Modeling and Simulation as a Service (MSaaS) for Education: Learning STEM Concepts through Simulation Use and Building

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ABSTRACT
Despite their proven advantages in science and engineering and their broad application in daily activities such as travel planning and financial planning, simulations are not widely utilized in education, particularly at the K-12 levels. One of the main reasons is that simulation use and simulation building is reserved for expert's use and remains out of the reach to a larger audience. One potential solution is Modeling and Simulation as a Service (MSaaS) for education in the form of a cloud-based simulation learning environments (CSLEs). CSLEs can provide worldwide access to many people for using and building simulations as well as exposing them to STEM concepts like data capture and probability. This paper presents a roadmap for CSLEs. The roadmap, six requirements for building CSLEs, draws on insights from 1) testing a cloud-based simulation environment for education purposes with students ranging from middle school to graduate school and 2) capturing longitudinal data of simulation-building activities. Insights from the students' testing of the environment suggest that using drawings as conceptual models facilitates the transition from a real-life system to abstraction into implementation of the model. Longitudinal data capture provides the potential for identifying simulation-building habits across levels of expertise and the development of metrics and models for simulation development.

Author Keywords
MSaaS, STEM, Cloud-based Simulation Learning Environments, CSLE, CLOUDES.

ACM Classification Keywords
I.6. SIMULATION AND MODELING; I.6.7 Simulation Support Systems; I.6.8 Discrete event simulation

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1. INTRODUCTION

Simulations provide an efficient and effective way to learn. Alessi [**Error! Reference source not found.**] phrases some impact of simulations on education as follows (p. 185).

"Studying by using a simulation is quite different than studying a book, listening to a lecture, or doing a computer drill. In a scientific discovery simulation, for example, the learner is performing experiments, varying input variables in a systematic fashion, observing and recording output, and (if the simulation is designed well) reflecting on the results."

The medical, military, and aerospace fields are among some of the best-known users of simulations for training purposes as simulations provide practice before engaging with real patients, firing expensive weaponry, and flying planes. However, simulation learning is more than a single activity and can be seen as a series of activities that move between using and building simulations. Alessi posits that simulation use and simulation building fulfill different advantages for learning: efficiency and depth.

Simulations are efficient for learning by exposing learners to complex systems, which they do not have to build a simulation themselves. In this case, the learner uses the pre-built simulation for training or for performing different experiments. Moreover, simulations are efficient as they facilitate learning by providing a virtual environment in which the learner interacts safely, without the fear of damaging equipment or endangerment. For instance, a learner might take on the role of a chemist performing various experiments in a simulated lab. Such a simulation might facilitate the mixture of various chemicals or compounds, show the chemical changes to the substances when heated or chilled, and graph data to show how the combined solution changes with temperature over time.

Simulations also provide depth in learning from the perspective of building the simulation, as they require knowledge of the system or phenomenon of interest. Additionally, building a simulation allows students to form their own representations of the system and to engage actively in changing that representation for creating new scenarios. Changing the representation of the system allows the learner to answer different questions by capturing different levels of abstraction from the system. For instance, one simulation may capture a restaurant with one queue, one process, and one server. This simulation allows for the exploration of several scenarios: scenarios with different inter-arrival times, with different processing times, and with a varied number of servers. However, it does not allow the user to study a system with several (parallel or sequential) queues or several processes with multiple decision points.

In this paper, we present a roadmap for developing and implementing cloud-based simulation learning environments. The roadmap is based on our experiences with developing and testing a prototype called Cloud-based Discrete Event Simulator (CLOUDES). The remainder of the paper is as follows: section 2 reviews the use of MSaaS for education; section 3 discusses the requirements for implementing cloud-based simulation learning environments (CSLEs); section 4 provides a brief on CLOUDES and how it covers two of the six CSLE requirements; section 5 discusses the broader impact of CSLEs; section 6 provide notes on lessons learned when developing MSaaS; and section 7 presents our conclusions.

2. MSAAS FOR EDUCATION - CHALLENGES

Let us consider, for instance, middle and high school students. They are not only actively use mobile devices and the Web for learning but also social media-engaged. Thus, it is important to leverage these technologies when providing education, especially STEM-oriented topics, to the new generation.

