with identifying a problem—a human need—and ends with choosing a solution—the production of a practical product. Learning science and technology is integral to the overall learning process when the student tries to deal with technological problems and to overcome physical constraints.

Our pedagogical approach stems from the constructivism theory of development suggested by Piaget (1954, 1973), which states that learning consists of building knowledge structures, and from the educational philosophy developed by Papert (1980, 1991, 1993) and others—the social constructionism approach. The pedagogical approach is based on independent inquiry and self-guided learning and facilitates personal construction of knowledge concerning the external world.

Further, we create a learning environment with activities that fit the learner's ability level and relate to his or her fields of interest. The technology activity will be as real and as significant as possible to the student.

For the learner to experience a process similar to the process of developing a technological product in real life, we decided to use a simulation system suitable to the learner. It needed to be easy to use, close to the content of the student's world of interest, and suited to his or her level of development. Moreover, in order to teach scientific and technological concepts and principles in a way that will lead the student from intuitive understanding of the concepts to a more formal, scientific understanding, the system needed to provide the student with a wide range of concrete experiences using simple models and familiar tools.

The Learning Environment

We found that LEGO DACTA (an educational company belonging to the LEGO group) computerized control systems (e.g., LEGO TC-Logo and ControLab) met our requirements. These are playing and learning systems that provide experiences in an environment that is a sort of model of reality. They may be considered "micro-worlds" that the kids can operate in (Resnick, 1993). The LEGO constructing systems involve activity in a well-defined knowledge domain and are based on defined scientific concepts.

The technology learning environment that we developed allows the learners to experience technological activities in two main areas: (a) building models from LEGO elements including motors, lights, and sensors, and (b) programming in TC-Logo language to control the operation of the models. The models include traffic-lights that simulate real operation, greenhouses that open and close doors according to the temperature inside the greenhouse, remote-controlled wheelchairs, washing machines, conveyor belts that identify boxes with dissimilar size or color, elevators, and racing cars. Activities with these provide students with practical experience in planning, constructing, and operating computer-controlled physical models.

THE LEARNING PROCESS

Based on the spiral model of technology evolution, we suggest that students go through the following stages in the learning process to become both users and developers of technology:

1. Learn about human needs or human problems that call for technology solutions—identify one need or demand.
2. Plan and design a solution chosen out of different solutions that had been suggested—propose a LEGO model that will provide an answer to this need.
3. Carry out the plan—build the model from LEGO bricks and program the computer to control the model's operation.
4. Market the product—exhibit the product in the classroom.
5. Suggest future developments—for your LEGO model to respond to new demands it may trigger.

Students Use the System

We have used the process with different groups of pupils of various ages and with different needs, including:

- Average students ages 8 to 14 in a special research setting and in normal class settings.
- Gifted students ages 6 to 8 and 13 to 14 in extracurricular activities.
- Students ages 12 to 14 with learning difficulties in a special research milieu.

The five stages of the learning process were kept for all groups of learners, with the level of activity and the opportunity for self-learning adjusted for each population. For example, in the first stage that requires research and investigation of possible needs and problems, we draw upon the close daily life for younger learners. For older age groups, we identify issues common to their wider interests. One such issue for eighth-grade students was how to answer the needs of people with physical disabilities; another for the ninth-grade students was planning and constructing computerized machines for recycling garbage.

The plan and design stage was very important, especially for those who suggested models of their own and had to build them from scratch without any instructions. This was a simple activity for those familiar with LEGO models, and more difficult for those who had less experience with LEGO models. Those with learning difficulties were offered to use the given LEGO models, so they had to build according to the instruction cards in Logo language. Their creativity was expressed when they met the challenge of conceiving a meaningful name and in the marketing phase when they presented the situation and their model as a possible solution.

Figure 2. **LEGO DACTA computerizd control system.**

Teachers Work with the System

As a result of our experience in preparing teachers to teach Logo and our research in using Logo in classrooms, we recognize the critical role the teacher plays in creating learning opportunities. Success in integrating technology subjects in the educational system is largely dependent on the ability of teachers. They must have knowledge of technology and understanding of the didactic and pedagogical approaches on which the technology learning environment is based. Consequently, we designed 30- to 56-hour workshops for elementary and junior high school teachers. In the first workshops, the teachers were learners and experienced the same learning processes that they were to present to their students later. The second phase allowed reflection on the earlier experience and included planning of activities that would best work in their classes.

Developing Materials for Students and Learners

Obviously, learning materials are a component of the learning environment. As such, we developed activities for learners to get familiar with the LEGO bricks, with the mechanical constructions, and with the programming software. We realized that there is also a need to support teachers since many were craft teachers with poor backgrounds in mechanics and physics. On the other hand, the craft teachers easily accommodated to workshop settings that suit the active constructivist learning approach.

EXPERIENCE SHOWS

Based on our experience with students and with teachers, we found that *LEGO models*, the LEGO DACTA mechanical systems answer the requirements for a simulation system that can help cope with the technological world. The LEGO bricks and the variety of products allowed us to choose different basic models for the different populations with which we worked. Moreover, the great variety of LEGO models and building elements made it possible to define an evolving line of models with increasing levels of complexity.

