TÜRK FEN EĞİTİMİ DERGİSİ
Yıl 4, Sayı 2, Eylül 2007

Journal of
TURKISH SCIENCE EDUCATION
Volume 4, Issue 2, September 2007

http://www.tused.org

System Dynamics Approach In Science and Technology Education

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Received: 23.11.2006 **Revised:** 01.04.2007 **Accepted:** 17.04.2007

The original language of article is English (v.4, n.2, September 2007, pp.91-108)

ABSTRACT

System Dynamics is a well formulated methodology for analyzing the components of a system including cause-effect relationships and their underlying mathematics and logic, time delays, and feedback loops. It began in the business and industry world, but is now affecting education and many other disciplines. Having inspired by successful policy changes in lots of fields, the system dynamics researchers targeted to apply the system dynamics approach in the educational fields too. There is a remarkable increase in the interest and understanding level of the students to the courses in the classes using system dynamics approach. Therefore some curriculum projects based on the system dynamics have been developed (Stacin, Cc-Stadus, Cc-Sustain, Science Ware) in order to apply it practically. By using these projects, lots of new ideas and useful models are provided for the practicing teachers to apply system dynamics in the classroom.

The aim of this study is to discuss the feasibility of the application of system dynamics approach in the science education. First part of the study explains the relationship of system concept and dynamics concept. A brief introductory information about system dynamics is given. The differences between system dynamics and computer based learning are explained. In the second part of the study, applications of system dynamics in education are explained. Then, curriculum projects based on system dynamics are examined. Finally, ideas on the introduction of system dynamics approach into the Turkish curriculum are suggested.

Keywords: System Dynamics, Science and Technology Education, Curriculum Projects Based On System Dynamics

INTRODUCTION

System dynamics has been applied in lots of fields outside the education. Most popular system dynamics study is the “Limits to Growth” book which was commissioned by the Club of Rome in the 1970’s (Meadows et al, 1972; Forrester, 1973). This study showed that the natural balance in the earth would be broken until the year 2000 if no precautions are taken. The study triggered lots of controversy but the discovery of the Antarctic ozone hole in year 1985 made the public opinion of the world citizens and political leaders to take precautions for the problems mentioned in the “Limits to Growth”. As a result of these actions, the many countries around the world started to take agreed decisions to prevent the production of the gases that cause ozone depletion.

System dynamics studies caused important changes in the fields of management and economy as well. Having inspired by these successful policy changes in lots of fields, the system dynamics researchers targeted to apply the system dynamics approach in the educational fields too. First educational applications showed that important improvements can be obtained in this field as well (Forrester, 1996). The students in the schools, where system dynamics approach is used, run voluntary projects in relation with their school courses even after the school time. The students became so enthusiastic with the subjects that they made their parents to take part in the projects too.

There is a remarkable increase in the interest and understanding level of the students to the courses. This increase caused an expectation in the practitioners that this approach will enter the general education system in the USA. But in the time that passed, the researches saw that the level of system dynamics applications have not reached the intended level (Forrester, 1996). There are various opinions on the causes of this gap. Most important reasons among these are the following: Applications of the system dynamics approach in the K-12 education has not focused on the development of the lesson plans and applications that are based on the pedagogical methods that enhance learning. The practicing teachers focused on the rules of system dynamics and they neglected practical principles for the successful applications (Forrester, 1996: Lyneis, 2000). Therefore a few curriculum projects based on the system dynamics have been developed (Stacin, Cc-Stadus, Cc-Sustain, Science Ware). By using these projects, lots of new ideas and useful models are provided for the practicing teachers to apply system dynamics in the classroom.

This paper makes a study of the curriculum projects based on system dynamics and it provides several suggestions for the successful application of system dynamics in Turkey.

System dynamics builds two-way communication between mental models and simulation ones. Mental models are the basis for every-day decisions. Mental models contain tremendous stores of information. But the human mind is unreliable in understanding what the available information means in terms of behaviour. Computer simulation meshes nicely with mental models by taking the mentally stored information and then displaying the dynamic consequences (Forrester, 1996). Computer simulation is not only useful for modelling systems that are difficult for students to observe in real life, but it is also more powerful in influencing the learning process when combined with real experimentation (Martin, 1997a).