MSaaS, as a cloud-based software delivery model [2] for learning, would provide simulation use, creation, and collaboration to students, teachers, and schools at a low cost and in a way they want to access information. The ultimate goal is to make simulation-building capabilities as ubiquitous as word processing capabilities or as sharing information using social media. To accomplish this goal, we need to make applications that can be consumed in the non-experts are comfortable with, while keeping the applications simple enough so that users are not scared away by steep learning curves. Yet, this is not without its challenges.

Wainer in Taylor et al. [3] posits that one of the grand challenges in modeling and simulation (M&S) is cloud-based simulation as they provide easy access to simulations by bringing them out of desktops or thin clients into mobile devices. However, there are many challenges to make this a reality. First, simulation tools are *built by experts for experts*, which limits the access to easy to use free tools. Second, even when they are free, most cases require desktop computers for installation and execution due to the intensive computational need. Lastly, in the rare cases where a tool is available on the web, they do not have modules for learning or teaching simulation use and building.

Moving computer intensive applications out of desktops and into the cloud is a major technical endeavor especially for existing simulation tool providers because:

- They need either to build virtualization capabilities or rely on third parties so that applications can run online. The limitation of running applications this way is that mobile access may be limited or not possible as some rely on technologies (e.g., Java applets) that cannot run on most mobile devices;
- They may have to rebuild (at least partially) existing applications using languages that provide mobile device execution (e.g., JavaScript); and

- They would now be required to develop and maintain applications for a platform that charges for storage, bandwidth, and processing needs when deployed on a cloud.

Ultimately, it becomes a business decision meaning that there needs to be enough users to support using a cloud-based simulation environment.

Based on our review there are few efforts for providing MSaaS to the public. Currently, we identify three efforts Insight Maker [4], CloudSME [5], and CLOUDES [6]. Insight Maker is a web-based tool developed at the University of California Berkeley for college and graduate student use and provides drag and drop functionality allowing users to build system dynamics and agent-based simulations. While not cloud-based, it provides most of the desired requirements of an MSaaS. CloudSME is a platform that consists of three layers: simulation and application, CloudBroker, and cloud computing resources, which together provide a tailored platform as a service for deployment of simulation software for small business in areas like manufacturing. One of the companies participating, in a consortium of sixteen, which is led by the University of Westminster, is Simul8, which is known for its discrete-event simulation application. Lastly, CLOUDES is a web-based, cloud-deployed simulation environment for building discrete-event simulations, developed at the Virginia Modeling, Analysis, and Simulation Center (VMASC) at Old Dominion University (ODU). CLOUDES is currently oriented to non-experts while providing functionality like drag and drop simulation building, simulation sharing, and built-in counters for data collection.

However, none of these efforts is oriented towards providing an environment for learning or teaching for the non-expert. Efforts like PhET Simulations [7] at the University of Colorado Boulder, while not cloud-based, provide a great access to simulation use by non-experts for learning about STEM concepts on both desktop and mobile devices. Unlike Insight Maker or CLOUDES, PhET does not provide access to simulation building capabilities.

In summary, we are moving in the direction of providing access to simulation use and simulation building online. It is argued that one of the goals should be educating not only students but also the community about the benefits of M&S and MSaaS is one way to do so. However, this is not a simple task. In order to move in that direction, we proposed six requirements for what CSLEs should consider in the following section.

It is important to note that while MSaaS provide certain advantages, cloud-implementation should not be a restricting requirement as long as 1) both simulation use and building capabilities are provided, 2) the capabilities are available across computing platforms, and 3) the capabilities are easy to use. Cloud computing is just one potential approach that enables the reuse of existing developments like simulation engines or APIs.

3. OVERALL REQUIREMENTS OF CSLEs

The high-level requirements for providing MSaaS are ease of use, mobile accessibility, and the ability to build simulations. On the other hand, we need educational requirements that facilitate basis for CSLE. In this case, a CSLE requirement list reads thusly:

1. Self-directed and instructor-directed modules;
2. A model/theoretical framework for education;
3. A model/theoretical framework for M&S;
4. Interactive/gaming experience;
5. Simulation use/build capability; and
6. Data capture for empirical research.

3.1. Self-directed and Instructor-Directed Modules: Learning from Simulation

A CSLE has the option of allowing a student to learn on her own at her own pace while being assisted by the environment. Options range from guided instructions, with defined objectives and evaluation options, to a more exploratory approach where guidance is provided when required by the student. An instructor-directed module is important for providing teaching support. This support ranges from class assignments to privacy controls in order to restrict outside access to class material. Both modules should be built around the following activities:

Getting to know simulations and their benefits: Clearly state what simulations are as well as their advantages and disadvantages when addressing real world problems. For instance, lines and queues are an important component in the study of modeling and simulation because they can portray a manifestation of inefficacies in a system.

