PhET Interactive Simulations for Active Learning in STEM
MP4 Video Transcript

Presenter: Yuen-ying Carpenter, post-doctoral researcher in chemistry, PhET Interactive Simulations project, University of Colorado Boulder
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Thank you guys for having me. So today I'm going to try and take you guys on a little bit of a tour of the project, if you haven't heard of us before. And then I'm going to get you guys a bit hands on with a simulation, so that you can get a feel for how they might function in your classroom, in your online environment, if you're a teacher, or in some other instructors' environment, if you are helping as an instructional designer. So we're going to see what we can do with that today.

So essentially, I have three goals for you guys. First, to be able to come out of this describing how some of the specific simulation features that we have very intentionally designed in our process are really there to facilitate student learning and exploration in sort of an inquiry-based environment. Because we do certainly come from a very specific design perspective when we make our simulations.

I want to tell you a bit about the range of sim uses, so focusing on the types of learning goals that you might have, or your instructors might have, and how you might facilitate that very differently in different environments.

And outline a few best practices. And a lot of these have been developed, in our case, in face-to-face environments. But some of those will also extend very well to how you might design a homework for an online system or design discussion prompts for a discussion forum, if you were doing that in your online course environment.

So what is PhET? So the short answer is we have about 130 free interactive simulations for science and mathematics, at this stage. And they extend all the way from early elementary-- we've had sims that have been used in grade 3 classrooms-- all the way up to college level sims, most of which are focusing on the introductory college and university levels. But there are some that target more advanced topics.

To give you a sense of where the project comes from, I'm going to take you on the speediest tour of the years that the project's been active. Because it'll give you a bit of a sense of why we have more sims in some areas than others.

So the project started in Physics. It was originally funded with a bit of seed money out of Carl Weiman's Nobel Prize money, as well as a few other NSF grants. And so our first sims were developed for college level Physics education.

From that, we had a bunch of years where we learned a lot through research in the classroom and in interviews about what worked in sim design. And then we branched out into Chemistry. And so my background is in Chemistry, and so this, for me, was a huge step forwards, because I really wanted to be able to use these tools in my teaching, as well. So we branched out into Chemistry in around 2008 and started designing, for still at the college level, Chemistry sims.

Around 2010, we moved into the middle school environment. And we started working with a couple of schools down in Texas to develop sims that were targeting these grade 4, 5, 6 science learning goals. We learned a lot about how to target different age groups.

We also moved into mathematics, as well, in 2012. And that's mostly at the middle school level. But we're now sort of moving into high school math sims. And some of those are obviously going to have some carry over into introductory college courses, particularly for students who need a bit of a brush up on some of their high school math skills, especially if they're coming back to college after some time away.

And right now, the focus of the project is what we call our next generation sims. What we've done is the early part of the project, all of our sims were coded in Java, which meant that you needed a laptop with a full operating system, Windows or Mac, in order to run all of the sims. And often times, there were a lot more technical issues. So instructors would try to run them, Java would have updated in the background. And all of a sudden, you wouldn't have a sim that ran.

So we've moved, we're slowly moving all of our sims, 130-odd of them, to HTML5. So the goal of this is that our sims should be able to run on any device that can browse the web. So this is really targeting tablet devices. So iPads, since we know a lot of educational markets have gone in that direction, as well as Chromebooks. Because a lot of college students coming in are purchasing a much lower cost device, like a Chromebook. And we wanted our sims to run for them in those environments, as well. It will actually run on smartphones, as well. But it's a bit tiny to be able to see everything. So not really advisable.

In addition, one of our big projects right now is to move towards designing into that code, as well, accessibility features. So we're starting to work on keyboard navigation, sonification, and other features that will make our sims more accessible to a wider audience.

So that tells you where we've come. At this stage, PhET's used pretty much worldwide, even though the majority of our users are still in the US. And they're used by teachers in their classroom, but also students on their own when they're looking up resources to help them through a given course. And at this point, we're at essentially about 75 million uses a year.

