Proceedings of the 2014 Winter Simulation Conference
A. Tolk, S. D. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.

CLOUD-BASED SIMULATORS: MAKING SIMULATIONS ACCESSIBLE TO NON-EXPERTS AND EXPERTS ALIKE

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ABSTRACT

The benefits of on-demand resources, limitless processing, storage and sharing capabilities, and multiplatform support, to mention a few; have made cloud computing the technology to adopt in recent years. While the technology has been used in simulation to some extent, it has not been widely available as it is expensive and complex. This paper reports on the design and development of a cloud-based discrete event simulator called ClouDES. ClouDES provides a platform for designing and building discrete-event simulation with all the advantages of cloud computing. Potential impact non-experts users like small businesses and especially middle and high school students are described. Small business barriers of entry in terms of costs and required knowledge are expected to be reduced with cloud-based simulations. Students can be exposed to STEM concepts like probability function, queuing, and functions considering technologies they are familiar with like mobile devices and social media.

1 INTRODUCTION

According to Foster, et al. (2008) “cloud computing is hinting at a future in which we don’t compute on local computers, but on centralized facilities operated by third-party compute and storage utilities.” User friendly cloud-based services, like Netflix and SmugMug have been sprawling and becoming ubiquitous in homes and workplaces. Their advantage is that they are simple to use and provide a simple service: in these cases, access to movies and photo storage/sharing respectively. Updates on these services are transparent to the final user as he/she cares not about the complexity of the platform but that he/she can watch a movie or a photo.

It can be argued that this type of services would not have been feasible (technically and economically) if they would have had to constantly buy resources like storage or processing capability. The advent to cloud providers like Amazon Web Services, Windows Azure and Google Cloud Platform delivered such scalability at lower prices. Scalability and wide availability at lower prices are the elements that could make cloud computing a great platform to make simulations available to many. However, it sounds easier said than done.

Wainer in Taylor et at (2012) posited that one of the grand challenges in modeling and simulation is cloud-based simulation. Cloud-based, according to Wainer, would provide ubiquitous access to simulations by bringing them out of workstations, clusters or thin clients and placing them in mobile devices. Onggo, Taylor and Tulegenov (2014) position is consistent with Wainer’s in that cloud-based simulation (CBS) is one of the grand challenges of M&S and suggest that perhaps CBS would be more popular due to the perception that it is a socio-technological tool. CBS seems to be the future of M&S tools because of the advantages that cloud computing brings to M&S. One of these advantages is accessibility.

Brailsford in Taylor, et al. (2013) posited an interesting question: "Could simulation models be as pervasive as spreadsheets in healthcare organizations?" The ramifications of this question can be taken to: could we make simulations as easy to use as spreadsheets? Can we get them out of the hands of scientists and engineers and put them in the hands of small businesses and middle/high school students? CBS can be the technology to make simulations accessible to non-experts and experts alike. The challenge becomes establishing CBS requirements, how it could be used and prototypes or final products.

Keeping up with Taylor's terminology, this paper reports on a cloud-based simulator (CBR) that allows cloud-based simulations (CBS) to be designed, created and shared in a scalable environment. We speculate that the difficulty in simulation adoption is not that we don't have tools. It has to do more that they are oriented to experts and that they are not easily accessible.

2 CLOUD-BASED SIMULATIONS MAJOR CHARACTERISTICS

The idea of cloud computing has existed for decades yet its execution has varied as technologies change. According to Foster et al. (2008), cloud computing is "a large distributed computing paradigm that is driven by economies of scale, in which a pool of abstracted, visualized, dynamically-scalable, managed computing power, storage, platforms, and services are delivered on demand to external costumers over the internet." This definition captures keep aspects of cloud computing: scalability having an impact on economies of scale, computing/storage on demand, and services delivered over the internet. Claheiros, et al. (2009) summarizes it as "cloud computing delivers infrastructure, platform, and software (application) as services, which are made available as subscription-based services in a pay-as-you-go models to consumers." Infrastructure as a service (IaaS) refers to computers or virtual machines as services, platform as a service (PaaS) refers to working environments as services, and software as a service (SaaS) refers to how the software is delivered (as services). Yet, despite cloud computing relatively long existence its conceptualization in use in simulation has been recent and scarce.

