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How Do Secondary Science Teachers Perceive the Use of Interactive Simulations? The Affordance in Singapore Context

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Abstract

Research has shown that teaching science with a modeling-oriented approach, particularly with interactive simulations, will promote student engagement and understanding. To date, many interactive simulations have been developed and adopted for classroom practices. The purpose of this study was to explore secondary school science teachers' perceived affordance of interactive simulation as well as their practical experience with simulation implementation in class. Twelve science teachers from seven schools were interviewed individually and the data was triangulated with their teaching plans and student assignments. Their past experiences of simulation implementation revealed that most teachers adopted simulations for demonstration purpose in teacher-led instruction. Their attempts to provide students opportunities to use the simulations to explore alternative modeling by themselves did not seem to work well. There are various reasons for this, such as the shortage of facilities, Internet bandwidth, and technological knowledge. There was also a pressing need for teachers to complete the required syllabus in limited classroom time. The majority of teachers' future intent to use simulation in class was quite weak, especially with the less proficient students who had some difficulty understanding simulations. Although interactive simulations have great potential to promote students' understanding in abstract science concepts, overcoming the difficulties of implementation may require other alternatives such as a flipped classroom approach. Future studies can investigate how to design learning activities outside class, to engage students in exploring modeling in simulations.

Keywords Interactive simulations · Technology implementation · Science education · Modeling-oriented instruction

Introduction

Interactive simulation has been increasingly influential in K-12 science education because it can help students visualize abstract scientific concepts (McElhaney and Linn 2011; Wu and Huang 2007), and then propose, consider, and test alternative models to explain the phenomena (Schwarz et al. 2009). Simulations thus have potential to play a role in supporting students' understanding of modeling as one of the core epistemic practices in science (Campbell and Oh 2015), typically because they afford opportunities for students to engage in inquiry-oriented ways (Minner et al. 2010). Science teachers tend to have high beliefs in the importance of technology integration (Howard et al. 2015), and the increasing prevalence of technology ownership and experience makes science teachers feel more self-efficacious for using technology in their classrooms (Yerdelen-Damar et al. 2017). Despite this, research has shown that increasing simulation implementation in the science classroom is sometimes slow and challenging. The reasons include material problems, such as limited school infrastructure, software access, and technical support that still persist (Brenner and Brill 2016; Pelgrum 2001; Schwarz et al. 2007), as well as non-material problems including teachers' time constraints, lack of general

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technology skills by the teachers themselves or cooperating colleagues, or capacity to use the technology for student-centered ways that promote deep understanding (Bang and Luft 2013; Brenner and Brill 2016; Pringle et al. 2015; Schrum 1999; Strudler and Wetzel 1999).

To solve the technological and pedagogical issues, most recent studies focused on increasing teacher training and developing pedagogical strategies to use interactive simulation in science classrooms (Khan 2011; Kopcha 2012; Schwarz and Gwekwerere 2007). However, despite organized teacher training and offering pedagogical methods, experience with participating teachers indicates that the extent of simulation implementation can still be low. Therefore, even in the presence of training and pedagogical methods, there are influences on teachers' implementation that demand further study.

To explicate such influences, we examine teachers' perceptions of the affordance of interactive simulations and their initial experiences with implementation, since teachers' perceptions can influence their implementation choices and student outcomes (e.g., Fulmer and Liang 2013; Ramnarain 2014). Our specific questions are: What affordances do science teachers perceive for simulations. What are science teachers' perceptions of simulations for implementing in their own classes? How did teacher perceptions shape their subsequent simulation implementations in class? How did their past experiences with interactive simulations shape their future intent to continue using simulations?

This paper reports a study to understand secondary school (grades 7–12) science teachers' perceptions and experiences of simulation implementation after workshop training. Individual interviews with different teachers from various schools across Singapore were the main source of data which were later triangulated with their lesson plans and students' assignments. Specifically, we aimed to understand (i) the challenges teachers perceived in using simulation in schools and (ii) the difficulties they encountered during the implementation of simulations in classroom teaching. The findings of the study will yield useful insights of the implementation process and will suggest an approach that could potentially support the implementation of interactive simulations in grade 7–12 science education in sustainable ways.

Literature Review

This section will provide a review of the development of modeling-oriented instruction in science education, and how this instruction is conducted differently in various approaches. In particular, our focus was on how the technological tools such as interactive simulations could facilitate the modeling-oriented instruction in science classrooms.

Modeling-Oriented Instruction in Science Education

Modeling-oriented instruction is a form of scaffolded inquiry, in which students use modeling approaches with support from their teacher to pursue questions about scientific phenomena (Schwarz and Gwekwerere 2007; White and Frederiksen 1998). A *model* is "a representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena" (Schwarz et al. 2009: 633). Scientists use models to help them think about and make predictions regarding natural phenomena and principles (National Research Council 2012: 56–57). We see a model as having one of four forms: (1) a two- or three-dimensional replica of an object, organism, or phenomenon; (2) a conceptual or graphical organizer to exemplify a principle, process, or relationship; (3) a mathematical representation of a process or relationship; or (4) a computational environment for making and testing predictions. These forms are not mutually exclusive. Computational models typically require a mathematical model and may exhibit features of both the conceptual model and the replica. The definition and forms of models reflect prior work on the nature of models in science (Frigg and Hartmann 2017; Lehrer and Schauble 2006). The role of modeling as a scientific practice is now also fully recognized as an important goal in science education (National Research Council 2012) and part of the long-term trajectory of students' understanding of science (NGSS Lead States 2013).

Modeling-oriented instruction is a pedagogical approach in which students develop models to describe and explain scientific phenomena (Schwarz et al. 2009) and can include any combination of conceptual models, mathematical models, and computational models. An extensive body of research shows that teaching with explicit attention to models can result in substantial student involvement in modeling instruction and increase their science understanding (Campbell et al. 2015; Fulmer and Liang 2013; Gibson and Chase 2002; Stewart et al. 2005). In their analysis of definitions of computational thinking, Weintrop et al. (2016) refer to computational models as "non-static representations of phenomena that can be simulated by a computer" (p. 137). We will build on this definition to define a *simulation* as a non-static representation of a phenomenon that is simulated by a computer. An *interactive simulation* is a simulation that allows for students to change one or more variables in the interface. Modeling-oriented instruction with interactive simulations should provide opportunities for students to recognize and adjust one or more conditions, variables, or features of the simulation, and then compare the effect on the behavior of an object or the system.

