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Evaluation of Student Models on Current Socio-Scientific Topics Based on System Dynamics

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Abstract

This study aims to 1) enable primary school students to develop models that will help them understand and analyze a system, through a learning process based on system dynamics approach, 2) examine and evaluate students' models related to socio-scientific issues using certain criteria. The research method used is a case study. The study sample consists of 10 primary school students, grades seven and eight. Students were first informed about the theoretical background of system dynamics approach, and then some applications were conducted using sample scenarios to show how to model a system with the Stella program. This experimental study lasted one hour for 14 weeks. For the last 8 weeks, students chose one of the previously determined topics and worked on developing a model based on system dynamics using the Stella program. Recordings of the models students had developed and interviews conducted with them were analyzed based on five criteria (using the correct concepts in the model, determining and using the variables, determining the relationship between the variables, locating numerical parameters, and creating and interpreting graphs). In addition, semi-constructed interviews and records by the observing teacher were analyzed and evaluated in relation to the models students had developed. Analytical results revealed that students had difficulty in determining the stock and flow in a system, could not easily perceive the system as a whole, and were unable correctly to form a relationship among various aspects of the system. However, students' interest in the topics they were working on increased while developing the model.

Keywords

System Dynamics, Model Development, Stella Program, Socio-scientific Issues.

Children, who are curious and enthusiastic about research and discovery in the earlier stages of their lives, gradually lose these characteristics as they mature. This is a most crucial concern in education. The current educational system fails to properly foster children's imagination and eagerness to learn. In the new curriculum, the Ministry of Education (Milli Eğitim Bakanlığı [MEB], 2006) aims to solve this problem with the help of student-centered teaching methods, based on constructivist learning. Hence the Science and Technology Curriculum aims to transform students into inquisitive individuals who can solve problems, make the right decisions, understand, use, and develop new technology—all of this while preserving their eagerness to learn throughout their lives (MEB, 2006).

To achieve these aims, socio-scientific topics should also be included in the curriculum, in addition to building the theoretical background related to science and technology subjects. This way, students can develop social awareness related to these subjects and use technology effectively (Ramsey, 1993; Sadler, 2011; Zoller, 1987).

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Socio-scientific topics help students develop responsibility about economic, political, social, and ethical issues related to science. They can also be used as tools to enhance students' critical thinking and decision-making skills (Lee, 2007; Pedretti, 1999). Socio-scientific topics are issues with social dimensions, debated among scientists. These topics involve moral beliefs and values' effectiveness in decision-making processes and risk-benefit analysis (Ratcliffe & Grace, 2003). Some examples of these topics are genetically modified foods, global warming, cloning, and nuclear energy (Sadler, 2011).

Zeidler, Walker, Ackett, & Simmons (2002) have observed that incorporating such topics in science lessons increases students' scientific literacy and facilitates conceptual learning. These topics also develop critical thinking, inquiry, and argumentation skills (Sadler & Zeidler, 2004; Zohar & Nemet, 2002). With the help of this study, presumably, working on real socio-scientific issues while developing models based on system dynamics will enable students to understand the system thoroughly.

In addition, although teachers think students have no difficulty understanding topics related to environmental problems, many researchers (Boyes, Chuckran, & Stanisstreet, 1993; Bozkurt & Cansüngü Koray, 2002; Grotzer & Basca, 2003; Rye, Rubba, & Wiesenmayer, 1997) indicate that students from different age groups have misconceptions regarding these topics. These misconceptions can likely be revealed with the help of the system dynamics approach when students are developing their models about socio-scientific issues.

Initial educational studies related to system dynamics (Forrester, 1992, 1996) showed that it possible to obtain substantial results in this field. In the schools where the system dynamics approach is applied, students voluntarily conducted projects related to their lessons, even after school hours (Alessi, 2005; Fisher, 1994; Forrester, 1992, 1996; Lyneis, 2000; Zaraza & Fisher, 1997). But eventually, such expectations were not met (Forrester, 1996). Investigations of the reasons indicated that teachers focused on teaching theoretical information and rules, while they ignored the lesson plans designed to support and enrich learning (Forrester, 1996; Lyneis, 2000). Upon this finding, new projects were developed (Alessi, 2005; Mandinach & Cline, 1994; Zaraza, 1995), and many new ideas and useful models emerged.

Using the system dynamics approach, simulation environments called *micro-worlds* are built. Primary school students usually build these environments using System Thinking Educational Learning Laboratory with Animation (STELLA; Brown, 1992; Forrester, 1996). Students working in simulation environments develop a deeper understanding of concepts and cause–effect relationships between concepts (Martin, 1997).

Students encounter many problems while developing and testing these models. For this reason, system dynamics can be considered a general problem-posing and -solving approach (Forrester, 1987; Sterman, 2000). With the help of this approach, students develop scientific discipline and sensitivity.

Individuals who are accustomed to systems know that complex systems cannot be managed with shortcuts and practical solutions (Meadows, 1997). System dynamics forces students to deal with dynamic, complex, social, economic, and environmental problems. It provides a concrete communication device for understanding cognitive models related to complex systems. As students learn how the system works, they expand their horizons and become more aware of what is happening in their surroundings (Stuntz, Lyneis & Richardson, 2002).