According to Onggo, Taylor and Tulegenov (2014), cloud-based simulation (CBS) can be traced back to Fishwick (1996) in terms of model design, execution and analysis of results as web-based simulation (WBS) . In this paper, Fishwick mentions that WBS was an idea, more than an existing field, focused on simulationists exploiting the web (at a point in time when the web had about 50 million users). Fishwick sees several advantages (inherent to the internet) of having simulations on the web: 1) Infinite storage. The internet provides limitless storage capabilities unlike personal computers. As such, models "can have pieces on the web that do not require local storage," 2) Reuse. People can access existing information at a global scale considering, of course, intellectual property issues. 3) Client-server relation. One entity provides services and others use them. 4) Browser accessible. No need to install programs. They are delivered through a web-browser. 5) Muti-user capability. WBS should allow multiple users to interact with each other. 6) Reduced costs. Simulations usually run in costly computers and in some cases using costly software. As observed, these were insights of the potential of using web-based technologies on simulations for these to reach a higher level not only of ease of use and convenience but also of reuse while keeping cost low.

Fast forward to the decade of 2000-now and we start seeing how these ideas start taking shape. Pullen et al. (2005) proposes a migration from network to web services technologies in order to facilitate simulation data exchange with grid computing (as an evolution of distributed computing) considerations. Tolk (2006), for instance, mentions that " web services, as seen within the actual M&S research, are a set of operations, modular and independent applications that can be published, discovered, and invoked by using industrial standard protocols, such as Simple Object Access Protocol (SOAP), Web Service Description Language (WSDL) and Universal Distribution Discovery and Interoperability (UDDI)." While these two perspectives are within efforts towards addressing simulation interoperation and reuse, they capture the ideas of scalability and multi-user capability when connecting heterogeneous simulations. However, these efforts, usually funded under defense budgets, are complex and expensive which limited their assimilation by the M&S community at large.

Wainer in Taylor et al. (2012) provides a potential list of requirements for CBS (in the form of questions): 1) Smartphone capable, 2) able to deal with communication disruptions, 3) able to support multi-user collaboration, 4) able to integrate online services and data, 5) able to advance while combining discrete-event simulation and cloud computing, 6) allow for combining, sharing and reusing models and experiments, 7) able to manage large amounts of simulation results. Onggo, Taylor and Tulegenov (2014), based on the Cloud-based Simulation for Manufacturing and Engineering (CloudSME) suggest the following scenarios for a CBS: 1) execute simulations from cloud infrastructure, 2) provide simulation development capability, 3) allow for customization options (mix and match components) and 4) provide control over storage and execution platform.

In summary, a CBS must provide all the advantages of current cloud computing to facilitate and democratize modeling and simulation capabilities. Facilitating them in terms of allowing 1) computing, storage, and reuse/combine simulation resources and 2) sharing and collaborating using web browsers. Demecratizing in terms of 1) allowing access across platforms (mobile and workstations), 2) reducing costs, and 3) being "transparent" to the final user. It is important to note that while Wainer and Onggo, Taylor and Tulegenov refer to CBS for discrete-event simulation, CBS would be as beneficial for other modeling/simulation paradigms.

3 CLOUDES: TOWARDS A CLOUD-BASED DISCRETE-EVENT SIMULATOR

The ClouDES effort started on the second semester of 2012 with the simple idea of putting simulation within the reach of many. Discrete-event simulation (DES) was decided as the first paradigm as it was considered easier to relate to real systems in scenarios like going to the movies, waiting at the airport, baking cookies or building a house.