And that's of the ones that we're able to track. If someone's downloaded it to their hard drive, we can't track it anymore. But these are just the usages that we know that they're running them online on the site or they're downloading in this year. And that's over 100 uses a minute, if you break it down by the number of minutes in a year.

And we are translated, by volunteers, into now 77 languages. So we have quite a diversity of folks who are using it worldwide.

So in designing all of these sims and in moving forward into this next generation of sims, we have a very particular set of goals in mind. And I want to share those with you, because our goals will not necessarily always meet your goals as a designer, as an instructional designer, as an instructor of a course. And so I want you to see where we're coming from so that you can mix and match and see how this fits.

So we have two big accessibility goals, in that we want these to be always and forever freely available and we want them to also be available online or offline. So we want them to be something that you can download to your device and then use if you don't have a very reliable internet connection. And that was discussed earlier this morning that some students might not always have internet access. So they might be able to download and then take it to their home space where they might not have internet.

And we wanted them to be designed as a flexible tool across various environments. Because we know as an instructor, you may be teaching in a face-to-face environment with a small number of students. You might be teaching in a large lecture. You might be teaching in a hybrid or online environment. You might have different learning goals. We wanted to build each of these simulations with learning goals in mind, but really allow them to be used in a diverse number of ways.

In terms of the pedagogy with which we designed, we really are coming from an inquiry-based framework. We wanted to use these simulations and design these simulations to support students in engaging in scientific exploration. So we want them to be asking questions, figuring out what it is that's interesting about a given phenomenon. We want them to be, when using these simulations, to be taking ownership of their learning. And we find that really important in keeping them motivated, particularly for folks who are just starting out in the college environment. That motivation piece, that ownership over their own learning can be really important.

We want them, obviously, to be developing conceptual understanding in these various topics. We want them, where possible and where relevant, to be making connections to their everyday life. And that ties into that motivation piece, as well. And we want them to view science or mathematics as something that's accessible and enjoyable to them. And so within that framework, you'll see some of the design that we've put into these that's sort of aiming to meet this sort of student-centered pedagogical focus.

So I'm going to get you guys exploring right now, just so that you get a bit more of a hands-on sense of this sim before you listen to me talk some more. So what I'll have you guys do is in preferably with a partner or with a group of three, load up our website. So that's phet.coloroado.edu. And we're going to explore some of these newer next generation sims. So these HTML5 simulations. So if you open the website, just on the right hand side will be a link that says HTML5 sims. And I'll get you guys to open that.

And once you're there, I will have, let's say, this half of the room, if you guys can open the color vision simulation once you're on that page. And you guys on this side, you're going to be exploring wave on a string, which is all the way at the bottom of the page. And I'm picking ones that I'm hoping will not necessarily overlap with your expertise, so that you will have a chance to really explore.

So students tend to have the type of conversation that I heard from a few folks that was more along the lines of, oh, what can I do with this? Oh, if I put the red thing in, what happens? More asking questions about the phenomenon that's in place, trying to figure out what are the things that I can play with and what can't I play with. And then starting to ask questions. What if I do this? Does this happen?

So students tend to get really involved immediately with the phenomenon involved. So whether that's how do waves travel on a string, or whether that's how do we see color when light is projected? Instructors, when we ask them to explore the simulation, some of them get into those discussions, and some of them go, wait, what am I supposed to be learning from this? Tell me exactly what my goals are and then I will go and explore.

Admittedly, some of our students will do this, as well. And for them, what we have to really talk about-- and I'll come back to this idea later-- is this idea of framing this activity as a chance to explore and get used to the tool and figure out what you, the user, the student, wants to explore. And then we can direct that conversation to a more specific learning goal if we have one.

So with color vision as an example-- OK, this will be a bit of an adventure. Great. So with color vision, for example, we can imagine students exploring how adding filters of different colors can impact how much light an individual is seeing or what color of light they're seeing. Or alternately, we can envision in this sim looking at how mixing of colors, so mixing of red, green, and blue light together, can mix to generate other colors and how that's different from, for example, what a lot of students are used to with mixing of paint colors and how that's a different process.

