MODELING SPRING MASS SYSTEM WITH SYSTEM DYNAMICS APPROACH IN MIDDLE SCHOOL EDUCATION

Hasret NUHOĞLU
Gazi Üniversitesi, Eğitim Bilimleri Enstitüsü, Fen Eğitimi ABD, Ankara
hasret.nuhoglu@gmail.com

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 manufacturing 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.

The aim of this study is to model spring mass system that is taught in middle school science and technology curriculum, using system dynamics approach and to learn the effect of the system dynamics approach with sample application group. This research consists of three sections: exploring system elements, modeling systems and testing models. In the first section of this research the theoretical information was given about how the models are developed and tested. In the other section two sample students' developmental data were examined and discussed.
Key words: System dynamics, STELLA program, Spring mass system

INTRODUCTION
One of the best ways to learn is to participate in a project. Educators can stand in front of students all day long and lecture on how to hit a tennis ball, change the oil in a car, or run a corporation. Once a student is in the position where it is necessary to complete one of these tasks, however, the student often cannot. The reason that a student cannot complete the task is because the student has created a mental model of the system, based on lecturing or reading that does not fit reality. A mental model is one's mental perception or representation of system interactions and the behavior 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 (Martin, 1997a).

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. Computer simulation is the imitation of system behavior through numerical calculations performed by a computer on a system dynamics model. A system dynamics model is the representation of the structure of a system. Once a system dynamics model is constructed and the initial conditions are specified, a computer can simulate the behavior of the different model variables over time. A good model attempts to imitate some aspect of real life. Real life does not allow one to go back in time and change the way things are. Simulation, however, gives students the power to change system structure and analyze the behavior of the system under many different conditions (Forrester, 1995; Martin, 1997a; Sterman, 2000).

Using system dynamics approach the modelers 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, 1996; 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)

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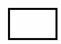
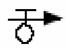
SYSTEM DYNAMICS COMPUTER SIMULATION PROGRAM

STELLA (System Thinking Educational Learning Laboratory with Animation)

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. Model builders and users, however, are not overburdened with complexity because all STELLA models are made up of only four building blocks: stock, flows, converter, connector (Martin, 1997a).



STOCK: A stock is a generic symbol for anything that accumulates or drains. For example, water accumulates in your bathtub. At any point in time, the amount of water in the bathtub reflects the accumulation of what has flowed in from the faucet, minus what has flowed out down the drain. The amount of water in the bathtub is the stock of water (Martin, 1997a).



AKIŞ: A flow is the rate of change of a stock. In the bathtub example, the flows are the water coming into the bathtub through the faucet and the water leaving the bathtub through the drain (Martin, 1997a).

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).

Table of stock and flows examples

inflows	stocks	outflows
Birth	Population	Dead
Growing	Oak trees	Harvesting
Eating	Foods in stomach	digesting
Learning	information	Forgetting

Figure 1. Examples of stock and flows

CONVERTER: A converter is used to take input data and manipulate or convert that input into some output signal. In the bathtub example, if you were to turn the valve that controls the water flow in your bathtub, the converter would take as an input your action on the valve and convert that signal into an output reflecting the flow of water (Martin, 1997a).

CONNECTOR: A connector is an arrow that allows information to pass between converters and converters, stocks and converters, stocks and flows, and converters and flows. (Martin, 1997a).In figure 2 Stella programs' elements are shown.

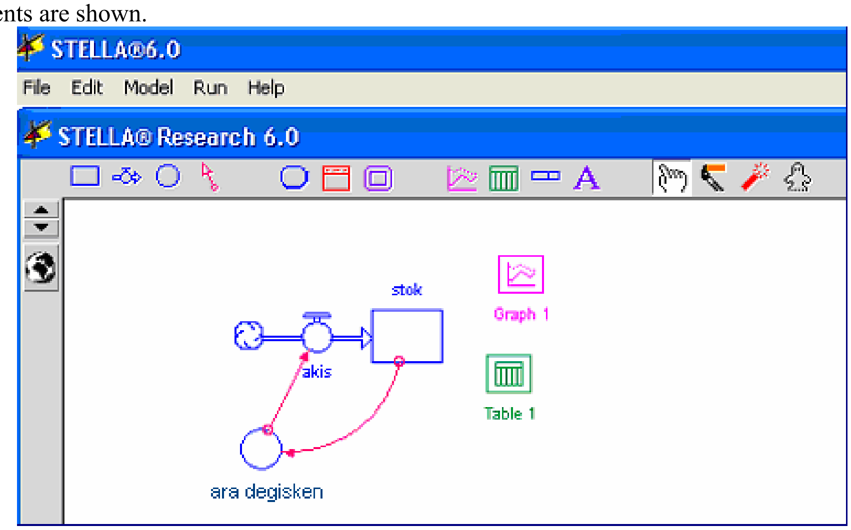


Figure 2. Stella Model Elements

Student's profile
Students learn force, force measurement with dynamometer, balanced and unbalanced force, and gravity force and velocity concepts in 6th grade in middle school. The subject of spring mass system takes place in 7th curriculum. The students are expected to learn the following knowledge on spring mass system according to the MEB curriculum:

Benefits for students
The students learn about spring mass system:

- They observe springs' elastically features.
- They determine that spring implement force in same size but opposite direction
- They notice that when the force that stretch or compress the spring is increase the force of application from spring is increase.
- They discover that the spring can be permanently deformed.
- They may design a dynamometer using springs' features.

Target students for application
Target students were 7th grades students. They should study in a computer laboratory. Student may use the computers for building models individual or cooperatively with friends. In the computer the STELLA software program must be installed. Students don't need to have prior deep computer skills. If they learn how to run Stella programs with a sample application before the lesson, they don't struggle with difficulties in the lesson while building models.

I. STEP: EXPLORING THE SYSTEMS' COMPONENTS
Three activities related to the spring mass system were made in the lesson. Firstly students observed springs' motion in laboratory environment, and then they explored cause and effect relationship between events and feedback loops while they were building models. The activities were taken from the 7th grade curriculum of MEB (2007).

Activity 1: Playing with springs
Several springs with different properties are distributed to students for this activity. Students apply push and pull force on the springs with different properties. They share observations and discuss the results of these observations with friends. They show the direction of the applied force.

Activity 2: Making a spring
Students make their own springs using different materials in this activity. They notice that the springs have elastic features. They can use wires that made of copper, iron and nickel-chrome. When a bigger force is put on them, they change shape. When the force is removed, they return to their original shape. Students must be careful to do not stretch the spring beyond what is called its elastic limit. It will not return to its original shape. It will be permanently deformed.

Activity 3: Designing a dynamometer
The aim of this activity is to provide opportunity to students to design a dynamometer using pocket tire or slim spring. Students attach a hanger of known weight. This stretches the spring. They measure and note the new length of the spring at the new position of the pointer. The extension is the extra length beyond its natural length. They record the extension of the spring by subtracting the natural length from this new length. In conclusion they learn that the extension of a spring is directly proportional to the force that is stretching it.

After these activities students review their learning.

- Springs are elastic object.
- When you stretch the spring beyond the elastic limit, it will not return to its original shape.
- Different springs have different features. If same force applies to different three springs, different changes occur.
- Every spring have special features and force constant.
- If you apply push and pull force to springs you observe some changes to spring motion.
- When spring push and pull you feel that spring apply a force to us.
- If we apply the more force to spring it apply the more force same size but opposite direction.
- If we hang some weight up on spring the extension point of the spring can change.

II. STEP: MODELING THE SYSTEM

Students built a model using Stella software program after experiment this activity. Firstly students tried to find which stocks or flows were. There are two stocks in spring mass system model. Stocks describe the system condition and give basic information about system. There are two factors to determine system motion: position and velocity. The change of position and velocity are flows because flows do the changing. The meaning of the bilateral arrow is that the flow has two directions both inward and outward.

Student built a new spring mass system model using their observation in the prior activities. This model can be like this:

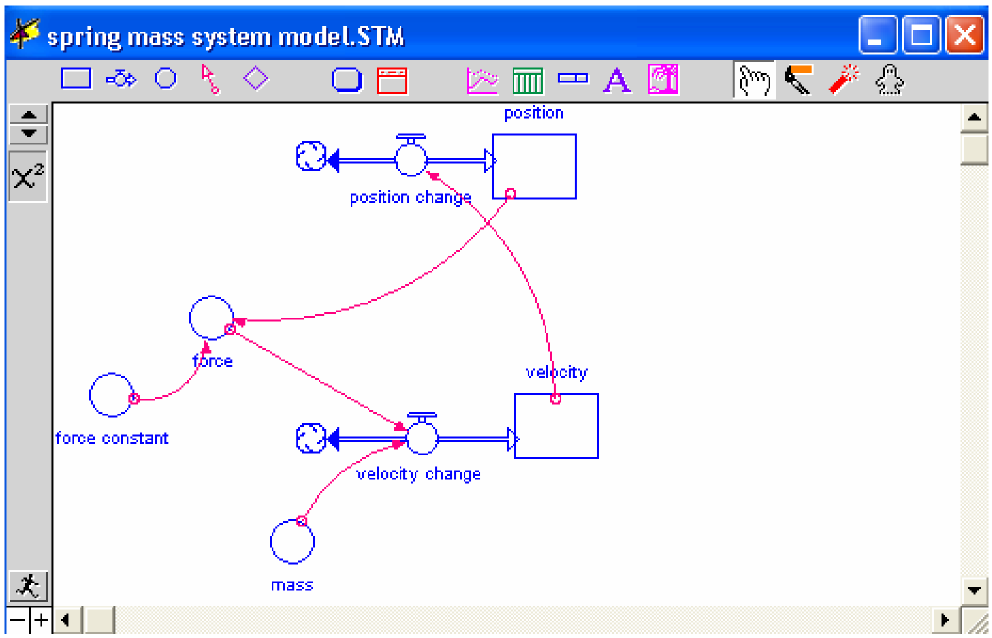


Figure 3. Modeling To Spring Mass System with Stella

Stock and flows in the system consist of feedback loops. "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to reaffect itself" (Roberts, 1983; quoted from Martin, 1997c). The structure of the feedback constitutes their dynamics. Feedback loop related to cause effect relationship in the spring mass system can be shown figure 4.

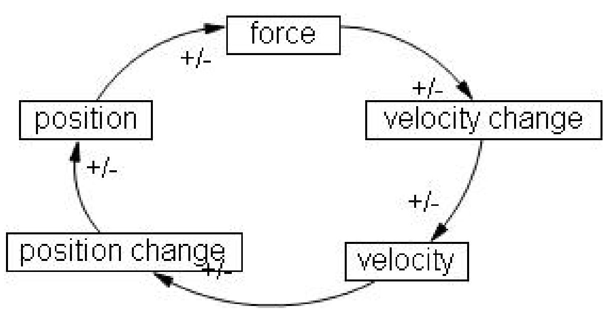


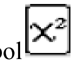
Figure 4. Feedback loop in spring mass system model

The feedback loop in the system begins with push and pulls force. Springs begin to have velocity via force effect. This effect caused to position change and position too. Then, spring exerts force in same size but opposite direction to us. This feedback loop continues in the same way.

Feedback loops join with non-lineer relationships. In other words feedback relationship about stocks gets feedback to stocks by non-lineer ways. And the simulation program is necessary in order to modeling complex dynamics systems. Spring mass system models built using Stella software and computer simulation.

III. STEP: TESTING THE MODELS

In STELLA, there are two ways to view a model: in mapping mode and in modeling mode. Right now we are in mapping mode, as seen by the little globe in the top left hand corner of the page. Let's go into modeling mode.

Click on the globe in the top left corner of the page. The globe should change to the algebraic symbol Notice that there is a "?" inside both the stock and the flow. A "?" means that the building block has not yet been defined by a mathematical equation. The new window open, like figure 5, then you can write in numbers, or arithmetic operators, in forming your equations. The mathematical equations for every systems component are shown at the following.

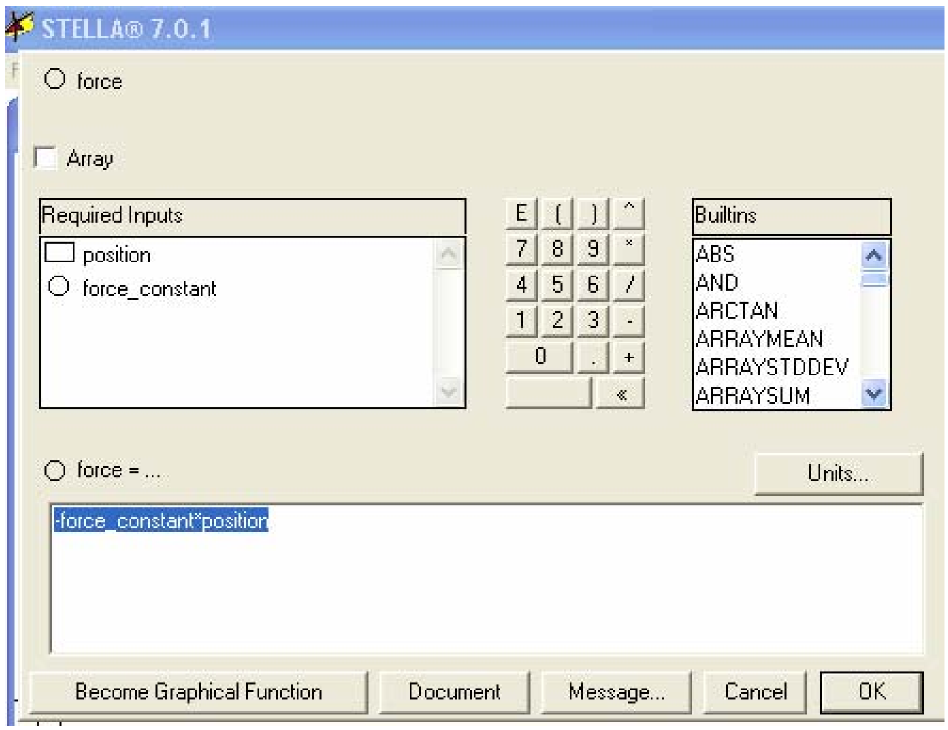


Figure 5. Showing mathematical equations

Position	0
Velocity	10
Velocity change	Force/mass
Position change	velocity
Force	- position∗force constant
Force constant	0.1
Mass	2

