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Science Teaching and Learning with System Dynamics Approach: The Effects of Attitude and Success of Causality Relationships

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Abstract: The aim of this study is to 1) apply the "system dynamics approach" in a "Science and Technology" course that is being instructed to 7th grade middle school students in Istanbul, Turkey; 2) determine problems of field applications; 3) improve negative attitudes of students towards specific skills (like understanding causal relationships 4) provide more effective tools of learning and teaching, respectively for students and teachers. In this research, the experimental design pre-post test with a control group is employed. The study was conducted with 81 students in middle schools in Istanbul, Turkey. Assessment tool is used: "Cause-Effect Relationship Scale". Improvements that stem from system dynamics are observed in the tests that measure capability of understanding causal relationships. However, in the boundaries of the research, no significant level of improvements was observed in the perceived understanding of causal relationships.

Key words: System dynamics approach · Science and technology course · Causality relationships

INTRODUCTION

System dynamics has been applied in many diverse fields. The most widely known system dynamics study is the Limits to Growth book which was commissioned by the Club of Rome in the 1970's [1, 2]. This study claimed that the natural balance in the earth would be unsettled until the year 2000 if no precautions are taken. The study triggered a lot of controversy, but the discovery of the Antarctic ozone hole in 1985 created a big effect on the public opinion of the world citizens, as well as political leaders. This discovery urged them to take precautions for the problems mentioned in the study Limits to Growth. As a result of these actions, many countries around the world started to take decisions in order to prevent emission of gases that cause ozone depletion.

System dynamics studies led to important changes in the fields of management and economy as well. Having inspired by successful policy changes in a lot of fields, system dynamics researchers aimed to apply the system dynamics approach also in educational fields. Early educational applications showed that important improvements could be obtained in this field [3]. In the schools where system dynamics approach is employed, students ran voluntary projects in relation to their school courses even after school. At some instances, students became so enthusiastic with the subjects that they made their parents to take part in the projects too.

There was a remarkable increase in the interest and understanding levels of students with respect to the courses they take. This increase led to anticipation by the practitioners that this approach will enter the general educational system in USA. Nevertheless, the researchers observed that the extent to which system dynamics applications have diffused into the educational system have not reached the intended level in the aftermath of these studies [3]. Various explanations have been suggested on the causes of this gap. The significant of these explanations are applications of the system dynamics approach in the K-12 education has not focused on the development of 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 [3, 4]. Therefore a few curriculum projects have been developed that are based on system dynamics (Stacin, Cc-Stadus, Cc-Sustain, Science Ware). By using these projects, a lot of new ideas and useful models are provided in order for practicing teachers to apply system dynamics in the classroom.

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System dynamics provides means of communication between mental models and simulations. Mental models of human beings are powerful in terms of knowledge, but they are weak in terms of calculating the behavioral results of the models. Simulation models that are based on mental models complement the inadequacy of human minds to calculate complex and dynamic behaviors [3]. Another benefit of simulation models is that it helps experimentations, which improves learning process [5].

Using system dynamics approach, modelers produce simulation tools that are called "micro worlds". Students use these tools to make certain experiments. These tools are actually replicas of the real world. That is why they are called micro worlds. The experiments in these micro worlds can be repeated easily, using varying parameters and alternative scenarios. This allows the student to see how the dynamics of the system work, 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. These experiments are conducted with the help of easily managable simulation software. Dynamo, Powersim, Vensim, Stella, ithink, Extend and Anylogic are some of the system dynamics software [5, 6]. Stella is the most widespread tool for K-8 students [3, 7].

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

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

The aim of this study is to 1) apply the "system dynamics approach" in a "Science and Technology" course that is being instructed to 7th grade middle school students in Istanbul, Turkey; 2) determine problems of field applications; 3) improve attitudes of students towards understanding causal relationships skills; 4) provide more effective tools of learning and teaching, respectively for students and teachers.