With wave on a string and looking at how movement propagates, you can envision talking about this in an introductory physics class, for example. So now with that framework in mind, I'd like to take us through a little bit of how we design these simulations and a little bit about some of the features that we build into these simulations that I hope you'll be able to relate back to this little experience you guys have had playing with some of those features. Because some of them don't make as much sense unless you've actually interacted with them.

When we actually design and plan one of these sims, like the two you guys just played with, we're really starting from a couple of learning goals. So for example, understanding how color perception works, how human vision works, and as well, how filters work, for example, in a system. Or for you guys, if we change different parameters, like amplitude, doing calculations can also be a goal for wave motion.

We start off with a really initial prototype design. And we do a lot of iteration on that. We redesign it based on student interviews. So we'll bring in students and have them play with the simulations without any real instruction, just to see, do they actually touch all of the controls that are there? Do they find them? Do they know how to use them? Do they know what turning a switch on and off does?

We'll redesign based on feedback from those interviews. We'll also bring them into classrooms and see if students are using these in classrooms, in groups, as individuals, are they getting at some of those learning goals we initially designed for? Are they having conversations around the topics that we think that should be critical to them learning about that concept?

And so we go through a lot of cycles before we come out with a final design that we publish online on the website. And in this whole process, we've done a lot of research to refine for us some of the design features that really get students the most involved with the simulation.

And to give you just a quick sense of what that looks like in time and in funds. To develop a simulation from scratch costs us about $60,000. To develop, to take one of our old Java simulations that we already have a lot of knowledge of and just convert it to HTML5, so it'll run, for example, on your iPad-- I saw a lot of you using an iPad today-- that costs about $20,000. And for that process, depending on how simple that simulation is or how complicated, that can take anywhere from four months to a year to come out with a product that we feel really is a work of love.

All of that design work, though, is really research focused on what works and what doesn't, what the controls of the simulation cue a student to do when they come in, what actions are being queued, and what constraints are there on the simulation so that students are doing productive things in much more likely ways.

So some of those features-- in some cases, what we want to do is we want to show the invisible. So in the screenshot that I'm showing here from a sim we have on molecule polarity, we're showing things like the dipole arrow or our partial charges, which are not visible in real life. In the sims that you guys played with, as an example in color vision, there's a mode where you can switch from a beam of light to a series of photons. That's not something that you can see with the naked eye. And so we want to be able to show some of these invisible phenomena so students can make connections between those pieces.

When we design, we're trying to design something that is highly interactive and, in a sense, game like. So you guys started playing around with it. And even those groups that sort of said, well, what's my goal here, what am I trying to get at, could go in and figure out, OK, well, what can I do? I can play around with these controls. There's often fun colors associated with it.

And we do get some instructors who say, well, maybe that's better for the elementary school kids, not for college kids. And then you actually watch 18- and 20-year-olds and they are just as engaged by the big red button that lets them add solution to the beaker. They are just as engaged by representations that are saying, touch me, interact with me, do things here. So we really want something that cues interaction, as opposed to a narrative.

We want the interface to be intuitive. We don't want something that we have to give an instruction sheet to students that says, in order to operate this simulation, you should click on this button or use this slider. So we use a lot of interface design that's really similar to what students are seeing in browsers these days, in iPads and things like that, that cue, OK, if I switch between two things, it should look a little like this.

We have a lot of scaffolding in our simulations. So even though we try not to be as explicit with our narrative, we know that we want students to be building from smaller ideas to bigger, more complex concepts. If we started with everything out there all at once, these more complex ideas, students we've actually seen in some of our early design work that students will come upon a very complex simulation and would physically back away from the computer. This is too much. This is frightening.

And so we want something where you get to that level of complexity, but you get there with some scaffolding. So sometimes we do that with separate screens. So the folks who were investigating color vision saw that in that there are two different concepts on two different screens. The folks investigating wave on a string, you guys only had one screen to explore, but we choose very carefully what the start up state of the simulation is. The wave isn't going immediately. You have to start by activating that. The parameters that we choose, that we're not displaying a lot of numerical values when they start out, is very intentional and has gone through some iterations to find a nice starting point that's both interactive and engaging, but not intimidating.

