Students’ Constructionist Game Modelling Activities as Part of Inquiry Learning Processes

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Abstract: Learning science requires the understanding of concepts and formal relationships, processes that -in themselves- have been proved to be difficult for students as they seem to encounter substantial problems with most of the inquiry-learning processes in which they engage. Models in inquiry-based learning have been considered as powerful ‘tools’ that may help students in enhancing their reasoning activity and improving their understanding of scientific concepts. Modelling, however, in the form of exploring, designing and building computer models of complex scientific phenomena has also been embedded in the constructionist learning approach. Working collaboratively with constructionist game microworlds that by design invite students to explore the fallible model underpinning the game and change it so as to create a new game, may provide students opportunities to bring into the foreground their conceptual understandings related to motion in a Newtonian space and put them into test making them at the same time objects of discussion and reflection among the members of the group. Apart from the meaning generation, we also study in this paper, the students' group learning processes i.e. the construction of emergent activity maps to either plan their actions as they engage in game modelling activities or to report on the outcomes generated when these actions are implemented. The connections between the students’ activities as they work with a constructionist medium and the inquiry-based learning activities from which the students are considered to pass when engaging in scientific inquiry also constitute one of the main issues this paper attempts to study.

Keywords/Key Phrases: modelling, games, half-baked microworlds, constructionist and inquiry-based learning.

1 Theoretical framework

Research in Science Education has been shifting focus with respect to positivist/relativist epistemology, learning concepts and learning processes, individualistic learning and learning in collectives. Inquiry learning for instance has been focusing on process, highlighting students' difficulties with each one of the phases of the inquiry-learning cycle, i.e. orientation of the domain(s), hypothesis formation, hypothesis testing through experimentation and drawing conclusions through an evaluation of the attained knowledge and the whole learning process (De Jong and Van Joolingen, 1998). Learning science requires understanding of concepts and formal relationships, processes that have in themselves been proved to be difficult for students. In particular the literature 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).

In science education, modelling is perceived as a key context for the supporting of inquiry based learning in students. Research efforts in science education reveal the impact the combination of inquiry and modelling 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). Recently, research has indicated that modelling processes could be a powerful ‘tool’ that may help students in enhancing their reasoning activity and improving their understanding of scientific concepts (De Jong and van Joolingen, 2008).
In model-based inquiry learning, the students may work with computer models that they explore by changing the values of the input variables and then observing the outcome of their actions at the values of the output variables. Restructuring, consequently, these models using the data gathered throughout the previous inquiry process with the objective to create a new model that behaves like a

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real system is also part of model-based inquiry learning. The computer models used in model-based inquiry learning constitute the underlying mechanism that controls the simulation that the students observe on screen. The difference between using these simulations and using games (that also contain an underlying model) in model-based inquiry learning is that simulations allow students to develop knowledge about a specific domain by using scientific tools and methods while games seem to bring forward mostly intuitive knowledge since the most important goal to attain when playing the game usually doesn't include systematically exploring and defining the underlying scientific model (De Jong and van Joolingen, 2007).

Apart from model-based inquiry 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 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 and Papert, 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. In case these pieces of software are games, the players of the initial game, soon become the designers of a new game, engaging in the way in mathematical and scientific meaning making (Kynigos et. al, 2010).

Although modelling has its own distinct place in the inquiry-based and the constructionist learning approach, the role of modelling in bringing together those two approaches remains an issue that needs to be further explored. In a recent study, De Jong and van Joolingen (2008) connect the "learning from models" process to inquiry-based learning and the "learning by modelling" process to constructionist learning. Presenting Co-Labs, an digital environment in which students may engage in both "learning from models" and "learning by modelling" activities, they attempt to identify and study the scientific inquiry processes from which the students pass as they work with the models which the find ready-made or create themselves. In their findings, they assert that the inquiry processes that appear when "learning from models" and "learning by modelling", resemble to the ones appearing at the inquiry-learning cycle proposed by de Jong (orientation, hypothesis generation, experimentation, and conclusion).

In this paper we look at the inquiry process focusing on constructionist modelling in student collectives. We studied students collectively trying to make sense of a model which was presented to them as questionable and malleable with respect to the rules underlying object behaviours and relationships and the influence of field parameters. The students addressed this activity as a group and discussed ways in which they would coordinate their investigations in order to change the models' functionalities as results of their experimentations. Apart from looking into the ways in which they generated meanings with respect to concepts in kinetics, such as velocity, force on an object, gravity, trajectories, collision rules we also wanted to study aspects of the students' group learning process, i.e. the construction of emergent activity plans, their mutual engagement with the task and their socio-meta-cognitive processes. Stahl (2005) has recently suggested that mutual engagement with a shared artefact is a learning context which may support group cognition.

Particularly, we focus on the students' game modelling processes as they work with a half-baked microworld designed for constructionist learning. Our interest lies in specifically identifying the connections between these processes that take place when the students interact with a digital artefact that invites them to engage in both "learning from models" and "learning by modelling" processes and the inquiry-learning activity stages from which students are considered to pass in the context of scientific inquiry. Moreover, we attempt to specify if and how students' game modelling activities when working with a half-baked microworld may provide them opportunities to gradually evolve their conceptual understandings regarding motion in 2d Newtonian space.

2 The Juggler Half-baked Microworld

"Juggler" is a 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 as they play a juggling game with two moving balls and two rackets (Figure 1).

