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

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ABSTRACT

The benefits of on-demand computing capabilities, broad network access, maintainability, and multiplatform support are some of the essential characteristics that 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 executing discrete-event simulations with all the advantages of cloud computing. Its web-based easy to use interface attracts even non-expert users. As an example, the potential impact on non-experts users like students and especially middle and high school students are described. It is believed that students can be exposed to STEM concepts like probability, queuing, and functions while using 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 won'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 easy 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 the user cares not about the complexity of the platform, but for the ability to watch a movie or display a photo.

It can be argued that these types of services would not have been technically and economically feasible if they had to constantly buy resources like storage or processing capability. The advent of cloud providers like Amazon Web Services, Windows Azure and Google Cloud Platform delivered such scalability at lower prices. Scalability and increased availability at lower prices are the elements that make cloud computing a great platform for making simulations available to a wider audience.

Wainer in Taylor et al. (2012) posited that one of the grand challenges in modeling and simulation is cloud-based simulation (CBS). According to Wainer, CBS 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) take a position that is consistent with Wainer in that 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 ever be as pervasive as spreadsheets in healthcare organizations?" The ramifications of this question can be taken to: can 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 middle school and high school students? CBS can be the technology to make simulations accessible to non-experts and experts alike. The challenge becomes establishing CBS requirements, and determining how it can be used for prototyping or developing simulations.

Keeping up with Taylor's terminology, this paper reports on a cloud-based simulator that allows cloud-based simulations to be designed, created, and shared in a scalable environment. Although simulation development tools exist, we speculate that the difficulty in simulation adoption is that they are oriented toward experts and are not easily accessible.

2 MAJOR CHARACTERISTICS OF CLOUD-BASED SIMULATIONS

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 key aspects of cloud computing: scalability having an impact on economies of scale, computing and 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 model to consumers." *Infrastructure as a service* (IaaS) refers to the use of computers or virtual machines as services, *platform as a service* (PaaS) refers to the use of working environments as services, and *software as a service* (SaaS) refers to the use of software as services. The conceptualization of cloud computing as a resource for simulation has been both recent and scarce despite the relatively long existence of cloud computing.

According to Onggo, Taylor and Tulegenov (2014), cloud-based simulation (CBS) can be traced back to Fishwick (1996) in terms of model design, simulation execution, and analysis of results as web-based simulation (WBS) . Fishwick (1996) mentions that WBS was more of an idea than an existing field and focused on simulationists exploiting the web at a time when the web had about 50 million users. Fishwick (1996) identifies several advantages inherent to the internet of having simulations on the web: 1) Vast amounts of storage. The networked infrastructures can provide greater storage capabilities than personal computers. As such, models can have pieces of information stored on the web that "do not require local storage" (Fishwick, 1996), 2) Reuse. People can access existing information at a global scale, 3) Client-server relation. One entity provides services and clients use them. 4) Browser accessible. No need for users to install additional programs, as the programs are delivered through a web-browser, 5) Multi-user capability. WBS should allow multiple users to interact with each other, and 6) Reduced costs. Simulations are usually run using costly computers and in some cases using costly software. These are insights into the potential of using web-based technologies for running simulations to increase ease of use, convenience, and reuse, while reducing costs.

Looking back at this past decade we see how these ideas started to take 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. 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)." These two perspectives are efforts towards addressing simulation interoperation and reuse, and 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 limit their assimilation by the M&S community at large.

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

In summary, a CBS must provide all the advantages of current cloud computing to facilitate and democratize modeling and simulation capabilities. Facilitation in terms of allowing computing, storage, and reuse to combine simulation resources while sharing and collaborating using web browsers. Democratization in terms of allowing access across platforms, including mobile platforms and workstations, reducing costs, and being "transparent" to the final user. It is important to note that while Wainer in Taylor et al. (2012) and Onggo, Taylor and Tulegenov (2014) refer to CBS for discrete-event simulation, other modeling and simulation paradigms can also benefit from CBS.

