METAFORA Learning Approach Processes Contributing to Students' Meaning Generation in Science Learning

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Abstract: Learning science requires high student motivation and understanding of concepts and formal relationships, processes that have been proved to be difficult for students. This paper, trying to study this situation deeper, uses data collected in Greece in the framework of a European Project called METAFORA and aims at exploring how two specific learning activities may contribute to students' science learning. In particular, the issue addressed in this paper concerns the ways in which processes of the METAFORA learning approach such as: a) planning of actions to be taken and b) constructing of a game model, are related to the students' generation of scientific meaning. The principal tool for this study is a half-baked microworld called "Juggler" and the activities developed for it. Half-baked microworlds (Kynigos, 2007), being incomplete by design, challenge students to deconstruct them (so as to find out why things don't work the way they would normally do), change them, build on their parts and create artefacts possibly quite different that the one originally given to them. The "Juggler" half-baked microworld is designed to challenge students to deconstruct and (re)construct the model underpinning the Juggling game, giving them the opportunity to engage in meaning generation processes that include making sense of motion in Newtonian space. Results of this study indicate that the students following processes of the METAFORA learning approach engaged in meaning making processes that allowed them to gain a deeper understanding of the scientific concepts and the relations between concepts the Juggling game embedded. Collaborating in planning their actions so as to deconstruct and reconstruct the half-baked microworld, the students mostly employed the inquiry-based approach (observe, make a hypotheses, experiment, etc.), which allowed them to address the deconstruction/construction issue in a scientific way.

Keywords: game model, half-baked microworlds, science learning, collaboration, planning

1. Theoretical framework

Learning science requires high student motivation and understanding of concepts and formal relationships, processes that have been proved to be difficult for students, since they encounter substantial problems with most of the inquiry-learning processes in which they engage (De Jong and Van Joolingen, 1998; Smyrnaiou and Dimitracopoulou, 2007). In particular, the literature of Science Education indicates that students have difficulties in translating theoretical variables from their hypothesis into manipulable and observable variables of the experiments they carry out (Lawson, 2002), they often attempt to control simultaneously too many variables (Keselman, 2003), they fail to make predictions and misinterpret the collected data (Lewis et al., 1993).

Recently, research has indicated that modelling as an inquiry-learning process, could be a powerful 'tool' that may help students in enhancing their reasoning activity and improving their understanding of scientific concepts. The impact the combination of inquiry and modeling may have on students' conceptual understanding of science, especially when suitable technology-based educational tools are used, is well documented (Smyrnaiou and Weil-Barais, 2005; Zacharia and Anderson, 2003; Zacharia, 2006), highlighting the strong link between those two (De Jong et al. 2002, Smyrnaiou and Dimitracopoulou, 2007).

Apart for inquiry-based learning, however, exploring, designing and building computer models of complex scientific phenomena has also been embedded in the constructionist learning approach (Wilensky, 1999; Wilensky and Reisman, 2006). Constructionism builds on the idea that that students learn more effectively when building external and sharable artefacts that are personally meaningful to them (Harel and Papert, 1991; Kafai and Resnick, 1996). Under this perspective, computer-based modelling, especially in the form of programming (Penner, 2001), may allow students to engage in processes that will bring into the foreground their own conceptualizations and ideas regarding the behavioural dynamics of the scientific phenomena they study and test these ideas by implementing them in the model they create. These models when created collaboratively or when published by the students become objects of discussion and reflection among the peers and provide students opportunities to go deeper in gaining an analytic understanding of the phenomena under discussion (see for example, Simpson, Hoyles and Noss, 2005).

Model designing and building, as described above, when it occurs in the context of working with game microworlds, may offer students opportunities to learn about academic subjects as they play a game themselves or create games for others to play (Harel, 1991; Kafai and Resnick, 1996). Microworlds embed a coherent set of scientific concepts and relations, combined all in an underlying model that is run when starting the simulation. When the microworld is built under the white box perspective (for a discussion on the black and white box approach, see Kynigos, 2004), this model is made visible to the students who may explore how it works and -having deep structural access (diSessa, 2000)- change it to incorporate their own ideas and conceptualizations regarding the scientific concepts the microworld embeds.

