# Investigation of the Post-Pandemic STEM Education (STEM 3.0)

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**Abstract:** In this work, we analyze the lessons learned from the COVID-19 pandemic and the prospects of the science education that evolved as a result of the pandemic. The two primary shortcomings that arose during the pandemic include: the poor presence of cross-boundary and interdisciplinary research as evidenced by the urgency in establishing cross-boundary research groups in the early days of the pandemic, and the lack of understanding of the scientific method in the general public as evidenced, for example, by the worldwide Hydroxychloroquine events of 2020. An effective approach to solving these shortcomings is increasing innovative research at the two-year tertiary education level. The focus of continuing technical education will shift towards technologies that provide self-sufficiency, such as artificial intelligence, intelligent robotics, augmented reality, digital twins, and additive manufacturing. These features likely constitute the cornerstone of the upcoming science education paradigm, which we denominate “STEM 3.0”.

**Keywords: STEM 3.0, COVID-19 Pandemic, Post-Pandemic Education, Junior Tertiary Education**

## *Introduction*

The COVID-19 pandemic has resulted in shockwaves that have reverberated in almost every aspect of human civilization. As a result of the pandemic, severe supply chain disruptions have occurred throughout manufacturing industries. As a result, the global economy has been hit hard with a loss of $28 trillion; an aviation industry was virtually paralyzed for months, and crippled services and tourism sector comprising restaurants to hotels, and retail commerce. It also exposed the need to develop local, regional, and national self-sufficiency after supply chains had been severed by the initial wave of the pandemic [1].

However, COVID-19 will not be the last pandemic nor the most lethal. It is estimated that there are between 650,000 and 840,000 unknown virus species in the wildlife that can infect humans [2]. Some of the viruses that have jumped from wildlife to humans (a process referred to as Zoonotic Spillover [3]) include very deadly ones such as Rabies (from bats), incurable ones such as HIV (from primates), and very contagious and deadly ones such as Smallpox (from rodents). Eventually, with the exponential increase in human population and the reduction in natural habitat for wildlife, new Zoonotic virus infections will be inevitable, and it is just a matter of time before the next pandemic hits [4].

In a study that was published recently, researchers suggested that the threat of a viral spillover from wildlife will be a “daily reality” and identified some of the newly discovered viruses that are very likely to spill over to humans [5]. For example, the Lassa virus, which is naturally found in rats and has a higher risk factor than the SARS-CoV-2 virus (which causes COVID-19), despite the potential, has not yet emerged at an epidemic level. Other viruses with a high spillover potential include the Bat strain 229E, CoV-35, and others, as shown in Table 1.

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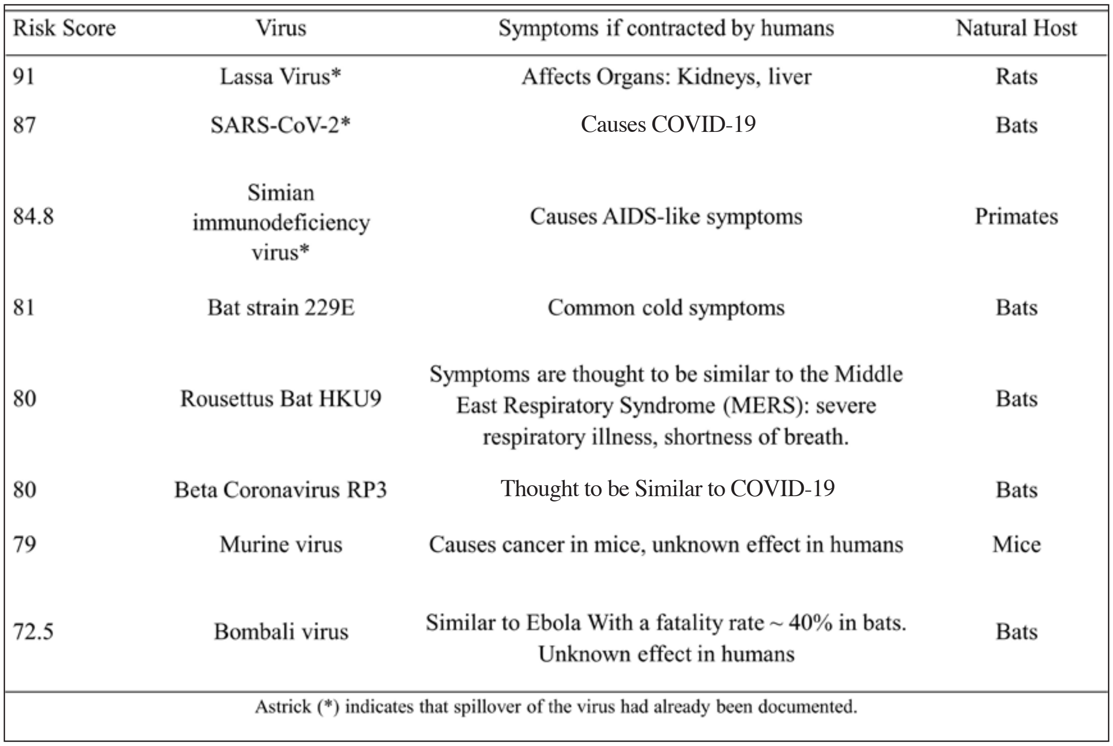