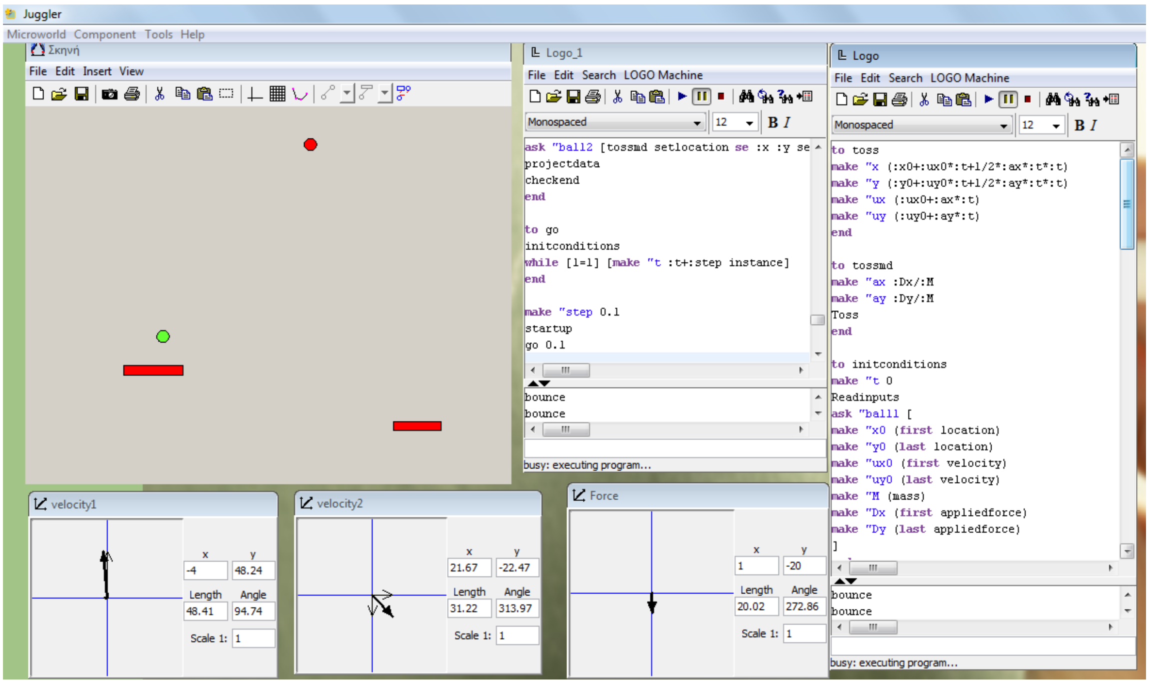


Figure 1: The Juggler half-baked microworld

In order to play the game, the students need to first define the initial conditions for running the model that underpins the game. To do so, three Vectors Manipulation Components are available: one for the red ball's initial velocity, one for the green ball's initial velocity and one for the field force. The students set the values for each of these physical quantities by dynamically manipulating an arrow (a vector) whose direction, angle and length are changeable. The vector's tail is attached at the 0,0 point on a Cartesian 2d pad that serves as a background, while its arrowhead's (X,Y) coordinates (Cartesian coordinate system) are displayed on screen along with the length and angle measurements (Polar coordinate system).

When the players start the game, the values for each one of the vectors' angle and length take their place in a set of motion equations integrated inside a Logo program and the model starts to run. From this point on and until the model is stopped, the velocity vectors become reading instruments as they show at each instance the direction and magnitude of the velocity for each of the two balls and the values for its Vx and Vy components.

Once the Juggler game starts, the simulation of the model shows two moving balls which the player must keep up in the air using the two rackets. If the field force vector is set to the magnitude and direction of the gravitational pull, the two balls move in projectile motion trajectories until they are hit by one of the rackets. The collision with the rackets makes the balls move in a projectile motion once again, only this time in the complete opposite direction in the horizontal and vertical axis.

The goal of the game is to juggle the balls up in the air as long as possible by moving the two rackets so as to hit the balls and not let them fall in the ground. To do so, it is crucial for the students to initially manipulate the three vectors in a way that would make it easy for them to hit the moving balls when the simulation starts. However, when designing a game so as to give it to their peers, the most important thing to do could be choosing initial conditions that would make the game extremely difficult for the others to play. In any case, no matter whom the game the students are creating is intended for, discussing in collectives about the initial values to select could bring into the foreground scientific explorations related to motions and collisions in a 2d Newtonian space.

3 The FreeStyler

FreeStyler (Hoppe and Gaßner, 2002) is a CSCL environment designed to support synchronous discussions between collaborative learners. The students (working individually or in groups), may communicate their ideas with their peers by adding textual contributions inside a shared workspace. Since these contributions also have a graphical form (the text is typed inside a shape) and links can be added to connect them to each other, FreeStyler can be used for the collaborative creation of maps -such as argumentation or concept maps- as well as for the collaborative creation of Plans depicting a course of action to be taken. According to the intended use and the scenario activities, the students can be asked to use one of the several predefined sets of contributions available through FreeStyler’s Palette. These contributions can be fully-structured and standardized (in terms of the shapes/cards and text/content used) or editable and semi-structured allowing the content inside the shapes to serve as sentence openers for the students’ ideas.

To customize FreeStyler to our own scenario needs, we created a set of contributions that we randomly placed on the environment’s main UI instead of inserting them in the system’s Palette. These contributions emerged from a synthesis of the main Activity Stages as these are proposed by a number of theoretical frameworks that describe students’ activities when engaging in inquiry learning processes (Wegerif and Yang, 2011). These key Activity Stages are: Make Hypotheses, Experiment, Observe, Analyze data, Gather information, Exchange ideas, Keep Notes, Build a model, Evaluate, Reflect, Rethink my hypothesis, Discuss, Explain, Draw conclusions, Find a mathematical expression, Reach an agreement and Present (Figure 2).

