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Why teach modeling & simulation in schools?

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Advancements in science and technology take place on a global scale without much consideration of the exact implications that they may essentially have on the species or our planet. Over the last few decades, things are moving very fast and not always in a good way. The climate of the planet is changing drastically. Ice caps are melting faster than ever. Known animal species around the world are declining at rates faster than ever previously known in recorded history. We humans, might have intelligent individuals amidst us. However, collectively, to any external observer, we would perhaps seem to act more like mindless scavengers stripping the planet of its resources faster than she can ever replenish them. And this all seems to be intrinsically linked with our seemingly insatiable "collective" urge to satisfy immediate needs. So, while the technological revolution has greatly benefited humankind, our continual reliance on technology also has considerable collateral effects on the planet.

Influential researchers with foresight have identified a large set of problems which we are either already facing, or are about to face very soon. Stephen Hawking, Elon Musk, Peter Norvig, Stuart Russell, and hundreds of other researchers have noted the dire consequences facing the human race. Considering the possibilities, some of these researchers have even suggested moving out of the planet to either other planets in the solar system or beyond. If we were to think about what makes these researchers unique, then perhaps, we can say that it lies in their cognitive abilities - the ones which allow them to model, simulate, and visualize in a better manner than others. However, unfortunately for the human civilization, "a hundred" or even "a thousand" is clearly too insignificant a number in the big scheme of things. To truly save the planet, we certainly need a lot more of such thinkers and visionaries. And we also need more science communicators who not only themselves learn science but also create effective visualizations and material for future human generations.

Whether it is the visualization of neurons to understand consciousness (Reardon 2017), or the estimation of the effects of drug-resistant bacteria over time (Willyard 2017) or even for the understanding of, or planning for, containment of future pandemics, it is clear that modeling, simulation, and visualization (MS&V) are extremely essential skills. These skills are important not only for the advancement of science and technology, but also for the continued sustainability of the human species on this planet.

We model, perhaps because we want to make sense of the world around us. The models in our mind or mental models can be implicit or explicit (Hanisch et al. 1991). Essentially implicit models give rise to models which we use to communicate our ideas to others—termed by some as explicit models. Ever since the dawn of human civilization, our ancestors have relied on using explicit models, to express themselves, albeit at different levels of detail. At the most basic level, these include cave art (Soubrier et al. 2016). Gradually these models appear to have lead to the development of languages. Using these skills, our ancestors were not only able to express and visualize their thoughts but also to document their experiences. Arguably, it was these initial models which evolved and eventually gave rise to tools and technology as we know today.

Modeling is also intrinsically linked with simulation. Simulation is an inherent feature of our cognition. Running mental models is a basic requirement for handling complexity in our everyday lives. We take complex scenarios in our mind and then run simulations in the head—implicit simulations . Subsequently we take appropriate decisions in a limited time. The results may not be optimal—but they can certainly be considered to be boundedly optimal. In other words, they are the best that we can come up with—given the limitations of time and resources—and their impact on our focus and attention.

Modeling complex events and systems is an extremely difficult problem. Its complexity stems from the need to build a model—a model which not only adequately reflects the reality but also, at the same time, has a manageable number of parameters to make its solution computationally feasible. So, the dilemma of building a model is that while it must be simplified enough to be solvable using the available computing infrastructure, the developed model may not adequately reflect reality—in other words, the model may turn out to be invalid, at least, to a certain degree. Whereas, if the model was designed to represent a large part of the real-world, it may end up becoming too complex to solve. So, the dilemma of modeling stems from the fact that the model would either be incomputable or else incomplete. Incomplete models are too simple and, thus, while being good for computation and communication, may not adequately reflect reality.

While these processes are ingrained in our cognition, the ability to explicitly use modeling and simulation is something often learnt by training. In life, parents or life experiences "teach" or help children in learning new skills. Arguably, this is the result of a combination of persistent repetition of tasks-and in some cases, by means of presenting a simplified representation of the real world. In school, teachers use diagrams, physical, and nowadays, virtual and augmented reality-based models (Yilmaz and Goktas 2017) to teach concepts. Doctors and other healthcare professionals use similar techniques in a number of different ways (Andolfi et al. 2016). Researchers use these to advance theories—even though some of the results of these theories can, at times, take decades or centuries to be validated. Thus it is very clear that MS&V comprise a collection of extremely important skills needed for all advancements in science and technology. Even still, MS&V still do not have any “official place” in the standard schooling curricula.