MATERIALS AND METHODS

Research Models: In this research, the experimental design with pre-post test with a control group is employed. Independent variable is the "system dynamics approach". Experimental group was instructed according to the system dynamics approach. Control group was instructed according to the standard syllabus. Students in the experimental and control groups were selected randomly.

It was critically analyzed whether there were statistical differences among scientific successes and an attitude of students in understanding cause-effect relationships.

Research Sample: The study was conducted with a total of 81 students (40 in experimental group, 41 in control group) who are in 7th grade in two different middle schools in Istanbul, Turkey. Research sample was selected randomly.

Assessment Tools: In order to assess the sub problems of the study, assessment tool is used: "Causal Relationship Scale" developed by researchers [8], in order to determine how students evaluate the relationship between cause and effect on sample events and to learn their attitude towards cause and effect relationships.

Causal Relationship Scale: Causal relationship scale measures students' perceptions of their abilities to understand the causality relationships between events. The scale has been developed by the researcher [8]. It consists of two parts. First part of the scale measures attitudes towards causal relationships. Its Cronbach's Alpha value is 0.88. Therefore it is assumed to be reliable in statistical sense. Its validity is verified by expert opinions and statistical factor analysis.

Tablo 1:Contents of the Causality 2 Scale

Questions	Contents
1	Detect the cause of graph that plotted as a result of an experiment
2	Thinking the cause of movements of a frog in boiling water
3	Find cause-effect relationships in an event clearly
4	Determine cause-effect relationships between more than one event, respectively
5	Determine cause-effect relationships among the spring mass system types, force and the amount of elongation.
6	Realize an event consist of cause-effect relationship and occurred in their environment.

The scale consists of 10 5-point Lickert-type questions where 5 of the questions are positive and the other 5 negative. The scale has a KMO value of 0.86 and a Bartlett's value of 543.5. Therefore the scale is appropriate for factor analysis. All the questions are clustered in the first factor that has an Eigen-value greater than 1. The explained variance is 50%.

Second part of the scale consists of open ended questions on the opinions of the students about exemplary events. Second part of the scale (Causality 2) consists of open ended questions on the opinions of the students about exemplary events.

Application Steps of the Research:

- Pre-application of the experimental study was conducted with a group of 20 students. The aim of pre-application was to discover probable problems that would be encountered during the study. Real application was designed by taking the findings obtained during pre-application into account.
- Application schools (two different middle school in İstanbul) and the experimental and control groups within these schools were determined by random assignment.
- Both schools have experimental and control groups. In one of the schools, control group was instructed by the actual teacher. In the other school control group was instructed by the researcher. Experimental groups were instructed by the researcher in both schools. Instruction was conducted in the Fall semester in the form of 4 weekly study hours in a "science and technology" course.
- After the pre-tests, system dynamics approach was introduced to experimental groups in 4 study hours. During the introductory course, students learned the basics of system dynamics approach and they built models presented as exemplary scenarios (example: bathtub dynamics).
- The topics "spring-mass systems", "work and energy", "energy types" and "preservation of energy" were studied in both schools and groups. Instruction of the curriculum material was same for both control and experimental groups. There were 4 study hours available in each week. 2 of them were used for the instruction of curriculum material in both control and experimental groups. The remaining 2 hours were used for exercises in control group, whereas these hours were used for system dynamics approach in experimental group. Design of experiment is shown at Table 2.
- Post-tests were applied and qualitative interviews were done
- Data were analyzed statistically.
- Total duration of the experimental study was 8 continuous weeks.

Learning Topics with System Dynamics Approach: Experimental group students attended introductory system dynamics lectures. During these 4 study hour lectures, they learned the relationship between system and dynamics, basic elements of a system (stock and flow, feedback loops, causality relationships). Also they learned using the Stella program to build and test models and interpret the dynamic behavior of a model. Students learned system dynamics tools with 4 different scenarios in the introductory lesson.

