UPPSALA
UNIVERSITET

Uppsala University

Project in physics and astronomy, 15 hp

Student-generated representations in Algodoo while solving a physics problem

Oskar Bengtz

supervised by

Bor Gregorcic

Elias Euler

June 19, 2018

Sammanfattning

Fysiklärare möter ofta den svåra uppgiften att representera abstrakta, väldefinierade egenskaper hos den fysiska världen (så som krafter eller energier) för studenter som går bortom ekvationer, grafer eller diagram. I denna studie tittar jag två fall av universitetsstudenter som löser en fysikalisk uppgift, användandes det digitala programmet Algodoo på en stor pekskärm för att undersöka hur studenter naturligt använder sig av sådan teknologi för att återskapa dessa representationer själva. Jag finner att när studenter skapar scener i Algodoo prioriterar de att behålla en viss mått av likhet från den fysiska världen, vilket går bortom den formella behandlingen av uppgifter som studenter kan ha fått lära sig i fysikundervisningen. Vidare, när studenterna använder sig av fysikaliska ekvationer vid lösandet av problemet, verkar de använda Algodoo som ett facit för att se huruvida deras numeriska lösning, uträknad på en klassisk whiteboard, stämmer. På detta sätt - vilket har föreslagits i tidigare forskning - ser jag hur Algodoo, och liknande digitala lärmiljöer, fungerar som en bro mellan studenternas konceptuella förståelse av den fysiska världen, och den mer formella, matematikbaserade beskrivningen vilket används inom fysiken.

Abstract

Physics teachers are often faced with the difficult task of representing abstract, formally-defined properties of the physical world (such as forces or energy) for students in a way which goes beyond equations, graphs, and diagrams. In this study, I investigate two cases of university students solving a physics problem while using the digital software, Algodoo, on a large touch screen to examine how students might naturally leverage such technology to create such representations of their own. I find that as student draw scenes in Algodoo, they tend to prioritze a degree of resemblance to the physical world which goes beyond the formal treatment of problems they might have been taught in physics classes. Additionally, as the students recruit physics equation into their solution of the problem, they appear to use Algodoo as a conceptual check for the numerical answer they calculate on the normal whiteboard. In this way - and as has been hypothesized in previous research - I see the potential for Algodoo and similar digital learning environments to act as a bridge between students' conceptual intuitions of the physical world and the more formal, mathematically-based descriptions used in physics.

Contents

1 Purpose and research question

My aim for this paper is to examine some ways that students choose to represent objects in digital learning environments, such as the simulation software, Algodoo. Specifically, I examine the scenes that two pair of students drew in Algodoo and compare those drawings to the representation used by the students to solve the problem mathematically on a whiteboard nearby, paying special attention to how and when the students moved between Algodoo and the whiteboard during the problem solving activity. From this analysis, I also discuss the advantages and disadvantages of using large touch screens for solving problems like the Monkey-Hunter problem and generate some recommendations for teachers who decide to use technology like this in their physics classroom.

2 Background

Physics is often percevied by students as a particularly abstract subject, a view which is likely arises from the disciplines' tendency to involve mathematical formulas or, at best, classroom demonstrations that are expertly set up by teachers to fit the results of the mathematical formulas exactly. Certain concepts such as forces or energy are particularly difficult for students to visualise. Students are typically given time to solve a couple of questions numerically, and occasionally complete laboratory experiments, which often require the students to follow a set of instructions from beginning to end, without them knowing what the experiment is good for, or what physical process they are supposed to observe.

Projectile motions is a topics where different ways of visualisation and demonstration have been proposed with the intention of making it relevant to the experiences of the student lives and that would act as examples of how the discipline of physics tends to visualise some abstract concepts. Two such examples are discussed in relation to how to throw a basket perfectly (Changjan and Mueanploy, 2015), or how to calculate the best way to play a live version of the video game Angry Birds (Edwards et al., 2014).

Hestenes (1992) discusses how students interact with the Newtonian and Physical World. He sees physics as a collection of modelling games with set rules, but where the students hardly know the aim of the game. He suggests that the students often believe that the aim is to memorise facts and ways to solve pre-set problems, missing the point that the real goal is to understand the models of the Newtonian World and apply those models to objects interacting in the Physical World. Hestenes states that the Newtonian World is strictly populated by point objects, and that all objects in the Physical World can be represented by these points.

In this paper I analyse a student activity which deals with two moving bodies, one in a vertical free-fall and the other with the initial velocity of a projectile. This problem, sometimes referred to as the "Monkey-Hunter" problem, requires students to determine the magnitude and direction of the projectile such that it hits the free-falling object (the monkey). This problem is sometimes presented to students in the form of a demonstration, but the apparatus required for the accurate timing and aim of the projectile can be difficult to construct. There are several articles suggesting and improving the apparatus of such demonstrations (Bartlett et al., 1975b,a). Moreover, the short duration of the resulting demonstration and the difficulties of its setup compel us to consider using computer simulation as a potentially useful alternative to a physical demonstration.

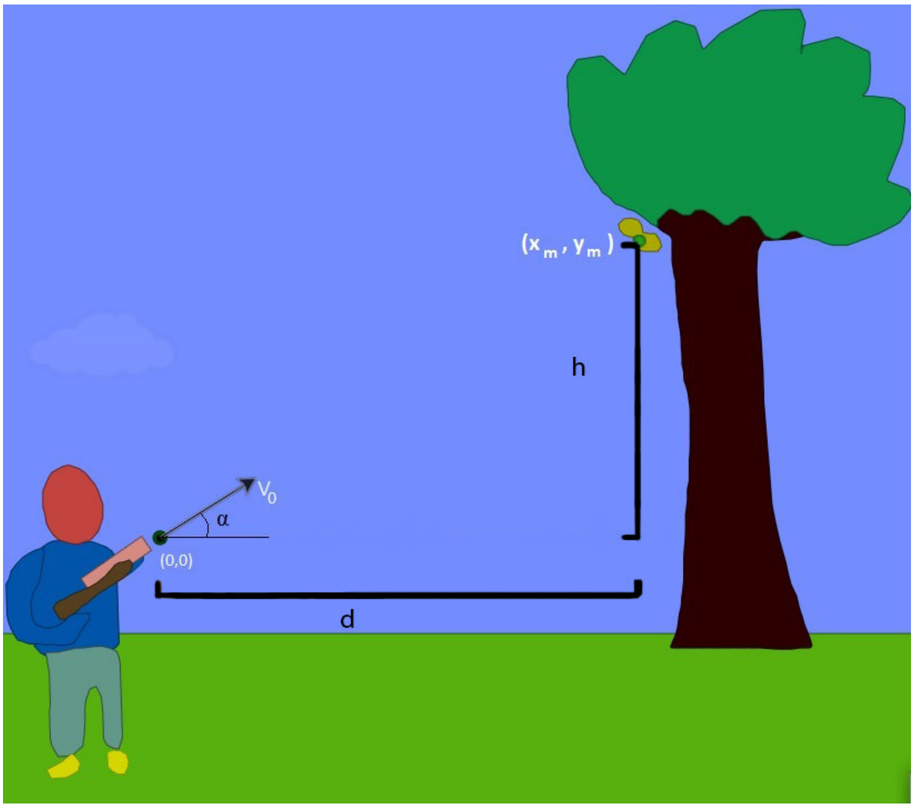

Figure 1: A screenshot of a scene in Algodoo where the hunter aims a projectile at a monkey created by me.

With the technology available today, simulation software have become much more common and useful. Educational software can visualise things that cannot be seen in the physical experiments, such as the exact component of an object's velocity, or the potential and kinetic energy of a falling object. Some of the software, like PhET simulations, have several different simulation modules available, which tend to focus on one specific phenomenon in each simulation.

In this way, PhET simulations allow the students to change a few relevant parameters - which depend on the phenomena that the simulation adressess - while keeping all other parameters fixed. In contrast, other programs like Physion or Algodoo function more like an open software, where it is possible to change most of the physical parameters within the digital environment at any given time. With this kind of program, it is possible for students to explore which parameters are important for a physical phenomenon and which parameters are irrelevant. Therefore, while programs like PhET are great for showing a specific phenomena, in detail, open-ended software like Algodoo and Physion are advantageous if the user wants to be able to test several phenomena within the same digital environment. Once the user gets familiar with the software, a wide variety of manipulations and tests can be performed.

In many Swedish schools, large touch screens (LTSs) such as Interactive Whiteboards (IWBs) have been installed in the classrooms, though my personal experience when talking to teachers is that many of them are not being used. Gregorcic et al. (2018) found that IWBs are often used as slightly enhanced whiteboards, so there is a potential that they are rarely being explored. They explain that this is due to several reasons. For example, many teachers are unaware of the technological capabilities of the IWB or simply do not know how to incorporate IWBs into their classroom practice. One potential use of LTSs such as IWBs in the classroom is that they can be used to let the students examine certain physical phenomenon with a simulation software, allowing students to visualise what otherwise would be impossible to see. When combined with software such as Algodoo, LTSs can allow the students to replay a simulation scene repeatedly, slow down and speed up time or trace the movement of bodies. This can help students discern patterns that otherwise would be difficult, or even impossible, to find. In this study, I have used a LTS which was not an IWB, but which I believe might have similar affordances for students in relation to physics.

2.1 Algodoo as a tool

In this study, I chose to use the Algodoo software instead of other simulation software like PhET because of the openness it provides. PhET can be a useful tool for students to explore dynamic representations created by a team of educational software developers, but for the problem the participants were going to work with, I thought it would be more interesting to have an open world where they could be creative and choose to examine and build what they wanted. In a PhET simulation, the scene would already be set, and the students would be given the opportunity to alter only a couple of parameters at a time.

Algodoo is a two-dimensional sandbox software which follows certain physical laws (Gregorcic et al., 2015). The software is availabe for all plattforms, and free to download (www.algodoo.com). The software is easy for any user to use without any computational programming experience (da Silva et al., 2014). Properties of the environment such as gravity or air resistance can be changed with the press of a button and properties of user-created objects such as mass or coefficient of friction can be changed by opening a drop-down menu with a double tap. Properties can be changed while the software is running, giving the user a wide range of possibilities to examine how these properties affect the software's behaviour. The playback-speed of Algodoo can be slowed down so that the user has a lot of time to observe what is happening, or sped up so a certain pattern is easier to detect. Algodoo is designed to aid in the understanding of conceptual topics in physics, and since it is easy to visualise many physical properties of objects, it is also easy to grasp certain topics which are otherwise difficult to visualise in the real world. The program can also graph quantaties such as velocity, forces and displacement. Algodoo can thus be seen as a bridge between the physical and formal, helping the students move between the physical world and the conceptual worlds (Euler and Gregorcic, 2017). Semi-formalism, as Algodoo would act as, would help the students move from the physical to the formal, mathematical as it is a half-way point between these two worlds. The students in the study used Algodoo both to have the physical represented (as objects in Algodoo) as well as the formal, in graphs that can be included in the software.