Researchers have explored how modeling-oriented instruction enhances learning. The proposed mechanism for the benefits of modeling is through cycles that allow students to propose, test, and reconsider competing ways of describing natural phenomena that they have observed (Schwarz 2009;

Schwarz and White 2005). Clement (2008) has called these "GEM" cycles because they involve generating a model, evaluating the model's predictions against the natural phenomenon, and then modifications to the model. It is not only the modeling process, but also its integration into a series of conceptually rich disciplinary discussions with students that yield support understanding (Schwarz and White 2005). Louca et al. (2011) study primary students and teachers as they develop models of physical systems, arguing that teachers who successfully support students in such modeling-oriented lessons need to understand the importance of students' discussions and how to guide attention to the features of the model and how to construct and refine it. Across these studies, a key goal is students' recognition of the model as a process of refining scientific understanding, rather than as an outcome in itself.

In terms of platform for conducting modeling-oriented instruction, more often than not, science teachers would prefer to adopt hands-on experiments in laboratory to facilitate modeling-oriented instruction (Brownell et al. 2012; Mulholland and Wallace 1996). Though teachers indicate preference for hands-on experiments, other platforms that offer technological tools can help students quickly pose, test, and revise scientific models. For example, a study conducted in the classroom context video-taped student learning as they used the modeling software over a 2-week period. It was discovered that software tool scaffolds can efficiently assist middle school students in modeling practices such as planning and making explanations, which was significant in scientific reasoning (Fretz et al. 2002). In recent decades, computer simulations have become increasingly employed by science teachers, which enables students to visualize abstract phenomenon and test alternative models (Chang et al. 2008; Dori and Barak 2001; Khan 2008; Zhang et al. 2006). In particular, Open Source Physics (OSP) simulation and its growing digital library of physics models support and enrich this practice of developing progressively complex models for computational modeling and thinking (Wee et al. 2012, 2015; Wee and Mak 2009). These tools enabled the adoption of computer-based modeling in science classroom.

Computer-Based Modeling in Science Classroom

Computer simulations are generally defined as a computer program that can simulate models of scientific systems, and users can manipulate the model to visualize it under different conditions (Khan 2011). On one hand, by allowing students to visualize abstract concepts as well as to explore and test scientific modeling, computer simulations have been claimed to promote students' deep learning and conceptual understanding in science. When students learn deeply, they do not focus only on retaining scientific facts but instead seek to understand the relationships and principles present in the phenomenon of study. To do so requires that students approach learning with a goal of understanding rather than simply achieving grades or passing tests (Baeten et al. 2010). This involves learning in ways that make the epistemic practices of science more salient (Kuhn et al. 2017), such as modeling as a scientific process. Previous work on integrating computer simulations has addressed applications such as glucose-insulin (Mulder et al. 2016), optical lenses (Chang et al. 2008), moon phases (Bell and Trundle 2008), trajectory motion (Jimoyiannis and Komis 2001), relative motion (Monaghan and Clement 1999), respiratory chain (Yaman et al. 2008), spatial structure of molecules (Dori and Barak 2001), among many others. In addition to greater achievement, computer simulations were also found to significantly enhance students' positive attitudes towards science subjects (Geban et al. 1992; Hounshell and Hill 1989; Zacharia and Anderson 2003).

On the other hand, other studies indicated that the influence of computer simulations might have been overenthusiastic. For instance, Carlsen and Andre (1992) discovered no advantages in using simulations as an alternative to traditional methods during conceptual instruction in physics. No difference was found, either, when comparing the overall learning between students using computer simulations and those with hands-on experience in a fieldtrip (Winn et al. 2006). Indeed, another study found that the implementation of computer simulations could be less useful in classroom compared to physical experiments, because extra time was needed to operate the computer simulations, and the program did not necessarily respond promptly and accurately due to technical issues (Marshall and Young 2006). Another possible scenario is that students tended to be more careless in the computer-based science inquiry, which could lead to reduced educational effectiveness (Hershkovitz et al. 2013); it would also be easier for teachers to spot students' carelessness and respond timely in a hands-on lab setting compared to the computer-based classroom. As a result, computer simulations have not been sufficiently implemented in classroom practice, although science teachers were well aware of the potential benefits to use simulations, such as enhancing student motivation and facilitating conceptual learning (Zacharia 2003).

According to prior research, the common reasons leading to the insufficient implementation of computer simulations included (1) material problems such as shortage of infrastructure and software in schools (Brenner and Brill 2016; Inan and Lowther 2010; Kopcha 2012; Pelgrum 2001) and the need for qualified and ongoing technical support (Kopcha 2012; Schrum 1995; Schwarz et al. 2007; Wachira and Keengwe 2011), as well as (2) non-material problems such as the availability of effective teacher training and supportive interactions with fellow teachers who use technology (Inan and Lowther 2010; Kopcha 2012; Schrum 1999; Strudler and Wetzel 1999). Without adequate training, teachers would usually hold unfavorable attitudes towards computer simulations, express concern with their knowledge in simulations, and demonstrate low self-efficacy to teach with simulations. Similarly, teachers' attitudes, knowledge, and self-efficacy in teaching with simulations were also found to significantly influence their decision to implement simulations (Baek et al. 2008; Khan 2011; Schwarz et al. 2007; Wozney et al. 2006).

While there is substantial potential for benefits of modeling-oriented instruction through simulations, previous research has shown a mixed response from teachers on taking up these tools. Training has been identified as a clear need, but prior work has also shown that science teachers were not fully determined to implement computer simulations and preferred other hands-on approaches (e.g., laboratory experiments) to facilitate modeling-oriented instruction in class even after training and practice (Zacharia 2003). This tension between the affordances of the technology and what teachers are willing to adopt is especially striking in Singapore, which is famed for its international performance on science in PISA and TIMSS. Here, science teachers have strong science content backgrounds, a student body that is rather tech savvy, and ready access to various technologies. Furthermore, Singapore's teachers are offered regular training on available tools. In this context, we wanted to understand science teachers' perceptions and anticipated use of the modeling-oriented simulation tools after training. Our prior interactions with teachers indicated that the modeling-oriented skills were not emphasized in Singapore schools, on that ground that they may not be assessed in the exams. This was in line with previous research in Singapore context that school teaching usually focuses on certain skills that were considered to appear on high-stake tests (Koh and Luke 2009; Koh et al. 2012). It is critical to understand teachers' post-training perceptions of teaching with simulations, and how their perceptions shaped their teaching practice when implementing simulations in science classroom. This study setting and context provide an excellent opportunity to understand these factors.