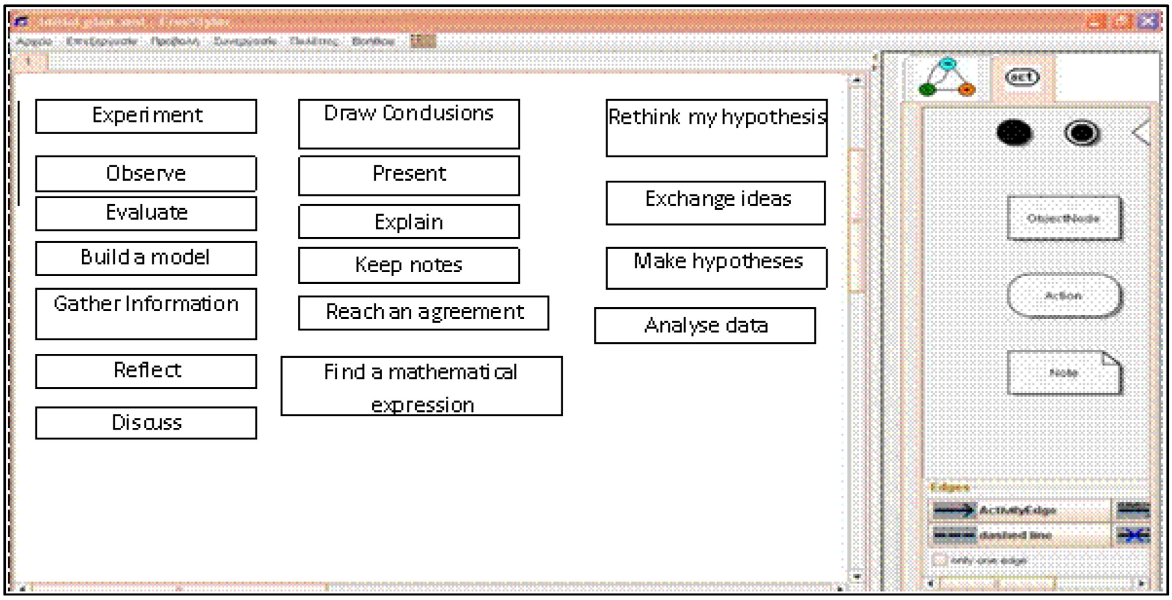


Figure 2: The FreeStyler environment with a set of contributions that correspond to the inquiry-learning framework

To make sure that all these contributions were conceived by students as being of the same type (Activity Stages), they were all represented by the same kind of shape (a rectangle). Although the type of shape was standardized and fixed, the content inside them was editable, since text could be added by the students after the words and phrases already inserted. The functionality that allows linking the shapes to each other was also activated giving students the opportunity to structure their contributions inside the shared workspace and connect them to each other to describe a kind sequencing among the Activity Stages they selected.

The idea behind creating a kind of “vocabulary” that corresponds to specific Activity Stages and putting them in shapes that can be structured and linked to each other inside a shared workspace, is to provide students an environment in which they can collaboratively create “Plans” to describe their course of action when addressing problems in the context of inquiry-based learning. Planning the actions towards as specific goal, monitoring the progress done towards these goals by looking at the Plan and evaluating it at specific time points are considered to be important parts of the students' regulative activities as the engage in inquiry learning processes (Njoo and de Jong, 1993). To scaffold these activities we didactically engineered an environment in which collaboratively creating a Plan would be for the students just a matter of choosing a contribution that corresponds to the scientific inquiry phase in which they engage and linking it to others to define a sequence of actions to be taken towards the goals they have set.

To support, however, the students in planning or reporting their course of action as they work with a constructionist medium, such as the Juggler half-baked microworld, this “vocabulary” needs to transform so as to correspond not to inquiry-learning processes, but to constructionist learning processes. Thus, a constructionist “vocabulary” (Giannoutsou et al., 2011) was designed to provide students with new tools to explain their actions as they were experimenting with microworlds. To support students in describing these actions, the available constructionist “vocabulary” includes contributions such as: Run an experiment, Change something, Observe what is happening, Draw conclusions, Make a hypothesis on what's going to happen, Interpret the feedback, Detect what is causing it, Explain, Find relationships, Predict, Create a model that explains the behaviour. These contributions were also randomly placed on the environment's main UI and were also designed to serve as sentence openers for the students' ideas.

The question that emerges here is if specific constructionist learning activities that belong to the second “vocabulary” may also be considered processes of Inquiry learning Activity Stages that belong to the first “vocabulary”. Special attention is given to the “Experimenting” Activity Stage as this is one the inquiry learning phases in which the students are considered to conduct controlled scientific experiments by manipulating variables and observing the outcomes their actions. These actions (i.e. “Change something” and “Observe what is happening”) are also part of the constructionist activities in which the students engage when working with the microworld.

4 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.

4.1 Context and Participants

The study took place at the Educational Technology Lab with six 9th grade students (14 to 15 years old). All six participants were students at the 2nd Experimental Lower Secondary Education School which has a long tradition in organizing extra curriculum activities for groups of students having a particular interest in specific school subjects such as mathematics and science. The students taking part in the study had formed with the initiative of their Physics teacher a “Studying Science Club” and came to the Lab voluntarily as part of their after school activities. For the needs of the study, two groups of three were formed by the students themselves without any intervention from the researchers and the members of each group worked together with the digital artefacts prepared from them for three school hours. The experimentation process was carried out by two ETL researchers while the class teacher was also present but didn't actively participate in all the experimentation phases.

The adopted methodological approach was based on the participant observation of human activities taking place in real time. Each researcher chose to focus on one of the groups throughout the experimentation process. The researchers' interventions were mostly restricted in posing intriguing questions and encouraging students to express clearly and explain to each other their ideas and strategies as they worked with the digital artefacts.