2.2 Formal treatment of the Monkey-Hunter problem

The following sections will introduce the Monkey-Hunter question in several forms and cover their formal mathematical treatment. This is done so that I can later interpret the approaches taken by the students in reference to a more formal solution to the problem. During the data collection sessions, the students were given the task described in section 2.2.1. If they solved this first task, they were given the question described in section 2.2.2 which one of the groups simplified to the question described in section 2.2.3.

2.2.1 Question A

A hunter with a bow and arrow is in the jungle searching for a monkey. In a nearby tree, the monkey hangs from a branch and the hunter aims the arrow towards the monkey. As the monkey hears the sound of the arrow being shot, it gets scared and releases the branch. With which velocity and at which angle should the hunter shoot the arrow in order to hit the monkey?

Question A is a popular question for physics teachers, and tends to vary in form depending on who is giving it. As Scherr (1979) formulates the question, the Earth's curvature also must be taken into account. In some cases it is given as a demonstration or a laboratory exercise (Rodgers, 1975; Brown, 1977). While each of these versions of the Monkey-Hunter problem are valuable excercises, in this study I chose to use the question as it is shown in italics at the start of this section.

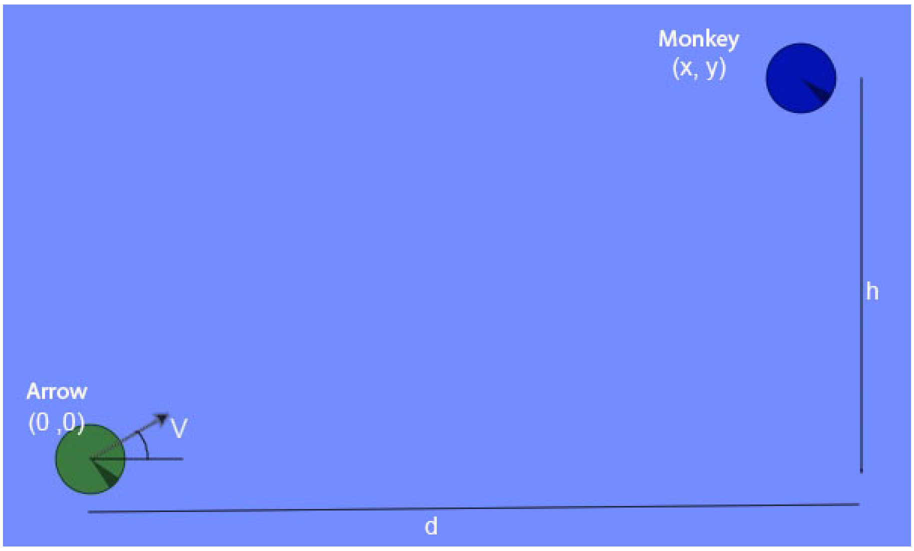

Figure 2: A screenshot of a scene in Algodoo with the arrow aimed at the monkey, created by me.

In this example there are two moving bodies: the arrow and the monkey. We define the arrow's initial position as $(0, 0)$, and the monkey's initial position at some distance, d, and height, h, from the origin (d, h). Since the monkey falls vertically downward, its position only changes along the y-axis. Therefore, the monkey's x-coordinate is constant ($x_m = d$ during the entire fall). It is the gravitational pull of the Earth that accelerates the monkey, so the acceleration will be dependent on the gravitational constant, g. After the time t has elapsed, the monkey's y-coordinate, y_m, can be expressed as

$$y_m(t) = h - \frac{1}{2}gt^2 \tag{1}$$

The arrow's motion can be described as a projectile with the initial velocity $\vec{v}_{a0}$, with the initial launch angle α. After the time,t, from being launched, the arrow moves in both x- and y-directions and its displacement, x_a and y_a respectively can be expressed as

$$x_a(t) = v_{ax}t \tag{2}$$

$$y_a(t) = v_{ay}t - \frac{1}{2}gt^2 \tag{3}$$

Both bodies have the same acceleration (assuming air resistance is negligible), which is caused by gravitational forces. In order for the objects to collide, y_m has to be the same as y_a. The arrow must have this displacement in y-axis in the same time as it has the displacement d in x-axis. The time at which this happens is t_c.

$$d = v_{ax} t_c \tag{4}$$

$$v_{ax} = \frac{d}{t_c} \tag{5}$$

Now, let y_m from equation (1) be equal to y_a from equation (3). This displacement also has to happen in the time t_c.

$$h - \frac{1}{2} g {t_c}^2 = v_{ay} t_c - \frac{1}{2} g {t_c}^2 \tag{6}$$

$$h = v_{ay} t_c \tag{7}$$

$$v_{ay} = \frac{h}{t_c} \tag{8}$$

From (5) and (8), we can calculate α, since $\tan\alpha = \frac{v_{ay}}{v_{ax}}$.

$$\frac{v_{ay}}{v_{ax}} = \frac{h/t_c}{d/t_c} \tag{9}$$

$$\frac{v_{ay}}{v_{ax}} = \frac{h}{d} \tag{10}$$

$$\tan\alpha = \frac{h}{d} \tag{11}$$

This means that the velocity $\vec{v}_{a0}$ should lie on the hypothenuse of the triangle seen in Figure 3, or in other words - if the hunter aims directly at the monkey, it will always hit no matter which initial speed the arrow has. The only thing that matters is the angle of the velocity vector. If the hunter in a real-life situation were to shoot with a speed that is too low, the arrow would hit the ground before hitting the monkey. If the ground could be lowered - or completely remove it (which we see is possible in Algodoo) - the arrow would hit the monkey with an arbitrarily low velocity but do so a long way down from the starting position. As long as there is a ground present, the arrow has to have a velocity that makes it travel the distance d before the monkey falls the distance h.

Figure 4 and 5 both show examples of successful arrow collisions when this problem is modelled in Algodoo. The initial launch angle is the same in both simulations, $\alpha = 32°$, but in Figure 4 $v_{a0} = 13.2$ m/s, and in Figure 5 it is $v_{a0} = 20.0$ m/s. If the initial velocity of the arrow were to be slower than $v_{a0} < 12m/s$, it would hit the ground before it could hit the monkey.

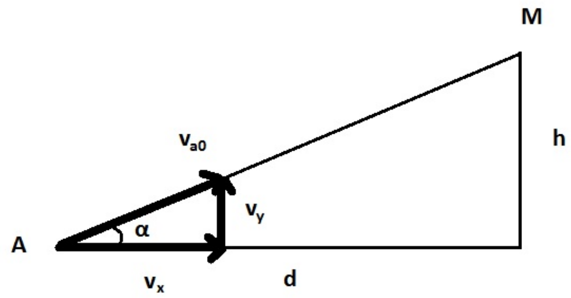

Figure 3: The positions of the arrow and the monkey simplified with the velocity vector and components.

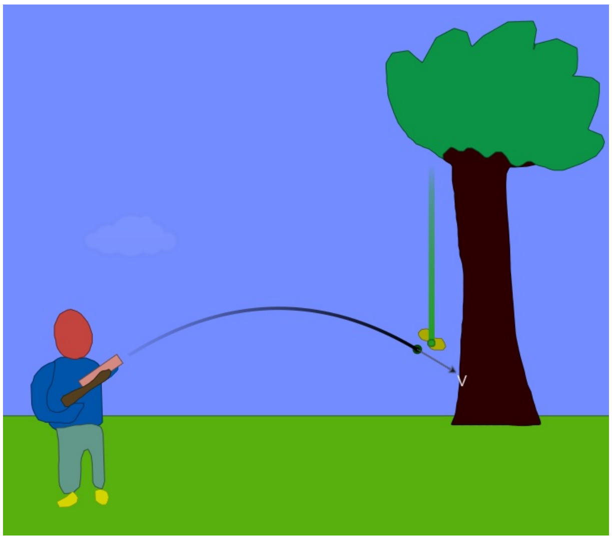

Figure 4: The hunter shoot the monkey with initial velocity $\vec{v}_{a0} = 13.2$ m/s.

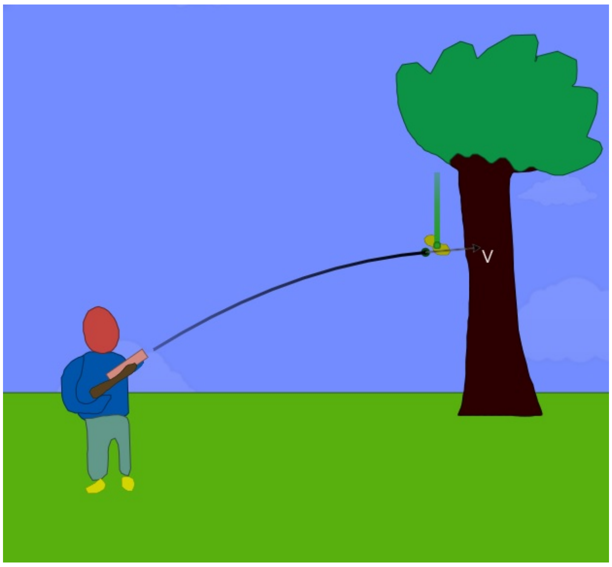

Figure 5: The hunter shoots the monkey with initial velocity $\vec{v}_{a0} = 20.0$ m/s.

2.2.2 Question B

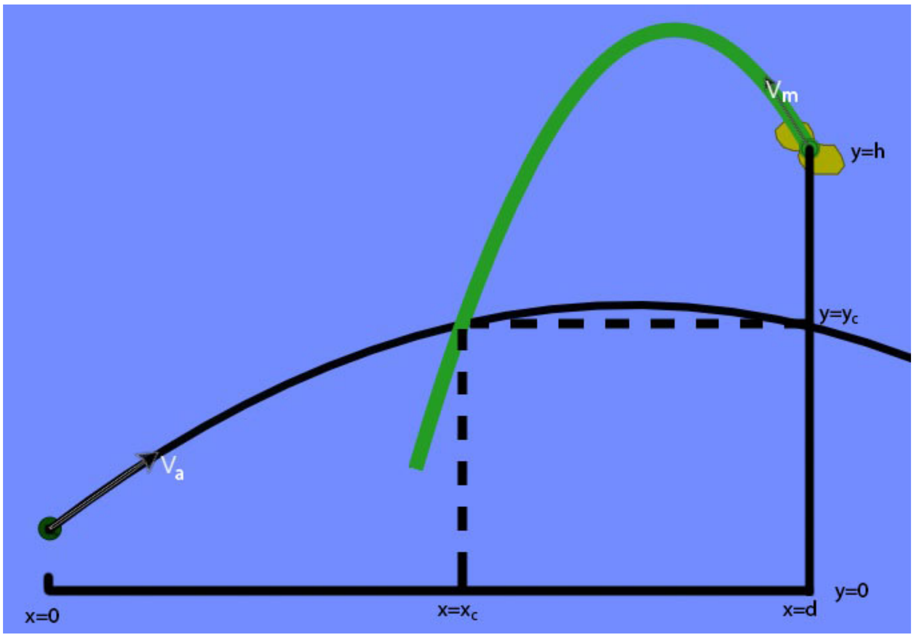

Figure 6: Screenshot from an Algodoo scene modelling the scenario of the monkey having an arbitrary velocity. The arrow (on the left) has the initial coordinates (0,0) and the velocity $\vec{v_a}$. The monkey (top right), has the initial coordinates (d, h) and velocity v_m. The place of impact has the coordinates (x_c,y_c).