Getting to know the CSLE: The following three components provide a comprehensive coverage for learning about simulations:

- *Simulation for STEM Education* is important because it provides students with a tool for learning about concepts like random number generators, queuing theory probability distribution, types of data, and graphical display of data among others. Simulations allow for learning by using the simulation and the content within the simulation as context.
- *Simulation Use (Playing with Puzzles)* focuses on familiarizing the student with the following activities: 1) question formulation (what the learner wants to know about the simulated system), 2) parameter variation (exploring the problem and solution space provided by the simulation), and 3) simulation-aided optimization (looking for a tentative parameter combination that provides the

best overall output). Lastly, the basic level simulation features the use of *counters* so that learners can capture data on the field and the intermediate-advanced level allows learners to use *replications*, which requires some basic statistics.

- *Simulation Building (Creating Puzzles)* provides learners with access to modeling and simulating capabilities in aid of decision-making and problem solving. They are expected to think about the system in real life and to 1) generate a modeling question, 2) formulate a problem, 3) conceptualize and 4) implement the simulation. The learner will deal with both building and modifying simulations.

- *Establishing Curricula and Tutorials* clarifies what will be learned so anyone with access to the CSLE has access to the same information. This manner students and teachers know what they can learn and how. As such, providing coursework materials like exercises, video tutorials or walk-through interactive lessons must be in place. In other words, the previous three options need to be conveyed in a manner that is easy to follow whether instructed or self-guided.

3.2. A Model/Theoretical Framework for Education

The online modules should be designed using pre-instructional strategies, such as pre-tests and advance organizers, as wells as generative strategies that keep learners engage in the instructional content and that will encourage them to partake in practice exercises. These modules could be designed using principles of learners' motivation such as the ARCS Motivation Model [8]. The ARCS model focuses on instructional content and activities that promote and sustain motivation in the learning process using: attention, relevance, confidence, and satisfaction.

Using the ARCS model as guidance, the activities in the online modules should provide the following benefits

- Stimulate the curiosity of the learners

- Establish how the new learning will use their existing skills and how they can use the skills in the future

- Help the learners understand the likelihood for their success at completing the tasks/activities

- Make the learners feel as through the skills acquired are useful and beneficial in a real world.

The primary goal of the modules is to provide an engaging learning experience in which the learners actively participate in knowledge creation rather than passive absorption of information. Important aspects of the design of the online modules include the organization of the instruction, active learning practices, assessment, feedback, and the creation of a learning community. These educational approaches should be combined with M&S-based methodologies like the Modeling and Simulation-System Development Framework – MS-SDF [9] and approaches like gaming to further the learning potential.

3.3. A Model/Theoretical Framework for M&S: The MS-SDF

The MS-SDF proposes that for building simulation models, users depart from a *complete as possible* description of the system/phenomenon in reality (reference model), generate a question of interest about the system/phenomenon (modeling question), create a subset of the reference model that is consistent, and use this conceptual model to build a simulation. The main idea is to verify the simulation model against the reference model.

Based on our testing of the environment with middle school and high school students, a narrative that describes a commonly known system (i.e. fast food restaurants and amusement parks) serves as a surrogate for a reference model in both simulation use and building. We capture this narrative using simple drawings as presented in Figure 1.

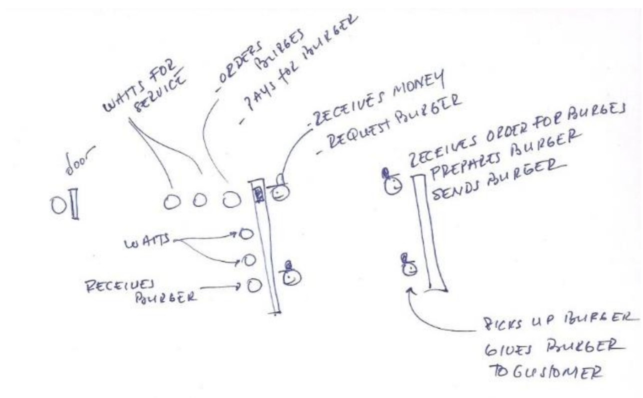

Figure 1. Drawing of the System as Observed [10]

