Qualities of an Effective Physics Simulation for Teaching
A Case study in Physics Learning

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Many kids in today's schools struggle with the subjects of math and science, and this problem spans all levels of schooling. My intention is to test a virtual set of lessons that can guide students through an interactive learning process. In this way, the abstract can be brought to students' attention and into the realm of experience so that it will interest students, pique their curiosity, and teach them without lecturing them. Though this is a pilot study, the addition of computers with interactive simulations into classrooms should dramatically boost kids' understanding of the usually abstract material in sciences.
Problem Statement and Literature Review

Many kids in today's schools struggle with the subjects of math and science, and this problem spans all levels of schooling. (Honey, 2011; Engler, 2012.) High school students as well as elementary school students have significant trouble with these subjects. Why are math and science so difficult for kids to understand? All sorts of ideas have been thrown around to try to get kids interested in science with varying degrees of success (Holdren et al., 2012), but obviously the issue is still common. I propose to help kids learn about science more intuitively and engagingly using simulations, and to show that in this pilot study.

More specifically, my intention is to test a virtual set of lessons that can guide students through a learning process that allows for insights and observations to be made non-linearly. In particular, my focus will be on planetary physics. Using 3D computer simulations of abstract science like the creation of planets and collisions in space could help students understand an otherwise abstract situation. This pilot study will involve a simulator called Universe Sandbox, which is fully programmed and can interactively simulate the solar system and much more. Observational notes about how the kids use the simulation and how tough or user-friendly they find it will give an effective impression of the usefulness of the simulation. Afterwards, I'd like to ask a few of them what they found helpful in it and what they like or dislike, maybe what they'd like to see in a hypothetical new simulation. I also will want to know a bit of their background on the material. Comparing what they saw in playing with it to what I see in it may yield some lines of inquiry that others may be able to study further. Primarily, I will ask what qualities of the simulation aid intuitive learning and which ones are not helpful. By using simulations, I think students will continue to be curious thinkers and learn from the simulated
environment in such a way that new knowledge is presented while taking for granted old knowledge. There is no re-learning, if you will.

However, it must be mentioned that the scope of this research is limited. Therefore, this is a pilot study meant to show a need for further research in this area. Frequently, researchers in Education do not work with astronomical simulators, nor vice versa, but this project shows a need for such multidisciplinary work. By investing much more time and preparatory effort, this project could be significantly improved.

Previous work has been done related to – but not exactly in – this area by G. Korakakis and colleagues (2009). They showed with 212 8th graders in Greece that physics simulations do seem to contribute to student learning primarily by increasing student interest in science concepts. Another interesting aspect found there was the concept of leaving control of learning to students. Simulations handle this rather well. The Committee on Science Learning attest in their book (Honey, 2011) that disinterest in the material is one source of learning problems. When students lose interest in science around middle school years, it should be a focus of persons trying to increase STEM ability (as many are) to keep science interesting at those grade levels.

When kids are allowed to experiment with planets in physics simulations (or molecules in chemistry, for that matter), they can learn about simple or complex science concepts, within the manipulable context of a computer screen. The hope of this pilot study is that kids will engage better with the simulation than the abstract descriptions science teachers usually provide. Corroborated by Korakakis’ and H. Niedderer’s separate work in other types of physics simulations, I will seek to teach planetary physics through simulations. Niedderer (1991) used STELLA software to assist students in learning various phenomena. A by-product of this lesson design was that the focus shifted away from the mathematics and into the concepts of the
phenomena. This is also the goal here. The difference is that the physics of this simulation will be experimentally indemonstrable.

What I am hoping to achieve may be called intuitive learning through Computer Aided Instruction. As we all should recognize, math and science are naturally abstract studies. In particular, physics and chemistry have very abstract concepts such as potential energy, entropy, and chemical kinetics, not to mention the hypothetical situations used to describe these concepts to students in the first place. These can be described on a board in a classroom, but this method is not very interactive. Students can ask questions, but they might not see all of the intricate detail involved in the real processes. Even some teachers could benefit from seeing the full picture of a chemical reaction or some other physical process. Making learning intuitive is as difficult as it would be beneficial. The intricacies are often hidden, and the complexity is broken down to make it more easily understood. When complexity is broken down this way, something valuable is lost. Making physics and chemistry – and perhaps other sciences – suddenly become intuitive is an issue of teaching methods and learning incentives.