4.2 Data collected

For the data collection, screen-capture software was used to record the students' interactions both with their peers and with digital artefacts provided. The corps of the data also included the maps the students created using FreeStyler, the games the students created using the Juggler half-baked microworld as well as the researchers' detailed field notes. The analysis of the data collected entailed looking at the students' activities as they interacted with the digital artefacts, giving special attention to the ways these were used by the students: 1) in order to plan or report their actions and 2) in order to make sense of the scientific concepts and relationships embedded in a game's underlying model. The interplay between the digital artefacts was also taken into consideration to study how the reporting of actions progressed as students' meaning making with regard to motion in 2d space evolved.

4.3 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 collaboratively design in groups a juggling game in which the balls would move in a similar way to the one they were watching on the video. To describe how they would work in order to design a model that would generate the phenomena they were watching, the students were asked to use FreeStyler to construct a "Plan" of actions to be taken.

In the FreeStyler environment we had already prepared a set of predefined contributions that we had randomly placed on the environment's main UI. These predefined contributions represented the cognitive phases of scientific experimentation according to the inquiry learning theoretical framework. The students were asked to select the contributions they considered best fitted and structure them in a way that would depict their course of action in the process of designing a Juggling game. As these contributions were created to also serve as sentence-openers, the students were encouraged to add supplementary content if the felt this was needed.

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 try to play the game. As the Juggler half-baked microworld is incomplete by design, the simulation invites the students to explore the model underpinning the game and change it, incorporating their own conceptualizations on how it should work. In this phase, the groups of students were asked to use the Juggler half-baked microworld in order to collaboratively design a game that they would consequently give to the other group of students to play with.

To describe their course of actions in the process of changing the game and designing a new one, the students were asked to go back to FreeStyler and create a new Plan using the constructionist vocabulary. The students were free not only to just use only the available ready-made contributions as they were, but also edit them so as to further explain their ideas on how they should proceed in working with the microworld. This new map created in FreeStyler was meant to be both for reporting their work with the microworld as well as for organizing what to do next.

5 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 designing a game in which two balls would be moving in similar ways as in the video they were watching.

The students of Group A after having observed the motion of the balls in the video shown to them and having "Discussed" it with their peers, determine the "Make a Hypothesis" Stage as the first Activity to be done in order to construct a model that would generate a simulation similar to the one depicted in the video. According to the Plan they made, this hypothesis should be examined using "Information" gathered about juggling, which should be consequently "Analysed" in order to come up with new ideas to be discussed and "Exchanged" with their peers. "Rethinking" the original hypothesis should be the result of this part of the process helping then 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 (“Present” and “Explain” are combined in one contribution). The final Activity Stage will be to “Evaluate the outcome” (Figure 3).

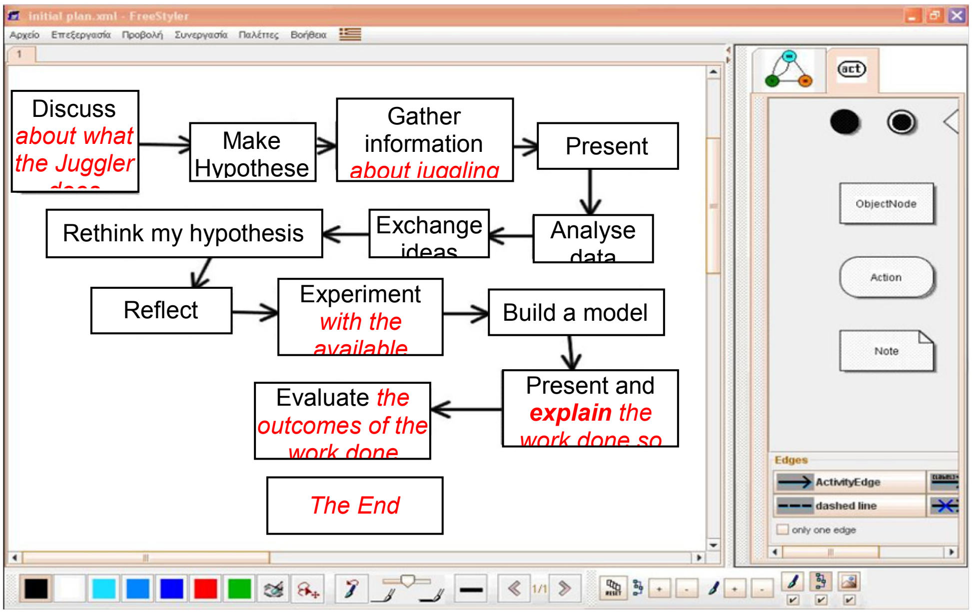


Figure 3: The Plan Group A prepared to explain their course of actions in designing a Juggling game (students’ additions to the predefined contributions are in italics)

The students of Group B, on the other hand, start with the “Gathering information” Activity Stage as they consider that they first need to know more about what a Juggler does. This would give them ideas about the functionalities to be implemented in the game which they should “Exchange” with each other so as to be able to “Discuss” all the data collected (“Keeping notes” seems to be is necessary so as to make sure nothing is missed). (Figure 4).