Table 2: Design of Experiment

	1. School		2. School	
	Experimental group	Control group	Experimental group	Control group
Curriculum material	2 hours/week	2 hours/week	2 hours/week	2 hours/week
Teached by	Researcher	school teacher	school teacher	school teacher
Supplementary material	2 hours/week	2 hours/week	2 hours/week	2 hours/week
Teaching method	system dynamics modeling	exercises	system dynamics modeling	exercises
Teached by	Researcher	school teacher	researcher	school teacher

Table 3: The activities and topics of the lectures in two groups

Courses	Topics	Activities
1.	introduction to spring mass systems	- Playing with springs
		- Making a spring
		- Designing a dynamometer
2.	work and energy	- Do we work in which situation
		- Is there any work?
3.	types of energy	- Velocity, mass and kinetic energy relationships
		- What is the potential energy depending on?
		- What is the spring flexibility potential energy depending on?
4.	conservation of energy	- How does the energy transfer?

The students built models of spring-mass systems step by step using concepts they have recently learned, as well as causal relationships between these concepts. They found out what kind of changes happened to springs after applying force. They decided how the mathematical equations can be applied on the model. They achieved to produce the graphical output of dynamic behavior of the system where more than one variable is shown together in the graphics. At each lecture, students made additions to the model. They discussed the model with their friends.

The curriculum material of the Turkish Ministry of National Education [9] for the year 2006 was instructed in both control and experimental groups according to constructivist learning methods. Students learned the topics through activities and class discussions. The only difference between the control and experimental groups were supplementary materials. Supplementary materials of the control group were exercise problems given in the workbook. This material was replaced with system dynamics modeling activities in the experimental group. The activities and content of the lectures are shown in Table 3. The final model developed by the experimental group is shown in Table 4.

Statistical Techniques Used in the Research: Collected data are analyzed with 3 statistical methods:

- Descriptive statistics of the means and standard deviations are found for scale and group.
- Paired t-tests are applied for comparison of pre- and post-tests for scale and group. Pre-test of the group is compared with the post-test of the same group to see whether there is any change in a group between pre- and post study. The aim is to show whether teaching activities indicates an improvement in the skills and attitudes of the students in comparison to doing nothing.
- Independent t-tests are applied for comparing the two groups on scale. The aim is to show whether the system dynamics approach indicates an improvement in comparison to the traditional supplementary materials.

Findings

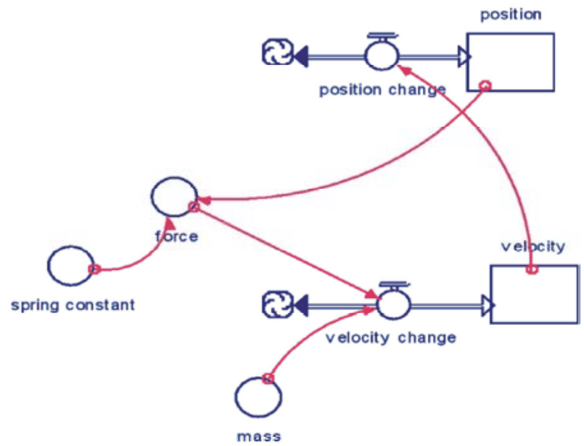
Statistical Values of Mean and Standard Deviation: The results of pre- and post-test score made on success of figuring out the causal relationships skills and attitude of students in experimental and control groups are shown on Table 5.

When Table 5 is checked, it can be seen that pre-test scores of experimental groups and control groups are not equal, but are quite close. The understanding scale of causal relationship has two sections. In the first section (causality 1) the interests and attitudes of students towards causal relationships are evaluated, while in the second section (causality 2) their skills of commenting on and discerning causal relationships in some sample cases are evaluated. When analyzing the first section by taking into consideration the mean values, which were taken from the students' data, it is seen that the initial scores of experimental and control groups are different in the beginning, whereas their mean scores are equal in the end of the empirical study. When analyzing the second section, in the end of the empirical study it is understood that causal relationship skills of the students have increased.