This study aims to: 1) design an instructional program that enables students to develop models for comprehending and analyzing a system through a learning process based on a system dynamics approach; 2) examine and evaluate students' models related to socio-scientific issues using certain criteria.

Method

Case study is the method used in this research (Cohen & Manion, 1989). This method is preferred so that the models students have developed based on system dynamics can be examined in detail and the methods they used during modeling and interpretation processes can be better understood. In a case study, the "case" is defined as a whole system with clearly defined boundaries (Stake, 1995). A case with predetermined boundaries can be chosen, or researchers can determine the boundaries of the case themselves (Bell, Bush, Fox, Goodey, & Goulding, 1984; Stake, 1995). This study is bounded by the researcher with system dynamics models of socio-scientific topics.

Sample

This study's sample consists of 10 primary school students in the seventh and eighth grades. The reason for selecting this age group is, according to Piaget's developmental stages, these students are transitioning from concrete operational stage to formal operational stage. Piaget and Inhelder (1969) state that students who have reached this stage can form assumptions, make logical inferences, and solve complex problems (concrete or formal) in a systematic way. Students in this stage are capable of hypothetical thinking and abstraction at analysis, synthesis, and evaluation levels. They can also evaluate abstract problems systematically and make generalizations (Selçuk, 2004). The system dynamics approach is suitable for primary school students who are at the beginning of the formal operational stage because it helps them develop skills such as understanding causal relationships and feedback loops, as well as recognizing and attempting to solve problems.

Instruments

Data were collected using three instruments.

Records of Student-Developed Models: The researcher examined students' models in detail, and numerical data was presented to see how students used the basic elements of system dynamics.

Observational Data Collected as Students Worked on Models: An observation form approved by an expert was used to collect these data. In addition, the researcher and two observer teachers took notes of the difficulties that students encounter while modeling.

Semi-Constructed Interviews with Students During and After the Modeling Phase: With a sound-recording device, the researcher recorded student responses to open-ended questions related to their completed classwork. Afterward, content analysis was conducted.

Findings

Findings Related to Understanding Student Models

In this phase, students' models were examined on a conceptual level, and descriptive analysis was conducted. Models developed by each group were recorded at every step, and groups submitted their models when they decided the model was finished. The researcher determined errors and missing parts in the models and guided students to develop an ideal model for their topic. The models evaluated are those students initially submitted before any modifications were made with the researcher's help. Each model was qualitatively analyzed in detail by the researcher.

After the student models were examined, a quantitative analysis was conducted on the system dynamics based models related to socio-scientific issues. Five aspects of system dynamics (number of stocks, number of flows, converters, relationships, and feedback loops) were considered during the analysis. Results of the analysis revealed that students generally chose topics with which they were familiar. The students thought the number of stocks in the system would be less than the number of flows, they did not include converters in the system, and, with the exception of two models, they could not form relationships between variables. An interesting finding is that, while students could correctly determine the basic concepts within the system, they had difficulties in adding new concepts to it and correctly forming cause–effect relationships between the concepts.

Another analysis on the data used the following criteria (Nuhoğlu, 2009) to evaluate the models and the relationships between the basic elements of the system as correct, false, partially correct, and incomplete: Using the correct concepts in the model, determining and using the variables, determining the relationship between the variables, locating numerical parameters, and creating and interpreting graphs. Results reveal that all participating students correctly identified the stocks and flows in the system although some of them could not determine the direction of the flows correctly. Converters were missing from three of five models, indicating that students were having difficulty in deciding what converters should be in the system. Models revealed that students could not correctly form the needed causal relationships. They also made errors in locating the numerical parameters, and this caused the system's dynamic behavior graph to be incorrect. When students realized that there were errors in the behaviors of their model, they repeatedly turned back to the model and made corrections. According to the observation reports, while this constant correction phase enabled some of the students to develop better models, some students became bored during this phase.

Findings Related to Student Views

Data collected from student interviews are examined under three categories.

Changes in Interest Toward Learning: Students stated that, with study, they tried to learn in detail about the topics they had heard of, but had not paid much attention to previously. They also said they tried to understand how concepts related to the topic connected to each other. As mentioned in the introduction, one of education's greatest problems is students' lack of curiosity and attentiveness toward the subject matter. In this study, however, students made progress in that regard.

Difficulties Encountered During the Modeling Phase: Students have stated that, after doing some research on the topic, they did not have any problems in determining the stocks, but that, at first, they had some difficulty deciding the directions of the flows, but figured them out after a couple of tries. According to the students, the hardest part was understanding how pieces affected each other while they were determining relationships between variables. In addition, they stated that, after the model was formed, they made mistakes writing the mathematical equalities and had difficulties when they had to write formulas instead of quantitative expressions. Additionally, when they realized the graphs were wrong and they had to correct the model, often more than once, they became frustrated, but somehow could not give up before correcting them.