How should the hunter aim if the monkey does not just fall, but jumps from the branch with an arbitrary velocity in an arbitrary direction?

This is a more general case of the first question, where the monkey's initial velocity is zero. As in Question A, the initial coordinates of the arrow and the monkey in Question B are still (0,0) and (d, h), respectively. The place of impact is called (x_c, y_c), see figure 6. In the figure, the rightward direction is considered to be positive direction. The arrow's velocity is $\vec{v}_a$ and the monkey's velocity is $\vec{v}_m$.

The displacement of the arrow can be expressed as in Question A.

$$x_a(t) = v_{ax}t \tag{12}$$

$$y_a(t) = v_{ay}t - \frac{1}{2}gt^2 \tag{13}$$

The monkey has a velocity which it did not have in Question A and the expressions are adjusted accordingly.

$$x_m(t) = d + v_{mx}t \tag{14}$$

$$y_m(t) = h + v_{my}t - \frac{1}{2}gt^2 \tag{15}$$

Both x_m and x_a must have the same x-coordinate when they collide, $x = x_c$. Let them be equal and solve for v_{ax}, since the arrow's velocity is unknown. The collision takes place t_c seconds after the monkey begins to fall and the arrow is being shot.

$$x_c = v_{ax} t_c \tag{16}$$

$$x_c = d + v_{mx} t_c \tag{17}$$

$$v_{ax} t = d + v_{mx} t_c \tag{18}$$

$$v_{ax} = \frac{d}{t_c} + v_{mx} \tag{19}$$

If equation (19) is compared to equation (5) from Question A, it is known that if the monkey had no initial velocity, we see that an arrow given the initial velocity $v_{ax} = \frac{d}{t_c}$ in the x-direction would succesfully hit the monkey. The time, t_c, is arbitrary and will only determine how long it will take before the arrow has the correct x-coordinate. In (19), the same equation applies, but with the x-component of the monkey's velocity added.

Let's examine the y-component as well. The y coordinate has to be the same for the monkey and the arrow for them to collide ($y_a = y_c, y_m = y_c$).

$$y_c = v_{ay} t_c - \frac{1}{2} g t_c^2 \tag{20}$$

$$y_c = h + v_{my} t_c - \frac{1}{2} g t_c^2 \tag{21}$$

$$v_{ay} t_c - \frac{1}{2} g t_c^2 = h + v_{my} t_c - \frac{1}{2} g t_c^2 \tag{22}$$

$$v_{ay} t_c = h + v_{my} t_c \tag{23}$$

$$v_{ay} = \frac{h}{t_c} + v_{my} \tag{24}$$

If we then compare (24) to (8), which in Question A was the expression for a successful hit, we see that the only difference is that the y-component of the monkey's velocity is added. Thus, we arrive at some general advice for the hunter. In order to hit a monkey which has any initial velocity, the hunter needs to follow two simple steps: first, the hunter should aim directly at the monkey as if it only fell, then the hunter should add the monkey's initial velocity to the original initial velocity of the arrow. With this solution, we see that the advice for the hunter in general (Question B) holds for the case when the monkey has no initial velocity (as in Question A).

2.2.3 Question B simplified

Question B can be further simplified to the specific case where the initial velocity of the monkey is horizontal (parallell to the x-axis) and the initial velocity of the hunter's arrow is vertical

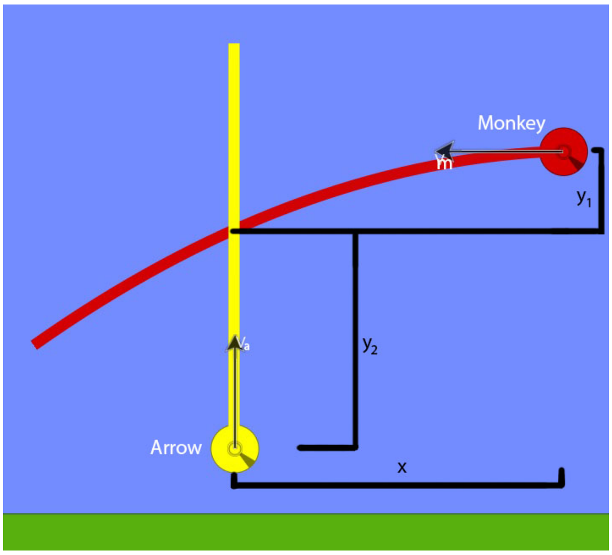

Figure 7: The monkey jumps in to the left and the arrow is being shot straight up.

(parallell to the y-axis, Figure 7). In this case, the only unknown is v_y. The distance y_1 is the distance in y-axis between the starting point of the monkey and the place of collision. The distance y_2 is the distance along the y-axis between the arrow's initial position and the collision. The distance in y-axis between the arrow and the monkey y can be expressed as $y = y_1 + y_2$. The arrow's displacement in y-axis can be described by the following formula.

$$y_1 = v_y t - \frac{gt^2}{2} \tag{25}$$

The monkey's displacement along the x- and y-axes after t seconds, respectively, can be expressed with the following formulas.

$$x(t) = v_x t \tag{26}$$

$$y_2(t) = -\frac{gt^2}{2} \tag{27}$$

We can rewrite the arrow's formula by inserting (27) into (25).

$$y_1 = v_y t - y_2 \tag{28}$$

In the time it takes for the arrow to travel y_2, the monkey will travel a distance x. Therefore, we can rewrite (8) and insert it in (10) and then solve for v_y.

$$t = \frac{x}{v_x} \tag{29}$$

$$y_1 = v_y \left(\frac{x}{v_x}\right) - y_2 \tag{30}$$

$$v_y = (y_1 + y_2)\frac{v_x}{x} \tag{31}$$

$$v_y = \frac{yv_x}{x} \tag{32}$$

This means that in order to hit the monkey, the hunter needs to take the angle between the arrow's initial position and the monkey's initial position and multiplicate with the monkey's velocity in order to get the vertical speed of the arrow.

In this section, I have discussed the formal solutions to the Monkey-Hunter problem in three forms. I will go on and analyze how the students treated the problem in this study.

3 The study

3.1 Context

The study was conducted during a single day in early February 2018. Two groups of two students each participated in one session each. The participants were first year students at Uppsala University, studying to become teachers of math and physics. At the time of data collection, the students were enrolled in a course in mechanics. Therefore, I assume the students had the necessary experience in physics to potentially solve a problem such as the Monkey-Hunter one.

I chose these specific students to be participants in my study because I thought that it would be interesting to see how future teachers would handle using an LTS and Algodoo since they might have thought more about how technology can be used for the learning of physics than a non-future-teacher. Another reason I found these students to be useful for this study was that they had already been introduced to Algodoo as part of a class. As such, they were expected to have rudimentary knowledge about Algodoo which would allow them to devote more attention to the problem and less attention to the technicalities of the software.

The study took place in Ångströms laboratory in a room equipped with a LTS, a normal whiteboard (WB) and recording equipment. The LTS was set in the front of the room and was mounted on a stand such that it could be raised and tilted. During the data collection, the LTS was tilted about 45°, as seen in Figure 8. The WB was placed to the left of the screen. In the centre of the room there was a table with chairs and the students had access to a stuffed toy dog and an eraser that could represent the monkey and the arrow if they wanted to act out the situation with real objects.

Both sessions were divided into three parts. First, the students got about 45 minutes to get to know the LTS and see how Algodoo responded on the screen. During this part, the students were not given a specific task other than to play with the program and see what they could come up with. After this, the students were given a quick break before asked to

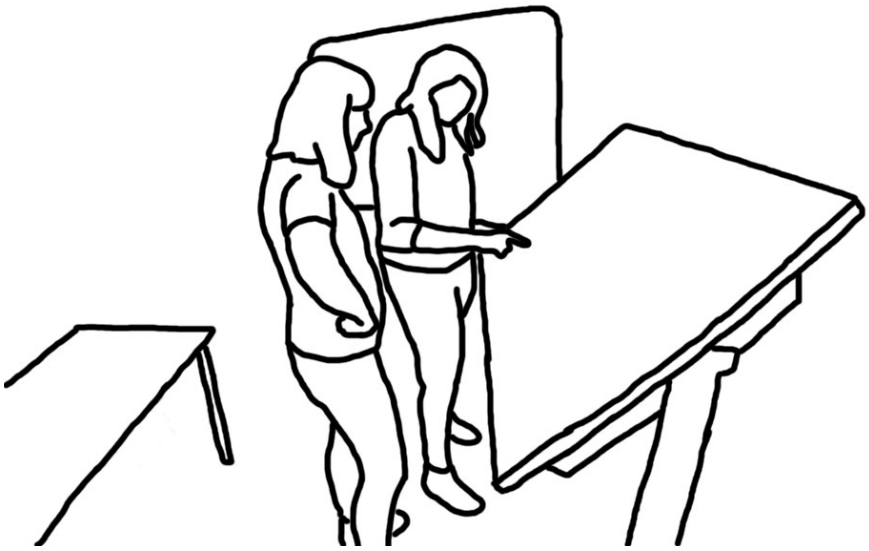

Figure 8: The set up of the room with the participants interacting with the IWB on the right, and a whiteboard to their left. The image is drawn from the video data.

move on to the second part of the session. Here, Question A (described in section 2.2.1) was given to the students and they were given about one hour to come up with a solution. If the students found a solution to the Question A before the hour was done, they were given the more general case of Question B (described in section 2.2.2). After the hour devoted to this second part of the activity, the students were given another break before starting part three. Part three consisted of a concluding interview where the students shared their impressions of the session, the questions, the LTS, and Algodoo. Before this interview part of the data collection, my role during the sessions was to sit in the back of the room and support the students in technical difficulties, answering any questions regarding the task and encouraging the students to describe their thoughts and actions during the session. To maintain their anonymity, I will call the students in the first group "Anna" and "Bianca", and the students in the second group "Carin" and "David".