| Risk Score | Virus | Symptoms if contracted by humans | Natural Host |
|---|---|---|---|
| 91 | Lassa Virus* | Affects Organs: Kidneys, liver | Rats |
| 87 | SARS-CoV-2* | Causes COVID-19 | Bats |
| 84.8 | Simian immunodeficiency virus* | Causes AIDS-like symptoms | Primates |
| 81 | Bat strain 229E | Common cold symptoms | Bats |
| 80 | Rousettus Bat HKU9 | Symptoms are thought to be similar to the Middle East Respiratory Syndrome (MERS): severe respiratory illness, shortness of breath. | Bats |
| 80 | Beta Coronavirus RP3 | Thought to be Similar to COVID-19 | Bats |
| 79 | Murine virus | Causes cancer in mice, unknown effect in humans | Mice |
| 72.5 | Bombali virus | Similar to Ebola With a fatality rate ~ 40% in bats. Unknown effect in humans | Bats |

Astrick (*) indicates that spillover of the virus had already been documented.

*Table 1. Recently discovered viruses in wildlife and their risk factor discovered between 2009 and 2019 [5,6].*

From the above discussion, it is evident that more preparedness is needed on the academic level to counter future health crises and/or pandemics. In this work, we evaluate the impact of the COVID-19 pandemic on Science, Technology, Engineering, and Mathematics (STEM) education, and we discuss the lessons learned and present a post-pandemic paradigm for STEM education that has emerged as a result.

### Shortcomings in the Science and Technology Education Exposed by the Pandemic

The COVID-19 pandemic exposed two primary shortcomings in science and technology education: poor interdisciplinary and cross-boundaries research; and the lack of understanding of the evidence-based scientific method for public policy and societal decision making.

**Poor interdisciplinary and cross-boundaries research:** Before the pandemic, many warning signs arose, anticipating a gap in interdisciplinary research on the undergraduate level. In 2018 a study led by Dalhousie University found that undergraduate level interdisciplinary scientific research is very poor (standing at only 28%) [7]. During the pandemic, the need for collaborative border-crossing research intensified to the point of forming consortia such as the COVID-19 R&D group [8]. After all, according to the famous mathematician and astronomer Laplace, “to discover is to bring together two ideas that were previously unlinked” [9]. Some of the challenges that were uncovered by the pandemic and effectively slowed down international collaborations were the lack of cross-boundary funding agency agreements and the lengthy procedures needed for visa and scientific work permits across boundaries [10].

Consequently, scientists found themselves unable to fund research beyond the political boundaries or get foreign talents timely. The CEO of the American Society for Microbiology stated in a joint publication with its president that in the post-COVID-19 world, there is a need for a new scientific system that gets rid of scientific isolationism [10].