Figure 2 and Figure 3 shows the transition from a reference model to a conceptual model, a simplified version of the reference that focuses on answering a research question. Figure 3 shows the simulation specification, which is then implemented in CLOUDES as depicted in Figure 4. According to McKenzie in Sokolowski and Banks [11], a conceptual model is a sketch of the system, which provides objects and actions related to systems but leaves out "unimportant details." (p. 149). Ultimately, the goal of a reference and conceptual model is to allow different modelers to discuss a representation of a system, disagree about their particular viewpoints, and facilitate the simulation building process. As such, a CSLE should have the option of not only drawing sketches of observed systems, but also provide more formal means of capturing these models, like using the Unified Modeling Language (UML), for more advanced students and to eventually facilitate verification efforts.

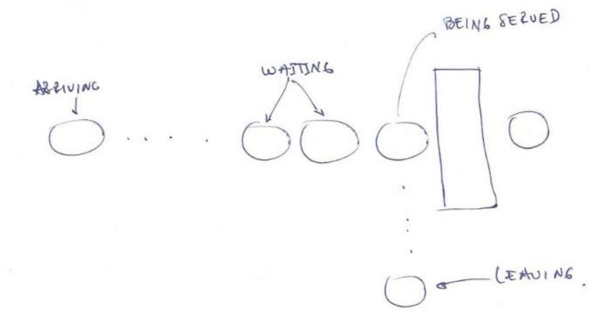

Figure 2. Drawing of the System (Simplified) [10]

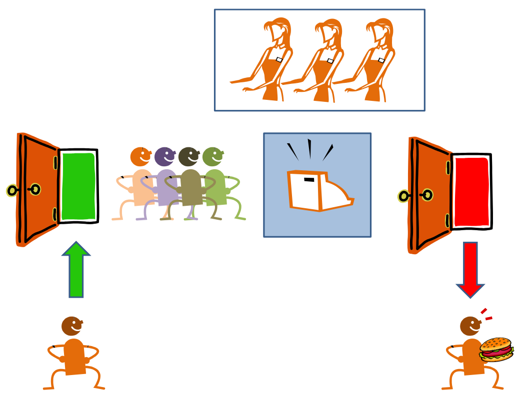

Figure 3. Graphic Transition [10]

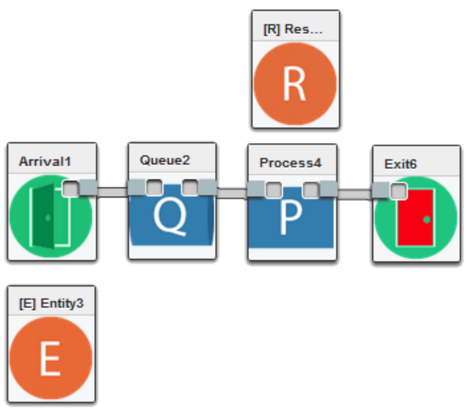

Figure 4. Simplified Representation in CLOUDES [10]

3.4. Interactive/Gaming Experience

According to Oblinger [**Error! Reference source not found.**], games in learning provide advantages such as: creating social environments which often involve distributed communities; acquiring necessary knowledge for playing; exploring problem solving techniques; transferring learning by bridging reality and games; and providing an experiential (multiple sense) and immersive learning understanding. In fact, humans have been playing games since the beginning of our species. The motivational aspect of digital games comes from the emotional appeal of fantasy and the sensory and cognitive components of curiosity [13]. Despite these advantages, games for high school students and college students that focus on simulation building are not available. Simulations for learning traditionally (i.e. within the medical, military, and aerospace fields) focus on the training of a skill through use but not on the training of building simulations. Likewise, and as mentioned previously, one of the potential advantages (some remain to be evaluated in this case) is the learning of STEM-related concepts through DESs for instance. Simulations provide a way of explicitly and tacitly exposing students scientific (random number generators, computability), technical (simulation design and execution), statistical (probability distributions), mathematical (functions), and engineering (queuing) concepts. Hence, it provides students access to higher levels of learning based on a Bloom's taxonomy [14].