3.2 Data collection

The data was collected using two video cameras, additional microphones for recording audio, and a screen capturing program running on the LTS. One camera was set in the back of the room and one in the front of the room. The participants wore microphones connected to mobile phones which they carried throughout the session in their pockets. The participants started the session by reading and signing a consent form, in which the goal of the project, information about the conditions of participation and the manner in which the data was to be collected and treated were described. The consent forms were formulated in accordance with Swedish research ethics Vetenskapsrådet (2002) and can be found in the appendix.

3.3 Data selection and representation

From six hours of video and audio data gathered in the two sessions, excerpts were chosen which would later form the basis for the analysis of this paper. In an Excel spreadsheet, an outline of each session was created, with notes of what the students were doing and what tool they were using at the time. I recorded every time the students moved from one task to another, as well as how long they had been doing each task. From this, relevant excerpts were identified and included. To be able to present the sessions, this paper makes use of a multi-modal transcripts, which describes the students' speech, gestures and interactions with the LTS. In the transcipts, a dash (-) is used to indicate that the person speaking was interrupted or cut off, and an ellipsis (. . .) is used to denote a pause in speech. Frames from the screen capture recording as well as recreations of the student's work done on the WB are included in order to give the reader further context for the transcriptions. As the students' drawings on the WB would not have been clear from the frames of video alone, I felt it necessary to replicate the students' work myself in the included figures. The speech in the transcriptions was translated from Swedish to English, with an effort to maintain the meaning of each phrase.

4 Sessions

4.1 Overview of sessions

4.1.1 Group 1

As Anna and Bianca are first introduced the problem, they admit to having seen the Monkey-Hunter problem before, though they are unable to remember the solution. The pair of students begin by drawing objects in Algodoo. They initially discuss whether they should include all the objects, such as the tree, but eventually decide to only include the monkey and the hunter. Anna draws the monkey as a large, oblong shape and both students comment that it is a big monkey in size. Then Bianca draws the arrow by making a thin, long rectangle that is supposed to resemble an actual arrow in dimension. At this point in the session, the distance between the monkey and the arrow in the Algodoo scene is relatively small, compared to the sizes of the objects (see Figure 9). After a while, Bianca makes the arrow less thin so that it is easier for them to select and move the object with their fingers on the LTS.

Once the objects are created, the group talks about whether or not they should use the physical objects (the stuffed animal and the erases) on the table in the room, or if they should just start running the simulation in Algodoo to find a velocity which will make the arrow hit the monkey. They decide to start with Algodoo and quickly find a velocity for the arrow that succeeds in a collision. They then proceed by varying the speed and angle of the arrow to see which range of values result in the arrow hitting the monkey and which range of values causes the arrow to miss.

After some time, some confusion arises about how to change the angle at which the arrow is 'shot' within Algodoo. The software allows users to rotate the velocity vector of an object in two ways: by rotating the object which already has a defined velocity or by entering the drop-down menu for that object and rotating the angle for the velocity directly (independent from the object's orientation). It is therefore important for a user to be careful in which order the object gets a speed and gets rotated. The danger with having a rectangle-formed arrow object is that the arrow needs to rotate along with the vector in order for the front (tip) of the arrow to be the part that collides with the monkey. If a circle is used to model the arrow, this issue with the rotation of the object in Algodoo is avoided. At first, Bianca tries to explain the rotation to Anna but soon realises that she may be wrong and states that she is unsure if she changed the correct parameter.

After a while, the students change the arrow into a ball to see if this changes the outcome of the scene. After half an hour at the LTS, they move over to the whiteboard in order to, as Bianca describes it, "say something intelligent" about how to solve the task. Both students are quite unsure about how they are supposed to calculate a numerical answer to this problem and are unable to remember the needed formulas from memory. I offer them to borrow a copy of Physics Handbook, but since niether of them is used to the book, it does not help that much. After ten minutes of rewriting different formulas, they start to discuss how the physics behind the task works. They start to remember how they are supposed to aim in order to hit the monkey from when they had seen the problem before. They walk back to the LTS to test their hypothesis. Bianca insists on letting the arrow be represented by a rectangle instead of a circle, and after changing it back, they try their hypothetical solution.

During their use of Algodoo, something in the scene is altered so that the monkey effectively has a non-zero starting velocity. Though the students were unable to determine the cause of the error during the session, after going back to the screen capture, I was able to determine the issue. I was able to see that the students did not reset the simulation fully in between aims of the arrow, instead just pausing the simulation a short while after the monkey had already started falling and assuming that the monkey had been at rest.

During the session, this alters the initial parameters of the question and changes the way Anna and Bianca has to aim the arrow (the problem has changed into the form of question B, but with a small velocity). The students however do not realise their mistake, so they lose faith in Algodoo and agree on the answer that there is a range of angles which will cause the arrow to collide with the large monkey.

4.1.2 Group 2

Like the students in the first group, Carin and David admit to having heard the Monkey-Hunter question before. However, Carin states that she *"[...] did not understand it that time"*. At the beginning of the session the students draw the objects in Algodoo and mostly discuss the scenario by pointing at the objects in the scene. They do not run the simulation at all, but decide to calculate an answer on the WB before continuing with Algodoo. Once they are able to come up with a numerical solution to the arrow's initial velocity, the students change the arrow's velocity in Algodoo to the calculated value and get the arrow to hit the monkey. Then they want to shoot the arrow with a lower speed to test the hypothesis that you only have to aim at the monkey to hit it. The arrow hits the ground before hitting the monkey, so they lower the ground and see that the arrow does, in fact, collide with the monkey. This all takes approximately the first ten minutes of the session.

When Carin and David are satisfied with their solution, the Algodoo scene is reset and I present the students with the task of how they would aim the arrow to hit the monkey if it had a non-zero initial velocity (Question B, detailed in section 2.2.2). They start by solving the new question by giving the monkey an initial velocity and experimenting with different launch angles in Algodoo. During this time, the arrow still has the velocity from part A. The students discuss whether they should continiue testing angles with the software or try to calculate an answering numerically on the WB, deciding after 10 minutes to simplify the problem even further (as described in section 2.2.3). When they cannot find a solution with their exploration in Algodoo, they move over to the WB to try to calculate an answer to Question B. Five minutes later, while looking at the LTS, they realise that they have simplified the problem there, so they try to adjust their calculations on the WB for this new simplified version. After ten more minutes, they get a numerical answer and decide to test the solution in Algodoo. Here, they walk between the WB and the LTS a couple of times to see if what they know is sufficient to answer the question, and what information they can get from the scene in Algodoo for the expression they have derived on the WB. After a minor calculation error, the students get a perfect hit in Algodoo and the session is over.

4.2 Student choices in representing the problem

Once the problem is introduced, both groups begin the problem solving in the same manner: first discussing how to draw the objects and how to set up the scene in Algodoo. Since the open-endedness of Algodoo allows users to create vastly different representations, I chose to focus on the ways that the two groups decided to draw their objects, and why they chose to represent the objects as they did. In this section I will first describe how the two groups of students chose to represent the problem in greater detail, including sections of relevant transcripts, and then I will discuss why each group seems to have chosen to address the issue of representation in the way they did. Along with what problems or benefits the group may have received due to their representations.

4.2.1 Group 1

Even before coming to the LTS, the first thing Anna says is, *how do you even make an arrow?* Both students automatically start by generating a representation in Algodoo, trying to set up the simulation even before discussing how they want to approach solving the problem at hand. Once they are both standing by the LTS, they start to talk about how they are going create the objects. Anna suggests beginning by making a tree, but they then both agree that a tree will not be necessary. Instead, Anna starts to draw a figure that represents the monkey in the top right corner. From their conversation it is made clear that the monkey is very big. Anna states that the monkey looks more like an aubergine than a monkey. The decision to make it big will affect the outcome of this task and will be discussed later.

Having constructed an object which represents the monkey, Bianca creates a very small, long rectangle and asks what their *"monkey-to-arrow ratio"* should be. Figure 9 is a screenshot from the students' scene in Algodoo with the arrow down on the left hand side (with its initial velocity displayed by a black vector) and the monkey up in the right hand side (with the net force displayed by a white vector). The group initially creates an arrow which is much thinner, but after having some difficulties manipulating the thinner arrow on the LTS, they choose to enlarge it to the size shown in Figure 9. In the bottom right corner of the figure, the length of 1 meter is represented.

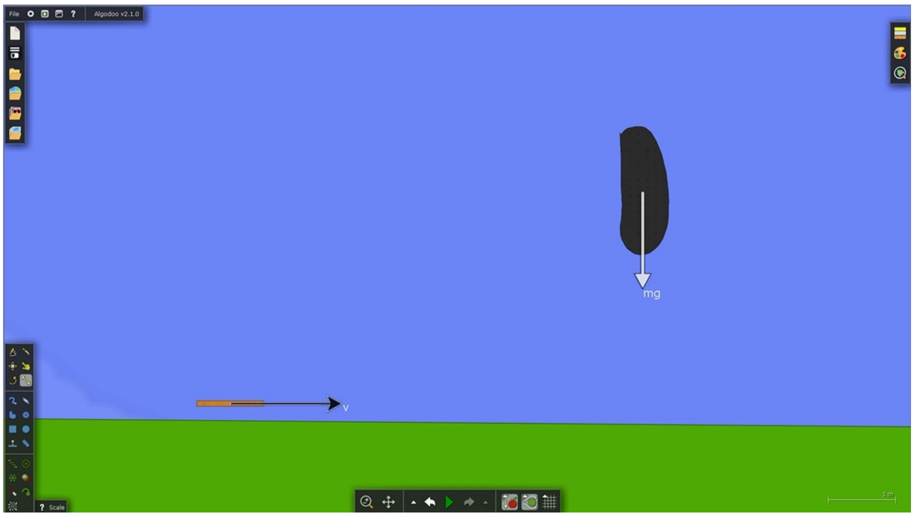

Figure 9: Screenshot of the simulation, the arrow on the left with velocity vector v, and the monkey on the right with all forces acting upon it drawn.

In the transcript that follows, Anna and Bianca have created the monkey and the arrow. They begin to look at the drop-down menu of the arrow object to see what properties they can change, and stumble upon the option to change the material of the object. The excerpt shows their conversation as they are trying to decide on what material to give to the two objects. All objects in Algodoo are made from a "standard" material by default, but can easily be changed into preset materials (wood, steel, glass and so on), such that Algodoo changes all the properties of the simulated object to resemble the properties of the material in the physical world. As seen in the excerpt, the students choose wood for the arrow. When they later change the arrow into a ball, they also change the material to steel, trying to maintain a degree of realism within the Algodoo scene.