Supposed that the velocity is 10 m/s in equilibrium position. Restoring force and mass of the spring effects the velocity change. Their mathematical equation related to force and mass. Velocity change is equal to force/mass (Newton's motion laws). Position change is equal to velocity. Velocity can be placed with stock or flow in the system. Mass and force constant are stable value in the system so their value can change for different situation. In this system force constant is 0.1. Changing this value doesn't effect mathematical equation in the system.

It is enough to click  button for drawing a graphic of model. When you click on the graphic button double, allowable and selected window open, like figure 6 and 7.

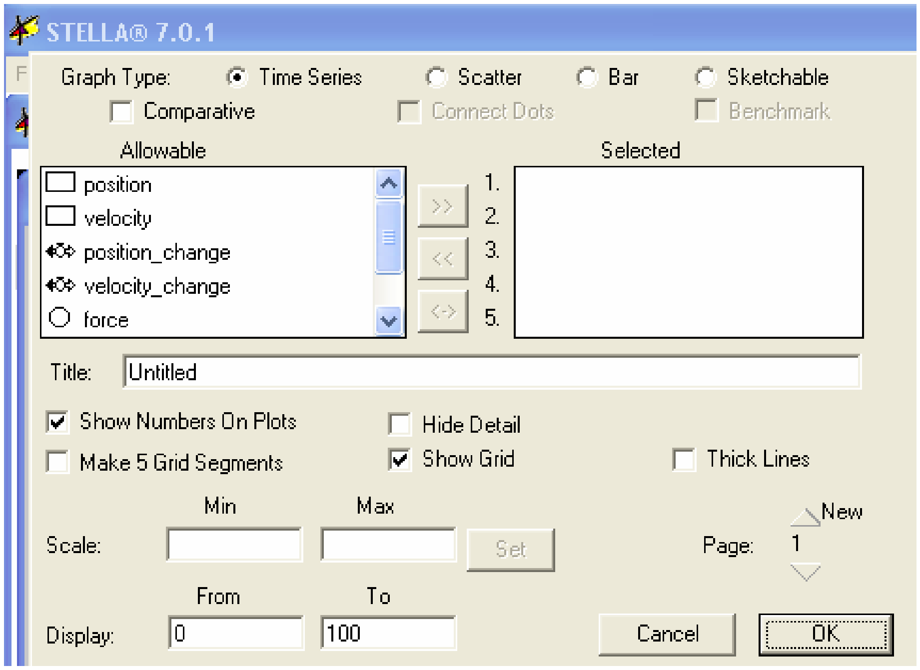


Figure 6. Allowable window

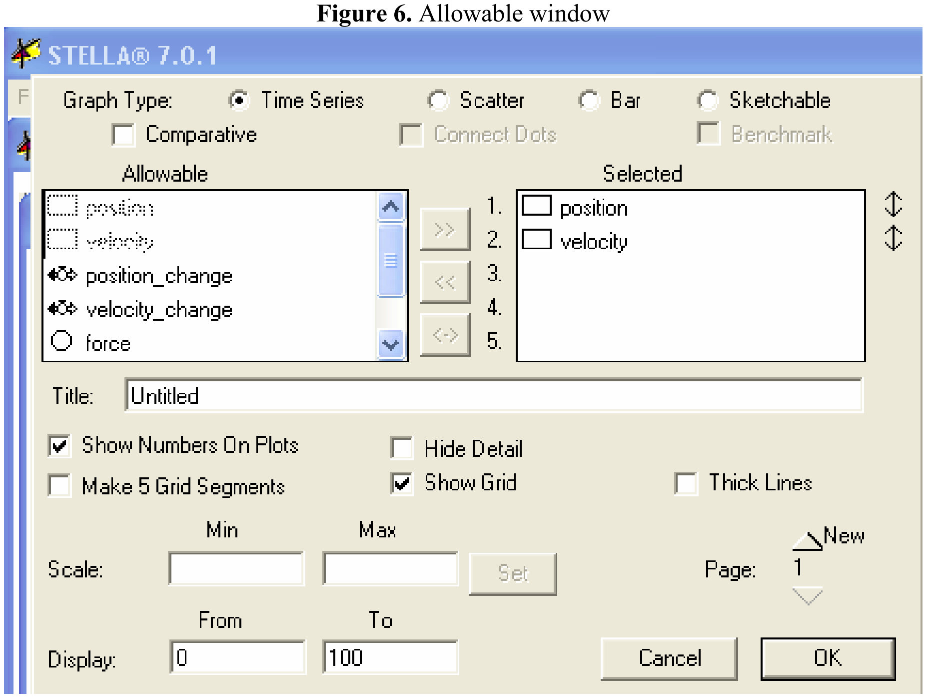


Figure 7. Selected window

The graphic draw after parameter is selected. The graphic of the spring mass system models has shown figure 8.

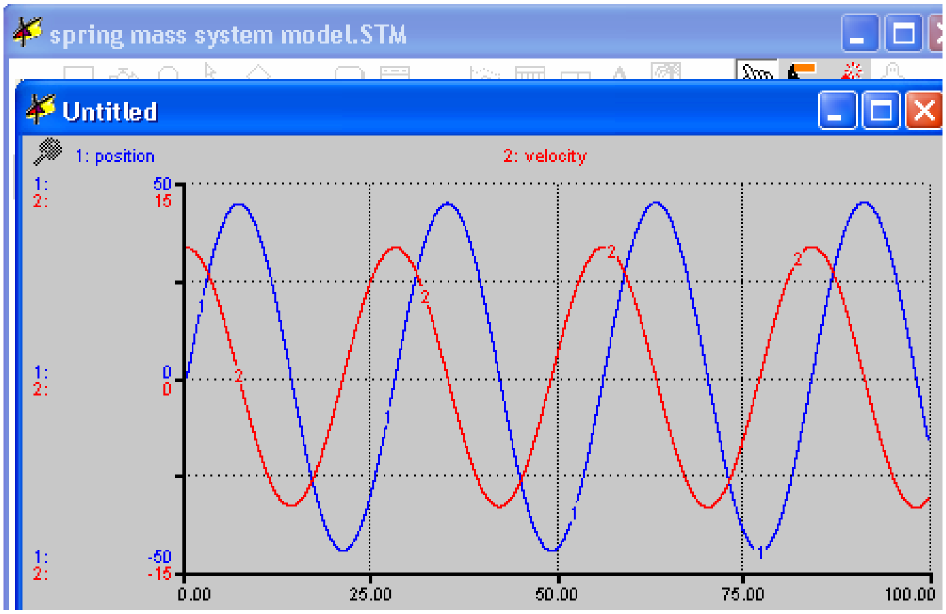


Figure 8. The graphic of spring mass system models

In this graphic only two parameter were selected: position and velocity. Position and velocity are shown different color in the graphic so the difference can be understood clearly. The graphic shows that the velocity curve has a phase lag of approximately 90 degrees with position curve. When position is maximum and minimum value the velocity is zero value. Like this when position value is zero velocity value is maximum.

METHODS

This research has a quantitative design which is not experimental. According to practice this research is a case study research model.

APPLICATION STAGES

This application was done with ten 7th grade middle school students in 6 lesson hours. Program was planned as to new MEB curriculum. New teaching methods based on constructivist learning and supported by system dynamics approach were applied. Firstly students made experiments about spring mass system in science laboratory with cooperative groups. Then, they modeled their observation in the experiments with Stella program in computer laboratory. They tried to find correct model changing it again and again. They tested their models and drew graphics that explain system behavior. They discussed and interpreted models with friends. Every student saved their model during the modeling by one by. Their saving data were evaluated by researcher and examined their improvement. In this research there are only two students' improvement data. In the end these data were analyzed and every data compared with each other.

PS: Students learned modeling with Stella in 3 hours introduction lesson that teached system dynamics components such as stock, flows, feedback and cause-effect relationship previously.

FINDINGS

Spring mass system models developed with ten 7th grade middle school students. In this section two students' (Gizem and Koray) improvement data were take place. Students' data were analyzed comparatively. Gizem developed her model in 4 step and Koray 3 step. The data table was prepared for each student. It was analyzed that stocks, flows and converters place are true or false, whether cause and effect relationships and connectors are correct or not, whether mathematical equations are correct or not for every systems' component and whether models' graphic drew correct or not. In the total it was calculated that students how many true or false point have got.