Half-baked microworlds (Kynigos, 2007) hold this potential since they are incomplete by design, a feature that invites and challenges students to explore the model that is responsible for the "buggy behaviour" and change it so as to make it work according to their own understandings. They are meant to operate as starting points, as idea generators and as resources for de-composing and building pieces of software, such as game-like simulations. Thus, the players of the game in the half-baked microworlds, soon become the designers of a new game, engaging in the way in mathematical and scientific meaning making (Kynigos et. al, 2010).

This paper uses data collected in Greece in the framework of a European Project called METAFORA ("Learning to learn together: a visual language for social orchestration of educational activities"). The METAFORA learning approach incorporates inquiry-based and modelling processes for science learning which are enriched by constructionist activities that we introduced by designing a half-baked, game-like microworld called Juggler. Under this perspective, this paper aims at exploring if and how specific activities such as: a) the collaborative planning of actions when addressing a scientific challenge and b) the collaborative construction of game models, may contribute to students' meaning making processes regarding scientific concepts related to motion in the Newtonian space.

1. The Juggler half-baked microworld

The Juggler is a game-like half-baked microworld (Kynigos, 2007) that is designed to offer students opportunities to explore and build models of 2d motions and collisions inside a Newtonian 2d space (Figure 1).

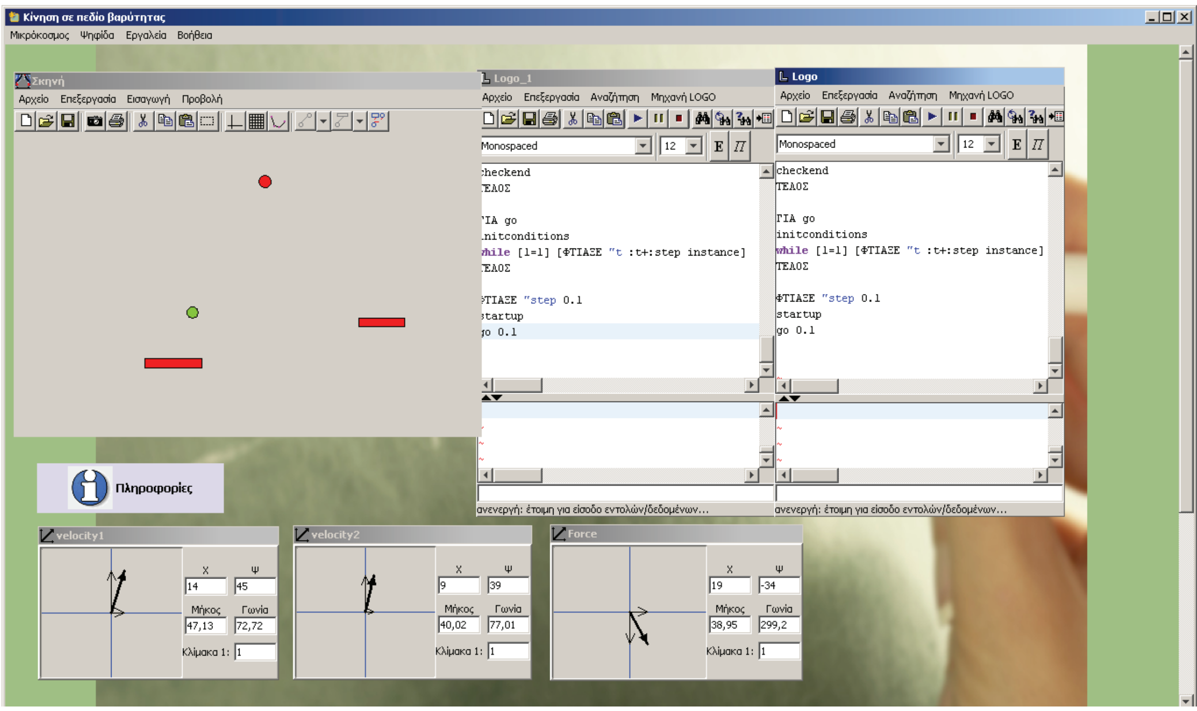

Figure 1: The Juggler microworld

Once the Juggler game starts, the simulation of the model shows two moving balls which the player must try to keep up in the air using the two rackets. The initial velocities for each one of the balls, as well as the field force, are set by means of dynamically manipulating vectors, while the initial positions of the rackets and balls are also of the player's choice. The velocity vectors during the simulation become on the fly measures of velocity and thus change continually, while the field force vector remains still during the whole game. The field force vector can be set to the magnitude and direction of gravitational pull, but the players are free to set the vector's direction and length according to their own conceptualizations of 2d motion and their scientific explorations.