ClouDES attempts to gives non-expert and experts alike the capability of designing and building discrete-event simulations using a browser. Middle and high school students are encouraged to use it in class or for exploring questions that catch their curiosities. Teachers are encouraged to use ClouDES for teaching STEM- related courses. College students, small business owners and professionals are also encouraged to use ClouDES for basic/intermediate simulation design and building needs in areas like manufacturing, healthcare, business or transportation. Overall, it was built for people that would like to know more about simulations but are afraid of its perceived complex nature.

When thinking about simulations, two words come to mind: complex and expensive. Existing software have so many options that one gets lost in them. They are designed with experts in mind for work in engineering and the sciences. Computer licenses are expensive in terms of software and of potential hardware requirements. They are limited to use in a computer and if there is a need of moving simulations across computers, emailing/transferring/exporting files is needed.

Current tools are built with professionals in mind. There is nothing wrong with that approach, however, the entry conditions limit broad use and discourage people to try. It is akin to photography. In the film days, professionals or serious amateurs knew how to use or were aware of techniques and the equipment necessary to achieve great pictures. Digital photography brought down barriers creating large awareness by mainly reducing the learning curve and facilitating the photo sharing experience. Having professionals in mind make current tools complex. This complexity in tool used is translated, in some instances, in the modeling process. In other words, it is not about modeling but about dealing with the tool.

ClouDES attempts to eliminates those restrictions. It satisfies most of the characteristics found in the literature in section 2. Emphasis was made on three: *Multi-platform accessible* (browser-based), *ease of use* and potential for *social growth*. Figure 1 shows how ClouDES work. Simulation design takes place at the client side. Information is then sent to the server where the simulation is executed and required data stored. Results are then fed back to the client for visualization purposes. As heavy execution takes place in the server, thin clients like mobile devices can be used.

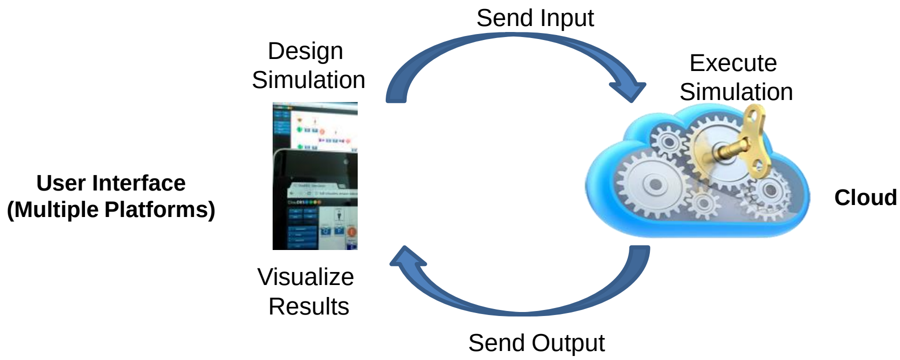

Figure 1. ClouDES Concept

3.1 Web and Mobile Access

While options for displaying simulations on a browser already exist, these options are not accessible on mobile platforms. Java applet is the current technology to which most simulation applications export simulations to. To make simulations accessible from mobile platforms, the standard now lies on two technologies: HTML5 or apps. HTML5 provides the advantage that programs can be executed on both computers and mobile devices by using a browser. This makes it easier in the developing process as programming is done for all platforms with considerations when the application is executed on each. For instance, mobile devices can run a simplified version of the desktop option that facilitates navigation in smaller screen sizes. The disadvantage is threefold: design options are limited, they are not as good in terms of performance and they may execute differently in different browsers. On the other hand, apps provide a variety of interface design options and are faster in execution time. However, this considerably increases development time as apps need to be built for different operating systems and in some cases, for different versions of the same operating system in order to reach the most people possible. Further, an option for desktop web browsers needs to be built as well.