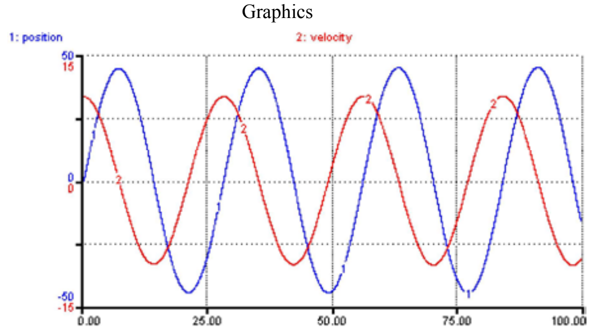
The Effects of the System Dynamics Approach on Students' Skills of Understanding Causal Relationships: The results of pre and post test scores of the tests that measure students' skills of understanding causal relationships in experimental and control groups are shown on Table 6.

Table 4: The final model developed by the experimental group

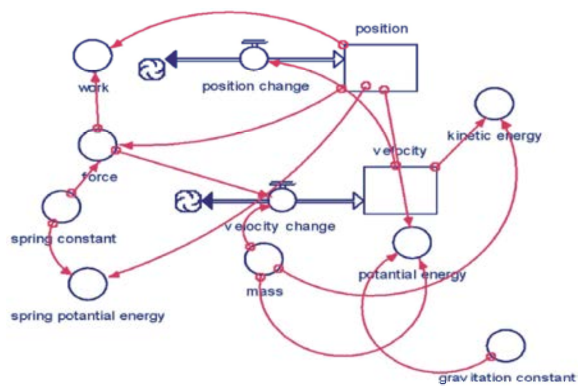
Models of Systems



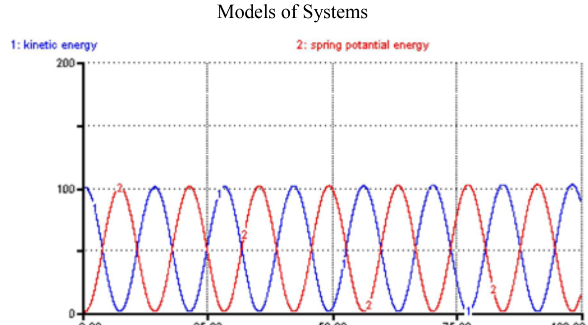
Introduction to Spring Mass Systems — Graphics



Work and Energy



Energy types
(kinetic, potential, spring potential energy) — Models of Systems



Conversation of the energy — Graphic

Table 5: Statistical Values of Mean and Standard Deviation

		Mean				Standard deviation			
		E1	C1	E2	C2	E1	C1	E2	C2
Causality	Causality 1	38.6	35.2	40.8	40.8	7.7	14.2	7.5	7.4
	Causality 2	-0.1	-0.6	2.2	0.4	0.9	0.7	1.8	1.1

E1: experiment pre-test C1: control pre-test

E2: experiment post-test C2: control post-test

Table 6: Statistical Values of Causality 1 and Causality 2

Tests	Groups	h	p (%)	t	Df	sd(1)	sd(2)	is difference significant?	SD useful or not?	Experiment biased
CAUSALITY 1	E1 E2	1	2.26	-2.07	38.00	5.88		Yes		
	C1 C2	1	1.95	-2.14	37.00	11.22		Yes		
	C1 E1	0	8.83	-1.37	61.70	14.16	7.69	No		No
	C2 E2	0	49.86	0.00	74.96	7.42	7.45	No	No	
CAUSALITY 2	E1 E2	1	0.00	-8.85	38.00	1.69		Yes		
	C1 C2	1	0.00	-4.64	37.00	1.30		Yes		
	C1 E1	1	0.92	-2.41	77.91	0.72	0.85	Yes		Yes
	C2 E2	1	0.00	-5.47	64.72	1.12	1.76	Yes	Yes	

The students' answers have been evaluated as causality 1 and causality 2 (Table 6). In the causality 1 scale, the ideas and attitudes of the students about causal relationships are evaluated; in the causality 2 scale, skills of commenting on and discerning causal relationships in some sample cases are evaluated. Statistically there is not any significant difference in the interests and attitudes of the students towards causal relationships (causality 1) in the end of empirical study ($t = 0.00$; $p>.05$). In the classes where the system dynamics approach is performed, it is obvious that ideas of the students about causal relationships did not change. The results gained from causality 2 scale shows that there is an increase in pre- and post-empirical study in both groups. Causal relationships are understood better by the students in the experimental group according to mean scores. It can be said that system dynamics provides the benefit of understanding and commenting on causal relationships.