**Lack of understanding of the evidence-based scientific method in public policy and societal decision making [10]:** the initial response to the spread of COVID-19 was characterized by a desperate need in the world, and people were "jumping to conclusion without any rigorous scientific evidence" [11]. For example, results from an initial study conducted in March 2020 on Hydroxychloroquine in test tubes led to what came to be known as the "hydroxychloroquine roller coaster" [12]. Nevertheless, by mid-April, almost every country in the world approved the drug for the treatment of COVID-19 despite that no study had been conducted on animals or humans.

Although the scientific method is taught in grades K-12 and at post-secondary levels, the dramatic events that unfolded around hydroxychloroquine during the pandemic could highlight the need for a different approach. Particularly, students do not usually engage in an actual implementation of the scientific method until entering a graduate degree program, when they participate in innovative research.

Moreover, recent studies show that in 2019, about 50% of adults in the U.S. aged 25-32 attained at least a 2-year degree, while the rate drops to about 40% for adults that attained at least a bachelor's degree [13]. Therefore, the vast majority of the adult population in the U.S. likely has not engaged in an actual implementation of the scientific method. At a minimum, an effective approach to enhance understanding of the scientific method should target that 50% of the adult population that does pursue higher education starting at the 2-year degree level. This should be initiated by including research at two-year post-secondary institutions such as community and technical colleges.

### *Broader Societal Shortcomings Exposed by the Pandemic: The Supply Chain*

On the technological level, the pandemic exposed the urgent need for more preparedness in developing self-sufficiency in the supply chain [1]. The supply chain disruptions seen during the pandemic have abruptly accelerated the use of next-generation intelligent robotics [14,15] and additive manufacturing [16] (Fig.1) as well as a shift from the two-decade-long trend of having complex benchtop Point-of-Need instruments towards simplicity and portability. This shift is expected to last into the next decade, as shown in Fig. 2 below [17].

*Fig. 1. Next-generation intelligent robots are highly portable, can work collaboratively with human operators and have the ability to self-learn.*

Despite the sharp fall in the global economic activity brought about by the pandemic and resulting supply chain jams, some industries experienced surges in demand, including the BioMEMS (Micro-Electro-Mechanical Systems for Biomedical applications) [18,19] and the Telecommunications MEMS industries [20].

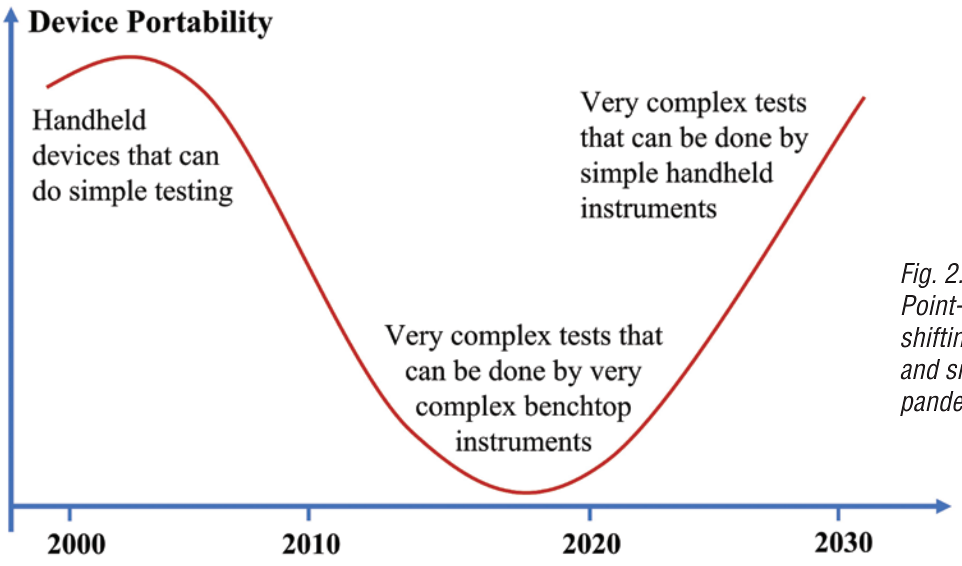

*Fig. 2.*
*Point-of-Need Instruments are shifting gears towards portability and simplicity as a result of the pandemic [17].*

### *The STEM 3.0 Paradigm*

With the start of the 21st century, a new approach in science evolved that is characterized by collaboration and openness and has been referred to by Schneiderman [21], Waldrop [22], and others as "Science 2.0".