Ultimately the decision of implementing ClouDES using HTML5 was made on two aspects: reduced cost of implementation and that the flexibility of mobile devices is great for capturing data or executing simulations, but not necessarily for building them. While a simulation can be built using a tablet, they are still perceived as means of consuming media not generating it. In addition, building hybrid apps, html5 in native “wrappers” is always an option or building the app from the ground up. HTML5, CSS, and Javascript are the technologies used to achieve the ClouDES’ client side functionality which includes the graphical design interface, the counter tool, and animation.

3.2 Ease of Use

Needless to say, ClouDES has two major components: a simulation component, a cloud component and a web component. On the simulation side, the Discrete-Event Simulation and MOdeling in Java (DESMO-J)(Gobel et al. 2013) is used as the simulation engine. The engine is maintained and updated by the Department of Computer Science at the University of Hamburg. After a new simulation feature is implemented, results are compared against results using the same or similar feature from existing simulation software. This comparison is done for validation purposes. DESMO-J is run on the cloud side on local computers for testing and on amazon web services for deployment.

A large part of the ease of use is built on the interface in a manner that contributes to simulation design. ClouDES uses the Meemoo Graph Editor (Oliphant, 2012) to facilitate the graphical design of the model. The graphical design components consist primarily of nodes and wires. A node is placed on the design canvas using a drag and drop interface, utilizing a mouse on desktop systems or a finger on mobile devices. Color and shape are used to easily identify node types and code those placed in pairs, namely, arrival/disposal, queue/process, entity/resource, and batch/separator. Nodes are connected by wires to describe the flow of the model, and wires are also placed using a drag on the screen. As part of the design process nodes may be freely added, removed, connected, disconnected, and repositioned on the canvas individually or in groups. Figure 2 shows a snapshot of ClouDES Design Interface showing a simulation design and the color-coded components used for building it.

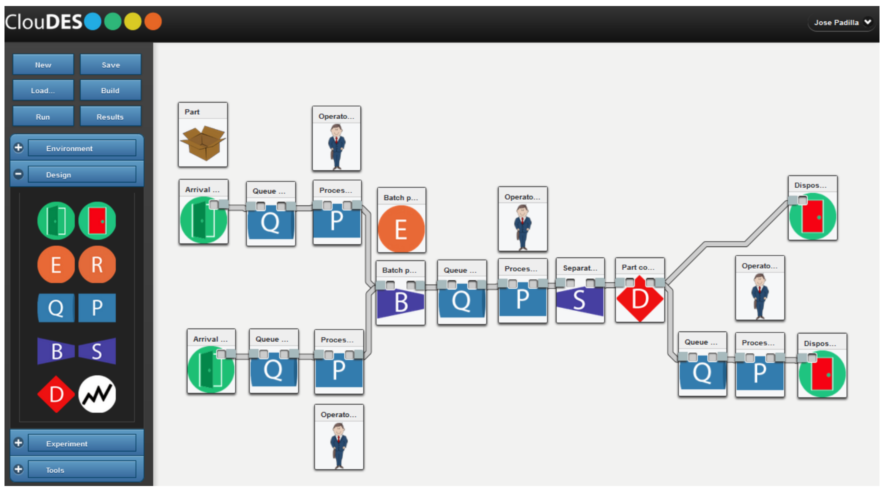

Figure 2. ClouDES Design Interface

Part of the simulation process is the capture and analysis of on-site data: measuring inter-arrival times. Capturing data, for it to be used in simulations, is usually a four-step process: 1) capture the data using a chronograph and usually pen and paper, 2) transcribe that data to a digital format, 3) conduct an statistical analysis of the data and 4) input the empirical distribution in the simulation. It is a process that takes time and also can be prone to human errors while transcribing information from analog to digital. Given that ClouDES run from mobile devices, a built-in Counter provides the advantage of capturing data, create an empirical distribution from the data and use it as in input in the simulation.

There two types of counters: single and dual. A single counter captures one inter-arrival time while dual captures two measuring for instance queue and server times. Figure 3a shows a dual counter. The counter can be saved, appended and shared (feature yet to be implemented).