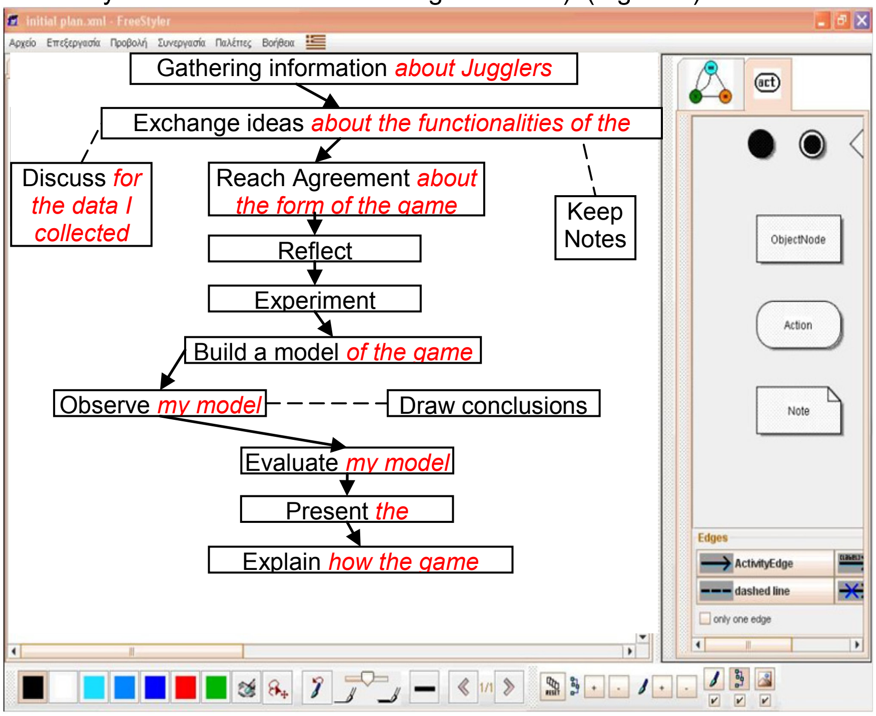


Figure 4: The Plan Group B prepared to explain their course of actions in designing a Juggling game (students’ additions to the predefined contributions are in italics)

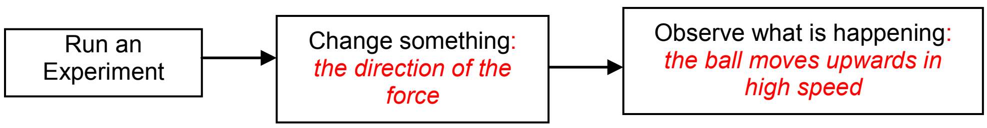
“Discussions” should eventually lead to some kind of an “Agreement” about what the game should look like. “Reflecting” on the design before implementing it seems to be an Activity Stage that would give students extra information on the functionalities and the form of the game. “Experimenting” seems to precede “Building a model” for the game which they would need to “Observe” in order to “Draw conclusions” and consequently “Evaluate” it. “Presenting” the results would be escorted by “Explaining” to others how the game works.

In this phase of the study, the students of both Groups seem to use the majority of the predefined inquiry-based learning contributions available to them in order to construct their Plan on how to design a juggling game. To make their ideas more explicit, for some of these contributions, they choose to insert additional information, expressing mostly issues concerning the existence of specificities in the process of addressing the problem at hand (e.g. the need to work with the “available resources” and to evaluate and explain “work done so far”). What is interesting here is that, although the task the students had at hand was to design a game in which two balls would be thrown up in the air and juggled so as not to fall in the ground, no reference is made in these two Plans to scientific concepts that relate to motion or collisions in a Newtonian space.

For the second phase of the study, we gave students the Juggler half-baked microworld (Kynigos, 2007) and asked them to collaboratively design a game for the students of the other group to play. After giving them enough time to play with the initial game, the students were encouraged to go the FreeStyler and create a new map using the constructionist ontology so as to describe their course of actions in the process of changing the game and designing a new one.

The students of Group A start their work with the half-baked microworld by placing the two balls at the same vertical distance from the two rackets. To make sense of how the initial model of the game works, the students start experimenting with the directions of the two vectors that control the initial velocities assigned to the two balls and consequently run the model to observe the simulation generated. Their experimentation process seems to be rather systematic, as, each time, they choose to manipulate only one velocity vector (either the first or the second ball’s) and maintain the force vector to its default direction (it was by default set to a vertical direction with a 270 degrees direction to represent the gravitational pull). This strategy seemed to be successful, as the students managed to find the suitable directions for the two velocity vectors to make the game quite easy to play.

After having played the juggling game a few times, the students move to the second task which was to design a new game for the students of the other Group to play. Their first action is to change the Force vector’s direction, making it vertical with a 90 degrees direction, and run the model to see how the balls move. Going to the FreeStyler environment, the students add three contributions to document this design choice. These three contributions are: “Run Experiment”, “Change something” (adding “the direction of the force”) and “Observe what is happening” (adding “the ball moves upwards in high speed”, which was the outcome they observed when changing the direction of the force).



The students move back to the microworld and change once again the direction of the force vector, giving it a 180 degrees direction (Figure 5).

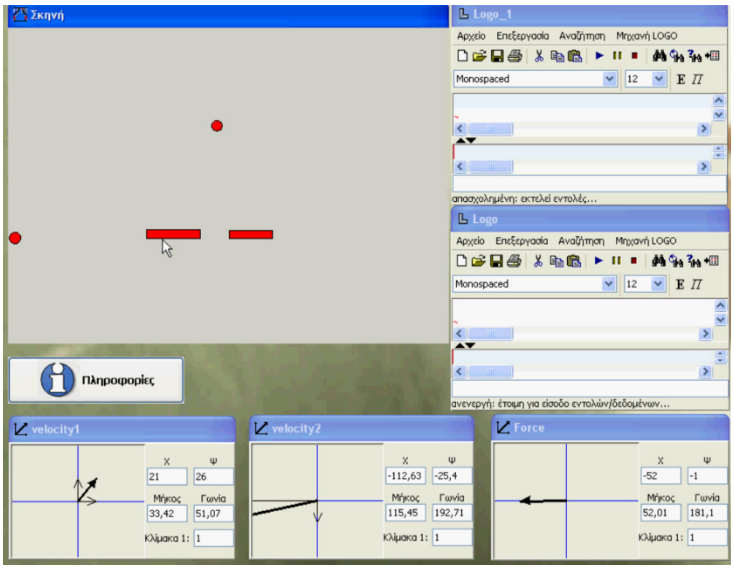
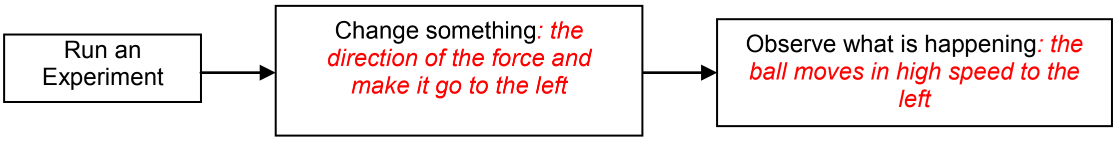


Figure 5: The students explore what happens when giving the Force vector a 180 degrees direction

Just before "Running this Experiment", they go to FreeStyler and add the same three contributions. This time the comments in the "Change something" contribution are more detailed, as they also insert information about the exact direction given to the Force vector ("make it go to the left"). The students also add the "Observe what is happening" contribution which they complete after going back to the microworld to run the model.