What Students Gained from System Dynamics Approach (Learning Outcomes): Data collected by model recordings, observations, and interviews indicate that students began to see phenomena as a whole and recognize cause–effect relationships between events. Students stated they realized that the outcome of an event could be something unexpected and that when phenomena affect each other differently, the outcome changes.

Discussion and Conclusion

Most research in the literature focuses on the system dynamics approach's effects on achievement and various skills. System dynamics approach is used for high school topics, for example, economics, social ecology, population, mechanics, Newton's laws of motion, and mathematics (Cruz, González, Restrepo, & Zuluaga, 2007; Davidsen, Bjurklo, & Wikström, 1993; Draper & Swanson, 1990; Schecker, 2005; Tinker, Nemirovsky, Mokros, & Barclay, 1990; Zuman & Weaver, 1988). Some studies considered the system dynamics approach as used at the primary school level; simpler topics, compared to high school, were considered, and the results were successful (Draper & Swanson, 1990; Klime & Maichle, 2000; Nuhoğlu, 2008; Penner, 2000; Ticotsky, Quaden, & Lyneis, 1999). Because little research exists for the primary school level and the learning materials and educational content for teachers to use in applications are limited, studies aiming to expose students to systems thinking at early ages cannot be widespread. For these reasons, considering it would be better to teach systems thinking at an early age, students from grades seven and eight were chosen for this study.

This study differs from other research by using current topics in science and topics related to current socio-scientific issues. Studies related to socio-scientific issues (Puig & Jimenez-Aleixandre, 2011; Sadler, 2004; Sadler & Zeidler, 2004; van der Zande, Warloo, Brekelmans, Akkerman, & Vermunt, 2011) include topics such as genetically modified foods, cloning, stem-cell studies, environmental problems, and diets. In this study, topics related to socio-scientific issues such as young and adult bluefish populations in Turkey, caffeine addiction, and traffic problems were used.

Ossimitz conducted an experimental study in 1996. Afterward, the students who participated stated that, even though they learned system dynamics as a new method, they found it very enjoyable and had fun with their group mates discussing the relationships between events (Ossimitz, 2000). Students in the present study expressed similar thoughts. The primary school students in this study stated in interviews that, even though they used a method that they had never seen before, they enjoyed using it with their group mates because it allowed them to learn by discovering new things. These statements are consistent with the behaviors they revealed in observation logs and model records.

Helen Zhu (as cited in Forester, 1996), who developed system dynamics materials for K-12 education, stated that students were making calculations to reveal population behavior in differential equations class and realized how much system dynamics simplified their thinking process. It was considered a surprising result that, while only college students had previously been able to understand this phenomenon, primary school students could also learn the same material through system dynamics modeling. Similar to Helen Zhu's observations, in this study, students also attempted to understand very complex socio-economical systems and environmental problems by developing models based on system dynamics. In addition, they generated ideas for possible solutions.

Research also reports that even though the system dynamics approach has positive effects on students and teachers, some problems occur in the application phase. One of the biggest mistakes teachers make is that they expect their students to develop complex models (including multiple stocks, flows, and cause–effect relationships) within a few weeks (Alessi, 2005; Forrester, 1992). Some results in this study parallel some of Alessi's (2005) findings. In this study, some students built complex models by adding converters not in the system. Too, they understood the difference between stock and flow although some were confused by the flow's direction. In addition, they had difficulty choosing correct variables while adding converters. Some of them built their models using only stocks and flows, without adding any converters. Since students had difficulty in correctly locating mathematical data in the system, errors occurred in the graphs. Fisher (2000) reported that while working with students on developing models for an accommodation problem related to increasing population, students made errors in plotting the graphs. In both studies, they were unable to develop high quality models. One reason for that, as Forrester (1992) and Alessi (2005) both suggest, might be that teachers wanted their students to complete the models within a short time. In this study, students were given eight hours for developing their models. Students could be provided another opportunity to build better models when the time allocated for developing models is increased and when they are provided with a detailed report about the errors in their models.

Suggestions

1. The introductory course in which the students learned about the elements of system theory, such as stock-flow and cause–effect relationships on five different scenarios lasted 6 class hours. This time period can be extended according to the interests and needs of the students. In addition, the course can be enriched with the addition of complex scenarios.
2. With the system dynamics approach, students consider the system as a whole and model it themselves while exchanging opinions with their friends. Students develop positive feelings and thoughts about various topics while they are building their models with their newly acquired knowledge and refining it.
3. One important finding is that students keep the system independent from variables affecting it, other than stock and flow, and they have difficulty in forming cause–effect relationships among the variables. Since the system is better understood when causal relationships are well formed, students should be supported more at this point.
4. Students who become frustrated when errors occur in their models, or students who do not like dealing with problems, can be presented with new and interesting information regarding their topic of interest, or they can be supported with patience exercises.
5. Teachers can detect the misconceptions and incomplete or incorrect information their students have related to the topic they are modeling and guide them through these misconceptions.
6. Providing students with technological opportunities might attract their attention and lead to effective learning, since nowadays information is acquired by using technology. But using computers alone is not enough to interest students or help them gain new skills. To achieve success in computer supported education, approaches that enable students to use their abilities in multiple dimensions, such as using STELLA to develop system models, can be used.

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