Using system dynamics approach the modellers produce simulation tools called as micro worlds. The students use these tools to make certain experiments. So these tools are actually replacements for the real world. That is why they are called as micro worlds. The experiments in the micro worlds can be repeated easily using varying parameters and alternative scenarios. This allows the student to see how the dynamics of the system works, by experiencing it in the virtual world. Usually there is no other way of observing the results of the experiments outside of the micro worlds. The experiments are done with the help of certain easy to use simulation software. Dynamo, Powersim, Vensim, Stella, ithink, Extend and Anylogic are some of the system dynamics software (Martin, 1997a;

Alessi, 2000). Stella is the mostly preferred tool for the K-8 students. (Brown, 1992; Forrester, 1996) STELLA is a computer simulation program which provides a framework and an easy- to-understand graphical interface for observing the quantitative interaction of variables within a system. The graphical interface can be used to describe and analyze very complex physical, chemical, biological, and social systems. (Martin, 1997a)

System dynamics approach makes it easy for students to focus on the causes of the events. Moreover the students understand that there are usually more than one cause and effect relationships under the complex systems. In addition, students see that the result of the combined interactions of all the cause and effects relationship cannot be analyzed by superficial studies.

System dynamics is a general approach for defining and solving problems (Forrester, 1961, 1973; Sterman, 2000). The students who learned this approach will be able to use this problem definition and solution tool for their whole life. This approach helps students to get the discipline and sensitivity of a scientist. In this way students can have abilities to actively observe their environment, discover new problems, model and investigate these problems in a scientific way. This is in contrast with the traditional educational methods where the students are passively supposed to answer the questions when they are asked to solve (Forrester, 1992, 1996).

Undoubtedly the goal of the education is beyond teaching the students certain courses. It is not sufficient to reach the goals of the education system, that the students can correctly answer the questions they are asked. Education system aims also that students should be able to construct the problems by themselves. Constructing problems necessitates a deeper look than answering problems. To construct problems, it is necessary to observe the environment. Moreover it is necessary to have a critical view for the issues and see the world from unusual perspectives. The individuals that gained this perspective are more flexible, tolerant, productive and worthwhile for the society. The reason for these qualifications is that students are aware that there is not a unique truth. They are aware of the truth can change with respect to the conditions and time. The individuals that have these qualifications are more worthwhile for their societies because they can discover the hidden problems in the life and they can provide effective suggestions to solve the problems.

The aim of this study is to discuss the feasibility of the application of system dynamics approach in the science education. First part of the study explains the relationship of system concept and dynamics concept. A brief introductory information about system dynamics is given. The differences between system dynamics and computer based learning are explained. In the second part of the study, applications of system dynamics in education are studied. Curriculum projects based on system dynamics are studied. Then ideas on the introduction of system dynamics approach into the Turkish curriculum are suggested.

LITERATURE REVIEW

Learning the system dynamics approach requires that teachers and students understand the concept of a system and the terms of dynamics.

I- Relationship between the terms of systems and dynamics

The term “system” is a very broad concept that relates to various areas such as social systems, technological systems, and natural systems. Therefore, this subject has been studied from different angles and points of interest (Mandinach, 1989; O’Connor &

McDermott, 1997; Penner, 2000). A system is an entity that maintains its existence and functions as a whole through the interaction of its parts. However, this group of interacting, interrelated or interdependent parts that form a complex and unified whole must have a specific purpose, and in order for the system to optimally carry out its purpose all parts must be present. Thus, the system attempts to maintain its stability through feedback (Ben-Zvi Assaraf & Orion, 2005).

The systems term is a general concept. Water cycle and electric circuits are an example of systems. Electric circuit's components like resistance, ammeter, and voltmeter are systems too. There are lots of examples about systems such as falling objects, friction between two objects, economics and organs of our organism.

All the systems are made of subparts and living beings. More abstractly, all the systems are compositions of sub-elements. But the sum of the sub-elements of a system is not equal to the system itself. The system is the sum of the sub-elements and the relationships among them.

For example, let's take a library. A library is not equal to the sum of a building and some racks and books. The relationships among these three elements are also required in order to make a library. A set in which the books are scattered and unorganized where some of them are inside the building and some of them are outside of it, is not called a library. In order for these elements to make a library, the books have to be arranged in an ordered way on the shelves inside the building. The books have to be classified. In this case, there are positional relationships among the books and the shelves. In the same way, there are certain relationships between the shelves and the building with respect to the arrangement of the shelves and their positions.

The library is a static system. That is the relationships between the elements are unchanging in time. But most of the important and interesting systems are dynamic systems.

An example for the dynamic systems is the water cycle on the earth. The elements of this system are clouds, atmosphere, sun, soil, seas, plants and other living beings. Sun warms up the seas and living beings. As the temperature increases, living beings and seas lose water through evaporation. The vapour goes up through the air streams and it intensifies. The intensified vapour forms the clouds. The differences in the temperature between different places of the earth causes pressure differences of the air. The pressure differences of the air cause the streams of weather. In certain conditions the vapour in the clouds gets denser and it falls off as rain or snow onto the earth surface. From there the water passes again to the living beings. This cycle goes on continuously. This system is a dynamic system, because the levels of the elements changes in time. Moreover, this system is an example for the so called complex systems because of the feedback cycles in the system. The water that comes from the seas and living beings goes back to seas and living beings after passing through the cycle. Another property of this system is that the causal relationships between the elements contain delays. That is the causal relationships don't occur instantly. For example the water loss in Caspian Sea is at its peak during the summer. Only after a few months does the water come back to the Caspian Sea.