Apart from changing the model by dynamically manipulating vector semantics to set the initial velocity, the students may also engage in Logo programming activities, changing not just specific parameters of the existing model but also the model itself. This type of activity involves engaging students in working with the Logo program that underpins the simulated phenomenon so as to identify the equations that control the motions and collisions and change them in order to modify the behaviour of the model that controls the game.

1.1 Pedagogical basis

The Juggler half-baked microworld has been designed with respect to a number of primary considerations and corresponding design principles. With regard to constructionism and modelling, two main principles were specified:

- Expression of concepts through a construction/deconstruction activity within the microworld
- Incorporation of different categories of models (semantic models as logic formalisms, algebraic formalisms) in a simplified and synthetic mode.

With regard to supporting students' expression and meaning generation, the following principles were incorporated:

- Expression through the greatest possible degree of visualization of objects, their properties, concepts and relations among concepts.
- Combination of different components (visualization components, programming code, control components). The simulations are necessary to validate the microworlds constructed.
- Incorporation of alternative and multiple forms of representation of the models (with their associated objects) and of the various kinds of data produced by the models. Multiple representations provide cognitive assistance for expressing oneself and consequently for meaning generation.

The construction/deconstruction of the microworld like the one described above may facilitate students in making connections among aspects of the reality, their conceptualizations regarding the scientific concepts embedded in the microworld and the representations used to express the model underpinning the game (symbolic programming code) or the dynamic representations used to manipulate the values attributed to the model's parameters.

2. The FreeStyler

FreeStyler (Hoppe and Gaßner, 2002) is a digital tool that provides a shared workspace in which students (or groups of students), using a specific visual language, may synchronously collaborate and communicate their ideas with their peers. According to the collaborative learning scenario implemented, FreeStyler's shared workspace may be used for argumentation, scientific modelling, model designing or concept mapping activities. The ontological elements used may facilitate either kind of these activities and at the same time provide a meaningful tool in a meta-learning level as students may keep track and regulate their own learning progress.

2.1 Pedagogical basis

Self-regulated learning is a process whereby learners think about their thinking (metacognitive process), act in a strategic way (plan, monitor, evaluate personal progress) and they are motivated to learn (Winne and Perry, 2000; Boekaerts and Corno, 2005). Students have difficulties in regulating several aspects of their cognition, motivation, and actions when they want to study complex topics using technology, because they fail to engage in key mechanisms related to regulating their learning (Azevedo and Cromley, 2004; Hadwin and Winne, 2001). For this reason, researchers have extended proposed approaches that entail training students to regulate their learning by using task planning, monitoring, and handling (Azevedo and Cromley, 2004).

3. Research design and method

In this study, we used a design-based research method (Cobb et al, 2003), which entailed the 'engineering' of tools and tasks, as well as the systematic study of the forms of learning that took place within the specific learning context.

3.1 Context and participants

Six 14 to 15 years old Secondary School students participated in this preliminary study that took place on the side of their ordinary curriculum activities. For the data collection, a screen-capture software was used to record the students' interactions with the computational environments provided. The corps of the data also included the maps the students created using FreeStyler as well as the researchers' field notes. The episodes presented in this paper were selected as indicative of the inquiry-based and constructionist learning processes in which the students engaged as they played with the game-like half-baked microworld.

3.2 Activities

For the first phase of the experimentations, the students were initially shown a You-Tube video in which a performer tried to juggle two balls and were asked to design in groups of two a simulation that would be similar to the one they were watching on the video. To describe how they would work so as to design a simulation representing the phenomena they were watching, the students were asked to construct a "Plan" (using FreeStyler) that would depict their course of action.

For the second phase of the experimentations, the students were introduced to the Juggler half-baked microworld (Kynigos, 2007) and were given enough time to play the game. As the Juggler half-baked microworld is incomplete by design, the simulation invites the students to explore the microworld's functionalities and uncover the model underpinning the simulation so as to change it, incorporating in the way their own conceptualizations on how it should work from a scientific point of view. The dynamic manipulation of the values attributed to the model's parameters may offer students opportunities to investigate and question the scientific laws -using extreme values (or even unconventional ones that wouldn't normally apply in a Newtonian space)- and interpret the visual representation on the screen as the effect of their actions. The students were asked to use FreeStyler as they worked with the microworld so as to document what kind of actions they had taken.