However, just like the older classical science, labeled "Science 1.0", the second paradigm targeted mainly the scientific research community. Therefore, it had little or no impact on scientific education, particularly in junior tertiary education (community and technical colleges).

From the above discussion, a new generation of science, technology, engineering, and math (STEM) education paradigm, STEM 3.0 is evolving in the wake of the pandemic. The main characteristics of this paradigm include cross-boundary collaboration and increasing knowledge of the scientific method in the general adult population. This is accomplished through practical innovative research that targets secondary and junior tertiary education. Furthermore, its implementation is greatly enhanced by reliance on smart technologies. The main features of each of the three paradigms (Science 1.0, Science 2.0, and STEM 3.0) are outlined in Table 2.

| Characteristics | Science 1.0 | Science 2.0 | STEM 3.0 |
|---|---|---|---|
| **Involvement of secondary and tertiary education** | Classical Classroom learning. No involvement in research | Classical Classroom learning, limited involvement in research | Engagement in innovative research as a cornerstone in education |
| **Main features** | • Rise of copyrights<br>• Data safeguarding | • Networkization<br>• Data sharing | • Intelligentization<br>• Involvement of the community (Citizen Science)<br>• Self-sufficiency |
| **Scientific research** | Multi-disciplinary | Inter-disciplinary | Cross-boundary |

*Table 2. The characteristics of the post-pandemic STEM 3.0 paradigm compared to the classical Science 1.0 and the 21st-century pre-pandemic Science 2.0 paradigms.*

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**Project-Based Learning as a Model to Integrate Research into Junior Tertiary STEM Education:** Capstone and end-of-study projects are known to constitute one of the high-impact educational practices [23], the importance of capstone projects in undergraduate education was acknowledged in the Boyer Commission report of 1999. The 2009 National Survey of Student Engagement reports that 75% of a randomly selected sample size of 360,000 students from universities and four-year colleges indicated a substantial impact of capstone projects in developing their intellectual curiosity and critical thinking [24].

However, the studies mentioned above primarily targeted four-year colleges. Furthermore, none of them considered the impact of the innovation aspect in the capstone projects on both the students and society.

In the STEM 3.0 paradigm, the two primary characteristics of the project-based learning model are that it is carried out in the junior tertiary level (two-year colleges) and the requirement of an innovative approach in the project.

**Technologies that Emerged During the Pandemic and their Role in the Next Educational Paradigm:** In the technical maintenance sector, the need for virtual technologies, augmented reality, and remote accessibility intensified, particularly in the first few months of the pandemic, when person-to-person interactions were curtailed, air transportation was virtually shut down, and cross-border travel was heavily restricted.

Manufacturing sites that created virtual models of their plant floors before the pandemic suffered far less from these disruptions, as technicians could conduct many troubleshooting tasks remotely utilizing augmented reality technologies.

Virtual classrooms, scientific conferences and workshops, and even engineering labs that are controlled remotely have emerged as a result of the pandemic [25]. In fact, STEM 3.0 appears at some level to be emerging organically due to the innovations that have allowed research, development, and manufacturing to continue.

Therefore, to be prepared for the next pandemic, educational systems will need to incorporate and stay current with up-to-date technologies that can provide the needed flexibility and ability in three primary routes:

1. Virtual conferencing and lecture tools.
2. Contactless laboratories: This is achieved with digital twinning of lab equipment and institutional facilities, Internet of Things (IoT), utilizing augmented and virtual reality, and intelligent robotics for equipment handling and conducting experiments remotely.
3. Self-sufficiency and portability: this is achieved by enhancing the use and education of technologies that enable self-sufficiency and portability, such as additive manufacturing with 3D [26] and 4D printing [27] (3D printing with smart materials that adjust their final shape with time), laser material processing, and following the trend of favoring portable over benchtop instruments, as well as robotized equipment handling with intelligent robots and drones to counter any possible supply-chain disruptions in the future.