We want, where it's pedagogically relevant, to allow for difficult or impossible actions. So as an example in molecule polarity, you can adjust the angle between all of your atoms to create different molecules. You can't do that with real molecules in the real world. Here you can also adjust the electronegativity of each individual atom. That's not a thing you can do with real atoms. But we want to do that because we're focusing in on the concept of how do those parameters affect this concept of molecule polarity?

For things like color vision, it's hard to switch between different light sources and then play around with filters. Here you can do that very easily in that simulation mode.

We try, especially where it's relevant to the discipline, but also where it helps students look at a concept from different perspectives, to use multiple representations. So the folks in color vision would have seen both a photon representation of light and a beam representation of light, to try and negotiate both of those two ideas.

Really critical to us is this idea of real-time feedback. So rather than having students input a series of parameters and then press go, see an output, record that, and then move on to the next scenario, we really want students to be, as they adjust a parameter, seeing immediately, oh, the wave is now bigger, the wave's now moving slower, the color, oh, it's blocking some of the color as soon as I put that filter in. And we find that dynamic feedback is really, really important to students making connections between these different ideas.

Where it's relevant we include real world connections. So in the molecule polarity sim, there's a third tab that actually deals with real world molecules and not ones where you can magically adjust the electronegativity of the system.

I mentioned, as well, this idea of implicit scaffolding, of building up from small concepts to larger ones. And I gave you guys two examples from the sims that you were working on. Having multiple screens and having a certain order to those screens, or having a particular set of initial conditions that's simple and low load.

Another way, sometimes when a sim initially opens, we'll actually have some of the feedback closed and minimized, so that when students first encounter a simulation, such as build an atom here, since those are minimized, they are much more likely to go to the left hand side of the screen and start dragging particles to build their own atom before they try to start building the concept of, well, how do these little particles affect the mass number? How does that give me feedback about that? So those initial states are really pretty critical.

So I told you a bit about how we design simulation, and given you a bit of time to be hands on with it. But realistically, the sims don't exist in isolation. Students might be using them outside of class. But in a lot of cases, we have particular learning goals as instructors. Or as instructional designers, you're helping someone get to something that fits into a larger course scheme, into a larger unit, et cetera.

So what I want to focus on for the last chunk of time here is how to take those features that I just described in a PhET sim and how to best leverage them in a classroom environment or in an online learning environment. And the two other pieces really are whatever teacher facilitation is involved, so whether that's in the types of prompts for a discussion-- there might be facets like that-- as well as what tasks or activities are designed around the sim.

So what I had you guys do was just go out about exploring. But if you were doing this in a classroom environment, you might then follow that up with, OK, now we're going to compare a specific set of scenarios and then collect some data, or answer some questions that direct you to a more specific learning goal.

And all of those pieces together really combine to craft that learning experience for the student. And that's a learning experience that can occur across a wide variety of classroom contexts. All of these are face-to-face. But you can envision how some of these would translate into an online environment. So the lecture demo is really one where the instructor might have a pre-recorded or in-class demo using the simulation.

There might be a guided inquiry activity that students are working through individually or in groups. Or you might have small multiple choice questions as they're going through to check in on their progress, whether that's in a classroom environment or between classroom meetings in an outside of class setting.

What I really want to give you a sense of is that there's span that I like to think of, where you can have a very instructor-led use of the sim, where they're giving a demonstration and then following that up with discussion questions, with multiple choice questions and the like. Or you can have a very student-directed, where in groups or individually, they're working on guided prompts, whether that's in class or outside of class, in an online environment, in a tutorial, et cetera, where the students are the ones who are hands on with the simulation. And there's a whole range sort of in between, where the teacher might do a bit of driving, do a bit of demo, and then the students are hands on to explore and maybe answer some questions.

Regardless of the context, though, I want you guys to think of a few really guiding questions of how you're going to make use of that sim. So based on your usage of the sim, ask yourself, what do students think they should be doing? And we'll talk a little bit about that in terms of how we prompt students. But when they come into an activity, when they have a worksheet, when they have a prompt and then a link to the simulation, what do they think is the goal of that activity?