In the first step; both students decided stock and flows in the model correctly but Koray determined only one converter false. If we evaluate according to connector is true or not, we observed that Gizem determined that velocity- weight and force-position relationship were wrong although Koray determined all connectors wrong without force- force constant relation. Gizem found four mathematical equations correctly but three wrong. In addition that Gizem drew models' graphic although it wasn't true. Koray didn't draw any graphic in this part.

Students determined systems' basic components stocks and flows clearly although determining connector between components was difficult for them in first step.

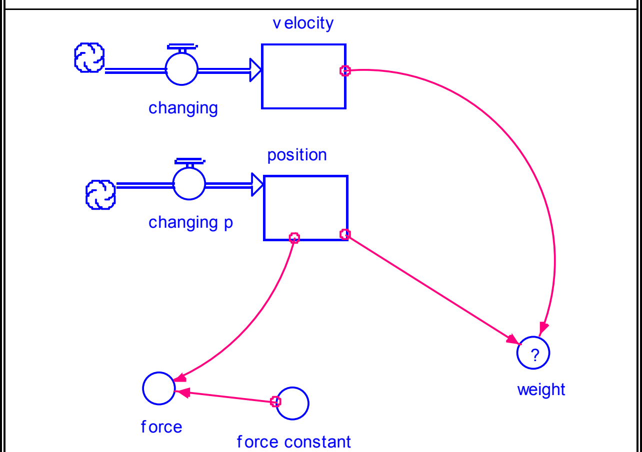
In the second step; Gizem arranged some mathematical equations in the model but it wasn't enough to correct graphics. Koray arranged only one connector wrong like position- velocity so he couldn't arrange mathematical equation and draw graphic correctly.

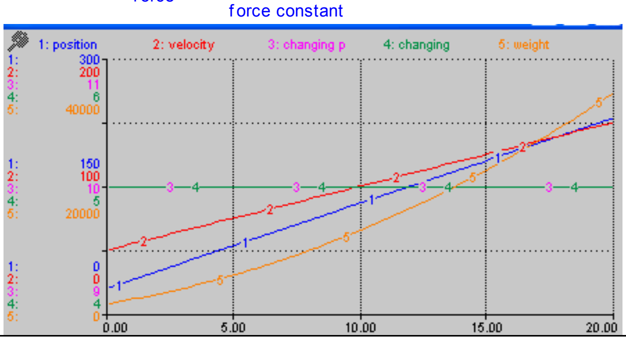
In the third step; Gizem drew wrong graphic because she didn't arrange mathematical equation correctly. Koray reached the correct model and graphic in the third step but Gizem in the forth step.
Gizem has tried to building and testing model since first step although Koray firstly focused on developing model then testing model. It is clear that both of the students have special methods while developing correct model.

IMPROVEMENT DATA FROM GİZEM AND KORAY

1. STEP

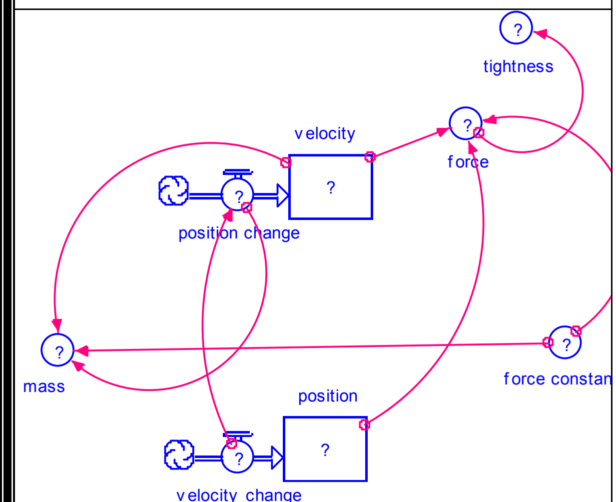
GİZEM





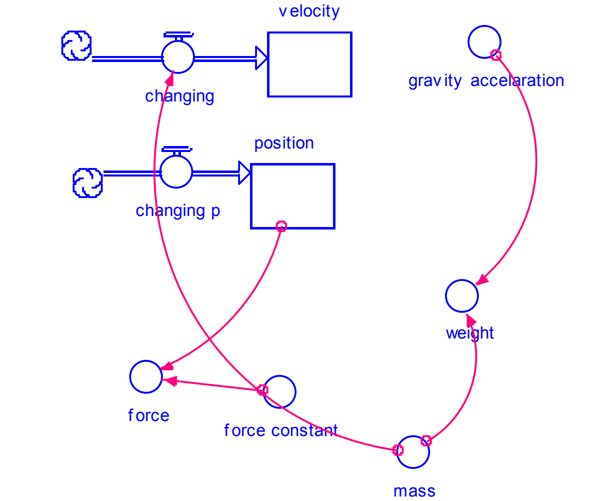
		True	False
Stock	Position	+	
	Velocity	+	
Flows	Position change	+	
	Velocity change	+	
Converters	Force	+	
	Force constant	+	
	Weight	+	
connectors	velocity-weight		+
	Force constant-force	+	
	force-position		+
Mathematical equations	Stocks-flows-converters	**4**	**3**
Graphic			+
Total		**12**	**6**