After running the model, the students return to FreeStyler to record the outcome they observed from the simulation generated ("the ball moves in high speed to the left").



Once again, however, the game that the students of Group A try to create has a disadvantage that can't be ignored: the balls move in really high speed which makes it practically impossible for the others to play. Having to make another design choice, the students try out making the Force's vector vertical with a 270 degrees direction once again. As this seemed to work just fine and the juggling of the balls became again a manageable task, they place in the FreeStyler the exact same set of cards ("Run an Experiment", "Change something" and "Observe what I happening") explaining that when the direction of the Force is vertical and downwards, the simulation generated makes the balls move in the opposite direction to the one set to the vector of the force. To make sure this idea works, the students go back to the microworld and try this design choice for the vector of the Force by placing the balls in different initial positions to make sure the students of the other Group will be able to play the game.

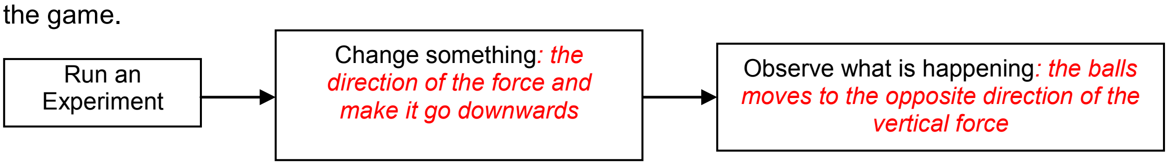


Figure 6: The three sequences of contributions from the map the students of Group B created to explain their actions with the microworld and the outcomes observed when attempting to create a Juggling game (students' additions to the predefined contributions are in italics)

The students of Group B also take their time in playing the initial game, making no changes to the default direction of the vectors controlling the field's force and the velocities assigned to the balls. After a while, and in order to address the problem of designing a game for the other Group to play, the students move to the FreeStyler environment so as to create a Plan on how they will work. Without first systematically experimenting with the microworld's vectors, the students immediately add four types of contributions on FreeStyler's interface: the "Make hypothesis", the "Run the Experiment", the "Observe" and the "Explain" contribution. Going back to the microworld, the students manipulate the Force vector and run the model to observe the outcome of their actions. In order to report this process, the students also add in FreeStyler's interface the "Change" contribution and explain that the change they made was to "the force applied to the ball by the hand". The also assert that what they "Observed" was that "the ball went away" and "Explained" this behaviour as a result of "changing the magnitude of the force" (Figure 7).

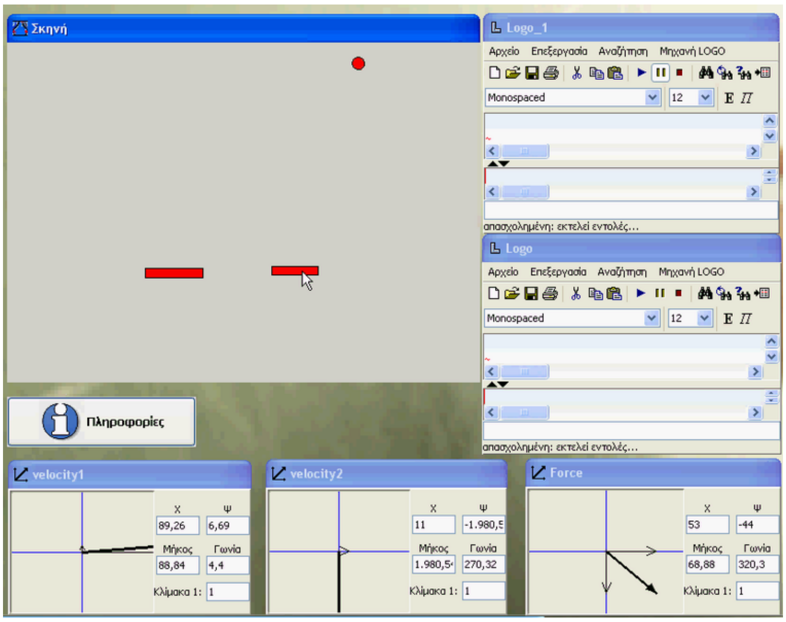


Figure 7: The students manipulate the Force vector and run the model. The ball is lost from the available simulation space.

The students re-open the microworld to recover the initial size and direction of the force vector and this time instead of increasing the magnitude of the force, they choose to substantially decrease it. They try a series of smaller values for the Force's magnitude both in the 90 and 270 degrees direction and manage each time to play the Juggling game without much effort. To make, however, the game a bit more difficult for their peers to play, they also try the 180 degrees for the Force vector's direction. Unfortunately, their choice makes the ball move to the left in high speed and to eventually disappear (Figure 8).