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

The ClouDES effort started in Fall of 2012 with the idea of putting simulation within the reach of the many. Discrete-event simulation (DES) was chosen as the initial paradigm as it was considered easier for people to relate to scenarios in real life, such as going to the movies, waiting at the airport, baking cookies, or building a house.

ClouDES attempts to give non-expert and experts alike the capability of designing and building discrete-event simulations using a browser. Middle school 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 are encouraged to use ClouDES for basic to intermediate simulation design and construction in areas such as manufacturing, healthcare, business or transportation. Overall, ClouDES 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. There are so many existing software options that one can get lost in them. They are designed with experts in mind for work in engineering and the sciences. Computer licenses are expensive in addition to the cost of potential hardware requirements and are often restricted to use within a computer. If there is a need to move models across computers, then a method for transferring or exporting the files is needed. Popular DES software, such as AnyLogic and Arena, require expertise in the areas of programming and model design, require specific operating systems, and the software licenses can be expensive.

Current tools are built with professionals in mind. There is nothing wrong with this approach, however, the entry conditions limit broad use and discourage people from trying the tools. It is akin to photography. In the film days, professionals or serious amateurs were aware of or knew how to use the techniques and the equipment necessary to achieve great pictures. Digital photography brought down barriers and created large awareness in a large part by reducing the required learning curve and facilitating the photo sharing experience. Having professionals in mind for tool development makes current tools complex. This complexity in tool design is transferred, in some instances, to the modeling process. In other words, it is less about modeling and more about dealing with the tool.

ClouDES attempts to eliminate the restrictions of complexity and expensiveness. Complexity is reduced by removing the requirement for the user to be a professional, allowing access to the tool through numerous devices, and providing a simple outlet for users to share their models with each other.

Expensiveness is reduced by removing the requirement for the user to purchase the hardware necessary to run large-scale simulations, providing the users with storage space to contain the results of the simulation runs, and allowing for reuse of simulation components, including the ability to modify existing models and reuse sets of input data. In addition to eliminating the restrictions of complexity and expensiveness, emphasis was placed on *multi-platform accessibility* (browser-based), *ease of use*, and potential for *social growth*. While *multi-platform accessibility* and *ease of use* involve a web-based interface, *social growth* involves both the larger audience that ClouDES targets, specifically middle and high school students, as well as the ability for users of ClouDES to share their models and results with other users.

ClouDES contains three main features for the user. First, web and mobile access involving a graphical design interface for building models. Second, a data collection tool for collecting data and storing it directly to ClouDES for use in the simulations. Third, the simulation output data is provided back to the user. These features are addressed in detail in the following three sub-sections. Figure 1 provides an overall view of how ClouDES works. Simulation design takes place at the client side. Information is then sent to the server which executes the simulation and generates the output data. Results are fed back to the client for visualization and analytical purposes. As the heavy simulation execution for ClouDES takes place in the server, thin clients like mobile devices can be used for simulation design, sending input to the cloud, and viewing the results.

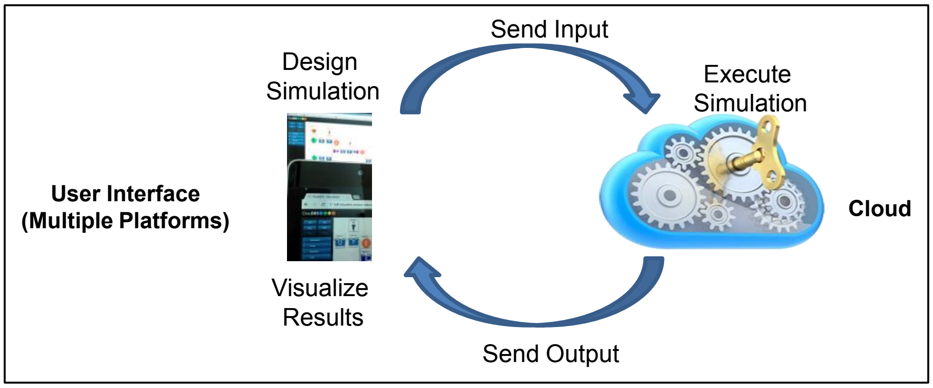

Figure 1. ClouDES Concept.