System dynamics cares about the complex systems. The complexity means that the system has the following three properties: 1.) Delays between causal relationships, 2.) Feedbacks, 3.) Several stocks. (Senge, 1990; Sterman, 2000)

II- Complex Systems

Not all the systems are complex. For instance the library example given above is a simple, static system. There are also systems that are dynamic but not complex. For instance, a stopped vehicle and a person who pushes the vehicle. The person pushes the vehicle by his force. This force causes a forward movement in the vehicle. This system is dynamic, but it doesn't contain feedback loops and delays. Therefore it is a simple system.

Why are the systems called as complex when they contain delays and feedback loops? Because the dynamic behaviour of the systems that do not contain delays and feedback loops are easy to formulate through explicit mathematical formulas. But the dynamic behaviour of the complex systems cannot be described through explicit mathematical formulas in general. The behaviour of these systems can only be described through simulations within some accuracy level. System dynamics is a science discipline that studies systems which consist of several stocks and the cyclic and delayed relationships between them. The aim of system dynamics is to build a methodology to understand how the systems change in time.

SYSTEM DYNAMICS

System dynamics is an academic discipline created in the 1960s by Forrester of the Massachusetts Institute of Technology. System dynamics was originally rooted in the management and engineering sciences but has gradually developed into a tool useful in the analysis of social, economic, physical, chemical, biological, and ecological systems. In the beginning Forrester (1961) focused on modelling and problem solving in industrial systems. Forrester (1973) applied to terms of industrial dynamics for social and urban systems and especially world dynamics. After that, system dynamics has been developed in the analysis of social science, economics, biology, physics, chemistry and ecological systems as a fruitful tool in time.

System dynamics is fundamentally interdisciplinary. System dynamics is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. System dynamics introduce to effect of non-linear relationship. (Sterman, 2000). Non-linear means that system behaviour has not a simple result-effect relationship. For example, the more we study the more we expect to be fruitful. But in real world the more our study time increase, the less our fruitfulness of per study hour. It is an example of non-linear relationship.

Systems dynamics provides a common communication tool connecting many academic disciplines. System dynamics forces people to think critically about problems because of the process they must go through to develop and analyze system structure. Most importantly, with system dynamics, one can make the mental link between the structure of a system and the behaviour that the system produces (Martin, 1997a).

The analysis of system dynamics phases are explained by Forrester (1961) in "Industrial Dynamics". These steps showing at the bottom can be followed in system dynamics approach:

1. Defining the problem.
2. Remove the factors interacting each other.
3. Determination to feedback and cause and effect relationship.
4. Formulation to decision of the politics explaining information flows.

5. Building the mathematical model of the interactions between the information sources, systems' components and decision policies.
6. Exposing to systems' behaviour explained with models using by computer simulation.
7. To compare the results with the real systems'information.
8. Revision to models until representation of the real situations.
9. Making changes on the models for improving of the systems' behaviour.
10. Redesigning the real system according to the policies that made performance improvement in the model.

System dynamics approach has focused on four basic ideas. First of all is to every dynamic behaviour consists of stock and flow (Sterman, 2000). What is the difference between a stock and a flow? Stocks are accumulations. Stocks hold the current state of the system: what you would see if you were to take a snapshot of the system. If you take a picture of a bathtub, you can easily see the level of the water. Water accumulates in a bathtub. The accumulated volume of water is a stock. Stocks fully describe the condition of the system at any point in time. Stocks, furthermore, do not change instantaneously: they change gradually over a period of time. Flows do the changing. The faucet pours water into the bathtub and the drain sucks water out. Flows increase or decrease stocks not just once, but every unit of time. The entire time that the faucet is turned on and the drain unplugged, water will flow in and out. All systems that change through time can be represented by using only stocks and flows (Martin, 1997b).

Second idea about system dynamics is to stocks and flows have feedback loop. Feedback is the process through which a signal travels through a chain of causal relations to re-affect itself. Feedback can be divided into two categories: positive and negative. Feedback is *positive* if an increase in a variable, after a delay, leads to a further increase in the same variable. Positive feedback is found in compounding, reinforcing, or amplifying systems that produce exponential behaviour. On the other hand, feedback is *negative* if an increase in a variable eventually leads to a decrease in the variable. Negative feedback drives balancing or stabilizing systems that produce asymptotic or oscillatory behaviour (Martin, 1997c).

Third basic idea is to feedback loops join with non-lineer relationships. In other words feedback relationship about stocks get feedback to stocks by non-lineer ways. Final idea is to simulation program in order to modelling complex dynamics systems. In this point systems dynamics can be confused with computer based learning. It should be review to differences between system dynamics and computer based learning in this section.