D. W. Shaffer writes about incentives in his book *How Computer Games Help Children Learn* (2006). He discusses the views with which society typifies games and the ideas about what makes a game a game. What differentiates a game from a simulation? Shaffer says that games involve playing a defined role within a simulation, which is an intriguing world in which to play and investigate. Creating such a world is the goal of any developer. In this research, I hope to find or create a world which engages the students with the learning process in an active and authentic manner. To do so, I will look to the advice in the conclusions of B. Banic (2013) and H. Wu and P. Shah (2004). These persons explored the effectiveness of simulations as teaching tools in fields other than physics. I will hope to corroborate their findings.
The intuitive learning process can be compared to learning to walk. People don’t learn to walk by studying the technique of walking and the muscles used to do it. There is no need to be familiar with the theory of walking. People play around with the basics of walking until the technique is second nature to them. They just learn it by doing it. If the simulator can allow kids to interact with “active” chemistry or physics, maybe they can learn science in the same manner as walking. Learning to walk is something hard but doable. If a similar level of freedom is given for students to see and interact with science, perhaps a similar outcome could be expected. The previous work explored by N. Rutten et al. (2012) seems to indicate that possibility. In Rutten’s research, he and his colleagues tried to determine the effectiveness of simulations as supplements or replacements to traditional education methods by reviewing previous research.

There is also a chance that students will not learn effectively from a simulation. As T. Huk (2006) explains, three-dimensional simulations benefit students who have a high aptitude for three-dimensional visualization already. However, the crux of Huk’s point lies in the converse statement: 3D visualizations do not help students with low spatial ability. Huk discusses two hypotheses for student learning. These hypotheses stress cognitive visualization ability and its role in learning. Students with high spatial ability benefitted, and those without, suffered. This result depends largely on the students being sampled and on the type of visualization. For this reason, it is important to have teachers in the room to help struggling students along. I, however, believe that interactive visualizations can help students understand material better. The interactivity, though not a total catch-all for students’ attention, certainly should help students with or without three-dimensional visualization capabilities. Perhaps spatial ability can be taught, but if not, it is important to allow these students to learn in other ways.
Learning in other ways is precisely the goal of a recent set of learning standards called the Next Generation Science Standards. These standards emphasize the idea that learning is a progressive act. As such, the standards recommend that teaching methods work with that progression, building on previously-learned material rather than re-teaching it. In this way, students with low spatial ability, as Huk says, will have already been exposed to the precursors of the material. The change from the current teaching process to these standards is a drastic one, but with visualizations in the classroom and a focus on new material rather than re-teaching, the change can be eased. At any rate, these standards appear beneficial.

This project will be pursuant to the Next Generation Science Standards (NGSS). Simulations could play a large role in the reform to these standards. The developers of the Standards recommend that technology play a larger role in the classroom, and they seem to believe, as I do, that learning can be aided by technology. Currently, students with low spatial ability are grouped among those with high spatial ability. Using three-dimensional computer simulations cannot be as effective to this group as they would be to a NGSS class. Given the popularity of the NGSS in the United States, it is likely that three dimensional computer simulations will be quite beneficial to more and more schools as they adopt programs aligned with these Standards and stop grouping students in the ineffective, jumbled way.

Often, humans learn things from example or through trial and error. In contrast, most of science is proven through strict experimentation and highly-directed observation. How can these methods be blended? Involving students in experiments can achieve a higher level of understanding and possibly teach by trial and error, but it is not always safe or feasible logistically, physically, or because of some other hindrance. In order to properly relay science to kids and engage them with the curriculum, it can be beneficial to show them how science occurs
in daily life. Science can be taught using both example and trial and error if just one addition can be made to the classroom: computer simulations. For example, a teacher could say that the process of dissolving salt crystals in water works a certain way, or a screen could “zoom in” on the process and show what it looks like.

Once kids learn the behavior of molecules or planets, teachers are needed to name these processes, describe the intricacies, and develop further discussion. Effective teachers can use computers and simulations as tools rather than as substitutes to teaching. Teaching is about furthering knowledge rather than struggling to introduce it.

In this way, the abstract can be brought to students’ attention and into the realm of experience so that it will involve students, pique their curiosity, and teach them without lecturing them. At the same time, we provide a high quality simulation that is essentially an embodiment of the real world, so far as the science community is concerned. We hypothesize that the addition of computers with interactive simulations into classrooms and the direct experience that students receive through them should dramatically boost kids’ grasp and understanding of the usually abstract material in sciences across all grade levels.