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 make simulations accessible from mobile platforms, the standard now lies on two technologies: HTML5 and apps that run on smartphones and tablets. HTML5 provides the advantage that programs can be executed on both computers and mobile devices by using a browser. This simplifies the development process as programming is done with respect to all platforms that will use the program. 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. In some cases, apps also need to be built for different versions of the same operating system in order to reach the most people possible. In order to run the app on a desktop, an option to run the app for desktop web browsers also needs to be constructed.

Ultimately the decision of implementing CllouDES using HTML5 was made on two aspects. First, using HTML5 reduced the cost of implementation. Second, the use of HTML5 allowed for increased flexibility since mobile devices are great for capturing data or executing simulations. While a simulation can be built using a tablet, they are still perceived as a means of consuming media, not generating it. In addition, constructing hybrid apps are always an option of building the app from the ground up, such as building HTML5 in native "wrappers." 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

ClouDES has two major components: a simulation component and a web component. The simulation component of ClouDES uses the Discrete-Event Simulation and Modeling in Java (DESMO-J) 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 the results of comparable simulation engines for validation purposes (Gobel et al. 2013). DESMO-J is tested on local servers and deployed on Amazon Web Services.

The web component of ClouDES functions as the interface for simulation design. A major focus of the web component has been ease of use. 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 and disposal, queue and process, entity and resource, and batch and 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 Graphical Design Interface showing a simulation design and the color-coded components used for building it.

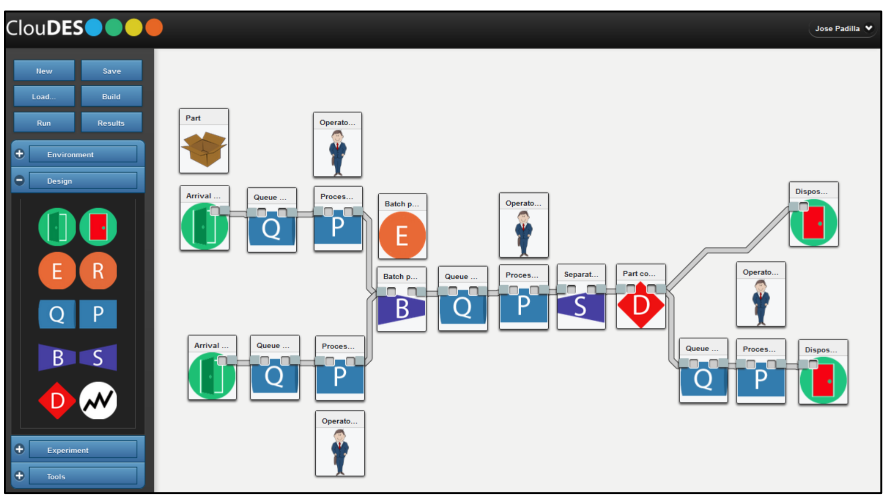

Figure 2. ClouDES Graphical Design Interface.

A major component of the modeling and simulation design process is capturing and analyzing on-site data. Depending on the system being modeled this can include, measuring inter-arrival times, processing times, transfer times, and wait times at various points in the system. Capturing data for use in a simulation usually involves 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 a statistical analysis of the data, and 4) input the empirical distribution in the simulation. It is a time-consuming process that can be prone to human errors while transcribing information from analog to digital formats.

Given that ClouDES runs from mobile devices, a built-in counter provides the advantages of capturing data, creating empirical distributions from the data, and using the distributions as input for the simulation. ClouDES contains two types of counters: *single* and *dual*. The *single* counter allows for the user to capture a single set of data at one time, such as inter-arrival times to the system. The *dual* counter allows for the user to captures two sets of data at one time, such as recording system inter-arrival times and server processing times, simultaneously. Figure 3a shows a view of the *dual* counter.