Research Context

Open Source Physics (OSP; Christian et al. 2011) is a National Science Foundation funded project (award number NSF DUE 04-42581) that provides tools and resources for interactive computer-based modeling. Different from non-editable animations and videos that are commonly used in teaching science, computer-based models with OSP enable users to create and use the free tools to customize the computer models, which can facilitate modeling-oriented instruction and students' conceptual understanding. OSP used open source codes and creative commons licenses for scaling up of interactively engaging modeling practices. In addition, models made with OSP can run on almost any device (PC, laptop, tablet, and mobile phone) through the Internet browser on multiple operating systems: Android, iOS, Windows, MacOS, and Linux.

OSP focuses on design of computer models, such as Easy Java Simulations (EJS) and the use of video modeling and analysis (Tracker). These allow students to investigate, explore, analyze, and interpret data which is either simulated or real. Specifically, the EJS authoring toolkit can be used to create computer models either by teachers to help students learn or by students to represent their understanding. By using Tracker, learners can record the motion of objects and create their own models to test their ideas in learning physics concepts. Tracker tools allow learners to visualize and analyze the microscopic parts of Physics phenomena and create stronger connections between scientific concepts and real-life applications.

Although it has been acknowledged that computer-based modeling using OSP simulations can facilitate modeling-oriented instruction and students' deep learning of physics concepts (Goh et al. 2013; Wee et al. 2012), research on how teachers can effectively integrate OSP simulations into grade 7–12 physics classes is rather scarce in Singapore.

The Singapore OSP project supported teacher professional development in the use of OSP simulations over several years. Science teachers throughout the city-state are welcome to register and attend. This article focuses on one phase of professional development and research on teachers' use of OSP simulations after participating in hands-on workshops about the OSP tools and related pedagogical approaches. In this phase, the project offered a series of workshops on the use of OSP for different topics, each matched to the content sequence in the Singapore physics syllabus. Each workshop on the use of OSP was 3 h in duration and included an overview of the OSP simulation, examples of student activities and worksheets, and discussion of the instructors' and users' experiences using the simulation in real lessons. Teachers could choose to join any one workshop in whole or in part. Previous phases of the Singapore OSP project have provided multiple-day workshops with experts from the Ministry of Education or from international partners.

Research Methodology

The goal of the present research was to explore Grade 7–12 science teachers' post-training perceptions towards simulation use in class, as well as their teaching practice when implementing simulation in science classroom. A qualitative study (Merriam 1998) was adopted for this study as it allowed for exploring the phenomenon through the perspectives and experiences of the subjects in the study.

Research Participants

This study used a maximum variation strategy (Miles and Huberman 1994) to identify a purposeful sample. The criteria were as follows: (1) the context of this research included both government schools and independent schools, (2) the investigated curriculum covered both secondary school and Junior College (JC) or what is called high schools elsewhere, (3) the interviewed teachers varied substantially based on the years of teaching experiences, and (4) level of target students.

In total, 12 teachers from 7 schools across Singapore agreed to participate in the individual interviews. Among the 7 schools, 5 were public schools where students' proficiency levels varied and 2 were independent schools with high achieving students in Singapore. Table 1 provides a summary of the profile of our research participants with further elaboration of their backgrounds, such as the years of teaching, subjects taught, number of Open Source Physics (OSP) training sessions attended during the present study and in prior years, other simulation tools they reported using, and their reported teaching style. Anonymous identifiers are used to protect the identity of schools and teachers.

Data Collection

The primary method of data collection for the teachers' perspectives was individual semi-structured interviews. Of the 12 interviews, 11 were conducted face to face and 1 was via telephone. A semi-structured interview protocol (see Appendix 1) was used so that it allowed for variation in the question order as well as potentially additional questions and probes to individuals (Creswell 2007). Teaching plans and student assignments from certain teachers were also collected as supplementary data when available.

Data Analysis

Thematic analysis (Miles and Huberman 1994) was used to abstract the data. The researchers began with open codes and then explored patterns within the data to categorize the codes and themes. Figure 1 presents a flowchart summarizing the analysis process from open codes to themes. Open codes were produced during the initial close reading of the interview transcripts. The codes were then reviewed in relation to each other based on frequency, common proximity, and conceptual links to create sub-themes and themes. Table 2 presents a summary of the themes, sub-themes, and codes that were used in our analysis. For example, codes derived from teachers' statements about using simulations to address abstract topics (including specific mention of topics like magnetism, atomic structure, or thermodynamics) were combined to form a sub-theme about abstract concepts leading to the overall theme for affordances of teaching with simulations. To ensure the accuracy of interpretation in the qualitative data, other experienced scholars in qualitative research were invited to review the codes and themes based on the research questions and literature. Disparity in developing codes

Table 1 Participant information

Teacher ID	School type	Level	Years of teaching	OSP training sessions*	Other simulations used	Subjects taught	Teaching style	Target students
Teacher 1	Govt	Sec	16	10–15 sessions	PhET	Physics	Teacher-led; Lecture-based	Average
Teacher 2	Govt	Sec	15	< 5 sessions	PhET	Chemistry	Teacher-led; Lecture-based	Average
Teacher 3	Govt	JC	10	< 5 sessions	None	Physics	Teacher-led; Lecture-based	Average
Teacher 4	Govt	Sec	3	< 5 sessions	PhET	Physics; Biology	Teacher-led; Lecture-based	Average
Teacher 5	Govt	Sec	7	10–15 sessions	PhET	Physics	Teacher-led; Lecture-based	Average
Teacher 6	Govt	Sec	10	< 5 sessions	None	Physics	Teacher-led; Lecture-based	Average
Teacher 7	Independent	JC	6	10–15 sessions	PhET	Physics; Astronomy	Student-centered; inquiry-based	Top
Teacher 8	Independent	Sec	13	15–20 sessions	None	Physics	Student-centered; inquiry-based	Top
Teacher 9	Govt	JC	1.5	< 5 sessions	None	Chemistry	Teacher-led; Lecture-based	Average
Teacher 10	Govt	JC	19	5–10 sessions	None	Physics	Teacher-led; Lecture-based	Average
Teacher 11	Govt	Sec	5	< 5 sessions	PhET	Chemistry	Teacher-led; Lecture-based	Average
Teacher 12	Govt	Sec	6	5–10 sessions	PhET	Physics	Teacher-led; Lecture-based	Average