Within our testing, we have found that students engage more when challenged with reducing queue length. As such, we take advantage of these situations to explain the potential ramifications these decisions can have in real life. While, this is not different from how a faculty teaches related topics, these options need to be built into the environment at a level that is not trivial but that also does not encumber the learning process. According to Van Eck [15], a game can be suitable for use in the classroom, if the game aligns with the class content and the game is so easy that it is not engaging. Additionally, the optimal learning state is that of being in a state of *flow*. This refers to a mental state of immersion and clarity [16]. Many individuals call it "being in the zone" and game players often discuss losing track of time for hours at a time.

3.5. Simulation Use/Build Capability

As previously mentioned, both simulation use and creation are crucial for engaging into simulation modeling. By using simulations, learners can interact in reality-based simulations to deal with day-to-day tasks or to handle emergencies that arise. Role playing such as this is used in crisis management, social science, and empathy-insight simulations are used for the education and training of teachers, managers, and therapists. These simulations provide a wide array of experience in a short amount of time, often facilitating both knowledge and affective learner outcomes.

An example of such a simulation is one where the learner *chooses* or *earns* various roles in a space station crew where they will be responsible for decisions necessary in that role. Roles might include ground-based commander, engineer, or scientist responsible for setting up and monitoring experiments aboard a space station. Another role could be that of an astronaut in space flying to and from the station as well as performing maintenance in space.

Simulation building allows students to create their representation of the system, which implies activities like problem formulation and problem simplification. Building simulations becomes crucial for two main reasons. First, it provides exposure to scientific and engineering activities, where the user is required to think in a systemic manner in order to observe, measure, and capture the real system. Second, it gives the student the power to build simulations of real or imagined systems as the created simulation needs to be captured in a manner that "makes sense" to the computer. This is perhaps the best reason why we compare the process of simulating with activities like programming.

3.6. Data Capture

In order to improve both the utilization of the environment as well as instructors' tracking of the progress of students, a CSLE should have the means of capturing behavioral data of users. Further, by capturing this data for research purposes, we can develop empirically grounded approaches for improving the use and building of simulations.

The questions now become what data to capture, for what purpose and how much? Initially, it may depend on the modeling paradigm being used. The goal is that the scientific community reaches a consensus of what variables to measure, across paradigms, to assess the impact of simulations on learning and cognition.

4. CLOUDES: SIMULATION USE, BUILD, AND DATA CAPTURE

Of the previously mentioned six requirements, the authors had made progress on the last two while exploring the ideas of the first four on informal testing sessions using CLOUDES, which lets users build, run, and share discrete-event simulations using a web browser. Technically, CLOUDES is a Java web application that relies on HTML5 standards at the front-end and Java Spring Framework at the back-end. Additionally, the back-end is coupled with an open source DES engine called DESMO-J [17] that handles the model generation and execution.

Learners have the option of *using* simulations from 1) provided examples, 2) simulations previously built by the learner, or 3) simulations made available by other users (Figure 5). Learners can *build* simulations from scratch or build on top of template or public simulations. Ease of use is facilitated by a drag and drop interface with no need for programming. The interface provides a link to the simulation as a thumbnail of the last state of the simulation instead of textual links or dealing with files. Additionally, users can search simulations by name, tag, or author. Cross-platform access allows users to play with simulations using a desktop or a mobile device. As the environment is web-based, users just need to use a browser and sign in to their accounts regardless of the device. Lastly, the environment is conceived to allow social interaction to grow by initially facilitating the sharing of simulations through email, social media, or by making them available to other users through the CLOUDES environment.

Currently, CLOUDES captures longitudinal data of consented users (IRB approval was obtained for this purpose) by measuring variables like the number of simulation components used and associated variables, such as the type of components and the number of connected components. These variables provide insight into learning constructs and their relationship. For instance, one can develop a model for predicting the time that a student-beginner user may take to develop a model based on the number of blocks and node types used.

One very short sequence captured by the system points to a suspected hypothesis: novices tend to use more blocks than experts when modeling the same system. In order to evaluate this hypothesis and put this observation to the test, more data needs to be collected.

Figure 5. CLOUDES' Landing Page

While these are basic metrics captured per individual, their aggregation can provide greater insight into challenges or semi-optimal sequences when building simulations considering variables like expertise level. For instance, the successful inclusion of several complex nodes in a simulation provides an idea of the complexity of the simulation. The consistent sequence of all nodes, when considering all the simulations built by a user, provides an idea of the dexterity of the user. Now, if we consider that there may be an "average" process of all the simulations built by a user, or in this case, a model of the simulation building process, we might be able to compare users and prepare knowledge transfer strategies from expert to non-experts.