Differences from computer based learning:

1. System dynamics focused on four basic system components: stocks and flows, feedback, non-linear relationships and computer simulations. Computer based learning look like system dynamics only one component, computer simulation.
2. Both of the system dynamics and computer based learning are utilized by simulation programs. There are many various simulation programs. General simulation programs can be event driven or agent based simulation. As for system dynamics simulate cause-effect relationship between events (Sweetser, 1999).

3. In computer based learning simulation programs are prepared formerly and students attain to results making changes in different parameter on simulation. But, in system dynamics students built a model by oneself and test the model. After that, they evaluate findings as table of data and graphics.
4. System dynamics consist of two parts: building and testing a model. These two parts provide to students understand the complex behaviour of systems and make an experiment about complex systems. As for computer based learning there is an available model and students make an experiment on this model.
5. Students gain a deep perspective to approach the events in a critical viewpoint and to reveal questions that have not been asked before. In computer based learning, the student doesn't build the problem by himself. Instead he works on the existing problems. Therefore the student is not encouraged to discover the hidden problems in his surrounding.
6. In system dynamics approach, simulations run by calculating the numerical integrals of the differential systems of the models. In the computer based learning, the simulations employ probability distributions in general.
7. System dynamics analyzes the whole of the system. Simulations in the computer based learning are not adequate to do inferences about the behaviour of the whole because they imitate the physical processes one to one (Sweetser, 1999)
8. The modelling process and the model itself have a great learning potential in system dynamics. But in other types of simulations the focus point is the simulation game itself.
9. The fundamental focus point in the system dynamics modelling is the structure of the system. The structure determines the behaviour. In other simulations the fundamental focus point is the interactions between the individuals. These interactions are defined by probabilistic functions and mathematical relationships. A person who studies these models has difficulties to draw out conclusions on the behaviour of the whole system. In contrast to the other simulations, system dynamics models simplify to make conclusions on the behaviour of the whole because the so called archetypes of the system give hints about the dynamics of the behaviour. Therefore modelling through system dynamics, experimenting on the simulation models, analyzing the resulting behaviour give to the analyzer information about what to do such that the system behaves in the intended way.
10. Computer based learning is a very general term. Building a spreadsheet table in Excel, plotting a mathematical function in some mathematical software, drawing a graphical design in Photoshop is also included in computer based learning. Developing models and doing experiments with them in the system dynamics methodology is a very specific way of working with computers.

SYSTEM DYNAMICS IN SCIENCE EDUCATION RESEARCH

In K-12 education, system dynamics modelling has been applied to mathematics, physics, social studies, history, economics, biology, and literature. System dynamics is developing rapidly, but does not yet have widespread public visibility. The international System Dynamics Society was formed in 1985. Membership has grown in every year. Annual international meetings have been held for fifteen years in locations as widely spread as Norway, Colorado, Spain, China, California, Germany, and Thailand. System dynamics books and papers are regularly translated into many languages including Russian, Japanese, and Chinese (Forrester, 1992; 1996). In this section some quotations from teachers and student using system dynamics in their class is presented:

Hopkins (1992), 11th grade English literature teacher, in the Desert View High School, Tucson, told us about their course taught Hamlet:

> "The *Hamlet* model was used with my students… "When we used a STELLA model which analyzed the motivation of Shakespeare's Hamlet to avenge the death of his father in HAMLET… The students were engrossed throughout the process… The amazing thing was that the discussion was completely student dominated. They were talking directly to each other about the plot events and about the human responses being stimulated. They talked to each other about how they would have reacted and how the normal person would react. … My function became that of listening to their viewpoints and entering their decisions into the computer. It was wonderful! It was as though the use of precise numbers to talk about psychological motives and human responses had given them power, had given them a system to communicate with. It had given them something they could handle, something that turned thin air into solid ground. They were directed and in control of learning, instead of my having to force them to keep their attention on the task."

Al Powers reports student reactions in his chemistry classes (Forrester, 1996):

> "Working in groups was incredibly effective. Often it is easier to understand concepts when they are explained by a peer." "I feel that everyone is heard and, therefore, the people are more willing to contribute to the discussions and admit to being uncertain about a concept." "The graphs and simulations brought the concepts to life." "I found myself explaining concepts to people in other classes. This has never happened to me before. I think they would have benefited just as much as I did if they had had the opportunity." "Being a visual learner, it really helped to see the reactions in easy schematics. The graphs produced were even more helpful. My father and I spent long hours discussing the graphs and talking about what was the initial change and what was the reaction to that change." "This was a great lab! Using the computer made it easier for me to understand what was going on in the reaction."