We encountered some basic difficulties with the programming software TC-Logo and later with the ControLab software:

1. It takes time to master a formal computer language, in this case the Logo language. This was a major obstacle considering that we had a 30-hour time limit.
2. For young and novice learners, the programming language is too complex, even if a time limit is not considered.
3. Lack of familiarity with the English language poses the greatest barrier for young learners.
4. We realized the need to have a programming control software that (a) keeps the powerful ideas of Logo programming such as algorithms, abstraction, structuring, and simple recursion; (b) is easy to use and master in relation to the level of the user, for example, has a consistent logic to allow self-learning; (c) is user-friendly, for example, in having commands represented as icons and not as words; (d) has on-line detailed help screens to allow inquiry and self-learning; and (e) does not require any previous experience in computers and in programming.

Based on these criteria, we developed programming software in cooperation with a softwarehouse in Israel under the name of TechnoLogica (1995). This TechnoLogica software along with the LEGO models, the learning activities, and processes based on our educational approach resulted in a new learning environment called LEGO-Logic. For the teaching of technology, we chose to emphasize the role of the logic of the control structures, defined by using *TechnoLogica*, rather than programming based on formal computer language. Therefore, TechnoLogica was developed as an icon-based software that permits the user to define various control structures (IF, IF-ELSE, WAITUNTIL, REPEAT) without the need to use any formal programming language.

TechnoLogica allows three modes of control:

- Immediate mode of manual control.
- Automatic control: Open-loop control, executing a list of commands.
- Feedback control: Closed-loop control, using sensors for feedback.

THE NEW APPROACH

Models are first operated manually to let students experience an instance of technology evolution. Then a motor and batteries are added to operate the model by electricity. At these stages the student operates the models in on/off operations, under manual control. At a more advanced stage, the model is connected to a computer and is automatically operated, controlled by TechnoLogica procedures, programmed by the learner. In the final stage, sensors are introduced to enable feedback in the control loop.

In the final exhibition, which is part of the marketing phase, each participant offers suggestions for further development of the product that may satisfy new advanced needs which may be triggered by the use of their model.

An elevator is an example of such a model. In the first stage the elevator is operated manually by the user who pulls a string connected to a pulley. In the second stage a motor is connected to the pulley via gears and is operated by batteries that supply electricity. The student decides when to stop the motor as it reaches each floor. The student visually determines when the elevator reaches a certain floor.

The more advanced stage is when the motor is connected to an interface box that is connected to the computer. A procedure is programmed to operate the model to run a four-times loop of 5 seconds "on" and 3 seconds "off" to allow people to get on and off the elevator. This operation is called an open-loop control or an automatic operation.

In the last stage a light sensor is attached to the elevator. It allows for feedback control: When the light sensors "sees" each floor, the computer "tells" the motor to wait for 3 seconds before going on to the next floor.

Future developments for this elevator model that are suggested by the student may be evoked by the need for safety that may arise when the elevator is operated. Another light sensor could be used to "see" if there are people standing in the way to prevent the movement of the elevator door. Another development can be to enable the elevator to "see" people who actually want to stop at each floor.

The LEGO computer-controlled models can be regarded as a bridge between the concrete physical world and the abstract world of computer science. The models built from LEGO blocks represent the physical mechanical world, and the programming in TechnoLogica allows the construction of abstract thought structures.

FEEDBACK FROM TRIALS

Three studies were conducted with different groups of pupils. One involved a group of sixth-grade students familiar with Logo programming. The experiment made it possible to reveal the students' prior technological knowledge and to identify their motivation factors (Krumholtz et al., 1993).

Another study engaged three groups of seventh- and eighth-grade learners who went through the process of developing a technological product according to the learning process described above. We sought to identify the physical concepts and principles and the technological phenomena that could be experienced in the computerized LEGO learning environment. In addition, the level of understanding of concepts and phenomena were tested in this group. Our analysis shows that for physical concepts such as speed, acceleration, static and dynamic friction, gravity, force, and balance, most learners (87%) reached intuitive understanding of the concepts. Some of the learners (24%) expressed more formal scientific understanding of the concepts. The technological phenomena that were identified as being experienced using the LEGO DACTA models were the mechanical advantage in tradeoff between speed and power in a combination of cogwheels; the relation between the feedback received by the sensors and the control of the machine's operation; and the distinction of manual control, automatic control, and feedback control.

A study of students with learning difficulties revealed that they had reached an intuitive understanding of the above-mentioned technology phenomena, to some extent (Krumholtz & Zodik, 1993). Most significant in their experience, as expressed by them at the end of the learning period, was the chance they had been given to create something of their own—a solution which they invented. Their expressions of creativity ranged from merely inventing a name to a given model to suggesting various new operations to its function to building their own mechanical models.

CHALLENGES REMAIN

TechnoLogica has been adapted (i.e., the "Help" messages are translated) for use in several countries including England, Denmark, Sweden, Germany, Korea, and Holland. Researchers in a junior high school in England and in an elementary school in Sweden report significant outcomes concerning its efficiency for developing logic thinking typical of programming. The adaptation of TechnoLogica to other countries has made it possible to continue with comparative research on the use of the new system which we call LEGO-Logic micro-world.

It is worth pointing out that implementing the spiral model in education is open for adaptation by various curricula approaches (Black, 1996). This can emerge from emphasizing one factor more than others such as the human factor in technology, the practical capabilities, or the cognitive aspects that are involved in the problem-solving activities. Yet we believe that the spiral model offers educators a guide and choice to emphasize any or all of the five stages of the learning process and that regardless of choice the instruction is more effective and goals more easily achieved with the simulation system we have described. With it we take a major step toward preparing students who will be more ready to become both users of technology and developers of new ones.

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