Figure 6 shows a model of a CSLE. The model showcases the role of each requirement and the ultimate goal of providing STEM concepts to students worldwide through simulation use and building. In our case, CLOUDES takes the role of simulation environment and data capture, MS-SDF of M&S framework, and ARCS Motivation Model of Education framework.

5. DISCUSSION

As mentioned in Padilla et al. [6], the potential for cloud-based simulation environments of influencing STEM education is great but remains to be explored. For instance, if we consider using these environments for teaching and learning about probabilities for K-12/advanced placement students, the adjustment to accommodate such a program might be minimal. Learning sessions might include topics like types of data, types of distributions, distributions of bivariate data, and even design of experiments. While these topics are complex, they could be presented in context and not abstractly to help engage the students and facilitate learning. Simulations are appropriate for putting complex system/topics in context as in most cases we do not have access to such systems. In addition, researchers and educators can build simulations to let others learn from them. For instance, queuing systems are encountered across engineering disciplines like Manufacturing, Industrial, Systems, Management, Electrical, and Aerospace to mention a few. Professionals in these areas can make their simulations available, thus further increasing the context for learning not only about simulations but also about STEM.

In addition to the potential impact on STEM education, there are also tremendous capabilities for having a positive impact on students' cognition. We hypothesize that, like programming, building simulations have a positive effect on skills such as problem solving and critical thinking. There is no denying that these skills are developed when using and building simulations but there is no evidence in the literature that these skills are developed substantially different from non-simulation-based class activities. In this case, standardized tests, like the Problem Solving VALUE Rubric, can be supplied in CSLEs to evaluate their improvement after learning about using and building simulations.

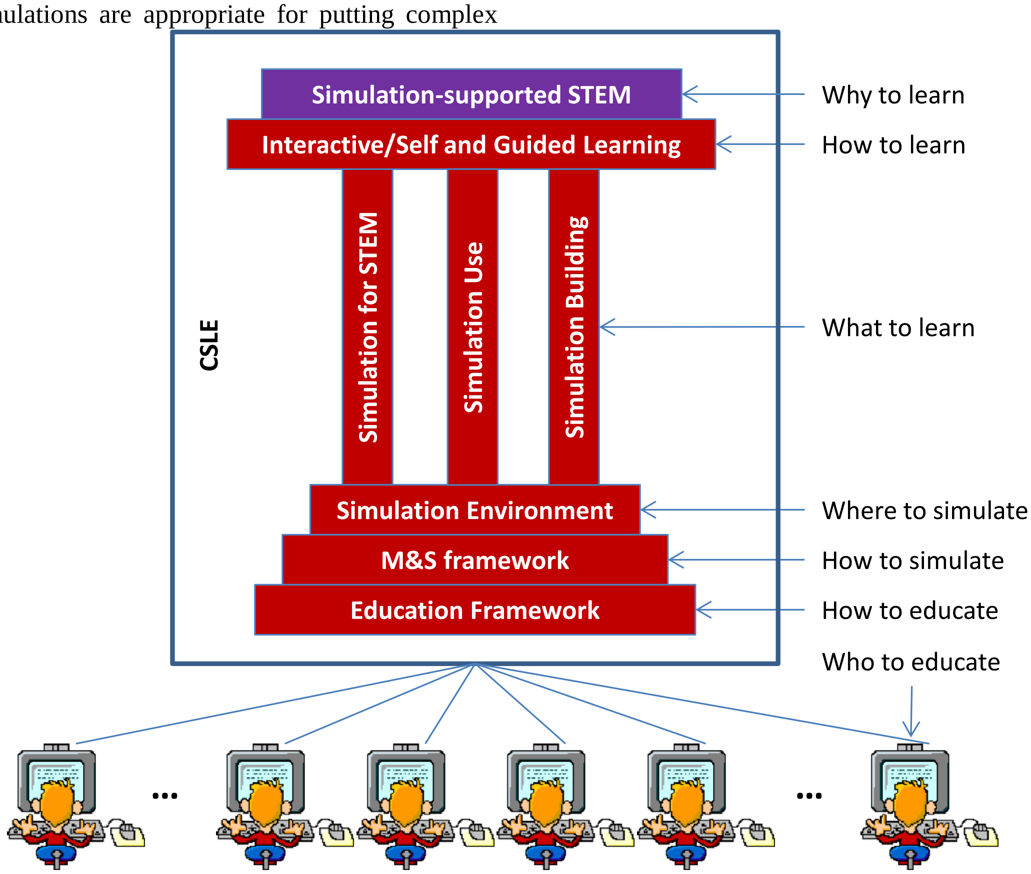

Figure 6. Model of a Cloud-based Simulation Learning Environment

Lastly, attitude and personality questionnaires can be provided in order to establish profiles of students for whom simulation-related activities are easier than others. If this is the case, the CSLE could be adaptable to the user and present information or provide feedback in a manner that targets a particular type of learner.