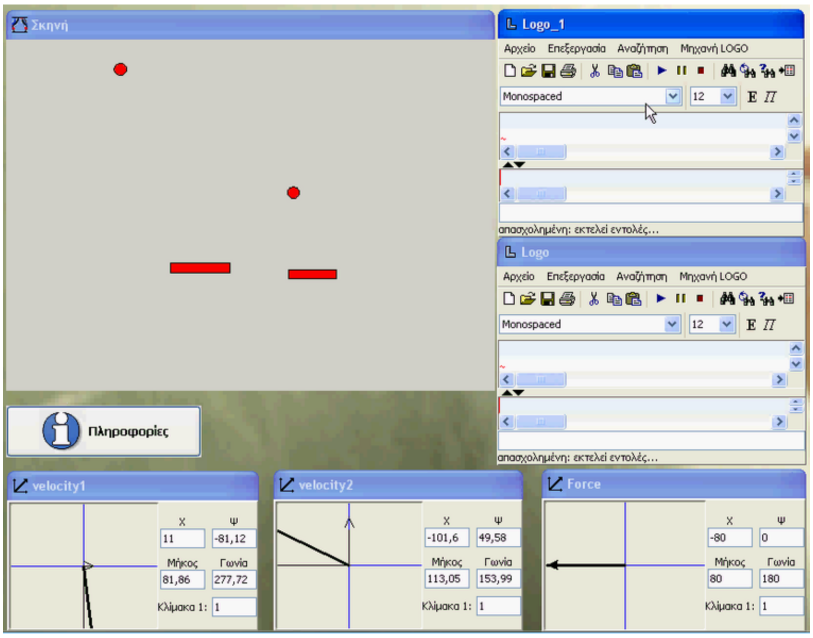


Figure 8: The students manipulate again the Force vector and run the model. The ball is lost from the available simulation space.

The students report their actions with the microworld by adding in the FreeStyler interface once again the "Make Hypothesis", the "Run the Experiment", the "Observe" and the "Change" contribution. This time, however, the additional information they provide for each contribution seems to be more detailed, especially when it comes to the hypothesis formed, the changes made/actions tested in the microworld and the observed outcome. Although, the students of Group B during the previous round of their experimentations with the microworld, had made a hypothesis that was quite generic ("I make a hypothesis on what is going to happen"), this time it seems that their hypothesis become more specific since they refer both to the action to be tested and to the outcome to be observed ("I make a hypothesis that when I will move the vector to the left (on the X axis), sooner or later, the ball will move to the left"). Similarly, the reference to the action tested when "Running the Experiment" is more precise since in the "Change" contribution, the students particularly focus on the "direction" of the Force ("I change the direction- turn it to the left") and not just to the "force applied to the ball by the hand". To explain the outcome observed after implementing this action, the students in the "Observe" contribution choose to insert one more physical quantity: the "time", which is considered to be one of the fundamental concepts in kinematics (i.e. "eventually – after some time") (Figure 9).

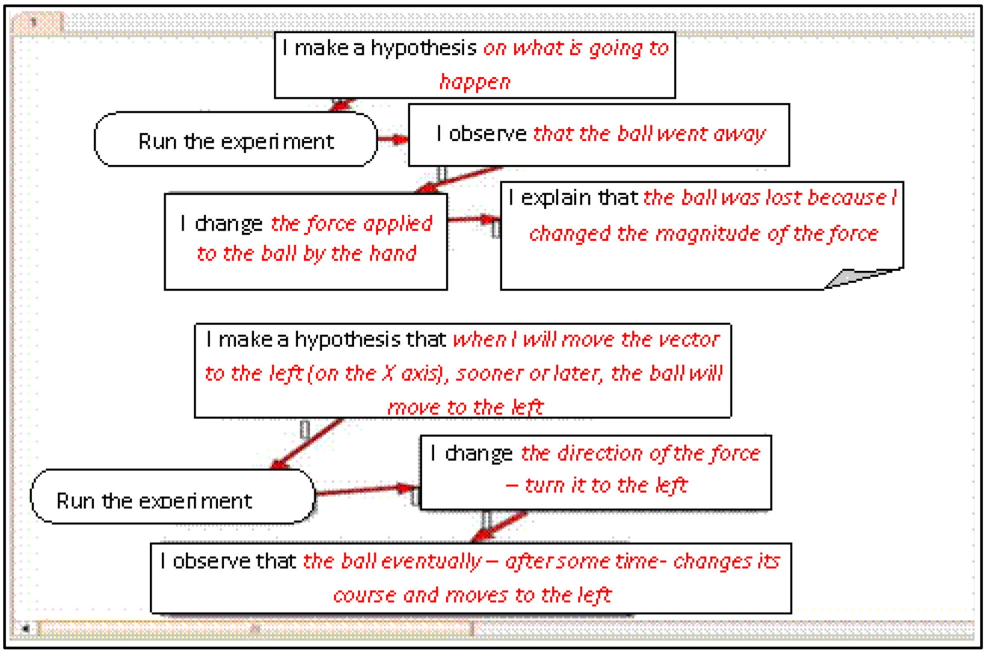


Figure 9: The map the students of Group B created to explain their actions with the microworld and the outcomes observed when attempting to create a Juggling game (students' additions to the predefined contributions are in italics)

The final form of the map created inside FreeStyler comes when the students connect their contributions to each other. However, they choose to preserve two separate sections inside their map, each one corresponding to a different round of their experimentations with the half-baked microworld. The two different sections of the map contain just about the same predefined contributions ("Make hypothesis", "Run the Experiment", "Observe" and "Change"), which are structured in just about the same way, creating a kind of a repeated pattern of actions to be taken when working with the microworld. The difference between the upper and the lower section of the map seems is situated at the supplementary information added by the students inside their contributions to explain the particularities of their actions and the details of the outcomes observed. At the lower part of the map, the students seem to take a more elaborated stance in their explanations, which seems to be fed by their gradual understanding of the Force as a vector physical quantity. In the first round of their experimentations, the students focus on the magnitude of the Force and explain the simulation generated without taking into consideration that they also had changed the direction of the Force (Figure 7). In the second round of their experimentation, however, the students try out different magnitude values of the Force for different directions. Considering making the direction of the Force 180 degrees a good design choice for their game, the students report on their FreeStyler map the outcome they observed for this action.