The reporting of the simulation results is just as crucial as capturing the system input data. There are two options within ClouDES for providing the results back to the user. The first option provides a summary report which provides information at the nodes within the simulation. Figure 3b shows an example of the summary report. The second option provides a complete report that can be exported for further analysis and reporting.

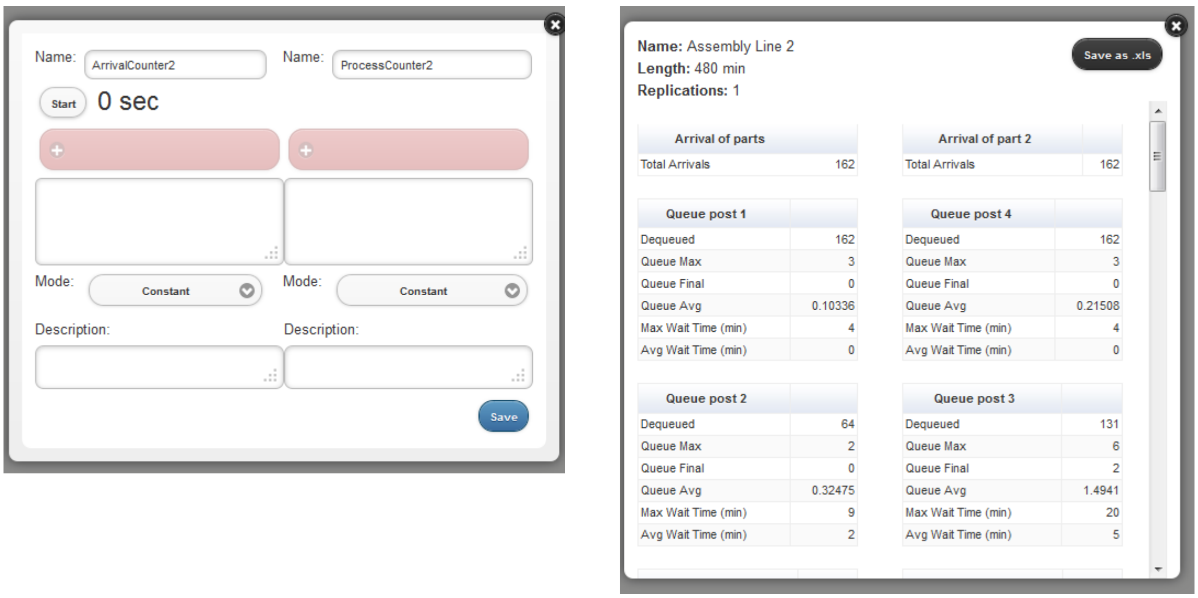

Figure 3a and 3b. Dual Counter Tool Interface and Simulation Summary Results.

3.3 Social Growth

Lastly, there is the consideration of how to share the simulations that are built in ClouDES. ClouDES provides 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 common, public simulations; or they can participate in workshops for data analysis.

4 PROMOTING STEM EDUCATION USING SIMULATION

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) (Kuenzi, Matthews and Mangan, 2006). 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. A study conducted by Sadler, Sonnert, Hazari, and Tai (2012) found that middle school students with high grades in mathematics courses had an increased propensity for joining STEM careers following high school. Simulation is a way of explicitly and tacitly exposing students to scientific (random number generators, computability), technical (simulation design and execution), statistical (probability distributions), mathematical (functions), and engineering (queuing) concepts.

Putting complex problems into context in a simple and unobtrusive way is one of the advantages of simulation. 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, two, or three ovens with 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, such as manufacturing and logistics, banking services, oil and gas, mining, aerospace, transportation, and healthcare among others.

ClouDES is setup for use by students, especially at the middle school and high school levels, to provide awareness of simulation to the students. As previously mentioned, ClouDES is currently focused on non-expert users. Purposefully, the tool has fewer options than other DES tools. However, there are more elements to support simulation design using these options. Students are the prospective first users of ClouDES, since students favor mobile devices and use social media.