Ossimitz reported that the students have positive attitude as his experimental research in 1996 (Ossimitz, 2000):

> "it was very funny activity although this teaching strategy was very new for me. Especially studying with my partners instead of that teacher explains about connection between objects in a long way was very amusing."

Pal Davidsen, professor at the University of Bergen in Norway, has led of a Scandinavian consortium for introducing system dynamics into high schools (Forrester, 1996):

> "In Norwegian and Nordic schools, we have chosen to utilize the conceptual framework offered by system dynamics for our educational purposes… Academic boundaries no longer constitute the boundaries of our imagination or our investigation. Historic and economic considerations are merged with physics and chemistry in our study of ecological issues."

Helen Zhu, an MIT undergraduate working to develop system dynamics materials for K-12 education observed (Forrester, 1996):

> "In my differential equations class we used calculus to figure out the behaviour of populations. I realized just how much simpler system dynamics made that thought process. Whereas only college students can understand such phenomena using math, elementary scholars can understand the same things by using system dynamics modelling. It's really amazing."

Teachers find that, in the process of using these tools, students' learning becomes more learner-centred and cooperative. System dynamics encourages students to figure things out, put puzzle pieces together, look for similar patterns, and work together to ask questions and find answers across disciplines. With system dynamics, however, they all fall together naturally, to the great benefit of children. In elementary and middle school, the work is genuinely interdisciplinary. At all levels, students do not do system dynamics all the time in every class—they still cover "the basics" (Lyneis, 2000).

In the traditional approach, teachers stand at the front of the class and dispense information about separate subjects to students who are passive receptacles. In contrast, the systems approach sparks inquiry and enables students to take charge of their own learning, something they are naturally driven to do. Teachers using system dynamics approach in class are no longer lecturers, no longer the source of all wisdom, not even necessarily authority figures. Teachers become advisors and coaches to students who are doing projects that may lie beyond the teacher's experience (Forrester, 1996; Lyneis, 2000). The system dynamics approach does seem to make education more fun for students and teachers alike.

SYSTEM-DYNAMICS-BASED CURRICULUM PROJECTS

I- STACIN (Systems Thinking and Curriculum Innovation Network)

The STACIN project (which stands for Systems Thinking and Curriculum Innovation Network) grew out of the Apple Classroom of Tomorrow (ACOT) project of the 1980s. The ACOT project provided schools with significant computer resources, enabling them to implement curriculum innovations which depended on intensive computer use. STACI project began as the with one high school in the state of Vermont, and became STACIN as six schools were added in the San Francisco area and one high school was added in Arizona (Alessi, 2005).

From Ellen Mandinach, Educational Testing Service, Princeton, NJ and Director of the Systems Thinking and Curriculum Innovation Project involving some eight schools in different parts of the country (Forrester, 1996):

> "The teachers in the STACI Project perceive the systems thinking approach to be both an effective instructional strategy and a professional development opportunity. Many of the project teachers have altered completely the way they structure their classroom activities. Both students and teachers benefit from the systems approach. For teachers, it is the stimulus for changing the fundamental role of the teacher to facilitator, coach, and mentor rather than the purveyor of information and facts."

The driving philosophy of the STACIN Project was to implement curriculum of a constructivist nature, in which learners and teachers worked collaboratively to create elaborated understanding of systems and processes, and to solve problems. In the beginning the project was somewhat less constructivist, but, in part due to their early experiences they began to implement a more learner-centred approach in which greater emphasis was on the students creating their own models. Their guiding philosophy was that knowledge should not and cannot be "poured" into students' heads. Rather, students and teachers must create, expand, and refine their knowledge together (Mandinach & Cline, 1994).

STACIN is more a research project. It has included a relatively small number of teachers and schools and its primary goals have been investigating and evaluating the educational effects of implementing System-Dynamics-Based learning environments (Alessi, 2005).

II- CC-STADUS (Cross-Curricular System Thinking and Dynamics Using STELLA)

CC STADUS began in 1993 with three years of funding from the United States National Science Foundation (NSF). They initially trained about 150 high school teachers to incorporate System Dynamics modelling with STELLA in their curricula. Teachers were trained during summer workshops. This Project was finished in three years. (Fisher, 1994; Zaraza & Fisher, 1998).

The CC-STADUS project has four primary goals. The first of these goals focuses on training teachers in the basics of system dynamics and in the development of computer models specific to their own content area. The second goal is only achievable after some progress has been made on the first. While a number of individuals and groups have developed, and in some cases, distributed single discipline models for use at the pre-college level, very few multi-disciplinary models were in the public domain. Use of the models developed by the teachers in the summer is the third goal of the project. The fourth goal of the project is by far the most ambitious. The real purpose of the CC-STADUS project is the training and encouragement of a large enough group of "users" and "developers" to become a self-sustaining movement (Zaraza, 1995).