After playing with the half-baked microworld the students we asked to go back to Freestyler and create a new Plan that would depict how they would change the game-like half-baked microworld initially given to them so as to integrate their own ideas about how the model behind the game should work.

4. Results

In the first phase of the experimentations, the students, after watching the juggling video, were asked to construct a Plan in FreeStyler (Figure 2) to explain their course of action in the process of building a simulation that would imitate the motion of the balls in the video.

Constructing the map, the students of Group A seem to employ mostly the inquiry-based approach. After having observed the motion of the balls in the video shown to them and having discussed about it with their peers, the students determine the "Make a Hypothesis" stage as the first thing needed to be done in order to construct a similar simulation to the one depicted in the video. This hypothesis will be fed by the "Information" gathered, which will be consequently "Analysed" with the whole corps of data collected so far in order to provide conclusions and new ideas to be discussed and "Exchanged" with their peers. "Rethinking" the original Hypothesis would be the result of this part of the process which will then help students Reflect on the situation at hand and prepare an "Experiment" with the available resources. To test the hypothesis the students expect that they will need to "Create a Model" which they would then have to "Present" to their peers and "Explain" how it works. The final stage of the process will be according to the students the "Evaluation of the outcome" stage.

In this map, the students seem to define a course of action that is in compliance with the inquiry cycle. According to De Jong (2006), this cycle consists of phases such as orientation of the domain(s), hypothesis formation, hypothesis testing through experimentation and conclusions drawing on an evaluation of the attained knowledge and the learning process. Although research (de Jong & van

Joolingen, 1998) has shown that that learners tend to skip essential phases of an inquiry cycle and just run the experiments, using the Metafora Learning approach in which planning the course of actions to be taken (and constructing a map to depict it) is needed, the students seem to have defined the process of their work addressing all the basic phases the inquiry cycle entails. This indicates that the students will approach the problem of building a simulation similar to the one shown in the video acting as scientists who employ scientific methods to address the problematic situation they encounter.