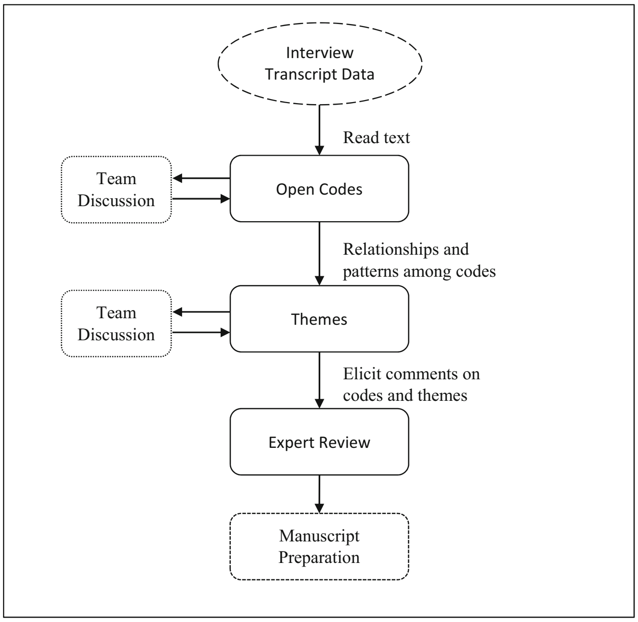

Fig. 1 Flowchart of thematic analysis approach

and themes was discussed until complete agreement was reached. The consistent triangulation in the data analysis among various researchers helps limit the potential risk that the interview analyses might be influenced by only one researcher's subjective standpoint (Yin 2013).

Findings

Based on our thematic analysis, our findings focus on teachers' perceptions of simulation use in science teaching first, followed by their implementation experience in class. Table 2 presents a summary of the codes.

Teachers' Perceptions Towards Simulation Use in Science Teaching

Although teachers agreed on how simulation can enable students to visualize abstract concepts in an interactive way, they

Table 2 Summary of themes, sub-themes, and codes

Theme	Sub-theme	Codes
Affordance of teaching with simulation	Suitable for abstract topics	• Kinematics • Thermodynamics • Magnetism • Atoms • Abstraction
	Target students	• Fit proficient students • Confuse weak students
Affordance of learning with simulation	Enhance learning engagement	• Variation of learning approach • More engaged • Useful to attract attention
	Complicate learning process	• Dislike needing to learn the technology • Misleading information in the software (e.g., color of carbon)
	Irrelevant to learning outcomes	• No testing of simulation in the exam • Exam preparation is priority
Affordance of simulation infrastructure	Access to ICT devices	• Insufficient computers in school (especially government schools) • Lack of computers at home
	Limited Internet bandwidth	• Simulation requires fast and stable Internet • Slow Internet at school (especially government schools)
	Lack of localized resources	• Content inconsistent with Singapore syllabus (e.g., Vernier calipers) • Insufficient content of Singapore syllabus
Simulation implementation in class	Demonstration purposes (government schools)	• Limited classroom time to cover syllabus • Limited classroom time to prepare students for exams • Weak students cannot follow simulation
	Inquiry-based learning (independent schools)	• Strong students have good foundation to participate • Strong students still expect more teacher guidance
	Simulation is not user-friendly	• Complicated interface to operate • Prefer other tools in class (e.g., Phet)
Simulation implementation after class	As required homework	• Save more classroom time to cover syllabus • Allowing more time to learn the technology and deepen learning
	As optional exploration	• Save more classroom time to cover syllabus • For students' personal interest

tended to demonstrate more concern than favor for it. Their concerns included three major aspects: (a) perceived affordance of teaching with simulation in the Grade 7–12 science classroom, (b) perceived affordance of learning with simulation in the Grade 7–12 science classroom, and (c) perceived affordance of simulation infrastructure in the Grade 7–12 science classroom.

Perceived Affordance of Teaching with Simulation in Grade 7–12 Science Classroom

Simulations afford visualization capacity for more abstract topics. All 12 science teachers considered interactive simulations to be useful only for teaching certain abstract topics, such as kinematics, dynamics, magnetism, etc. They all admitted the "innovative and fun part of technology in teaching", but the major advantage of simulation in science teaching seemed to be limited to the visualization of abstract concepts. For example, teacher 4 explained,

> Of course topics like kinetic model of matter, where the concepts... you know they can't... atoms, molecules, all these... very difficult to imagine, right? And so topics like kinetic model of matter, sometimes dynamics when you talk about forces, what happens you apply this kind of force, how does it accelerate, how does the graph look like? So these are the topics that I choose to show some examples through Simulations.

Under such circumstances, teachers would consider using simulations in class based on the availability of resources provided as well as the match between the provided resources and their teaching plans of specific topics. Teachers with more technical backgrounds in ICT tools were also open to the customization of simulations while adopting them in teaching, making them more likely to see a match with their specific topics. Unfortunately, only one interviewed teacher (teacher 8) from an independent school explicitly mentioned using the simulation tools to explain phenomena to students as well as guide students to build modeling in the classroom.

> So, they were given a bottle and they were supposed to do some oscillation as well. And then they were supposed to do a bungee jump to have a toy, and then drop so you've predict, based on earlier experiments, you predict and then you record, to check and then do some modelling.

Teacher 8 explained the reason that students were able to use interactive simulation to explore the modeling was that they had a solid foundation of knowledge in physics, being the top students in one of the best schools in Singapore. A similar phenomenon was also reported by teacher 7, who works at another independent school where students' academic levels are quite high. Instead of guiding the students to build the modeling like teacher 8, teacher 7 was encouraging students to freely explore the modeling by simply playing with it on their own.