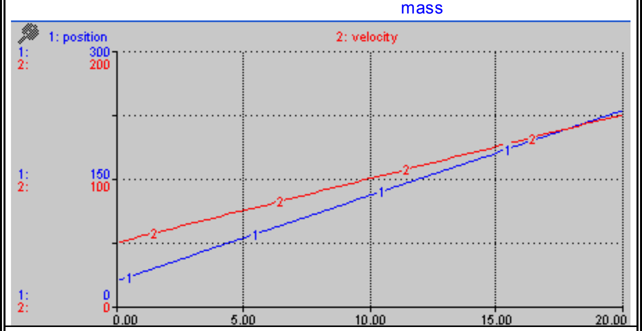
KORAY



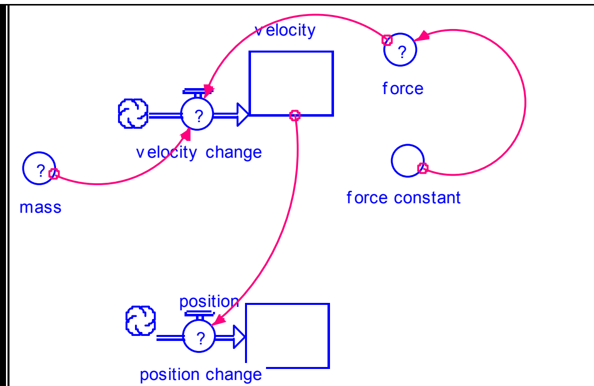
		True	False
Stock	Position	+	
	Velocity	+	
Flows	Position change	+	
	Velocity change	+	
Converters	Force	+	
	Force constant	+	
	tightness		+
	mass	+	
Connectors	velocity-force		+
	Force constant-force	+	
	force-position		+
	Force constant-mass		+
	Position change-mass		+
	velocity-mass		+
	Velocity change-position change		+
	force-tightness		+
Mathematical equations	Stocks-flows-converters	**0**	**0**
Graphic		**0**	**0**
Total		**8**	**8**

2. STEP



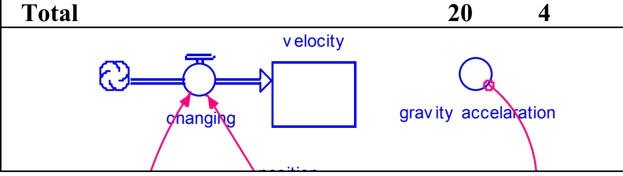


		True	False
Stocks	Position	+	
	Velocity	+	
Flows	Position change	+	
	Velocity change	+	
Converters	Force	+	
	Force constant	+	
	Weight	+	
	Gravity acceleration	+	
	mass	+	
Connectors	mass-weight	+	
	weight- gravity acceleration	+	
	Force constant-force	+	
	force-position	+	
	mass-velocity change	+	
Mathematical equations	Stocks-flows-converters	**6**	**3**
Graphic			+
Total		**20**	**4**

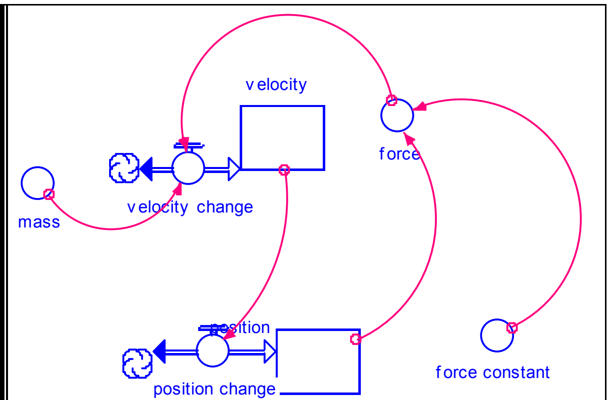


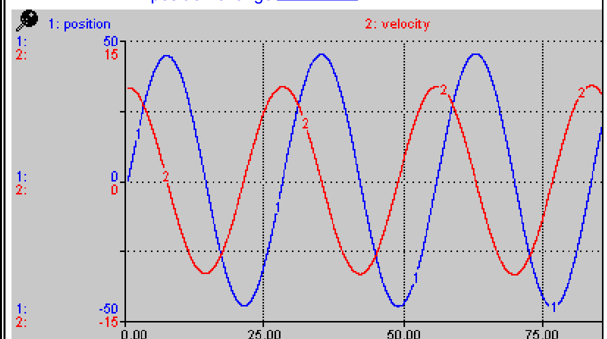
		True	False
Stocks	Position	+	
	Velocity	+	
Flows	Position change	+	
	Velocity change	+	
Converters	Force	+	
	Force constant	+	
	mass	+	
Connectors	velocity-position		+
	Force constant-force	+	
	force-velocity change	+	
	mass-velocity change	+	
Mathematical equations	Stocks-flows-converters	**0**	**0**
Graphic		**0**	**0**
Total		**10**	**1**