And are you leveraging those design features that I mentioned? Are you making the most of this tool that you have in getting to student learning of concepts and practices, or motivating students to want to explore that idea or concept more?

So on the learning goals front, we always recommend to instructors to start with a very short list of learning goals when they're thinking of designing a sim-based activity. So two or three really focused ideas that they want to focus on. And considering whether those goals are targeting concepts or a practice. And so in a practice it might be in how to design a scientific experiment, how to make hypotheses and test them. Or it might be how to balance a chemical equation. Now that is my bias towards chemistry, when I bring up these examples.

As an example, one of our older sims, pendulum lab, which is currently in the redesign process, we've seen used in physics classes to target conceptual learning goals around pendulum motion. So how do these factors of height or length of the string or mass, or things like this, affect the motion of a pendulum. Very director, very concept focused.

But we've also worked with Chemistry faculty, one in particular at a community college, who uses this as an introductory exercise at the start of his semester. He's now, I think, in a hybrid learning environment. And he uses this to talk about control of variables. So he doesn't really care, in his Chemistry course, whether students come out remembering the formula for how a pendulum moves and how these variables are related. But he wants them to understand that if you're trying to understand a phenomenon, you have to design experiments where you're not modifying everything all at once. And so he has them go outside of class, collect some data and fill in some tables, and then they come back together and discuss how that went for them.

So the goals can be really quite diverse. But depending on what your goals are may really determine what kind of activity you design. And again, whether you're doing that, which parts of it you're doing online and which parts you might come back together face-to-face for.

One of the other big pieces in thinking about using a simulation in a learning environment is how that usage is framed. And that comes back to that question that I said earlier, what do student think they're supposed to be doing in this interaction? What do they think is the goal? And this piece is especially important for that.

So when you frame student activity, whether that's how you situate it in the sequence of your online course, or whether that's how you set it up in a face-to-face environment, you want as open an introduction as possible. So if the instructor's the one who's hands on, giving them a quick tour of the sim features and then giving them some sort of open ended question that they can explore and think about on their own is a good way to start.

In a student-directed, prompting students to really spend some time exploring the sim on their own before they start an activity is really something that we've found to be particularly successful at getting students to take ownership of their learning, as well. Because it orients students to what all the features are. So for example, when you guys explored those two sims I put in front of you earlier, you found all of the buttons and controls and switched them on and off and played around with them.

So if I were to follow up with a targeted prompt or learning question, you wouldn't be trying to figure out, well, how do I go about doing this? You would be focused on, oh, well, how do I figure out the answer to this question? Not how do I use this tool. And that's really the space you want your students to be in is focusing on those concepts, not on technical issues.

So we really recommend that if you're going to put an activity in front of your students, whether in a classroom environment or in a group activity, in a homework setting, that we really encourage you to move to minimal guidance and to less explicit guidance. And usually when we tell this to instructors, the first thing that happens is the transition from the image at the far left, which is actually excerpted from one of my camera manuals, very detailed, lots of words, not very easy to understand. And they say, OK, you want me to use fewer words. And they move to our middle diagram, which I have excerpted from Ikea. There are no words there. However, it's still very explicit and very directive. Step A, step B, step C.

And what we want to encourage is for people to be designing activities that have some room for students to explore in them. So even if you are guiding students to make a comparison, you can have a table that sets up, OK, compare these two samples according to these specific variables. And now discuss what comes out of that. So really treating student activities as a structured guidance that you're giving them, rather than as a sheet of instructions.

So prompts. The top prompt here, add 100 silver bromide pairs to the water, how many silver and bromide ions dissolve, so on and so forth, is very much like that yellow sheet activity. It gives them instructions on what to do and instructions on exactly what parameter to observe, record and take note of. And that focuses student attention on task completion. They're like, I have to get from the beginning of the activity to the end. And if I do that, I have succeeded.