> Most of them have a play button, so you've a play and a pause and a reset button, so that's the first thing you can do… And then if you have a moving object, there's a mile and a speed, perhaps, you can find the force but... so you can start by varying one by one, it's very good physics concept.

Overall, teachers perceived simulations not to afford benefits equally for all topics. More concrete and easily observed phenomena may be better introduced in a hands-on laboratory setting or even a traditional classroom, as described by interviewed teachers—either instead of or as a precursor to using simulations. When it comes to other topics, however, most teachers considered simulations to be redundant, especially when you have the option of demonstrating scientific concepts in real-life settings, either in classroom or laboratory. Teacher 3 indicated his preference and elaborated:

> If you want me to use Simulations, I'd rather bring the students to the laboratory and then they experience it… because I press, press, press (in the simulation), and they just look. To them, it's just like another video, so when you talk about simulations, maybe you give them a hands-on experience, they can really experience it, then it's better.

Furthermore, teachers find simulations are also limited to the more proficient students while using it in science teaching. As described above, among the 12 interviewed teachers, 10 teachers raised the concern that students are unable to catch up with the simulation in class. The exceptions to this were the two teachers from the independent schools, as these schools have students with proficiency levels among the highest in the country. According to the teachers' interviews, teaching with simulations seemed to confuse many of their students, especially the weaker ones. Therefore, they felt they had "no choice but to revert back to pen and paper".

Perceived Affordance of Learning with Simulation in Grade 7–12 Science Classroom

After receiving training on interactive simulations and trying it in class, teachers reported seeing mixed effects on student learning. On one hand, there was a consensus among the interviewees that students became much more engaged in learning when simulation was used to demonstrate abstract phenomenon in science. Different from the traditional approach where students would just sit down, listen to the teacher and look at the textbook, simulation was believed to be “a strong variation of learning approach” (teacher 1), which was effective to link different topics as well as promote students’ learning interest. As teacher 12 elaborated, “I find that they’re more engaged… And then I think it is more enjoyable, rather than just sit down and listen to me, and look at the textbook that is two-dimensional and static.” Thus, the inclusion of the simulation gives teachers the sense that lessons are more engaging for students.

On the other hand, some teachers noticed complications that simulations brought to learning in class, especially when the students were asked to operate the simulations themselves. They mentioned two major reasons: the need for students to get familiar with the software and the potential for misleading representations in the simulation. To illustrate, teacher 9 from a government neighborhood school described the extra learning of simulation in his interview:

> Because sometimes you want to... you must also take into account, you want to introduce students to the software, you need to tell them how to use it, and after telling them, you know… first time, they will be a bit blur and then you tell them again. That’s only the instructional part; you have not yet gone inside the details of it.

Similarly, teacher 2 considered the students from neighborhood schools who may not be as academically inclined, saying “they might not be much appreciative of the new technology in learning.” As a result, these students would dislike needing to learn the technology itself prior to getting into the content, and therefore feel less engaged in the lessons.

Regarding potential misleading information in the simulation, teacher 9 also provided an example in chemistry:

> In addition, they’ve to understand what are some things that can be seen by the Simulations, what are some things which are not so clear... something like that. Especially for chemistry, sometimes we show certain colours, like Simulations, we show that carbon is black colour or whatever red colour, then the students may also be misled that this thing is red colour, black colour, so these are the things we've to be careful. That’s what I generally find.

Notably, despite the learning engagement or learning complication simulation has brought to students, the teachers’ biggest concern is about whether simulation will really benefit students’ learning outcome, especially in examinations. Teacher 1 from a government school pointed out that, at the end of the year, the students must be prepared for a pen-and-paper test without any simulations or other computer-aided visualizations. Hence, teachers usually prefer to continue with learning in traditional ways such as hand-written problems and calculations that more closely resemble the assessment experience. Teacher 11, also from a government school, echoed teacher 1, saying, “ultimately we still need to get them to be prepared for examinations... It is really the less proficient students that we are very worried about, because they tend to be less engaged in class and even after the form of activity, they don’t go back and reflect on what are the (simulation) activities for, what are the learning points, and how can they improve on whatever they have built up (in simulation).” In such a situation and with the limited class time for the students to learn, she tended to give up using simulation and maintained a conventional approach. On the other hand, teacher 8 from a high-performing independent school shared his experience to encourage students to learn the phenomena with the help of simulation tools in class.

> Still, they learnt most of the software and then they stopped there. … So the next year I expanded, I said, "Okay, that's not enough, we need even more lessons." So I had the software and had a project. Every student had to do a project, because actually our school did that, so I thought that was a good idea... they do a project, they can film any video that has an object moving and you try to analyse the motion, so using the software to analyse the motion. So I thought if they could analyse, surely they must know what is happening.

In this case, the policies at this elite independent school gave the teacher further opportunity to push students to use the simulation tools for a longer-term project. This project let the students gain deeper knowledge of the software and apply it to improve their physics understanding. Most of the government neighborhood schools, in contrast, have less room to provide extra time for such projects and would focus on the examination drills that will help their students develop higher standardized test scores.

Perceived Affordance of Simulation Infrastructure in Grade 7–12 Science Classroom

Teachers identified a variety of challenges in school infrastructure which they thought constrained the implementation of simulation in grade 7–12 science teaching. First and foremost, students do not always have individual access to computers when needed. So, teachers in government neighborhood schools struggled to implement technology in class due to the shortage of school facilities to begin with. This issue was repeatedly mentioned by 8 out of the 10 interviewed teachers from the government neighborhood schools. For example, teacher 2 described,

> We can possibly book the computer lab… That is operationally feasible but usually the time, the time is more like the technical issues. By the time, it doesn't mean that every time you book, they have it because other classes might book it earlier and you just can’t...

Internet bandwidth is another challenge that most government neighborhood schools encountered, because interactive simulations require fast and stable networks, but many school Internet connections barely reach the requirement for some simulations, especially with multiple students using the interactive apps simultaneously. As mentioned by teacher 6,

> Definitely the faster (the internet), the better, because sometimes it downloads depending on what kind of simulation is that… If it’s a simple one, I think it doesn’t matter, but it’s maybe a slightly complicated one, then good to have the faster (internet).