3. STEP



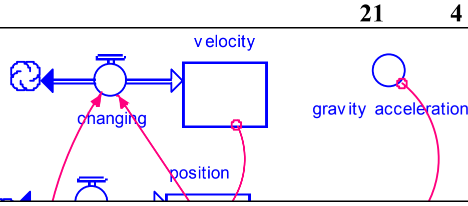
	True	False
Stocks Position	+	
Velocity	+	
Flows Position change	+	
Velocity change	+	
Converters Force	+	
Force constant	+	
Weight	+	
Gravity acceleration	+	
mass	+	
Connectors mass-weight	+	
weight- Gravity acceleration	+	
Force constant-force	+	
force-position	+	
mass-velocity change	+	
force-velocity change	+	
Mathematical equations Stocks-flows-converters	6	3
Graphic		+
Total	21	4





	True	False
Stocks Position	+	
Velocity	+	
Flows Position change	+	
Velocity change	+	
Converters Force	+	
Force constant	+	
mass	+	
Connectors Force constant-force	+	
force-position	+	
mass-velocity change	+	
Mathematical equations Stocks-flows-converters	7	0
Graphic	+	
Total	18	0

4. STEP



	True	False
Stocks Position	+	
Velocity	+	

Flows	Position change	+	
	Velocity change	+	
Converters	Force	+	
	Force constant	+	
	Weight	+	
	Gravity acceleration	+	
	mass	+	
Connectors	mass-weight	+	
	weight- Gravity acceleration	+	
	Force constant-force	+	
	force-position	+	
	mass-velocity change	+	
	force-velocity change	+	
	velocity-position change	+	
Mathematical equations	Stocks-flows-converters	**9**	
Graphic		+	
Total		**26**	**0**

DISCUSSION

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). Then teachers focused on developing more applications. Forrester and his students prepared to road maps (Road Maps, 2005) including system dynamics samples in different subjects for teachers helping with education project. Schecker, (1994) developed an application using system dynamics approach in physics education using motion of meteors that contain force, momentum, velocity and position concepts.

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 to us about their course teached 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."
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 behavior 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 schoolers can understand the same things by using system dynamics modeling. It's really amazing."

Teachers find that, in the process of using these tools, students' learning becomes more learner-centered 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).

Everyone who teaches System Dynamics modeling 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).

In this research the subject of spring mass system in middle school curriculum was modeled through STELLA program with 7th grade students. The aim of developing this model is to give new ideas about system dynamics applications to teachers. The real effect of modeling spring mass system will be understood when the model is applied in more crowded student groups.

RESULTS AND SUGGESTIONS

The advantage of system dynamics modeling about spring mass system to science and technology course can be summarized like in the following:

1. Using system dynamics approach the modelers produce simulation tools called as micro worlds. Simulation environment to students about spring mass system:

- Provide modeling to activity doing with cooperative groups.
- Provide developing the model after try it again and again.
- Provide learning that how spring mass dynamics occur in the different situation.

2. Student realizes that different springs have different features after they make spring mass experiments. They learn different dynamic pattern in spring mass mechanism during the modeling with system dynamics. Different dynamic pattern to students:

- Description how springs' behavior is in different situation.
- Research the reason why springs indicate different dynamic behavior.
- Give an opportunity to discover how different dynamic occur using cause-effect and stock-flow diagrams

3. System dynamics orient to students to learn cause and effect relationship between systems' component. It is observed that the student in this research had some difficulties in determining cause and effect relation. Especially they have troubles in replacement mathematical equations during the modeling. If the mathematical equations teach to students during the course the students can learn the meaning of concepts about subject easily.
4. System dynamics is a general approach for defining and solving problems (Forrester, 1961, 1976; 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.
5. At the end of this sample application students learn the concepts of the subject, cause and effect relationship and dynamic behavior of the systems via modeling more effectively. It is observed that students had some difficulties on putting the mathematical equations into the model. It is observed that this was due to the false identification of the connector variables. Because of this error they failed to obtain the correct graphics at the first try.

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