**Research Question and Rationale**

My specific research questions are:

a. What features promote student access to information about astronomical mechanics?

b. What do students learn about astronomical mechanics by playing the simulation?

c. Do students’ attitudes towards astronomy change after experiencing the simulations?

To test the teaching effectiveness of a simulation, one must allow some students to use the simulation. The mark of “effectiveness” will be students’ interest in the simulation and their
uses of it; that is, do they want to continue playing and what are they doing within the simulation.

The target demographic of students is middle school. Students can begin to lose interest in science around this age as it becomes abstract and quickly goes beyond their realm of understanding. If a simulation can interest students of this age group in science, perhaps that enthusiasm will stay. Although, this is an overall, long-term goal of the research; this pilot study will focus on raising enthusiasm about astronomy and space physics. The hypothesis is that the students will understand astronomical mechanics better for having experimented in the simulation environment.

**Methods and Data Collection**

The data for this research will come in two forms: observations and user responses. The questions and observations will be directed to determine the qualities of the simulation that illicit curiosity in the students and foster their learning of concept knowledge of astronomical mechanics. Given that there is information available in the simulation, what features promote access to that information; and how much of that information do the students intuit from the using the simulation in conjunction with the guiding presentation?

The criteria of selecting the simulation were the following: (1) user-friendliness: there should not be a steep learning curve to simply use the simulation; (2) capability of simulating physics: one cannot expect, of course, that students will learn planetary physics from a simulator that cannot show the physics itself; (3) accuracy to real physics: the mechanics must be fairly accurate because one would not wish to teach students the wrong information; and (4) visual simplicity: the simulator must be able to accurately and smoothly simulate astronomical
mechanics without shutting out the user or overwhelming the user with too many variables. It should neither underplay nor overplay the complexity of the solar system.

In particular the physics situation that would be simultaneously the most useful and fun to present to the students would be a planetary collision game. One scenario would be purposefully colliding asteroids into specific targets. This would be similar to macroscopic pinball or billiards. Another more realistic possibility is to avoid collision from another body, that is, deflecting an asteroid bound for Earth. With these criteria in mind, the simulation chosen for the pilot study was Universe Sandbox™.

A collaboration was established between the Vancouver iTech Preparatory High school and Washington State University Vancouver so that the study could be conducted at iTech. Parental consent and child assent forms were passed out by the teachers at iTech in mid-November, 2014. Though the students of a technical preparatory high school were not ideal for testing, those in attendance were enthusiastic about the material and were eager to help.

Rather than waste precious time with preliminary and post-questions, the questions were asked in a focus-group interview format; this was also chosen to allow a freer flow of ideas than a questionnaire format. However, one student who could not attend the focus-group did provide feedback in a questionnaire format. In either case, several questions were written to determine what knowledge the students saw in the simulations, if they thought further than the simulation, and what they thought might improve the simulation for the future.
### Timeline

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<tr>
<th>Task</th>
<th>Deadline</th>
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<tbody>
<tr>
<td>Locate a teacher, school, and classroom</td>
<td>September, 2014</td>
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<tr>
<td>Define method of running simulation</td>
<td>September, 2014</td>
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<tr>
<td>Develop simulation program</td>
<td>September–October, 2014</td>
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<td>Run simulation with test audience</td>
<td>October, 2014</td>
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<td>Develop question protocol</td>
<td>August, 2014</td>
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<tr>
<td>Review question protocol</td>
<td>Continuous August to October 2014</td>
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<tr>
<td>Collect data</td>
<td>October/November 2014</td>
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<tr>
<td>Analyze data</td>
<td>December, 2014 to February, 2015</td>
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### Data Analysis

In the presentation to the students, one simulation involved firing a bowling ball at an asteroid in order to deflect it. Most of us would think this is infeasible or ineffective, but in the simulation, variables could be changed to make this method more viable. Ignoring a feasible method of launching the balls, was it possible to deflect the asteroid? It was possible, but difficult. The mathematics would tell you that many, many bowling balls would be needed, and indeed they were, in the simulation. Regarding this, my first question to the students was as follows: How do you think launching a bowling ball or a rocket might actually work differently than in the simulation? The students agreed that launching would be more difficult because of factors not included in the simulations. Along the same lines as the first question, the second question asked whether the students thought that launching bowling balls at an asteroid was viable. The obvious answer is no. Recognition of the hindrances latent to the simulation is
important, but equally important – if not more so – is identifying the similarities to the real world. After all, that is why the simulation is useful in the first place.