This incorporation of smart technologies is coupled with a project-based learning approach; where students are required to apply the scientific method, critically assessing their approach, and arrive at effective solutions.

The increased demand for highly automated and intelligent systems further emphasizes the need for training programs on intelligent technologies and systems in the STEM 3.0 era. The term “Intelligentization” was first introduced by the Chinese State Council in its National Artificial Intelligence Strategy [28] translated as “ Next Generation Artificial Intelligence Development Plan” to refer to the next generation of intelligent systems that include decision making, as opposed to the current generation “advanced autonomous” systems, which lack the ability to make decisions. This concept is integral to A.I. The importance of A.I. technology and the gradual presence of the technology in almost every industry and every application will result in a shortage of the skilled A.I. workforce on two levels: the applied technology-handling level and on the research level, and it has been rapidly widening, and is starting to have a tangible effect [29]. Furthermore, the demand for A.I. increased during the pandemic with the increased dependence on technologies that rely on artificial intelligence.

## Discussion and Conclusion

Scientific studies show that future pandemics are inevitable, and more preparedness is needed academically. Recent studies indicate that more than 50% of the adult population in the U.S. holds at least a two-year tertiary education degree, which means that preparedness will be most effective starting at that level. Here we propose a science education paradigm that we refer to as STEM 3.0 that addresses the two major scientific concerns that arose during the COVID-19 pandemic: Lack of interdisciplinary cross-boundary research, in this case at the 2-year undergraduate level, and the poor understanding of the scientific method among the adult population. In this paradigm, the approach for teaching the scientific method will shift to increased incorporation of innovative interdisciplinary and cross-boundary research in community and technical colleges.

Finally, to be more prepared for the next pandemic or other societal disruption, academic institutions will need to continuously consider contactless laboratories and self-sufficiency. This is achieved by creating digital twins of laboratories, incorporating remote machine-assisted labs with intelligent robotics and augmented reality. Knowledge of using additive manufacturing tools and integrated A.I. will be integral in all educational fields to ensure self-sufficiency.

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## References

[1] N. Ayati, P. Saiyarsarai and S. Nikfar, "Short and long term impacts of COVID-19 on the pharmaceutical sector," *DARU Journal of Pharmaceutical Sciences*, 2020.

[2] M. C. Lu, "Future pandemics can be prevented, but that'll rely on unprecedented global cooperation," *The Washington Post*, 2020.

[3] K. J. Olival, P. R. Hosseini, C. Zambrana-Torrelio, N. Ross, T. L. Bogich and P. Daszak, "Host and viral traits predict zoonotic spillover from mammals," *Nature*, vol. 546, pp. 646-650, 2017.

[4] K. Tantawi, "Literature Review: Rethinking BioMEMS in the aftermath of CoVid-19," *Biomedical Journal of Scientific & Technical Research*, vol. 31, no. 1, pp. 23944-23946, 2020.

[5] Z. Grange, T. Goldstein, C. Johnson, S. Anthony, K. Gilardi, P. Daszak, K. Olival, T. O'Rourke, S. Murray and
S. Olson, "Ranking the risk of animal-to-human spillover for newly discovered viruses," *PNAS*, vol. 118, no. 15, 2021.

[6] S. Payne, "Family Arenaviridae," in *Viruses* From Understanding to Investigation, Academic Press, 2017, pp. 215-218.

[7] M. A. Ülkü, A. M. Karkowski and T. D. Lahm, "Perspectives on interdisciplinary undergraduate research," *Educational Studies*, vol. 44, pp. 247-263, 2018.

[8] D. Kwon, "How the Pharma Industry Pulled Off the Pivot to COVID-19," *The Scientist*, July 2020.

[9] S. V. Gill, M. Vessali, J. A. Pratt, S. Watts, J. S. Pratt, P. Raghavan and J. M. DeSilva, "The Importance of Interdisciplinary Research Training and Community Dissemination," *Clinical and Translational Sciences*, vol. 8, pp. 611-614, 2015.