Anna			Bianca		
Talk	Gestures	Interaction with LTS	Talk	Gestures	Interaction with LTS
			That's a good arrow		
			Should we make it out of a material… Should we make it… Wood material, it's an arrow!		Open the drop-down menu for the arrow object
			See if this should have a material		Open the drop-down menu for the monkey object
Is there monkey material?					
			What resembles a human the most… or monkey		
Rubber					
			Rubber		

In this transcript, the students find the drop-down menu where they can change the material for the objects. They find the material that most resembles the physical objects that are being represented. Since there are no "Monkey-material", they use what they find the most fitting - rubber material.

4.2.2 Group 2

Carin and David, much like the first group of students, start their session by discussing if they should include a tree. When they move over to the LTS, the first thing Carin says is, *"should we make a tree then?"* before starting to draw a tree. A difference between this group and the first is that Carin and David choose to include the tree in their representation. They, nonetheless, have some difficulties with getting Algodoo to do as they want; a couple of times they both try to draw two objects directly after each other without letting go of the screen (for example, later in the session, Carin draws a circle that will be the monkey and tries to draw a rope that will attach it to the branch in the same move). Algodoo tries to make one objects from that move, which leads to the program creating different objects froom those that Carin and David intended. The LTS has a small outer frame that is not a part of the screen and, when Carin tries to draw the tree, the finger with which she is drawing moves from the screen over to the frame without her noticing. Algodoo interprets this just as it would any other interruption of a touch and connects the last point of contact to the point where Carin began the tree. This results in the "really ugly tree" Carin mentions in the transcript below.

Carin			David		
Talk	Gestures	Interaction with LTS	Talk	Gestures	Interaction with LTS
So, should we make a tree?		Starts to draw a tree			
Perhaps we should make a branch for the monkey to hang from… here’s the branch		Draws a branch and continues drawing the rest of the tree			
			I’m thinking that the higher the tree is the better, we have time to see everything happen		
Oh, right. Let’s do everything again		Stops drawing			
Wait… erase…		Erases the tree			
			Zoom out a bit…		Zooms out
Yes, that’s good. But I mean, what’s the difference? It will still be the same space…	Holds her hand up to indicate vertical distance in the air				
			Yes, but it will fall… slower		
Okay					
			It will fall slower	Gestures in the air to convey that the word “slower” is in quotes	

From this transcript, the students talk about how to represent the tree from the question. Initially, Carin made a tree that was too small, so they chose to remake it, making it higher so that they will be able to observe the monkey falling for a longer time.

Once they have finished creating the tree, Carin and David continue by creating a monkey. Carin has some difficulties drawing the monkey, so David takes over and draws a circle to represent the monkey, dragging it to just below the branch of the tree in the scene (see Figure 10). David says, *"we'll just make an object here"* and draws a box in the lower left corner. This object leads to some confusion, as seen in the following excerpt. It is initially unclear what the use of the box is, and Carin does not seem to understand what David meant by drawing it. Carin initially thinks that the box is meant to represent the arrow, but David explains that it is supposed to be the hunter (or as he phrases it: *"That's us"*). Carin eventually creates a ball and puts it on top of the box and states that the circle will be the arrow (or "bullet" as they sometimes refer to it).

Figure 10 shows the students' setup of the scene in Algodoo. The hunter is represented by the box in the lower left corner, with the arrow represented by a circle on top of the box, and the monkey is "hanging" (or rather floating) beneath the branch of the tree on the right-hand side.

The following excerpt shows how Carin and David talk about the creation of the hunter, and the confusion regarding it.

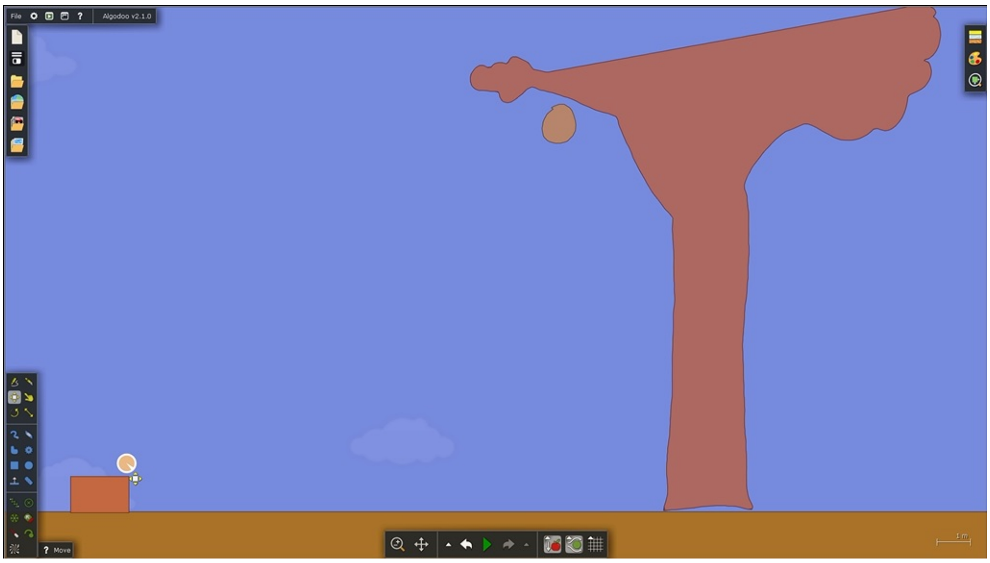

Figure 10: Screenshot of the setup of the simulation for group 2. To the left is the box representing the hunter, with the arrow as a circle on top. The monkey is beneath the tree in the upper right.

Carin			David		
Talk	Gestures	Interaction with LTS	Talk	Gestures	Interaction with LTS
			Now we only have to make an object to be shot and then we see what angle…	Holds his hand parallell to the screen by the hunter object and points at the monkey object	
Oh, right				Angles the hand up and down	
			Like this?		Makes an object in the lower left corner
Wait, are we going to shoot this? Shouldn't we have something a bit more…	Points at the new object				
			No, we're not going to shoot that, that's just… That's like us		Moves the object a bit
Isn't it better if we have it on the ground so we have it… don't have to think… difference in height	Holds her index finger and thumb in a "distance"-motion				
If we're gonna think angle					
			It's doesn't matter how high up we are		
Hmm, no					
			We're not gonna test when the monkey hits the ground, we're just gonna hit the monkey?		
Oh, right					
			Right?		
Yes, but then we have to think about the angle from here					

Carin			David		
Talk	Gestures	Interaction with LTS	Talk	Gestures	Interaction with LTS
Okay, but I don’t understand what we’re gonna have that for					
			Eeh,, that is only, that is the one who shoots		
Okay, the one who shoots. This is the one who shoots					
			And then we add an object that we give a certain speed in a certain angle	Hold the hand parallell to the screen at the hunter object and points at the monkey object	
That’s right, with a certain angle. We take a ball… this is the bullet					
			Yea, that’s good		

While creating all objects, David creates an object for the hunter. This confuses Carin, and she thinks that it is the bullet. David explains that it is the hunter a couple of times before Carin understands.

4.2.3 Reflection on students representation in Algodoo

Both groups, in their own ways, tried to replicate the authenticity of the problem in Algodoo. The first group began the session by discussing how to create a realistic arrow in Algodoo. The monkey that they created was quite large, but once the students have drawn the monkey, they try to give the arrow a realistic relative size. Bianca asked what size they should give the arrow, specifically which "monkey to arrow-ratio" they needed. There was a desire to have detail in the Algodoo scene. Later, the students in the first group discussed which the simulated material of the monkey and arrow, commenting about which material was most "monkey-like", for example. From the formal perspective of the problem (as discussed in section 2.2), the material of the monkey and the arrow would not have affected the students' answer to the question. Indeed, if the monkey was made of rubber it would have bounced more when hitting the ground, but the question is stated in such a way that students should have only been focused on the part of the phenomenon when the the monkey was in the air.

In a similar way, the second group also went for realism in their drawing of the problem in Algodoo. They drew the objects from the problem (the tree, monkey, hunter and arrow) with shapes in Algodoo that vaguely, if at all, resembled the physical appearance of those objects. They also chose to include objects which were unnecessary for their solution. The tree seemed to be included in Algodoo so that the monkey had a visual reason to start higher than the hunter. The hunter was only included in the Algodoo scene so as to have a visual reason for the arrow to get an initial velocity and angle. Neither the tree nor the hunter played a formal role in the solution of the task. Still, the students in the second group included them in Algodoo so as to maintain some of the realism with the physical phenomenon of the question. Interestingly, this actually lead to some confusion between Carin and David during the sessions. Several times Carin had to go back and ask David what the box (used for the hunter) was and what it was meant to do. Carin then asked if it would have not been better for them to have the arrow start on the ground, so that they would not have to take the height difference between the ground and the arrow into account. This lead to an interesting discussion that brought the two students' reasoning forward as they talked about whether the height mattered or not.

As proposed by Euler and Gregorcic (2017), I interpret the students' use of Algodoo in the two examples above as an environment which was somewhere between physical reality and the formal descriptions used in physics. In this way, Algodoo seems to act as a bridge between the "Physical World", where real objects and processes take place, and the "Newtonian World", a world of models and simplifications. In both groups which I observed, the students modelled the objects from the Physical World, but not as point particles. This is an indication that Algodoo might have been acting as a bridge between the Newtonian and Physical World.

Later in the session the students moved over to the WB in order to calculate an answer to the problem, and when they sketched the problem there, they drew the arrow and the monkey as simpler, point-like objects (see Figure 11 and 12). In doing so, they seem to demonstrate that they know how physicists often solve problems, simplifying the "real-life situation" of the question to a formal model. When the students solved the problem on the WB they stepped into the "Newtonian World" of simplification and models in order to focus on the salient features of the phenomena. However, Algodoo is not in the formal world, as solving equations on a WB is, but is not the in physical world either. Therefore, it is natural that the students make some simplifications by removing some objects (as the first group of students did), or represent the objects with circles and boxes (as the second group of students did). They try to have some elements of realism left, like when the first group made an arrow that would resemble an arrow in relative size and material, and when they found a "monkey material" for the object representing the monkey. The second group chose to maintain some realism when they drew a tree and the hunter even though they would not affect the outcome of the scene.