III- CC-SUSTAIN (Cross-Curricular Systems Using STELLA: Training and In-service)

The CC-SUSTAIN project has goals and characteristics similar to the STACIN project, but also has notable differences. They initially trained about 150 high school teachers to incorporate System Dynamics modelling with STELLA in their curricula. Teachers were trained during summer workshops. Subsequently, teachers worked with their students (all at the high school level) to create models in many areas, but again, primarily science, math, and social studies. CC-SUSTAIN is primarily an implementation (rather than a research) Project. Its philosophy generally includes encourage learners to start modelling immediately. Involve only teachers eager to embrace System Dynamics thinking (Alessi, 2005).

IV-SCIENCE WARE PROJECT

ScienceWare project was applied at the University of Michigan's Highly Interactive Computing (Hi-C) research laboratory. Unlike the previous two projects, which were multidisciplinary, Science Ware and Model-It are designed specifically for learning science, primarily at the secondary school level. The underlying philosophy and assumptions of the Science Ware project are that modelling is central to the doing and learning of science, that modelling includes several important components (collecting data, visualizing data, creating models to represent and explain data, and reporting the data), and that student motivation for modelling cannot be assumed. Like the STACIN and CC-SUSTAIN projects, Science Ware and Model-It are based on constructivist foundations (Alessi, 2005).

These projects provide new opinions and useful models for teachers in order to applying in their class.

APPLICABILITY TO SYSTEM DYNAMICS APPROACH IN MINISTRY OF NATIONAL EDUCATION IN TURKEY

The level of education in Turkey could not achieve the goals set in the curriculum according to many national and international researches. As a result, the Ministry of National Education (MNE) started a reform action in primary curriculum in 2004. The Turkish curriculum for Grade 1 to 8 is redeveloped considering social constructivist theory of education. New curriculum was piloted in 2004–2005 school year and put into practice nationwide in 2005-2006 school years (MEB, 2006).

While the new curriculum program has been developing, the basic points about curriculum are:

- Little information is pure.
- The aim of the new curriculum is to educate students with scientific literacy.
- New program was founded on social constructivist theory of education.
- The alternative measurement and evaluation tools rooted by constructivist learning were used in new program.
- Students' level of mental and physical improvement was considered.
- The helical structure was main principle.
- All of the courses were parallel and completeness with each other.

The vision of the new curriculum is to educate students with scientific literacy. Scientific literacy is knowledge and understanding of the scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (National Research Council, 1996).

Scientific literacy means that a student can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a pupil has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions (National Research Council, 1996).

In science and technology curriculum program based on scientific literacy emphasizes on following issues:

- Improving to skills and perceptiveness
- Alternative measurement and evaluation techniques
- Constructivism
- Learner-centred learning/teaching
- Cooperative learning
- Learning as multiple intelligence
- Applying to program flexibility

Like these new program vision system dynamics' vision is to gain some skills to student. These skills are the followings

1. Using system dynamics approach the modellers produce simulation tools called as micro worlds. Simulation environment gain to students:
   - experiencing it in the virtual world.
   - can be repeated easily using varying parameters and alternative scenarios.
   - see how the dynamics of the system works.
2. A mental model is one's mental perception or representation of system interactions and the behaviour those interactions can produce. Due to an incomplete or incorrect mental model, a student cannot apply the principles taught in lectures to tasks in life. System dynamics offers a source of direct and immediate feedback for students to test assumptions about their mental models of reality through the use of computer simulation (Martin, 1997a).
3. System dynamics propounds the different mechanism of the dynamics patterns. Different dynamic patterns provide students:
   - description of the different dynamic pattern,
   - research to what the different dynamic patterns' reasons are,
   - learning how to different dynamic patterns spring up using cause/effect and stock/flow diagrams.
4. System dynamics helps to teacher about determining some misconception in science and technology issue. It makes the students to understand the logic of events in a deeper and more comprehensive way.
5. Focusing on the causes of events and acknowledging that the behaviour of the complex systems are determined by several feedback loops makes the student understand that the problems cannot be solved by superficial solution patterns. This enlightenment enhances the curiosity and motivation of the students to the science and technology courses.
6. System dynamics is a general approach for defining and solving problems (Forrester, 1961, 1976; Sterman, 2000). The students that learned this approach will be able to use this problem definition and solution tool for their whole life. This approach helps the students to get the discipline and sensitivity of a scientist. In this way the students can have abilities to actively observe their environment, discover new problems, model and investigate these problems in a scientific way.
7. The skill of developing problems is a deeper viewpoint than answering a given problem. Approaching the problems in a critical way and finding out questions that have not been asked before causes the students to gain capabilities for being aware of that there is not a unique answer and that there might be different truths with respect to the conditions, time and people.