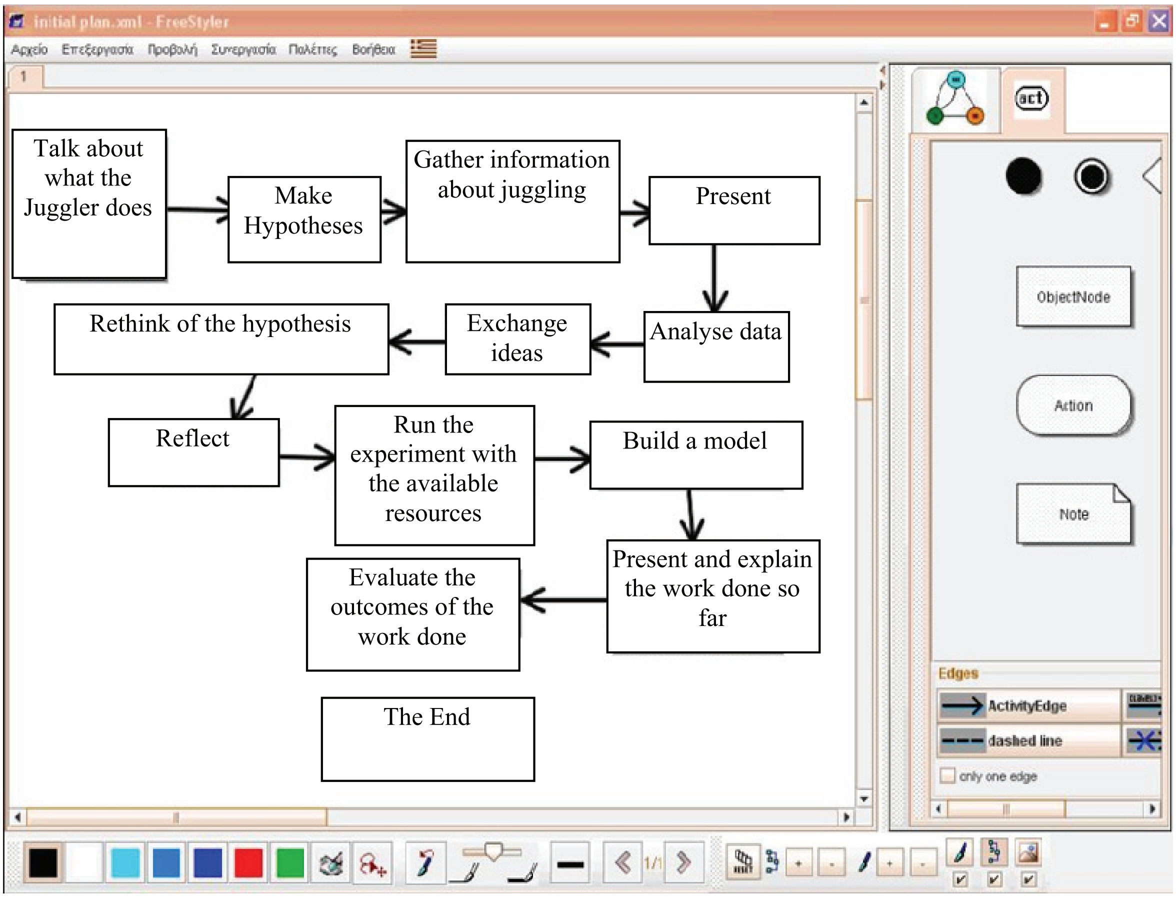

Figure 2: The plan group A prepared during the 1rst phase of the experimentations

Working consequently with the half-baked microworld, the students engaged in a series of actions that were described in detail by the Senior Researcher who kept field notes during the experimentations.

"When we gave students the half-baked microworld, the first thing they did was to start the simulation so as to see how the game works. However, Juggler is a half-baked microworld, deliberately designed to be incomplete and thus challenging. So the students –when they started the simulation- came across the fact that the two balls were made to move so fast that it was practically impossible to hit them with the rackets and juggle them up in the air. The students were asked what they were going to so after that observation and S5 and S6 decided that they needed first to brainstorm about the game so as to find out what to do in order to make the game "playable".
S5: we will brainstorm about the game

R1 went on pointing that they need to specify more what brainstorm will be about

S6: We will brainstorm about how the game should be and how it would be played.

"It was then that they started working with the microworld's functionalities so as to find ways to make this game playable. The students changed the direction and the length of the vectors representing the velocity and the gravitational force in order to change the magnitude and direction for those quantities. To explain the course of action to be taken next and document what they had already done, the students were asked to use again Freestyler (Figure 3)."