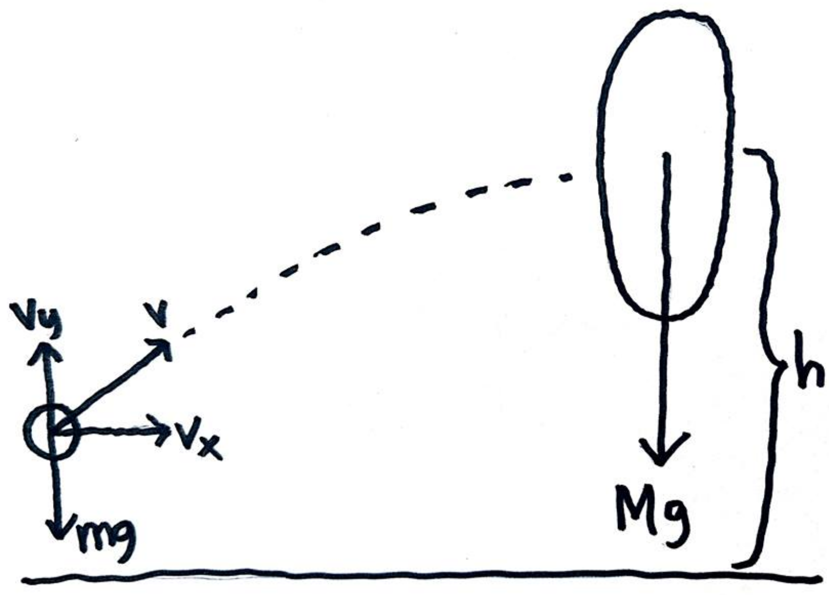

Figure 11: A replication of the drawings made by Anna and Bianca on the WB.

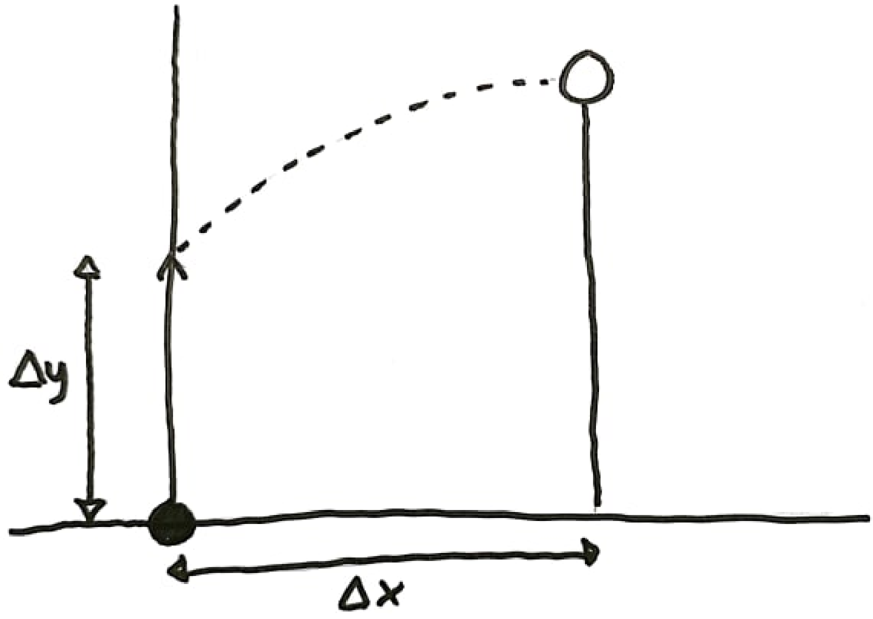

Figure 12: A replication of the drawings made by Carin and David on the WB.

Though both groups seem to have aimed for some realism in their Algodoo scene, the differences between how the two groups set up their scenes is equally interesting. The second group included the tree in their scene, which was an idea the first group discarded. When Carin and David created the tree, it lead to a discussion about which parameters were important for the task. They came to agree that as long as the relative height difference between the arrow and monkey was perserved from the physical situation, they would have had the same problem to solve. These students also created an object to represent the hunter, which was something the first group avoided. Instead, the first group of students focused on making the objects in the Algodoo scene as life-like as possible. The objects of the first group are meant to resemble the real-life objects in appearance and material, whereas the second group creates circles that aim to resemble the point particle often used in the Newtonian modelling world.

4.3 Movement between LTS and WB

During this study the students main tool to solve the problem was the LTS. They had access to a WB as well, which the two groups used to a different degree. This section will describe how the students moved between the LTS and the WB, analysing if there are any patterns in when and why they moved between the two different tools. Only group two will be analysed in this section, because the first group did not move naturally between the LTS and WB. Instead, the first group only used the WB once the instructor reminded them they could use it during the session.

With the second group, however, we saw the students move between the LTS and WB by their own initiative. Initially, both Carin and David participate actively, standing together by the LTS or WB, both interacting with the tool in front of them. At a few instances, Carin and David split up and stand by different boards. David has a cold that makes him tired as the session progresses, so after a while he participates by sitting in a chair close to the boards and thinking out loud while Carin interacts with the LTS and the WB.

In the beginning of the session, as they try to solve Question A (as described in section 2.2.1) the students work to find what speed the arrow needed, and which angle from which it needed to be shot. They draw the scenario in Algodoo and then come to agree that only the angle will affect whether the monkey will be hit. The following conversation takes place once they have agreed that it is sufficient to find the angle for the vector of velocity. As this conversation takes place, Carin and David move the objects around. Figure 13 shows the two different ways they place the objects. To the left, the centre of the object is on the intersection of the lines in the grid and to the right the bottom of the object is on the line of the grid. This is important when measuring the distances from the ground to the object and the distances between the two objects.

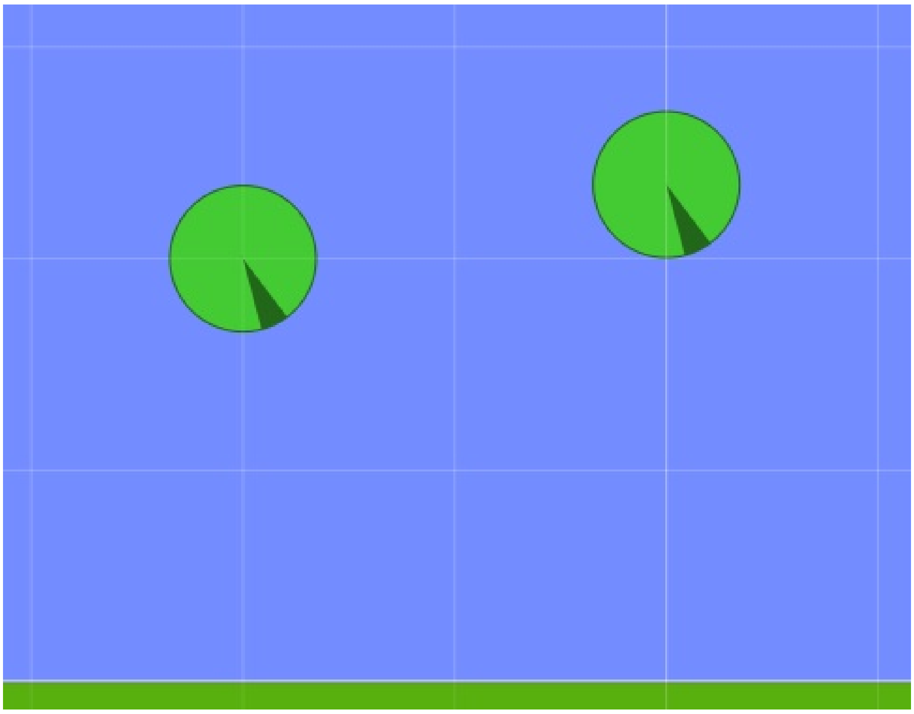

Figure 13: Two ways of placing objects in the grid in Algodoo.

Carin			David		
Talk	Gestures	Interaction with LTS/WB	Talk	Gestures	Interaction with LTS/WB
So the only thing we need to know is what angle this has in relation to that	Points first at the projectile and then at the monkey				
And then add its velocity that much					
			Right, that's correct		
Okay, but I think we should place this here		Moves the monkey around			
so we can know what its-					
If we place this here, it will be in the centre there		Places the centre of the monkey on the intersection of the grid			
so it has some- (whispers to herself) one, two..	Counts the number of grid squares between the ground and the monkey				
Ten					
(Whispers) One, two, three…	Counts the number of grid squares horizontally between the monkey and the projectile				
Five… Oh, now I got lost.					
Wait, and we can- Can I move that?		Begins to move the projectile around			
			Yes		
Wait, so we can have that there?		Moves the projectile to the intersection of the squares in the grid			

Carin			David		
Talk	Gestures	Interaction with LTS/WB	Talk	Gestures	Interaction with LTS/WB
No, we will have it there, it was ten		Moves the projectile down one step in the grid			
			On the ground that is? We remove this completely then		Removes the hunter and moves the projectile so it lies on the ground
Then we have one, two… oops… twelve-	Counts the number of squares in the grid horizontally				
			Can I recommend that we do like this? Because it will be better, because it will touch the ground when it is at the line		Moves the monkey so that the bottom of the body lies on the bottom of the square in the grid
Oh right. Now I have to think. Well, we have one, two…, ten full squares, and what was this… I can't count, can you write it down? Ten… Ten in y-axis and twelve in x-axis	Counts the number of squares again				Draws the figures on the WB and the distances between them and writes down the numbers Carin tells him
Okay, eeehm. Now we kinda have to do math and all that					
			Oh nooo		

The students transition to the WB and realise they need to calculate $\tan(10/12)$ in order to obtain the angle for which the arrow will hit the monkey. While they discuss if they can calculate it without a calculator, Carin then realises that it can be solved by using the x- and y-distances between the objects as components for the velocity of the projectile instead. Both Carin and David move over to the LTS, change the velocity of the arrow and play the simulation to find that the arrow will hit the monkey. They come to the conclusion that the hunter should aim the arrow at the monkey in order to hit it. Since there were a lot of time left of the session, they were introduced to the next question.

Carin and David are introduced to the second part of the problem (Question B), and begin to think about this new problem within Algodoo on the LTS. The students vary the velocity and angles of the arrow, and experimentally find the parameters for a collision. However, with only a velocity it is unclear for the students how to draw any conclusions. At the LTS they discuss the scene and try to describe the movements of the bodies and the proportion of the distances travelled by the different bodies, eventually getting themselves confused. The natural progression of their thought process is lost. Carin asks if the goal of the task is to find an answer. I say that it would be nice if they could find some kind of connection between what velocity to give the arrow in order to get a collision, and Carin gives a heavy sigh and asks David if they should "calculate and write on the damn whiteboard". They move over to the WB.

After some calculations and reasoning by the WB, David notices that Carin has drawn the situation differently from how it actually plays out in Algodoo. In Figure 12, Carin's drawing is replicated. In Algodoo, the monkey object has an initial velocity upward and to the left, but as Carin has drawn the scenario on the WB, the monkey only jumps left and not up. At this point, David sits down on a chair close by the WB and looks at the drawings while Carin writes and thinks out loud. The following transcription takes place once David notices that the initial velocities of the monkey in Algodoo and on the WB do not correspond.