Further thought beyond the simulation was indicated by the responses to the third question. If one did hit an asteroid, what might the aftereffects be? That is, could the asteroid break up, and if so what may happen to the pieces? This is a matter of real NASA concern. The students gave some thought to this. They believed what fragments may result from collision would be small enough to do no harm, but it was possible that large fragments could do damage. This was very important insight for the students to intuit.

The first three questions addressed the subject matter taught in the simulations and the students’ ability to gather and understand that information, but the subsequent questions inquired about the simulations themselves and the simulator. These questions were an effort to understand the usefulness of the Universe Sandbox simulation in teaching.

The first of these asked whether it was easy to grasp what happened in the simulation. After all, if the simulation presented physics more complexly than a typical lesson, it would not be a valuable teaching tool. The students agreed that the simulation was easily understandable and that it was more enjoyable than a lesson on the same material. They mentioned that the tutorial provided in the simulation helped tremendously. While the presentation instructed them about physics, they also required instruction about the operation of the simulator.

Further, the students reported on the next question that they had no problems using the simulations and interacting with them. All of the tools were easily accessible. However, it was mentioned that the simulation did have its flaws specifically regarding trajectories and time scales. If further effort was put into lessons and simulators/simulations like this, the time scale could be more directly addressed for most accuracy and simulation speed.
Since this presentation was focused on collisions and the mechanics of impact, Universe Sandbox came up lacking in this area quite evidently, so naturally, the students remarked on it when asked what they liked least about the simulator. On the other hand, the students reported that they greatly enjoyed the freedom to do what they wanted in the simulation and play in the environment of space. Additionally, variables that are difficult or impossible to change in reality are easily changed in the simulator. That is one advantage Universe Sandbox has over other simpler simulators of planetary collisions. Many smaller simulators exist for physics principles such as collision dynamics, but Universe Sandbox especially has many changeable parameters.

One student said that he would very much like to see more from simulations like this. Another responded the opposite. His explanation revealed that his disagreement hinged on the lack of detail in impacts and trajectories. With that caveat, the simulations seem to have been very good teaching tools. Most importantly of all, the interactive lesson boosted thought and curiosity in physics.

It must be mentioned that the students from Vancouver iTech Preparatory High school are more than a bit biased toward science and technology. With this in mind, the simulator seems to have achieved the goal of this pilot study. It was intuitive and engaging, but certainly these qualities could be improved. It could be better tailored toward classroom use in general. With the understanding that iTech students are more science savvy than the general high school freshman, it makes sense that some of the aspects the iTech students pursued were even more abstract than typical physics classes might explore.

As a last note, Universe Sandbox 2 alpha version was released after these tests. Many of the improvements the students were so eager for seem to be in the new version. As a future test, Universe Sandbox 2 may be a good place to start.
Conclusion

To summarize, many kids struggle with math and science. My intention was to test a virtual set of lessons that could guide students through an interactive learning process using a computer simulator. In this way, abstract science concepts could be more directly and intuitively experienced. Specifically, I used a simulation geared toward astronomical mechanics and planetary motion called Universe Sandbox. With the assumption that there is knowledge to be gained from the simulation, I sought to determine what features of it facilitate learning those concepts and how much of that information could be communicated to students.

The feature of Universe Sandbox that promoted student access to astronomical mechanics information was the freedom within the simulation. The ability to say “what if…” and “let’s find out” was extremely beneficial. What do students learn about astronomical mechanics by playing the simulation? They experienced lessons like conservation of momentum in a more intuitive manor. That is, not by equations, but by observation. Lastly, do students’ attitudes towards astronomy change after experiencing the simulations? These students were already enthusiastic about science and astronomy before the simulation, but by no means did that stop.

As a pilot study, the purpose of this research was to create interest in further testing. Toward that end, it may be beneficial to state the primary issues of this study that should be improved for future testing. Future studies should put effort into creating an informative but freely interactive lesson. The freedom within the simulation was the best aspect for students and should not be sacrificed or undervalued. The simulations should align if possible with an existing curriculum. Most importantly, the physics principles simulated in the lesson should be modeled accurately such that free experimentation will yield results consistent with real physics. Simulations like this should assist students’ learning, understanding, and enthusiasm.
References