As with the captured data, the reporting of simulation results is crucial. There are two options: one provides a summary report while a second provides and a complete report that can be exported for further analysis/reporting. Figure 3b shows the summary result. It is noted that when running more than one replication, the report is only available for export.

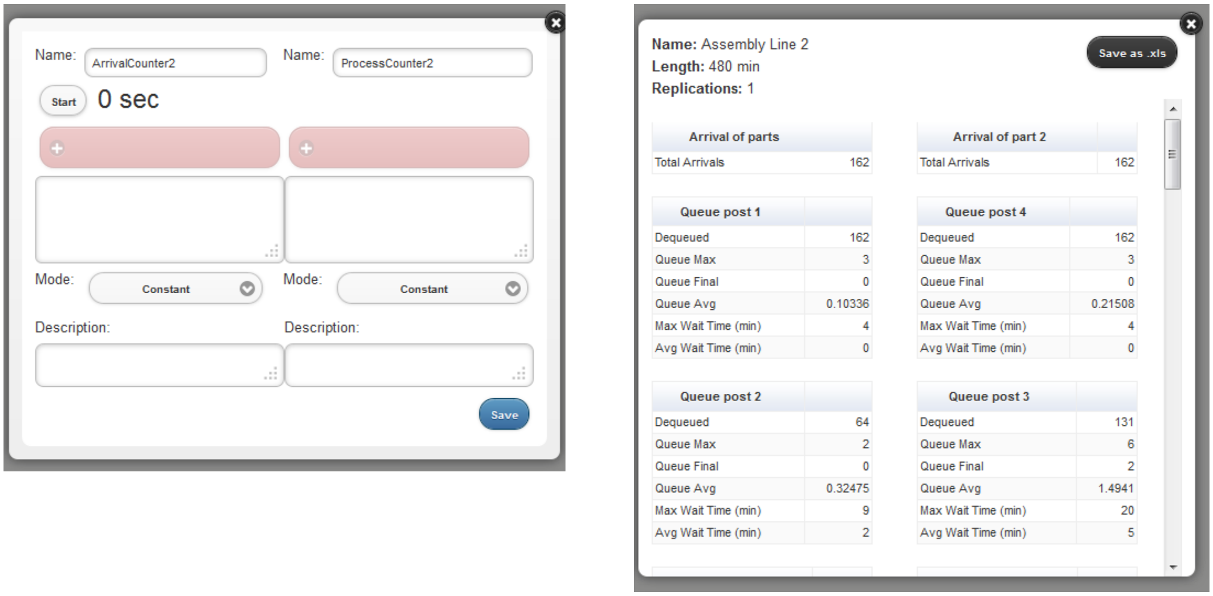

Figure 3a and 3b. Dual Counter Tool and Simulation Summary Results

3.3 Social Growth

Lastly, borrowing a page from social media, there is the consideration on how to share our simulations. ClouDES provide a simple login option either by creating an account or using a Facebook account. Basic information is captured and stored in a database (PostgreSQL) with associated simulations. Simulations are by default private but they can be made public thus sharing them with the ClouDES community. The authors expect to have the ability to export simulations in an html format so they can be shared (using links) in social media sites like Facebook, Twitter or LinkedIn.

The expectation is that students use the tool to explore simulations, do homework assignments, and work on large simulations projects jointly. For instance, using the counter they can share the duties of data collection and generate one comprehensive data set of a system in question; they can work on a common public simulation; or participate in workshops for data analysis.

4 PROMOTING STEM EDUCATION USING SIMULATION

As previously mentioned, current focus is on non-expert users. Purposefully the tool has fewer options but with more elements to support simulation design using those options. The prospective first users of ClouDES are those that favor mobile devices and social media use: students.