Carin			David		
Talk	Gestures	Interaction with LTS/WB	Talk	Gestures	Interaction with LTS/WB
			Do you imagine that the monkey flies out only in x-axis or do you still imagine that he flies up first?		
I am thinking that these are both- This is for the monkey		Circles in the equation that describes the monkey's movement in x- and y-axis			
This is for the bullet	Points at the equation for the bullet's movement in y-axis				
			But the monkey flies up now… In y.-axis?		
Up?					
			Yes, did it go up as it did in our- He flies up a little in y-axis in the beginning, then it begins to fall		
That's right, it had some speed in y-axis also… Oh, it had a trajectory like this		Draws the movement of the monkey if it jumped up as well			
[Here they have a discussion if they want to continue as if the monkey only moved in x-axis or if it had a y-component in velocity as well. I comment that I gave the monkey an arbitrary velocity and that they could change it to be only in x-axis if they wanted to]					
Okay, we can change it, that's really chill in that case					
Okay, but then we do it in xaxis only. I feel too stupid to think					

Carin walks over to the LTS and changes the setting of the monkey's velocity so it only has a velocity in x-axis. She does not play the simulation or watch how the scene has changed. She simply walks back to the WB right away, and erases everything they have written so far, stating that she wants to begin from scratch and do it properly. They now spend some time drawing the new situation (where the monkey only jumps sideways) and try to find equations to describe the motions of the two bodies and see if they can find an expression for the projectile's velocity (since the projectile's velocity is strictly in y-axis they need not calculate which angle the velocity vector should have). With David sitting on the chair and Carin holding the pen, they derive an expression that seems to contain all the necessary information to be able to calculate a velocity for the projectile. The following excerpt shows how Carin and David talk about the expression which they find. These equations are similar in form to equations (24)-(32) as shown in section 2.2.3.

Carin			David		
Talk	Gestures	Interaction with LTS/WB	Talk	Gestures	Interaction with LTS/WB
All of this we know, or…	Points at the equations				
			Yes we do. Or… Do we?		
Yes, we can see all of it	Points at the equations again				
			We can see that the monkey will hit here in delta y. Can we say that?		
Eeeh yes. Wait. If we test this we can see if it works.		Finishes the derivation of the equation			

Once Carin has finished the derivation, she goes to the LTS to retrieve the different values needed for the calculation from Algodoo. Carin stands by the LTS, but turns her body to the WB, interacting with both simultaneously. She notes the monkey's velocity on the WB and can not find the dimensions of the grid in Algodoo. David realises that it is not possible to find all the information in the expression from Algodoo, without pausing the simulation at exactly the right moment and measuring the distances in the collision. At first, they try to find the collision by running the simulation and pause and play the simulation many times. They stop and state that it feels like cheating, and that they should return to the derivation of the expression and see if they can solve it mathematically instead. It does not take a long time before they realise how they can express the distances in a different way, so that the expression can be used. They retrieve all relevant information from Algodoo and use the expression to get a numerical value for the speed of the projectile after some miscalculation. The simulation is run and the projectile and the monkey collide, and the problem is solved.

4.3.1 Discerning patterns

It can be quite difficult to categorise how and why each movement between the LTS and WB happened. Nonetheless, before each transition, I imagine that there was something that triggered the students to move to the LTS or WB. However, these triggers are quite different from each other and to label them is not as easy as first believed. A few times during the sessions, the students move from the LTS to the WB in order to write some numerical values down, essentially using the WB as a notepad. At such times, the trigger which motivates their movement between the two surfaces seems to be a realisation that they cannot memorise too many values simultaneously and instead should write them down on the WB. In another situation, the students had found an expression for the velocity of the projectile and needed values from the simulation to solve the problem. Therefore, they seem to have been triggered to move over to the other board to do something specific (in this example retrieve the values needed).

Once the students had been introduced to the second part of the problem, they talked about how to begin the problem solving. The students viewed their options as either to "try it out in Algodoo" watching how the scene unfolded, or to "calculate it with mathematics" which meant finding a numerical solution from equations. As described earlier, they chose to begin by looking at it in Algodoo. Once in Algodoo the students were able to find a velocity for the projectile so that the projectile and monkey collide, but soon got lost in their thought process.

They did not know what to do with the information they had collected from the simulation and were unable to see the next step in their process of solving the problem. I reminded the group that they should find some kind of connection on how to aim the projectile in order to hit the monkey. The students interpreted this as meaning that they needed to move over to the WB and calculate it mathematically. I identify this as being a different kind of trigger, since the students had succeeded in hitting the monkey in Algodoo, but were unable to express what this succesful hit meant in terms of where to aim the arrow. The trigger is therefore the realisation that they have come as far as they can with Algodoo, and revert to the initial plan to solve the problem mathematically.

Generally, the transitions to the WB can be categorised as the group wanting to solve the task “properly” (as they are heard saying a few times), which entails solving it mathematically. This kind of transition is the most reoccurring during this session. This leads me to reflect on Algodoo’s role in a tool to solve problems. While the students seemed to apprechiate the tool while visualising the phenomenon, Algodoo is not seen as a ’proper’ tool for solving the physics problem.

5 Discussion

When solving a physical problem, my experience is that students are often taught to begin by drawing a diagram or sketch of the situation. As Hestenes points out, physicists almost always represent objects as point particles. Interestingly, the students we analyse in this session did not create point particles. Instead, they created semi-simplified objects which maintained some of the characteristics of the physical objects they were meant to represent but omitted many others. In this way, while solving the Monkey-Hunter problem, the students’ seem to use Algodoo as a digital space to represent the problem in a style somewhere between the way it would look in the physical world and the way a physicist would tend to represent it in a Newtonian world. The students are able to display certain variables within the scenario such as velocity and force vectors just as they would appear in the Newtonian model, but they are compelled to make the arrow and the monkey better resemble the version of those objects in the physical world. The students were aware of the difference between the real-life objects and their models the objects, which results in interesting discussions around the things that should or should not be included in the Algodoo scene.

For the teacher, a few things can be concluded from these sessions regarding students’ self-generated representations. First, it is important as a teacher to discuss how we model objects in physics. The students might follow the formal procedures for drawing objects as point particles when solving a problem, but do they know why? It would likely be fruitful for the teacher to open up a discussion with the students as to why physicists tend to use point particles in their solutions. As seen from group 1, by maintaining realism, issues can arise that will make the simulation, and furthermore the calculations, much more difficult than when simplifications of the objects are made. A teacher could ask those students why they choose to represent objects as they do in Algodoo, to better determine if they want to have the feeling of realism, or if they are unsure which properties matter for the scenario. As long as the teacher encourages the students to reflect on their modelling of phenomena in Algodoo, the students can benefit from modelling the objects as realistic as they want. As digital learning environments like Algodoo are allowed to function as a bridge between the "real world" and the modelling world some students may be more inclined to believe that their answer from the calculations actually connect with the physical solution of the problem.

For the students in this study, the LTS and Algodoo seem to be good tools for visualising what happens in the Monkey-Hunter problem, especially since executing the task with physical objects can be very difficult. The students were able to grasp how the objects moved in relation to the other objects in the scene and were also able to see how the changes to parameters affected the behaviour within the simulation. They were able to get a feel for the physical properties, and how they should approach the problem. Nonetheless, when looking at how the students use the LTS as compared to the WB, it is seen that Algodoo did not seem to present a solution to the problem. The students generated ideas about how to solve the problem when looking at Algodoo, but rely on the WB and the equations they write there to come up with the 'proper' solution. This is especially visible when the students from the second group got lost in the process and had to ask what the aim of the task was. When they were asked to find a connection between velocity and angle to hit the monkey they clearly stated that they had to solve it mathematically, even though I never asked for a formula. For these students, and I suspect for many others, there seems to be an unofficial ranking of how good an answer in physics is, where finding an expression or formula is deemed the most accaptable solution. For such students, discussing conceptual physics is only a tool to find out what formulas can be used. Thus, as a way of cultivating students who see many ways to do and express physics, I suggest that teachers talk with the students about what can be seen as a good answer to a question. A physics teacher might ask their students, does every physical question have to be answered with a definite calculation, or can a physicist draw some conclusions without explicitly using mathematics?

The disadvantages I see in students using Algodoo to learn physics result from the openness of the software. The open-ended structure of Algodoo can lead to a steep learning curve for new users. The students in this study were fortunate enough to have used the software before, but if a teacher were to have students who were less familiar with Algodoo than the ones from this study, more structured instructions for how to use the software might be necessary. If this problem was given to an entire class, the teacher could prepare a scene in Algodoo, and upload it so the student had access to it so that if they did not know how to solve the problem, or how to get started, they could get some guidance from a pre-factured scene. This would lead to the students not getting the chance to make their own representation of the objects, and lose some of Algodoo's function as a bridge between the physical and formal. However, it is more important that the students get guidance to be able to solve the problem than not knowing how to start. If it is only a few students struggling with this, the teacher could discuss with them how to represent the objects. The students might not go through the process of thinking of the problem through before trying to simulate the scene. This can lead to the students not drawing conclusions based on the physics, but merely based on what they see on the IWB.

A limitation in Algodoo as a software is that it does not provide a way for the user to make notes in the scene. When the second group wanted to remember the distances between two objects, they had to make notes on the WB instead. If Algodoo had a pen-function, these notes could have been taken within the scene, allowing the students to stay involved with the LTS. As mentioned earlier, Algodoo is not used for drawing conclusions. In the eyes of students, a 'proper' answer is likely a mathematical answer. At one point, when the second group stood by Algodoo, Carin says that *"we just have to calculate it, we will never find a connection"*. The conceptual parts of physics appeared to be more difficult, while the mathematical procedures appeared to be less exciting, yet easier.

One of the big advantages of Algodoo from this study is, ironically, its openness. The students I observed were able to get a different understanding of the conceptual physics behind the question than they had before they used Algodoo, as they are able to change any parameter they want. The power of the software is to visualise many different events. As can be seen when the second group of students are presented with part B of the task and wants to see the scene a couple of times before discussing what they have seen. It is also easy to change parameters quickly, be able to see different outcomes easily and then let the user reflect on the outcomes.

Another advantage to using Algodoo as a tool to learn physics is that so many parameters are changeable. Other simulation software have pre-constructed scenes in which only one, or a couple, parameters are changeable. This means that the students cannot even begin to discuss what would happen if another set of parameters are changed.