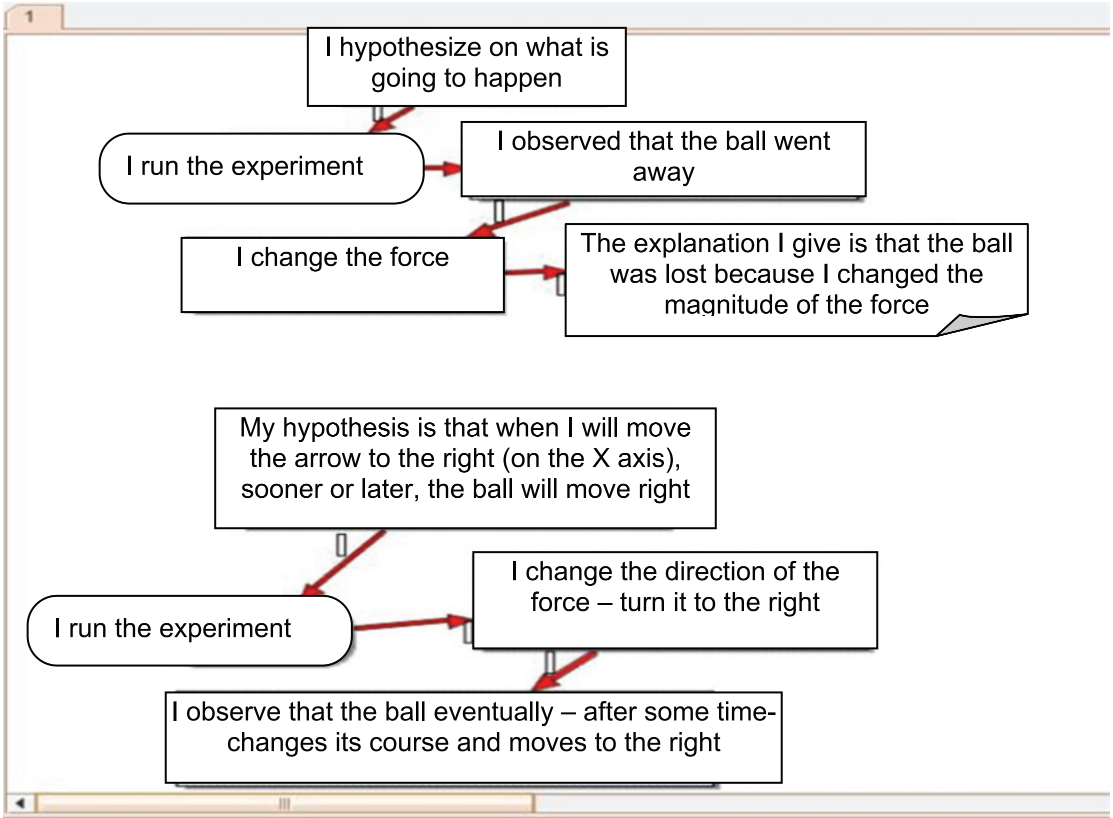

Figure 3: The plan the students prepared during the 2rst phase of the experimentations

Constructing the new map, the students seem to employ the inquiry-based approach once again, enriched, however, with their understandings regarding specific scientific concepts that they came across as they interacted with the Juggler microworld. Exploring the functionalities of the microworld, the students manipulated the vector controlling the gravitational force to test the effect of their actions at the simulation generated.

According to the researcher's field notes: "Their observations on the fact that the dynamic manipulation of the force entails both the manipulation of the direction of the vector as well as the manipulation of the vector's length, led them divide their map in two sections, one for each type of manipulation. The upper part of the map relates to what will be the effect of changing the magnitude of the gravitational force, while the lower one to what will be the effect when changing the direction of the gravitational force."

Both parts of the map start with a "Make a Hypothesis" stage accompanied with a "Run the Experiment" one. Their "Observations" on the simulation generated after "Running the Experiment", leads them to "Change" either the magnitude or the direction of the force and then make new Observations for which they also provide "Explanations". The Explanations they give and the new Observations they make also encompass, however, their meaning making regarding the scientific concepts embedded in the simulation generated when running the experiment. The students seem to make links between the manipulation of the vector controlling the gravitational force and the graphical representation of the effect of their action at the simulation, engaging in the way in meaning making processes regarding the notion of gravitational force and its specific role in the motion of the balls at the juggling game.

5. Discussion

In this paper we attempted to explore the ways in which activities related to the METAFORA learning approach such as: a) the collaborative planning of actions when addressing a scientific challenge and b) the collaborative construction of game models, may contribute to students' meaning making processes regarding scientific concepts related to motion in the Newtonian space. For that purpose we used two pieces of software: FreeStyler which allowed students to construct their plan in the shared workspace it provided, and the Juggler half-baked microworld. The students were initially asked to create a plan of actions for building a Juggling simulation, while in the 2nd phase of the experimentations they were given an game-like half-baked microworld and were asked to create a plan so as to explain and document the course of action to be taken next when changing the microworld and designing a new game.

The results indicate that the students in the process of collaboratively addressing the scientific challenge of creating a simulation in which two balls would move according to Newtonian laws, the students employed the inquiry-based approach. The map they created includes actions such as "Making hypothesis", "Gathering Information", "Analysing", "Experimenting", "Creating a Model" and "Evaluating the outcome" which are indicative of the inquiry cycle. In the process of deconstructing and reconstructing the half-baked microworld so as to redesign the Juggling game, however, the students seem to construct a plan that is like the first one based on the inquiry-based approach but it also includes their understandings regarding motion in the Newtonian space. Working with the first activity, the students seem to develop a method for addressing challenges in a scientific way (inquiry-based method), which they then reuse in the second activity. The method they developed helped them specify, in the second activity, how the functionalities of the microworld controlled the simulation generated on the screen. In the process of making links between the dynamic manipulation of the values attributed to the model's parameters and the graphical representation of the effect of their actions, the students seem to engage in meaning making processes regarding scientific concepts embedded in the microworld and their specific role in the motion of the balls in a Newtonian space.

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