Teacher 3 also pointed out this problem of spending excessive time to use simulation in class. Therefore, he would only select the simple simulations to implement in classroom. He explained, “the simpler the Simulation, the faster I can show it, and then don’t need to spend too much time to set it up.” These emphasize that teachers are trying to find a balance for use of time and for the nature of the simulations themselves.

Even though certain schools might have eliminated those two challenges in hardware, the limited materials in simulation software were still restricting the potential adoption in class, especially the materials matching the specific context of the Singapore science curriculum. Teacher 5 gave an example in his physics class:

> We use Vernier callipers simulation; I find that very interesting. However, the... for example the... the scale was not exactly same as the Singapore syllabus although we know that the student can learn…

Without overcoming the challenges both in hardware and software, teachers would often doubt the possibility to implement simulation in science class, even many of them might have realized the potential benefits simulation can bring to science teaching and learning.

Teachers’ Experience of Simulation Use in Science Teaching

With the attitudes described above, most teachers mainly had the experience of adopting simulations for demonstration purposes in teacher-led instruction. Attempts to let students operate the simulations themselves and explore competing scientific models did not seem to work well. As we show below, examining alternative models would require even more classroom time, make more demands of limited school facilities, and require further technological training about how to test models in the simulation.

Practice of Simulation Implementation in Class

According to self-report accounts during interviews of how the teachers attempted to use simulations in their teaching, 10 out of 12 teachers used mostly direct instruction even as they adopted the simulation in their classes. The implementation was mainly for demonstrating scientific concepts without involving student interaction. These 10 teachers happened also to be from the government neighborhood schools, which have relatively average student academic background, but also greater variation in students’ previous academic performance than the elite schools. They explained that they had limited classroom time to complete the school syllabus and prepare students for their final exams, so they could not afford to make the class more student-centered and provide opportunities for their students to operate the simulations themselves in class. Teacher 10 described in his interview:

> Because the thing about getting students to bring out their hand phones in the middle of lecture and start interacting... you can’t spare that time... it would take too long. By the time they log in and find out what the address is... by the time they finish all that, 15 minutes of your 1-hour is gone. The pace of the lessons is quite fast so if I were to use, let’s say, 1 or 2 lessons to conduct such (interactive) activities, I would tend to fall behind in my coverage of tutorial. Then I can't finish in time for the major exam.

A few teachers reported designing inquiry-based instructions occasionally in computer labs after they have completed the required syllabus. However, only the more proficient students seemed to be engaged while the less proficient students found difficulty catching up and hence lost interest in the lesson. As teacher 11 described, the less proficient students in her class had no idea what the aim of the inquiry-based activity was, and they would always tend to look for answers, asking “what exactly do you want me to look out for? What do I have to do? Can you tell me what to do?” As a result, the lesson became more teacher-centered as the teacher shifted to use more direct instruction to help guide these students. In the same vein, teacher 4 mentioned this issue arising in her class, especially among the weaker students who “either were not confident in self-directed learning (via interactive simulation) or were just lazy to do, so they may not finish the work (of simulation) in class.” Therefore, even among those teachers who might have prepared more student-directed activities and worksheets to go with the interactive simulation, they found that it was almost impossible to implement the teaching plan with their lessons.

In contrast, the two teachers from the independent schools used inquiry-based instruction to a far greater extent when implementing interactive simulation in class. Admittedly, students were expecting more teacher guidance in such activities, but no obvious difficulty was indicated when they were asked to use the simulations and explored the alternative modeling under minimal teacher guidance. Teacher 7 described his class as follows:

> With their worksheets... um... well some students said that they would like to have a little bit more teacher interaction... um... but other than that, it worked quite well… So instead of a lecture in seeing, there is a law, there is a law... let them play, see do you notice something and then try for them to deduce, eventually you've to confirm, that's what the teacher's for and to see the link, can we put it together.

It was worth noting that seven interviewed teachers mentioned the use of PhET as an alternative tool to OSP simulation, since OSP simulation was repeatedly described as "not so user-friendly". For instance, teacher 12 tended to use PhET sometimes in class, which seemed much more convenient to operate within the limited classroom time.

> So it (PhET) is more… how to say, user-friendly because you just go to the website and you can just select (the simulation) and do it… So it's not like a software which you have to install and operate.

Teacher 7 also expressed his preference to use PhET in the physics class compared to OSP simulation, particularly because of the user interface:

> The OSP Simulations, sometimes they're simpler with the purpose, and we can focus on the specific topics, concepts … but sometimes the user interface is kind of horrible, too many slides and buttons and all that.

In addition to its use in physics, PhET was also preferred by teacher 2 for chemistry, where the simulations were adopted for demonstration purpose in teacher-centered lessons.

It was obvious that in most of the schools where students' proficiency level was average, both the teachers and students preferred direct instruction while using simulations in class. This enabled the teachers not only to cover the required content within limited classroom time but also to feel more efficient and less confusing for supporting students' knowledge acquisition and exam preparation. In contrast, teachers in the top schools were more willing to adopt inquiry-based instruction because their students seemed more able to follow.

Practice of Simulation Implementation After Class

Though adoption of simulations in class was limited or else more teacher-directed than intended, all the 12 teachers reported their attempts to integrate simulation in science teaching and learning after class. This took the form either of a required homework or an optional exploration for students to use simulation in their spare time. In this way, teachers felt they "did not have to distribute the limited classroom time to the use of simulation" (teacher 2), since the extent of simulation implementation substantially "depends on the time constraint" (teacher 6). Outside classroom students were also enabled to explore the alternative modeling at their own pace. Notably, teachers reported that students were more responsive to learning with simulation after class only when it was required as homework; they tended to ignore the exercises when it was optional. As teacher 1 explained, it was more manageable when he tried to ask students to explore the modeling via simulation as part of e-learning homework. Furthermore, certain amount of teacher guidance was also needed when students conducted self-learning after class as they needed help not only with the subject matter knowledge but also the technological knowledge to operate the software. Teacher 3 recalled,

> There are certain Simulations I feel that might be good for students to work around, to play around with. I'll just point them to, 'Okay, this is good, go and explore if you need to explore.' Uh... and that's it… ... the only issue with that was that the simulations designed, that was being used, was... there were too many buttons, and therefore it took the students quite a while to know how to manipulate the stuff...