Over the last decade, considerable resources have been invested by private and government entities encouraging more students at the middle and high school level to pursue fields in science, technology, engineering and math (STEM). While there may be many reasons why students choose not to pursue STEM fields (a lack of awareness, a fear of math, or ineffective methods of inspiring students to pursue STEM programs), a potential way forward is one that facilitates the introduction of complex STEM-related problems and solutions at an early age using simulations. Putting complex problems into context in a simple and unobtrusive way is one of the advantages of simulations.

Simulation is a way of explicitly and tacitly expose students to scientific (random number generators, computability), technical (simulation design and execution), statistical (probability distributions), mathematical (functions), and engineering (queuing) concepts. More importantly, simulations can facilitate the communication and the exploration of potential solutions of complex problems by familiarizing students with situations through *what-if* questions and scenarios: *what* would be the total number of cookies produced *if* we have one oven (or two or three) and five family members participating? *What* would be the queue length at the movie theater *if* people arrived in groups of four for one hour? The issue remains that students are exposed late in life to simulations due to the lack of awareness or because of complexity or costs associated with simulation.

Putting simulations within reach of students, in environments with which they are familiar and comfortable, would more readily and effectively facilitate students' exposure to simulations. Further, building and running simulations would: 1) help students develop skills like abstract reasoning; 2) expose students to statistical and mathematical concepts gradually and within applicable contexts; and 3) engage students with applications across industries like manufacturing and logistics, banking services, oil and gas, mining, aerospace, transportation, and healthcare among others. Using pre-built simulations, for instance, elementary students can become aware of how real systems can be represented in a computer; middle and high schools can run simulations of day-to-day activities like queuing in a movie theater and compare to the real world *while* at the movies. In other words, they can use their smartphones for learning in an entertainment context.

Having access to simulation resources from different platforms opens the level of access for users, and especially those that rely on mobile. According to a study conducted by Harris Interactive for Pearson in April 2013[1], students are embracing mobile technologies in their learning process. Figure 4 shows some of the statistics of the report.

The potential of reaching these students is encouraging. In Virginia alone there are over 330 high schools supporting almost 400,000 students. In addition, there are over 300 middle schools and over 1000 elementary schools in the state. Employing Modeling and Simulation (M&S) in the classroom could produce 60,000 future STEM-aware professionals annually in the state. This is assuming a modest one out of every six high school students is stimulated by the engagement. Extrapolating these numbers, the potential impact of ClouDES (or any other cloud-based tool made available to students), not only at the state level (middle and elementary schools) but also at the national and international level would be significant. Further, in terms of job growth, the growing numbers of jobs requiring STEM skills are not being filled as rapidly as the job market demands it. According to Carnevale, Smith, Stone et. al (2011), STEM job demand is projected to grow by 9% between 2010 and 2018 with 70% of these positions requiring a Bachelor's degree (or better).

It is noted that ClouDES can and will be used by small businesses. However, as resources are limited, the effort now is reaching and training the next generation of modelers and simulationists.

[1] The sample was of 3,556 students, of which 500, 750 and 1100 were of elementary (4th and 5th grade), middle (6th, 7th and 8th grade) and high school (9th, 10th, 11th, and 12th grade) respectively. Interviewing was conducted from January 28 to February 24, 2013