Whereas a prompt that asks them to investigate the different salts and look at common features or discrepancies really is focusing them in on, OK, I need to understand what's similar about these cases. I need to look at all the solutions that are available and start to figure out, well, if this number is lower, does that mean it's more acidic or more basic? And those are the kinds of discussion questions that you'll want students to be having, so they're focusing in on sense making.

And five great guidelines for how to design a prompt that will get you there is using minimal words, certainly very positive. Focusing in on the why and the how and not just on fill in the number, fill in an answer here.

Really using the sim features and examples. So what we often see instructors do, particularly once you've been teaching for a long time, is they've got examples in their back pocket that they tend to pull out for great comparison cases on a given topic. But that might be a solution that students can't access in the simulation, in the case of pH. And that's great for an extension, but when you're just building that sim activity up, the more that you can keep students with the sim and having them view the sim as a useful tool for them building their understanding of that concept, the more they're going to make use of it. Whereas if we have-- we've seen instructors design activities where really early on in the activity there's an example that students can't create in the simulation environment. And students will say, OK, I'm done with the sim portion, they'll push away the computer, and they'll focus on that activity worksheet.

And so what you want is for as long as possible for them to be leveraging that tool to try and understand that concept. You want them to reason with words and diagrams, especially because this is a very visual tool. It has multiple representations. Leveraging that can really assist in student understanding.

And having prompts that help them monitor and check their understanding. So asking them, make a prediction and then check with the simulation is a really powerful way for them to be looking at a concept and making sure that they understand it.

Another great thing to leverage is tables. This is one of my personal favorites. And these are two examples. The one in the back and at the top is one that we've seen an instructor use in a lecture environment, where she was annotating this table in a tablet. And then on the bottom is one from a student activity. In either case, the beauty of tables is that they really immediately cue students towards comparisons, towards focusing in on particular variables that you want them to focus on, without having a lot of explicit direction. So it really can be really powerful to use those.

The last thing that I would mention on making use of the sims is really trying, to whatever extent you can, to integrate the sim into the rest of their course content. And that doesn't necessarily mean you will use a sim for every topic in your course. As much as I wish we had sims on all possible topics, we don't. We have a heavy focus on physics and chemistry, and we're building up in math. But we have only very few sims right now in biology or earth science content. There's a few in there, but they're pretty minimal.

So often times, we'll find instructors who use these for topics that fit really well. But within that topic, getting the students using some of the sim screen shots in the supporting materials, using some of those visuals in lecture summaries, in follow up questions, in assessments. So assessing around, here's a sim visual, talk about some of those representations, or a multiple choice question there. So a really focusing on integrating that for its utility.

So before I leave you guys, I want to give you a quick resource on how you can get started with PhET simulations. So in particular, start just by getting to know the simulations.

So if you go to the website. Maybe I can do this. So on the website, if you click Play with Simulations, essentially it'll give you a full listing. And we're in the process of revamping the website. But in either case, on that left hand side, there's a nice little category that will sort by device. So for example, if you know you're going to be using a Chromebook or an iPad, you'll want to sort by that, or by topic area, or by grade level. So getting to know those sims to see if they match your learning goals.

In addition, the website has a great set of teaching resources. There's a For Teachers section that has a number of videos that we've created on PhET in general, but also on using PhET with particular teaching modes. There's also some strategies and some various tip guides that you can download PDF copies of.

In addition, for any given simulation, so if we go back up here, for any given simulation, there are activities that are either built by PhET or submitted by part of our teacher community. So in this case, this is Force in Motion Basics. And there's numerous activities that have been submitted for various grade levels, various types of activities. And especially when you're just getting started, maybe those aren't perfect for your context. But it's great to have them as a starting point. So we really strongly recommend looking there as a starting place.

You can also connect with us on various social media. Because we do post and blog about some of the new developments and updates. And we do encourage you to connect with us there.

So with that, I'd love to thank you guys for inviting me to come speak, you guys for participating and getting involved. And the entire PhET team of researchers, developers, student workers who helped us along the way, and all the organizations that have given us funding to put this resource out there for folks to use in their teaching and learning. Thank you guys.