6 Discussion

In this paper, we attempt to study the students' game modelling processes as they work with a half-baked microworld designed for constructionist learning and identify their connections to inquiry learning activity stages. To do so, we initially asked the students to watch a video in which a performer was juggling two balls and then create a Plan to describe their course of action in designing a similar game. To create their Plan, we provided students with a set of predefined contributions that represented the Activity Stages used to describe students' actions when engaging in inquiry and model-based inquiry learning. The students created a Plan in the FreeStyler environment using the majority of the available contributions and added supplementary comments to further explain their ideas. In the second phase of the experimentations we gave students the Juggler half-baked microworld (Kynigos, 2007). Being incomplete by design, game half-baked microworlds invite students to deconstruct the model underlying the game and reconstruct it to create a new game according to their own conceptualizations. To report on their actions when creating a new game to give to their peers to play, we also gave students a pre-defined set of contributions that were considered to relate more to constructionist learning processes than to inquiry learning processes. The students could choose any of those constructionist learning contributions and add any information they considered necessary to describe their actions with the microworld and the outcome these actions generated.

Taking a look at the maps the students created to report their actions with the game microworld, it seems that the contributions that they chose to use were mainly the: “Make hypothesis”, “Run the Experiment”, “Observe” and “Change” contributions. The students of Group A performed several experimentations with the half-baked microworld in their attempt to find a direction for the Force vector that would make the game to be given to their peers quite difficult to play. Their investigations were reported each time in FreeStyler using first the “Run the Experiment”, then the “Change” and finally the “Observe” contribution. The “Run the experiment” contribution in this sequence, however, serves more or less as an opener, as it is placed first in the row so as to signify the general activity within which the “Changing something” and “Observing the outcome” actions are included (i.e. Run an Experiment: that means first “Change” something and then “Observe” the outcome). Similarly, the students of Group B also used the “Run an Experiment” contribution in both sections of their map, before the “Change”, “Observe” and “Explain” contributions.

Matching the “Run an experiment” contributions the students use in their maps when interacting with the game half-baked microworld with the “Experimenting” contributions they use in their initial Plans to define a course of action in designing a game (Figure 3 & 4), we attempt to identify the kind of specific constructionist learning activities “Experimenting” as a inquiry-learning Activity Stage entails. We view “Experimenting” in the students' initial Plans as a generic inquiry activity that includes specific actions which were revealed only when the students engaged in actual game modelling activities. Looking at the maps the students created to report their modelling activities when experimenting with the microworld, it seems that these specific actions are: “Change” something, “Observe” and “Explain” the outcome generated. We consider these specific processes actual parts of the general “Experimenting” Activity Stage that appears in the inquiry-based learning cycle. Moreover, as the students' experimentations with the microworld evolved and each time the outcome of their previous tryouts fed the next ones, it also seems that the “Change” something, “Observe” the outcome and “Explain” sequence repeats again and again making the “Experimenting” Activity Stage an iterative one as conclusions turn into new hypotheses inducing new explorations.

Our interest also lies in identifying how students' game modelling activities with the half-baked microworld provided them opportunities to evolve their conceptual understanding regarding motion in a Newtonian space. Taking a look at the Plans that the students initially created to describe their course of action in designing a Juggling game (Figure 3 & 4), it seems that their understanding of the what they needed to do from a physics point of view restricts in “Building” a “model”, which they would then “Observe” and “Evaluate”. However, the use of the word “model” in their maps is not escorted by any references to concepts or relationships between concepts related to motion in a Newtonian space. These come into play at the second phase of the study where students explore the half-baked microworld and attempt to create a new game for their peers to play with. At this phase the students, engage in a number of investigations mostly about the role of the Force in the model created. The students of Group A working rather systematically change the direction of the Force vector and record the outcome of their actions for 90, 180 and 270 degrees of direction before selecting the 90 degrees as an appropriate game choice.

The students of Group B add more supplementary comments in their contributions and the evolution of their understandings is better illustrated in their map. These students initially view Force as a scalar quantity and, although they change both the magnitude and the direction of the Force vector, they explain the outcome of their actions taking into consideration only the magnitude of the Force. Trying different values for the magnitude for different directions of the Force vector the students come to add a set of contributions in their map in which they specifically refer to the direction of the Force vector as an important element in explaining the outcome generated. The supplementary information added by the students inside their contributions to explain their actions seem to become more precise and detailed as -through their exploration with the microworld- they gradually come to perceive Force as a vector physical quantity. Moreover, it seems that their understanding of the concepts and rules embedded in the underlying model starts to include not only the visible and directly manipulable variables (Force and initial velocities), but also concepts such as "time" which are not operationalized in variables but constitute an integral part of the simulated phenomena.

In this paper we focused at students' constructionist modelling activities as they collaboratively work with the Juggler half-baked microworld. The model underpinning the Juggling game was presented to them as questionable and malleable with respect to the rules underlying the behaviours of the objects and the effect the available manipulable variables had on it. The students addressed this activity as in groups and immersed in a series of investigations in order to change the models' functionalities and create a game for their peers to play. The group learning processes in which the students engaged related to meaning generation regarding concepts such as velocity, force on an object and gravity and to the collaborative construction of activity maps in which the students depicted the course of action to be taken when designing a juggling game and reported of the actual actions put into test when creating a game using the half-baked microworld. The development of group cognition aspects as a result of the students' mutual engagement with the two different kinds of shared artefacts (i.e. the models and the activity maps) and the ways it could result in progressing students' conceptual understanding with regard to science concepts remains an issue that needs to further researched.

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