As can be seen, teachers in our study seemed to embrace simulation use after class, especially to promote more discovery-based learning under the students' own direction. The use of simulations after class also mitigated the barriers presented by limited facilities, since students would have more space, time, and bandwidth to use simulations on their own.

Discussion

Faced with the challenges, both material (e.g., infrastructure, technical support) and non-material (e.g., teacher training), in implementing simulations in science education, most of the current literature focused on creating instructional models and strategies in classroom teaching (Khan 2011; Schwarz and Gwekwerere 2007). Unfortunately, we found that the affordances of the simulation tools and the modeling capabilities did not always provide students the rich opportunities to engage in modeling-based reasoning during curriculum time. Furthermore, we also noted that teachers' comments about the affordances for teaching and learning did not address the attention to *modeling* as an epistemic practice in science that would inform teaching strategies and how students learn content. Rather, teachers found positive capabilities for engagement of particular simulations or identified topics where simulations provided visualizations but did not raise this to the next level of seeing these as instances of model-based reasoning tools.

Based on our findings that teachers perceived and experienced some of the affordances for teaching simulations but also faced substantial challenges in implementation for modeling, we propose a more sustainable approach: flipping learning with interactive simulation. We extend the FLIP model (Hamdan et al. 2013) and FLIPPED model in higher education (Chen et al. 2014) by proposing the FLIPPING framework with eight key components: **F**lexible environment, **L**earning culture, **I**ntentional content, **P**rofessional educators, **P**reparedness for learning, **I**nfrastructural readiness, **N**ovice-proof interface, and **G**uided pragmatism. Informed by the present findings, this extension better fits grades 7–12 science education, especially the Singapore context. Below, we outline these eight components by discussing the relevance of the four FLIP components (Hamdan et al. 2013) and describe the four additional components we propose as summarized in Table 3.

Flexible Environment

As demonstrated in the findings of the present study, the benefits of the simulations' use in the teachers' classrooms were not realized, especially in mainstream public schools where the school facilities were insufficient and when classroom time was limited. Therefore, flipping learning could provide a more flexible environment where students are able to choose where and when they learn with the interactive simulation. This advantage has been pointed out previously in higher education (Jones and McLean 2012; McLoughlin and Lee 2010; Wanner and Palmer 2015), but could be more beneficial in grade 7–12 education since the classroom time in many contexts is much more rigid to cover the required syllabus and prepare for exams. Furthermore, the shortage of school facilities (e.g., computers, Internet connections) would also be alleviated when students have alternatives to use computers or handheld devices at different times and in different places.

Learning Culture

When flipping learning with interactive simulation, it is important to make the in-class session student-centered, so that in-class time can be used for discussing alternative modeling as a result of student exploration, and hence for strengthening the scientific concepts in depth. As reflected in the findings, 10 out of 12 interviewed teachers were using simulation solely

Table 3 Proposed FLIPPING model for simulation implementation in Singapore context

	Component	Summary
F	Flexible environment	• Greater flexibility of the flipped environment for diverse students with varied prior knowledge and who proceed at different paces. • Optimal use of curriculum time by teachers
L	Learning culture	• Student-centred classroom environment with in-class focus on modeling and student activities • Reduction of teacher-led activities
I	Intentional content	• Careful teacher planning to include appropriate content for simulations, especially abstract concepts and processes • Greater use of simulations for self-paced learning of the concepts
P	Professional educators	• Skillful teacher facilitation in integrating content knowledge and technology tools • Establishment of classroom structures and routines to support students' exploration in simulations without directly guiding students to specific answers.
P	Preparedness for learning	• The importance of students' prior knowledge to benefit the most from abstract simulations, especially for struggling students • The encouragement of an active-learning mindset among students to stimulate engagement with simulations.
I	Infrastructural readiness	• Necessary conditions in hardware and software • Faster or more reliable Internet and devices at school sites
N	Novice-proof interface	• Complex modeling tools appropriate for novices. • Intuitive interfaces with appeal to novices.
G	Guided pragmatism	• Cognizance of powerful external factors, e.g., policy demands, external pressures, and cultural expectations. • Alignment of simulations with assessment criteria • Use of simulations for assessment preparation

for demonstration purpose in a teacher-centred approach, while students were the passive learners. On the other hand, only two teachers from the independent schools attempted to let students actively explore the scientific modeling via interactive simulation, although those students were reported to demand more teacher scaffolding. As a matter of fact, with certain teacher guidance, students should be encouraged to conduct active learning in class, which is more likely to achieve deep learning of scientific concepts (Baeten et al. 2010; Prince 2004). As can be seen, flipping learning model first enables students to start exploring modeling outside the classroom, and then promotes their active sharing of exploration inside the classroom. Both steps emphasize students as the center of learning, promoting their active engagements in the entire learning cycle.

Intentional Content

Although students are the center of flipping learning, teachers should still carefully plan the learning content, both for students' self-paced learning and teachers' classroom instruction. To specify, the content should be intentionally designed to promote students' deep learning and teachers' modeling-oriented instruction. As pointed out by all the 12 interviewed teachers, interactive simulation seemed to simplify certain abstract topics for students' understanding, but might be redundant in other topics and hence complicate the learning process. While the FLIPPED model in higher education from literature (Chen et al. 2014) focuses more on activity delivery than content planning, FLIPPING framework in the present study tends to attach equal emphasis to content planning as well. This is because syllabus coverage was found to be one of the biggest consideration in grade 7–12 education (Crocco and Costigan 2007; Grossman and Thompson 2008), which has also been indicated in the findings described above.

Professional Educators

With students being the center of learning, the role of teachers in flipping learning is not diminished, but on the contrary is more critical than that in the traditional approach. On one hand, it is necessary that teachers provide guidance to students' self-paced learning outside class, including technological knowledge of simulation operation and science content knowledge. The teachers in the present study were all subject matter experts in their content knowledge, and the majority (10 teachers) had more than 5 years' teaching experience. However, their ICT backgrounds varied, particularly in the area of OSP simulation, which might cause their discomfort to use simulation extensively in class. More targeted professional training is required for them to become professional educators, especially among the fresh users of OSP simulation. On the other hand, there is a need for teachers to scaffold student discussions in class with a focus, which was reflected by all the interviewed teachers in the present study. Having been used to the teacher-centered approach in classroom, students might be "uncomfortable with the freedom they were given and tended to rely as much as possible on the textbook and the teacher to guide them" (DeBoer 2002, p. 409). Therefore, teachers must be trained beforehand, in order to facilitate students' exploration of scientific modeling without directly guiding them to the right answers.