DISCUSSION

Many researchers and teachers [6, 10-22, 26], applied system dynamics approach in their classes or experimental studies and attained positive results.

A common finding of these teachers is that by using system dynamics tools, learning becomes more learner-centered and cooperative. System dynamics lead students to discover problems by putting puzzle pieces together, looking for similar patterns and working with their friends to actively generate questions in various disciplines. All these activities are coherent and make a great benefit for children. The work is interdisciplinary in primary and middle schools. Students can learn the basics of system dynamics very efficiently [4]. In this research it was determined that students developed some skills like realizing and interpreting causal relationships, competence in problem solving, competence in drawing and analyzing graphics by using system dynamics approach. These results are similar to general findings in the literature.

Everyone who teaches System Dynamics modeling has reported how difficult it is, even though the benefits are great [3, 4, 23, 24]. There are some common difficulties when applying system dynamics in school. Students have difficulty ib distinguishing stocks from flows. Instead of understanding the system under study, they try to fit the mathematical formulas they have in mind without thinking thoroughly. When simulation doesn't produce expected behavior, they include "fudge factors". Fudge factors are variables specifically designed to fix the problem artificially. They are not representations of any reality. Students don't test their models well. Therefore the models don't work under different conditions. They build unnecessarily complex models. They try to build imitations of textbook models. The teachers don't realize that building a realistic model requires really long time. Patience is a pre-condition for students and teachers when building system dynamics models [3, 24].

In this research, middle school students learned various topics of science and technology course with supplementary activities of system dynamics approach. The topics taught are spring-mass systems, work and energy, energy conversion. The students learned basic concepts (stock-flow, causality relationships and feedback loops) of system dynamics in applying them in those science topics. Students had difficulties at first on what the stock and flow variables were, when they were modeling spring-mass systems. Reminding them the stock-flow relationship in the bath-tube example helped them to build the model of spring-mass system. Adding causal feedback loops to the model was another difficulty for students. Teachers have to be patient in order for the students to build better models with time.

RESULTS AND SUGGESTIONS

Results of analysis show that the system dynamics approach has some benefits in learning science topics.

In the boundaries of this research, system dynamics approach had no effect in the perceived understanding causality relationships (causality 1 scale). Since the study was conducted in a setting of 4 weeks, these results did not deviate from estimates. According to the researcher's observations, the interests and attitudes of students towards the system dynamics approach increased steadily during the study. However, according to the pre- and post-tests of the attitude scale, any change in the perceived attitude towards causality relationships were not detected. This is not surprising since the attitude towards a subject depends on more than one factor. Therefore in order to increase the positive attitude, these factors should be studied in detail.

Second part of causality relationship scale consists of open-ended questions. These questions help us to assess whether the students have the ability to determine the relationships between causes and effects correctly. The answers of the questions were evaluated as true or false. After the study, both control and experimental groups had an increase in comparison to their pre-study levels. The increase in the mean of the experimental group was higher than the control group.

Therefore it is reasonable to conclude that the system dynamics approach has a positive impact on the ability of understanding causal relationships for students although the perceived attitude towards causality did not increase in the experimental group. The steadiness of attitude may be due to external factors that are not handled in the research.

A spring-mass system is an ideal topic to apply system dynamics approach in a science course. Before starting with the modeling of the spring-mass system, the students need to be introduced to the Stella software and basics of model building. Basic concepts like stock-flow, feedback loop, causality relationships and graphics drawing and reading abilities need to be introduced to the students as well, with exemplary scenarios.

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 behavior 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 [5].

The use of computers in the classroom in contrast to computer lab has important results. Students learn and build simulation models in parallel. They work in groups. This helps communication between students [25].

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