This is clearly problematic. Researchers, often end up having to learn skills associated with MS&V informally. Likewise, these skills are also essential for the future generations as acquiring them helps creating individuals who can become valuable members of the human society. Somehow, however, even till today, we have been unable to come

up with a sequence of school-level courses which would explicitly engage students pedagogically and specifically target the learning of skills associated with modeling, simulation, and visualization. It is interesting to note here that we are not talking about a set of some arcane skills—rather these are skills which we are essentially born with. All that is needed, is that these skills need to be honed and reinforced by means of inclusion in basic schooling.

One thing that we can all agree upon, is that the current educational system is far from perfect. It is actually quite easy to identify a number of problematic trends in the current schooling models prevalent around the globe. A testing model in the West—the so-called "Multiple choice exams" requires students to choose from given choices. If examined closely, this model essentially does not really enforce learning of the subject matter—rather it enforces skills related to guessing. The reason is that focusing on MCQs comes with an implied assumption that, for every question, there exist solutions/answers and that they are essentially right in front of the student. What that really means, is that the task of the student is hereby simplified from being able to confirm knowledge of the topic, to simply being able to guess the correct answer from the given choices. The problem here is that this particular test paradigm does not reflect the reality of real life problems—a number of which do not have any known or easily solvable solution. Take the examples of complex problems such as the continual growth of a stockpile of electronic junk or the prevalence and dependence of the human species on non-biodegradable plastics, solving Cancer, or sending people to distant stars. Likewise, training students using this testing scheme also does not prepare students for challenges that they will face in the real world. As Epstein puts it very nicely (Epstein 2009):

> *"Models can surprise us, make us curious, and lead to new questions. This is what I hate about exams. They only show that you can answer somebody else's question, when the most important thing is: Can you ask a new question? It's the new questions (e.g., Hilbert's Problems) that produce huge advances, and models can help us discover them."*

If modeling, simulation, coupled with visualization were to be taught in basic schooling, it is clear that the result of teaching these skills would increase the probability of more useful individuals in the society-individuals who know how to first simulate complex scenarios before making decisions. Some of these children will subsequently become the leaders of tomorrow. And these leaders should be able to make considerably better decisions about where our planet will go. It is hopeful that such individuals might be more inclined to join hands and work together towards the betterment of the environment as well as the entire planet. They would be able to re-imagine the world and the planet in a much better way.

Here we would like to acknowledge that the current schooling curricula in modern education are not without their own benefits. Overall, the evolution of pedagogy over the human civilization has ensured our sustenance on the planet and led to all technological advancements. The point, however, is that the schooling system is missing a set of basic and very essential skillset. We believe that it is important that MS&V should be added to the basic schooling at a global scale. In our opinion, these skills can be considered as extremely essential for the long term survival of the human civilization on

this planet. It is also pertinent to note here that this means that there is a need for more work on part of experts in the domain of MS&V. Experts need to work together to simplify these skills for communication to very young minds. Books and courses might need to be designed from the perspective of teaching very little kids these essential skills. In other words, we need to strive to ensure that these skills are simplified so much that they can be included at various levels of schooling. A reasonable goal could be to aim for perpetuating these skills in schooling curricula around the world in perhaps within the next 20 years, or even earlier, if at all possible to make them a of the basic repertoire of every educated child of the future. If these skills are taught as part of basic schooling, arguably, the nations of our future planet earth would have a better chance of being led by more scientifically prudent people.

While we cannot change the past, the survival of the human civilization requires a newer and more "intellectually-evolved" generation—humans who are better equipped at making intelligent decisions by the use of the essential skills of modeling , simulation, and visualization for each outcome rather than first trying everything out in the real world. Such individuals would thus have the ability to understand and find solutions to complex problems -problems that may not have any easy solution primarily due to their inherent complexity. These individuals would be better equipped to approach these problems by using mechanisms involving advanced techniques such as simplification and abstraction by gradually representing the real-world with less computationally involved models. Learning such abilities is paramount in not only educating future researchers but also for the sustainability of the human civilization.

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