6. NOTES ON MSAAS COSTS AND CONSTRAINTS

It is important to note that while there are some technical differences and complexities in developing MSaaSs compared to perpetual licensed software, a major issue is the continued cloud computing costs for the MSaaS provider. One of the advantages of relying on cloud services is reducing the computing costs, especially when the endeavor is starting and the number of concurrent users varies. Therefore, if an existing simulation software effort provides their application free of charge, they now have to account for the expenses related of providing such service from the cloud. Potential approaches are charging a subscription fee, asking for donations, offering memberships, and charging for computing resources used among others.

Charging a subscription fee is the way to go for commercial endeavors that want to provide an alternative or altogether the only alternative to perpetual licenses. This follows the ongoing "traditional" subscription vs perpetual license business model such as those provided by Microsoft Office 365. Charging for computing resources used is another option for commercial endeavors. However, it is either for companies wanting to provide MSaaS to end-users or for companies that need computing intensive simulation capabilities. For instance, company *x* wants to run a series of scenarios for a new power plant design. Running these scenarios locally may require expensive hardware, but using MSaaS, the associated costs might be low, especially as these scenarios are needed either once or with low frequency. This is, for instance, part of CloudSME's (cloudsme.eu) model as it looks to reduce simulation costs for small businesses. For non-commercial endeavors, donations and memberships are viable options. Khan Academy relies partly on donations. Insight Maker is offered free but there are memberships available.

It is important to note that there are options for getting a cloud service off the ground. Amazon Web Services offers a free tier for a year so new projects can be tested and established. It is noted that if the resources used go over the free tier threshold then you incur some costs. Microsoft and Google offer free trials but in the form of credit to spend over 30 and 60 days respectively. Another relatively new alternative is provided by chameleoncloud.org. Chameleon is a research-oriented Infrastructure as a Service alternative service funded by the National Science Foundation. This option is free, but there is an evaluation process to go through and as mentioned, it is for conducting research that could rely on cloud computing services.

It is also noted that the above requirements are not without their constraints. For instance, the number of simulation building features may be limited or performance may be reduced compared to perpetual licenses options. This tradeoff can be due to many reasons: cloud-computing costs, bandwidth requirements, or computer-demanding scenarios. In these cases, users can rely on perpetual license options, pay-per-use cloud-computing resources, or combination of these options. These practices are commonplace in SaaS and PaaS. For instance, Google Docs provides great functionality for word and spreadsheet processing, but its features are limited compared to a desktop version. Adobe Photoshop just recently went subscription-based in its creative cloud version. However, it needs to be installed in the user's computer.

On the other hand, extra functionality may have a negative effect in the learning process as a growing number of options may overwhelm a novice user. If one of the challenges of existing tools is that they are too complex for non-experts, the idea is to reduce complexity by either limiting functionality or simplify their use.

7. CONCLUSION

While cloud services have made movies, music, word processing, and data analysis available to many, it is still in its infancy when it comes to providing simulation use and building capabilities in a user-friendly manner to experts and non-experts. Our ongoing research focuses on how to build these capabilities and extend them towards potentially enhancing learning and teaching activities. Providing access to these environments to students at an early age might not only increase the awareness but also has the potential for learning STEM-related concepts in context and motivate them in selecting STEM careers.

In this paper, we provide a roadmap that consists of requirements for creating a CSLE. These requirements include modules for self and instructor-guide learning, uses of simulation building methodologies like the MS-SDF, provide gaming-like interactivity to learners, and have the means for capturing data for both learner feedback and M&S research on simulation learning. These requirements include basic cloud-based requirements like ease of use, mobile accessibility, and social considerations.

Lastly, we provide a discussion on the potential broader impacts of MSaaS on STEM and cognitive skill development.

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