[10] S. Bertuzzi and V. J. DiRita, "After COVID-19 We Will Need a New Research System. We Need To Start Planning Now," *MBio*, vol. 11, no. 6, pp. e03251-20, 2020.

[11] B. Giesbrecht, "Hydroxychloroquine is Widely Used Around the Globe," Frontier Centre for Public Policy, 2020.

[12] University of Washington, "The end of hydroxychloroquine as a treatment for COVID-19," March 2021. [Online]. Available: https://newsroom.uw.edu/postscript/end-hydroxychloroquine-treatment-covid-19. [Accessed 31 December 2021].

[13] M. T. Nietzel, "In Just Two Decades, U.S. Drops From Second To Sixteenth In Percentage of Young Adults With A College Degree," Forbes, 2021.

[14] K. Tantawi, A. Sokolov and O. Tantawi, “Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration,” in 4*th Technology Innovation Management and Engineering Science International Conference* (TIMES-iCON), Bangkok, Thailand, 2019.

[15] K. Tantawi, I. Fidan and A. Tantawy, “Status of Smart Manufacturing in the United States,” in *2019 IEEE SoutheastCon*, Huntsville, AL, 2019.

[16] S. Terry, I. Fidan, Y. Zhang and K. Tantawi, “Smart Manufacturing for Energy Conservation and Savings,” in *NSF-ATE Conference*, Washington, DC, 2019.

[17] A.-F. Pelé and M. D. P. Emilio, “Microfluidic Technologies Diagnose World’s Return to Normal,” *E.E. Times Europe*, 22 June 2020.

[18] K. H. Tantawi, R. Cerro, B. Berdiev, M. E. D. Martin, F. J. Montes, D. Patel and J. D. Williams, “Investigation of transmembrane protein fused in lipid bilayer membranes supported on porous silicon,” *Journal of medical engineering & technology*, vol. 37, no. 1, pp. 28-34, 2013.

[19] K. H. Tantawi, R. Cerro, B. Berdiev, M. E. Diaz, F. Montez and J. D. Williams, “Lipid Bilayer Membrane with Incorporated Protein on Porous Silicon,” in *22nd NSF EPSCoR National Conference*, Coeur d’Alene, Idaho, 2011.

[20] Yole Developpement, “MEMS industry: the headwinds from COVID-19 and the way forward,” 2020. [Online]. Available: http://www.yole.fr/MEMSIndustry_MarketUpdate.aspx. [Accessed September 2020].

[21] B. Schneiderman, “Science 2.0,” Science, vol. 319, pp. 1349-1350, 2008.

[22] M. M. Waldrop, “Science 2.0,” *Scientific American*, vol. 298, pp. 68-73, 2008.

[23] C. F. Riehle and S. A. Weiner, “High-Impact Educational Practices: An Exploration of the Role of Information Literacy,” *College & Undergraduate Libraries*, vol. 20, pp. 127-143, 2013.

[24] National Survey of Student Engagement, “Assessment for Improvement: Tracking Student Engagement Over Time, Annual Results 2009,” 2009.

[25] K. Tantawi, I. Fidan, G. Chitiyo and M. Cossette, “Offering Hands-on Manufacturing Workshops Through Distance Learning,” in *ASEE Annual Conference*, Virtual, 2021.

[26] S. Terry, H. Lu, I. Fidan, Y. Zhang, K. Tantawi, T. Guo and B. Asiabanpour, “The Influence of Smart Manufacturing Towards Energy Conservation: A Review,” *Technologies*, vol. 8, p. 31, 2020.

[27] Z. Zhang, K. G. Demir and G. X. Gu, “Developments in 4D-printing: a review on current smart materials, technologies, and applications,” *International Journal of Smart and Nano Materials*, vol. 10, no. 3, pp. 205-224, 2019.

[28] G. Webster, R. Creemers, P. Triolo and E. Kania, “Full Translation: China’s ‘New Generation Artificial Intelligence Development Plan’,” New America, 2017.

[29] D. Gehlhaus, “The reality of America’s A.I. talent shortages,” The Hill, 2021.

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