DISCUSSION

System Dynamics is a well formulated methodology for analyzing the components of a system including cause-effect relationships and their underlying mathematics and logic, time delays, and feedback loops (Forrester, 1973; Senge, 1990; Sterman, 2000). It began in the business and industry world, but is now affecting education and many other disciplines. More and more people are beginning to appreciate the ability of the System

Dynamics methodology to bring order to complex systems and to help people learn and understand such systems (Forrester, 1996; Alessi, 2005).

System dynamics has been applied in lots of fields such as engineering, physics, economics and social sciences. Having inspired by successful policy changes in lots of fields, the system dynamics researchers targeted to apply the system dynamics approach in the educational fields too. First educational applications showed that important improvements can be obtained in this field as well (Forrester, 1996). The students in the schools, where system dynamics approach is used, run voluntary projects in relation with their school courses even after the school time. The students became so enthusiastic with the subjects that they made their parents to take part in the projects too.

There is a remarkable increase in the interest and understanding level of the students to the courses. This increase caused an expectation in the practitioners that this approach will enter the general education system in the USA. But in the time that passed, the researches saw that the level of system dynamics applications have not reached the intended level (Forrester, 1996). This situation means that system dynamics approach was fail to apply practically. The improvements gained in the schools in USA, Germany, Scandinavia, China, Japan and other countries where system dynamics approach is applied in the education were so high that it is worth to do further study to solve the related problems. If the curriculum and techniques that simplify the application of system dynamics approach in the education can be developed, we believe that significant improvements in the education levels of the students will be gained. A few curriculum projects based on the system dynamics have been developed (Stacin, Cc-Stadus, Cc-Sustain, Science Ware) in order to apply system dynamics approach easily in courses. By using these projects, lots of new ideas and useful models are provided for the practicing teachers to apply system dynamics in the classroom (Alessi, 2005).

Everyone who teaches System Dynamics modelling has reported how difficult it is, even though the benefits are great (Forrester, 1992, 1996; Lyneis, 2000, Alessi, 2005). There are errors all students make and difficulties they all encounter. Students tend to confuse stocks (levels) with flows (rates of change). They try to incorporate the formulas of previous science and math classes (which they often do not fully understand) instead of doing true system analysis. When models do not work correctly, they include fudge factors. Fudge factors are formulas, constants, or logical conditions designed to artificially fix the problem, not to realistically model the system. Students fail to test their models well, so the models tend to work only for common conditions, rather than the wide range of real-life conditions. Students confuse flows with cause-effect relationships. They create models that are unnecessarily complex and abstract, rather than having a close correspondence to reality. They try to copy and adapt models from instructors or textbooks, instead of thinking through the phenomenon and generating their own models from scratch. The main error made by teachers is thinking that students can create their first sophisticated models in a few weeks, when doing so (and overcoming all the above problems) may take several months. Patience, with yourself and with your students, is essential. Learning System Dynamics is slow in the beginning and it takes some time before there is visible payoff (Forrester, 1996; Alessi, 2005).

The question of can teaching system dynamics trigger systems thinking abilities was solved using experimental design by Klieme and Maichle (1991; 1994) and Ossimitz (1994; 1996). They take positive feedback from students and teachers about their research. Klieme and Maichle (1991; 1994) applied to system dynamics modelling in the field of mathematics, biology, chemistry and social science at the grades of 9 and 10 students in order to research developing system thinking skills. Klieme and Maichle (1994), claim that the achievement of the students depends more upon their motivation and prior experience with computers. Ossimitz (1996) studied at the field of mathematics and physics including totally 130 students the grades of 9 and 12. He researches that how system thinking skills can be developed using system dynamics software programs (Translation from Germany: Ossimitz, 2000).

Booth Sweeny (2000) studied the system thinking skill abilities of students of the business school at MIT who had a very solid background in mathematics and science, but no prior exposure to system dynamics concepts. She used a system-thinking inventory to assess particular concepts of systems thinking such as feedback, delay, stocks, and flows. The results strongly suggest that those highly educated subjects showed a poor level of understanding some of the most basic concepts of system dynamics' specifically, stock and flows relationships, and time delay. For instance, the subjects tended to be unaware of fundamental relationships between stocks and flows, including the conservation of matter.

The result of these studies show that most students and teachers considered the system dynamics teaching modules very interesting. (In some classes it was the first attempt both for teachers and students of computer-based learning). Moreover measurement of systems thinking skills and their improvement is very difficult. "Systems thinking are no general ability. To understand the dynamics of Modus-models is something different than predicting effects in verbally described models." (Translation from Germany: Ossimitz, 2000).

CONCLUSION AND SUGGESTIONS

The new 2004 Turkish curriculum for Grade 1 to 8 is redeveloped considering social constructivist theory of education. Scientific literacy provides that a student can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a pupil has the ability to describe, explain, and predict natural phenomena.