At the elementary school level, ClouDES allows for elementary students to become aware of how real systems can be represented in a computer by using pre-built simulations within ClouDES. Students at the middle and high school levels can experiment with simulations by running simulations of day-to-day activities like queuing in a movie theater. These students can then compare the observations that they gain from the simulations to their observations of real-life and gain first-hand knowledge of using simulation. The ability to access ClouDES on a smartphone provides an extra benefit to the students in that the students can conduct data collection for real systems while interacting with the real system.

Having access to simulation resources from different platforms opens the level of access for all users, especially those that rely on mobile technology. According to a study conducted by Harris Interactive for Pearson in April 2013, students are embracing mobile technologies in their learning process. Figure 4 shows some of the statistics of the report. The sample was of 3,556 students, of which 500, 750 and 1100 were of elementary (4^{th} and 5^{th} grade), middle (6^{th}, 7^{th} and 8^{th} grade) and high school (9^{th}, 10^{th}, 11^{th}, and 12^{th} grade) respectively. Interviewing was conducted from January 28 to February 24, 2013.

The potential of reaching middle school and high school 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 that a modest one out of every six high school students is stimulated by the engagement.

Generalizing these numbers, the potential impact of ClouDES (or any other cloud-based tool made available to students), not only at the state level 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.

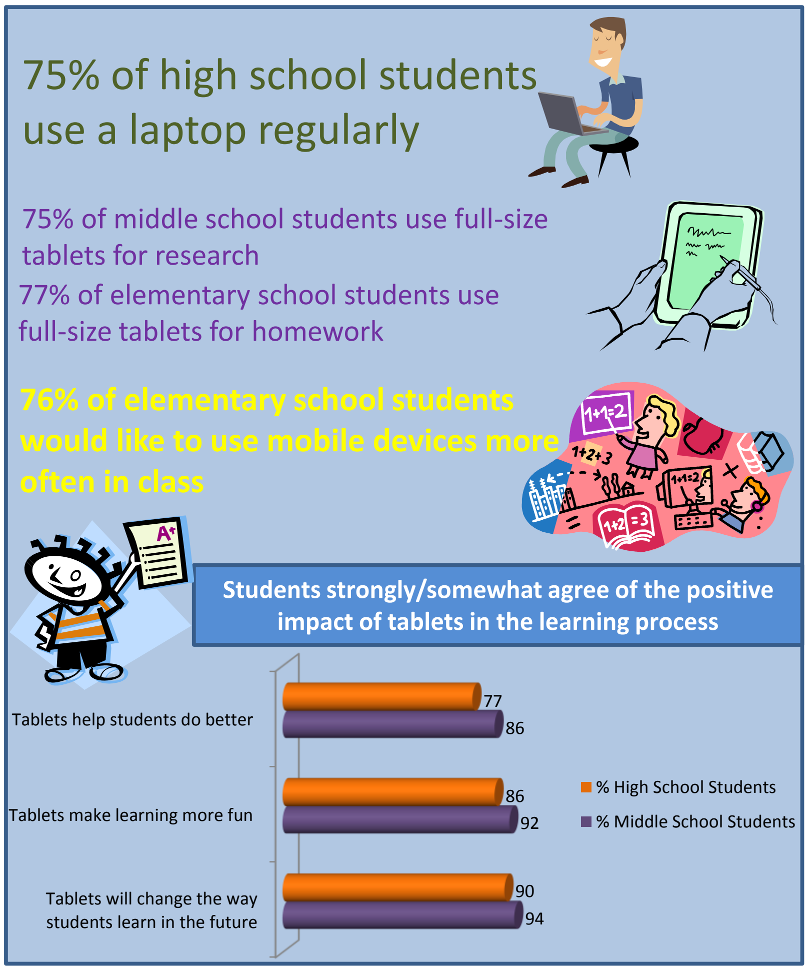

Figure 4. Summary of Pearson Student Mobile Survey 2013 (National Topline Results).

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 in 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 have 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 queuing. 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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