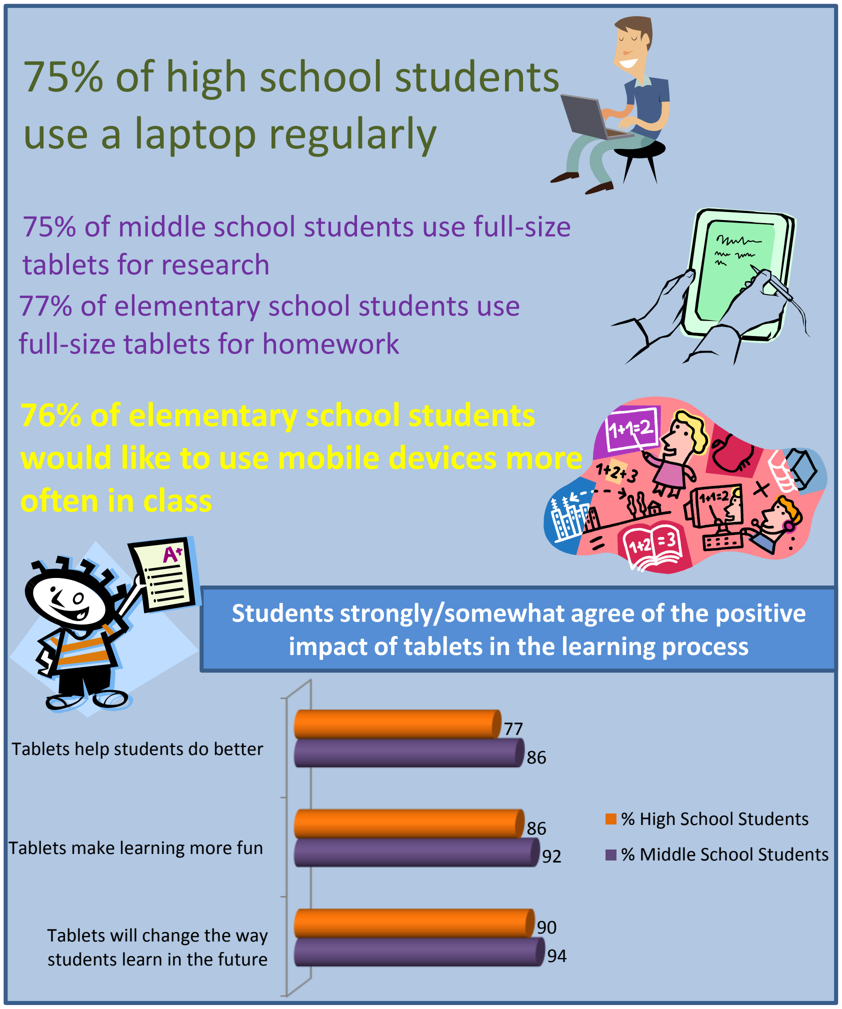

Figure 4. Summary of Pearson Student Mobile Survey 2013 (National Topline Results)

5 DISCUSSION

Facilitation and democratization of simulations on the web would go a lot farther by just making simulations available on the web. Efforts like Anylogic's "Run the Model", Netlogo's "Community Models", University of Colorado Boulder's "Phet Interactive Simulations" or market places like the newly created Simulr.com, are on the right direction. Not only do we need simulation repositories, but we need to generate awareness of them to non-experts. Today, most people are familiar with the activity of programming or coding. In recent years there has been a tremendous effort of bringing coding to the masses. However, the same cannot be said about simulation. Anecdotally, many of us can speak about people asking what we do and receiving a stark look back or just a question: what do you mean by modeling and simulation?

Cloud computing is here and many has made it an M&S challenge. Not because of fads, but because it facilitates accessing models and simulations by the community. Efforts like that of CloudSME would provide the per run capability that small and large business may need in the near future and further provide support for simulation practitioners. Come Fall 2014, ClouDES will provide non-experts and experts the capability of building simple but meaningful simulations using a browser and that is one step in addressing the challenge. ClouDES can provide simulation awareness and access to simulations to many, especially students. Simulations are a great way of teaching them STEM concepts, like probability distribution and queueing in DES case. The impact of cloud-based simulation and STEM education are not trivial as many STEM jobs go unfilled.

It is important to emphasize the potential of cloud-based simulations in K-12 education: students can share data collection, simulation design and data analysis duties led by themselves and instructors. Tools must provide the means for group learning in challenging areas like STEM. A concerted effort to create simple to use online simulation training modules, like Phet Interactive Simulations, is needed. The technology is there and that is perhaps the greatest challenge of cloud-based simulations: making simulations, and the technology to create simulations, available to the masses in a manner not more complex than creating a Vine video or an animated GIF. This would allow people to engage others and trade groups with simulations of interest while capitalizing, among other technologies, on social media to do so.

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