System dynamics is a general approach for defining and solving problems (Forrester, 1961, 1973; Sterman, 2000). The students that learned this approach will be able to use this problem definition and solution tool for their whole life. System dynamics properties help to new science and technology curriculum program in order to fulfilment their vision.

The structure of system dynamics and the new curriculum have some similar aims and properties. As system dynamics is a general problem definition and solution method, it orientates the students to focus on the causes of the events. These properties of system dynamics will certainly enhance the implementation of the vision of the new science and technology curriculum.

The new curriculum is iterative. The models in system dynamics are very appropriate to be developed according to this principle. The students can model the system in its basic elements in the first iteration. In the next iteration, they can add the elements that make the system more realistic. In the next iteration, the boundary of the system can be extended. In this way, the same subject can be modelled in various levels of detail and scope for the students of various grades.

The essence of the new curriculum is student centred learning based on the structural learning theory. System dynamics does not only serve to this purpose, it is also an invaluable tool for the teachers to realize this purpose. In structural learning, the information is not transferred from the teacher to the student. Instead of this, the teacher helps the student to learn the topics by discovering on his own through questions that make student think deeper. This process requires that the revealing information should be related with each other and the picture of the whole should be drawn step by step. A teacher who uses system dynamics' modelling approach reveals the elements of the system one by one with the students. Then they draw the whole system by finding the relationships between the elements. So this method is a very effective and simple way to implement the structural learning method.

Another essential point of the structural learning is to find out the misconceptions of the student and to replace them with the true concepts. System dynamics approach helps student to absorb the scientific topics in a deeper and more comprehensive way since it helps to reveal the cause and effect relationships that determine the dynamic behaviour. Many of the misconceptions and lacking knowledge can be discovered and fixed in this process. So the student understands the causes of the events in a better way.

An ideal learning environment would include discussion of a topic, student-directed research, laboratory experimentation, model building and exploration, and computer simulation to verify the link between model behaviour and experimental observations. The overall goal is to teach students critical thinking skills and a methodology for dealing with complex problems that they can use later in life as managers, company presidents, journalists, generals, pilots, and engineers (Martin, 1997a).

Alessi (2000) has observed students learn a significant amount in complex subject matter both using simulations created by other people and by creating their own simulations in her article called designing educational support in system-dynamics-based interactive learning environments. These are simulations which embody a model of a scientific theory or phenomenon, and allow the student to engage in simulated research by formulating hypotheses, doing experiments by systematically manipulating variables, collecting and analyzing data, and making interpretations.

The use of computers in the classroom (not in a computer lab) has, resulted in a very unique learning environment. Students learn what they need to know as the teacher guides them in conducting a simulation in class. They work in groups, two or three to a computer, certainly not one per computer, and thereby help one another. Before doing a simulation the students spend several class periods gathering information about the topic; they take notes during lectures, learn about a library and read references, and, working as a group, plan the simulation (Brown, 1990)

System dynamics approach consists of two parts: building the model and testing it. Both parts employ mathematical equations. The relationships between the elements are established through the mathematical relations. New curriculum does not contain as much mathematical relations as the older one. But a student that doesn't know the mathematical relation between the concepts cannot build the model of the system.

System dynamics, a very big idea, is not quick and easy to learn. It takes time, patience, good instruction and follow-up support. Systems education also involves much more than model-building. Faith Waters believes that training should begin with behaviour over time graphs, causal loops, and stock/flow diagrams. Teachers should learn how to use these tools in their curriculum before moving to models. Jeff Potash and John Heinbokel at the Waters Center for System Dynamics at Trinity College of Vermont in Burlington add that before actually building models, teachers should see how models apply to the curriculum, play with little models, and learn about generic structures and transferability. George Richardson of the Rockefeller College of Public Affairs and Policy at the University at Albany, New York cautions that teachers can get discouraged and feel inadequate or incompetent if they think that they are supposed to be able to build models right away (Lyneis, 2000).

But another example about system dynamics shows that it can be applied in three hours for teachers none of whom had prior knowledge of system dynamics. Cruz et al (2007), was conducted an experimental study in Colombia. For the history, civics, and physics experiments, participants were high school students. Three different schools participated, with students drawn from grades 9-11, the last three years of high school in Colombia. At each high school, prior to the classroom experiments, they conducted a three-hour in-service training session for teachers, none of whom had prior knowledge of system dynamics. The bathtub analogy was used to introduce stocks and flows, followed by explanation and illustration of feedback loops. The teachers participated in a physical simulation game—the Infection Game2—the purpose of which was to illustrate dynamics and the impact of structure on behaviour. The teachers were attentive and enthusiastic. They wanted to find new ways to motivate their students and improve their instructional methods. As they learned about SD and experienced the epidemic game first-hand, they began to understand how such generic models could be used to pursue learning goals in a variety of academic disciplines, and they became enthusiastic and interested in learning how to use the SD tools.

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