Algodoo was apart from visualising the scene, used to make sure that the groups found the correct answer. Once the groups found a numerical answer on the WB, they moved over to the LTS and entered the answer, to see that it actually was the velocity needed to be able to hit the monkey. As one student said when deriving an expression on the WB: *"Let me finish* [the derivation] *and then we can see if it works* [in Algodoo]". I suggest that using Algodoo in this way allows students get a feel that a calculation in physics, and more specifically the numerical answer, is something that should be used for something else. In textbook problems, the students are supposed to calculate a number of tasks, check their answer with the key, and then move on. Algodoo could be used to give the students a connection between experiences from life and questions from the text book.

The students also use Algodoo to find specific information during specific events. For example, one of the groups paused the scene just before the two objects collides to see what velocity the arrow had. Then, when the group had derived their expression for the velocity of the arrow, they discussed which information they were "allowed" to retrieve from Algodoo.

From these two sessions, a lot of advantages can be found when students use an educational simulation software as a tool to solve a task like the Monkey-Hunter problem. If a teacher is interested in using Algodoo in their classroom, I emphasize that it is important to know what disadvantages the software has, and suggest that the teacher prepare ways to work around the eventual problems the software might cause.

6 Conclusion

Based on the data presented here, it is clear that both groups of students tried to maintain a degree of realism when modelling the Monkey-Hunter problem in Algodoo, though they executed this realism in two different ways. One of the groups included objects from the problem that had no relevance for the physics or solution to the problem (the tree that the monkey falls from). They eventually came to represent the monkey and arrow as point particles. The other group did not include irrelevant objects, but modelled the arrow and monkey in a more realistic manner, changing the material of the objects to resemble the real-life objects as close as possible.

From the transitions between the LTS and WB, some conclusions can be drawn concerning what the IWB is used, and not used, for. The students used Algodoo to get a sense of the scenario, and to begin a discussion regarding the physics and how to approach the problem solving. It is with mathematics at the WB that the students actually solve the problem, though. Based on the conversation the students are engaged in, they state that they have to do math in order to find the solution for the problem. The LTS was also used by the students as a way to check their answers. Once they had found the answer on the WB, the students moved over to the LTS to enter the numerical value from their derivation to see if they are correct.

It is interesting to see how the students talk about the different solutions of the problem. To discuss the problem, and draw conclusions based on the simulation is not deemed a good enough answer. Instead, the students need to find a final numerical value and enter it in the simulation to be satisfied. A task like this, I believe can lead to interesting and important discussions in the classroom. Why do we represent objects the way we do in problem solving in physics? Why do we model the objects in a different manner when using a simulation software?

The usefulness of Algodoo's role as a brigde between the physical world and the Newtonian modelling world is that the students get a better "feel" for the problem. The problem is not about some point particles on a piece of paper, but is a real problem with a real solution, and they get to see that a numerical answer leads to a collision of the two objects. In conclusion, Algodoo can be seen working as a bridge between formalism and experiment as the students do not represent the objects in full realism, as would be in experiment, and not as point particles, as one would in the formalism. The way the students move between the IWB and whiteboard, and the conversations during the sessions also supports the claim of Algodoo being a bridge between the two worlds in physics. Algodoo can thus be seen as a tool to make abstract ideas of physics more accessible to students.

References

Bartlett, A. A., Clark, H., and Stoller, R. (1975a). Improvements in the "monkey and the hunter" demonstration apparatus. *Americal Journal of Physics*, 43(6):561.

Bartlett, A. A., Fladstol, G., and Laingor, L. (1975b). Accuracy of the "monkey and the hunter" demonstration. *Americal Journal of Physics*, 43(6):562.

Brown, W. P. (1977). Monkey and the hunter in slow motion. *The Physics Teacher*, 15:368.

Changjan, A. and Mueanploy, W. (2015). Projectile motion in real-life situation: Kinematics of basketball shooting. *Journal of Physics: Conference Series*, 622(1):012008.

da Silva, S., da Silva, R., Guaitolini Junior, J., Gonçalves, E., Viana (E. R. Viana, E., and B. L. Wyatt, J. (2014). Animation with algodoo: a simple tool for teaching and learning physics. 5:28.

Edwards, B. F., Sam, D. D., Christiansen, M. A., Booth, W. A., and Jessup, L. O. (2014). Angry birds realized: water balloon launcher for teaching projectile motion with drag. *European Journal of Physics*, 35(3):035009.

Euler, E. and Gregorcic, B. (2017). Exploring how students use sandbox software to move between the physical and the formal. *American Association of Physics Teachers*, pages 128–131.

Gregorcic, B., Etkina, E., and Planinsic, G. (2015). Designing and investigating new ways of interactive whiteboard use in physics instruction. *American Association of Physics Teachers*, pages 107–110.

Gregorcic, B., Etkina, E., and Planinsic, G. (2018). A new way of using the interactive whiteboard in a high school physics classroom: A case study. *Research in Science Education*, 48:465–489.

Hestenes, D. (1992). Modelling games in the newtonian world. *American Journal of Physics*, 60:732–748.

Rodgers, E. (1975). Portable "monkey and hunter" apparatus. *The Physics Teacher*, 13:308.

Scherr, C. W. (1979). The monkey and the hunter. *The Physics Teacher*, 17(3):184–184.

Vetenskapsrådet (2002). Forskningsetiska principer inom humanistisk-samhällsvetenskaplig forskning. Stockholm.

A Appendix

A.1 Consent forms

Medgivande att delta i vetenskaplig studie

UPPSALA UNIVERSITET

Som mitt examensarbete kommer jag[1] och min handledare[2], i samarbete med forskargruppen inom Fysikens didaktik vid Uppsala universitet, att genomföra en studie med syfte att undersöka hur gymnasieelever kan lära sig fysik med hjälp av digitala verktyg och simuleringar inom ämnet fysik. Vi är intresserad av hur du, dina klasskamrater och andra fysikstuderande interagerar med mjukvaran som en del av en lärandeaktivitet.

Villkor för deltagande

Om du väljer att delta i denna studie kommer du, tillsammans med en kamrat, att få besöka oss på Ångströmlaboratoriet där du kommer att få en introduktion till programmet *Algodoo*, och därefter genomföra en aktivitet om kaströrelser. När vi är klara avslutar vi med en kort intervju där du får reflektera över aktiviteten. Introduktionen, laborationen samt intervjun kommer att filmas med videokamera och beräknas ta cirka tre timmar.

Hur genomförs forskningen och hur kommer det insamlade materialet att behandlas?

För att se till att alla deltagare behandlas etiskt kommer datahanteringen i denna studie ske i enlighet med etablerad svensk forskningsetik.

Det är viktigt att du förstår hur din personliga information och integritet kommer att skyddas under hela processen. Personlig information innefattar data som ditt namn, adress, telefonnummer, eller någon annan information som kan koppla dig till denna studie. Om någon sådan information samlas in kommer den inte att finnas med i det transkriberade analysunderlaget, utan kommer istället lagras separat. Du kommer att identifieras med ett påhittat namn om/när det hänvisas till dig i analysen av datan.

Om det finns risk att du kan identifieras utifrån en video-bild kommer den att censureras. Om annan personlig information kan härledas ur ett visst avsnitt av aktiviteten kommer den inte finnas med i någon sorts publikation, om vi inte får ett separat skriftligt tillstånd att offentliggöra sådana episoder. Du kan när som helst kräva en kopia av all information som rör dig och ditt deltagande och du kan välja att avsluta ditt deltagande när som helst under aktiviteten. Väljer du att avbryta ditt deltagande under studiens gång kan vi fortfarande komma att använda den data som vi samlat in, i enlighet med principerna ovan.

Enligt svensk lag är vi tvungna att arkivera forskningsmaterial. Materialet från denna studie kommer att arkiveras på ett säkert sätt på en krypterad eller på annat sätt låst hårddisk och ingen obehörig person kommer att ha tillgång till materialet. Resultatet av denna studie kommer att publiceras i akademiska journaler eller i en avhandling. Studien kan även komma att diskuteras vid vetenskapliga konferenser före eller efter publikationen.

Om du samtycker till denna beskrivning av användandet av forskningsdata och är villig att delta i denna forskningsstudie, vänligen skriv under nedan.

______________________	______________________________	______________________________
Namn (textat)	Signatur	Datum

---

[1] Oskar Bengtz, oskarbengtz@gmail.com
[2] Bor Gregorcic, bor.gregorcic@physics.uu.se

Ytterligare medgivande för användning av ocensurerad videodata

(insamlat som en del av ett forskningsprojekt om användning av digitala verktyg inom fysikinlärning. Kontaktpersoner Oskar Bengtz[1] och Bor Gregorcic[2])

Efter slutförandet av dagens aktivitet bör du ha en bättre uppfattning av hur pass känslig den insamlade informationen är.

Analysen av den insamlade datan från denna studie kommer, bland annat, inkludera en diskussion om hur du och din partner interagerade med simuleringarna och med varandra. I den tidigare medgivandeblanketten förklarades det hur all data kommer att anonymiseras till den grad att ingen identifierande information kommer att delas med någon utanför forskningsgruppen; vi vill dock nu fråga om du vill tillåta användandet av ocensurerad video i publikationer och presentationer till allmänheten.

Användandet av ocensurerade bilder eller videoklipp i det material som publiceras från denna studie skulle kunna låta forskningsgruppen beskriva hur du och din partner kommunicerade mer ingående. Majoriteten av nuvarande forskning om studenters användande av teknologi använder sig av statiska, censurerade bilder, så användandet av dynamiska videoklipp från dagens aktivitet skulle kunna vara banbrytande inom forskningsfältet.

Forskningsgruppen kommer fortfarande låta bli att publicera någon annan sorts personlig information, i enlighet med den tidigare medgivandeblanketten. Närhelst det är möjligt kommer vi att använda videodata som visar så få identifierande drag som möjligt och vi kommer avstå från att använda data som vi tror kan porträttera deltagaren på ett negativt sätt.

Utökat medgivande

Vänligen indikera nedan din grad av villighet att tillåta användande av ocensurerad video i publikationer eller presentationer (välj endast en):

☐ Jag tillåter användandet av video av mitt ocensurerade ansikte och min kropp, i vetenskapliga publikationer och presentationer

☐ Jag tillåter ett begränsat användande av videodatan. Mer specifikt så tillåter jag användande av ocensurerad video av

mitt ansikte	☐ ja	☐ nej
min kropp (inkluderar ej ansikte)	☐ ja	☐ nej

☐ Jag tillåter inte användandet av mitt ocensurerade ansikte och min kropp i vetenskapliga publikationer och presentationer.

Vänligen skriv under nedan efter att ha bockat för en av rutorna ovan.

Namn (textat)	Signatur	Datum

[1] Oskar Bengtz, oskarbengtz@gmail.com
[2] Bor Gregorcic, bor.gregorcic@physics.uu.se