Preparedness for Learning

The first additional component in the FLIPPING framework is "preparedness for learning". Based on the findings of teachers from different schools with students at different proficiency levels, it was obvious that interactive simulation seemed to be more useful to students whose background knowledge was more solid, whose inquiry skills was more profound, and more importantly, whose mind-set was more open to self-exploration. This is consistent with previous studies that indicated students who were better at higher abstract reasoning benefited more from simulation-based learning (Chang et al. 2008; Zhang et al. 2004). The current study further showed that students' prior knowledge and learning mind-set are also critical to implement interactive simulation in science learning, especially in a student-centered approach. Therefore, flipping learning will enable students to prepare themselves before the class and get ready for the modeling-oriented discussions during classroom instruction. This preparedness prior to classroom learning is particularly important for the mainstream public schools where usually students' academic backgrounds are relatively weaker.

Infrastructural Readiness

The second added component in the FLIPPING framework is "infrastructural readiness". As previously pointed in the literature of technology integration in grade 7–12 education, availability of facilities has been one of the biggest challenges (Pelgrum 2001; Tondeur et al. 2008), and this was shown to be especially true in public schools in the present study. Without adequate infrastructure, simulation implementation was impossible to begin with, even when some teachers and students were willing to try. Independent schools in Singapore with additional financial resources, in contrast, were well equipped with both hardware and software that contributed substantially to the development of simulation implementation in schools. Therefore, the component of infrastructural readiness is critical in the proposed flipping framework, including school context and out-of-school context (e.g., home environment, public facility environment, etc.).

Novice-Proof Interface

The third addition is "novice-proof interface" in the FLIPPING framework. Previous literature in simulation implementation has repeatedly emphasized the importance of increasing teachers' as well as students' technological knowledge (Guzey and Roehrig 2009; Kopcha 2012; Margerum-Leys and Marx 2002; Wachira and Keengwe 2011; Windschitl and Sahl 2002), but it is even more crucial to simplify the software interface for the end-users, in order to achieve extensive and sustainable integration of interactive simulation. As reflected in the teacher interviews in the present study, this is mostly because both teachers and students lack the extra time for additional training on the use of the technology, especially in the long term when each newly added function might require further training. This was also reported to be the reason that the seven teachers preferred to use PhET rather than OSP simulation for science teaching, since the former was described to have a much easier interface to operate in. Furthermore, despite the widespread use of handheld devices by students, this does not mean that all students will be adept at handling complex user interfaces. Richer interfaces can also be more complex and confusing for novice users. Hence, it is probably more practical to simplify the interface to a novice-proof level, so more time can be allotted to the science learning with simulation rather than to learning the technology of simulation.

Guided Pragmatism

The fourth additional component in the FLIPPING model is "guided pragmatism". Based on the findings of the present study, it is clear that simulation implementation was only considered after fulfilling the school requirements: covering the curriculum and preparing for exams. This is not surprising, since examination results have always been the priority in teaching plans and classroom practices in Singapore context (Curdt-Christiansen 2010; Hogan et al. 2013), particularly in grades 7–12. Even when teachers decide to use simulations in class, an examination focus continues to influence their teaching plans and student exercises. Therefore, it is critical to align simulation use with assessment criteria, or even contribute to the assessment preparation if possible.

The integration of the four components of F-L-I-P schema (**F**lexible environment, **L**earning culture, **I**ntentional content and **P**rofessional educators) with our added four components P-I-N-G (**P**reparedness for learning, **I**nfrastructural readiness, **N**ovice-proof interface, and **G**uided pragmatism), provides a FLIPPING framework that could promote simulation implementation in more accessible and sustainable ways in grade 7–12 science education.

Conclusion

The findings in this study suggest that, despite teacher training and technical support, the implementation of interactive simulations was perceived by the grade 7–12 science teachers to be difficult. Although certain teachers attempted to use simulations in their class, future intent to continue using simulations was low due to the limited classroom time to complete the required syllabus, and the pressing concern over whether the use of interactive simulation can directly contribute to exam results. For some schools that were not well equipped with technological infrastructure, simulation implementation was impossible to begin with regardless of how positively the teachers perceived the use of simulation in class.

To maximize the potential affordance of interactive simulation in grade 7–12 science education in the Singapore context, we propose the FLIPPING framework—using interactive simulations outside of class to support richer in-class teaching. We believe the eight key components in FLIPPING framework (**F**lexible environment, **L**earning culture, **I**ntentional content, **P**rofessional educators, **P**reparedness for learning, **I**nfrastructural readiness, **N**ovice-proof interface, and **G**uided pragmatism) can alleviate both material difficulties of simulation implementation (e.g., infrastructure) and non-material challenges (e.g., student readiness) and promote the use of interactive simulation in grade 7–12 science teaching in sustainable ways.

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Compliance with Ethical Standards

Ethical Approval All procedures involving human participants were approved by and conducted in accordance with the ethical standards of the Nanyang Technological University Institutional Review Board (NTU/IRB), and consistent with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Conflicts of Interest The authors declare that they have no conflicts of interest.

Appendix 1

Semi-structured interview questions:

1. What did you think of the simulations/teaching with simulations?
    a. Did you find them easy to use? [how so, whether yes/no]
    b. Were they interesting? [how so, whether yes/no]
    c. What feedback do you have about the simulations themselves?
2. Did you try the simulations in your class (give examples: such as lesson plans and student artifact to support)?
    a. What ways did you use the simulation? [e.g., context, platform, topic/content, purpose of the lesson, activity design, duration,]
    b. How did the students respond to/interact with the simulations?
    c. What are the challenges you encountered while using simulation in class?
3. Do you have plans to continue using the simulations? Why/Why not?
    a. If yes, how will you be using them in the future? [e.g., frequency, context, platform, topic/content]
    b. What feedback would you give on using the simulations in class? [e.g., format, materials, supplementary worksheets, etc.]

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