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Digital Futures of Learning Pharmacology and Organic Chemistry

Fun Man Fung^{1}, Etienne Blanc and Xavier Coumoul^{2*}*

¹ Department of Chemistry, College of Humanities and Sciences, National University of Singapore,
Singapore

² Inserm UMR-S 1124, T3S, Université Paris Cité, Paris, France

*Corresponding authors

Abstract:

Traditional pharmacology and organic chemistry teaching often rely on the trusted textbook visuals that students may struggle to grasp mechanisms that appear too complex. Because the pandemic has mandated the majority of educators to use new techniques and innovative technology in their communication approaches including with students, we offer several digital strategies for educators to explore and/or to enhance student learning. These technology-infused strategies are drawn from our cross-country (Singapore and France) teaching and research experiences/expertise.

Pharmacology and Organic Chemistry

Organic chemistry's allure goes beyond test tubes and textbooks. It delves into the very fabric of life, even reaching back 66 million years to the fossilized remnants of dinosaurs.¹ Yet, this captivating field also presents a formidable challenge for students aspiring to careers in pharmacology, toxicology and other areas where understanding drug-molecule interactions is paramount. Grasping the intricate mechanisms of organic reactions unlocks the secrets of how and why molecules interact with each other, a knowledge base vital for designing and synthesizing novel therapeutics and molecules with tailor-made properties. Indeed, some organic compounds within molecules hold the potential to modify the bioavailability of drugs for example, used in cancer treatment, offering a glimpse into the transformative power of this fascinating field.²

Embracing Digital Revolution in Science Education

While pharmacology and organic chemistry offer fascinating glimpses into the molecular world, their inherent complexities can pose a steep learning curve for students. Traditional teaching methods, often relying on didactic lectures and textbook illustrations, can struggle to engage students with the high cognitive load required for encoding and retrieving information. An example that speaks to many junior or senior scientists is the course which introduce the Krebs cycle which could be dramatically boring through regular lectures, while presenting essential concepts in biochemistry. This could also be the case for structural biology if the drug-target representation is not depicted in an inclusive way (from bench to bed), presenting the concept that goes beyond the pharmacological interactions.

Despite their success in training generations of scientists, these classical paper-based approaches might benefit from a modern twist. With the rise of technology and the ubiquity of digital devices,

we believe that strategically employing digital tools can significantly enrich the learning experience in these critical disciplines. This conviction is further bolstered by the unforeseen surge in E-learning during the recent global health crisis, a period that also saw a flourishing of innovative digital teaching and learning approaches.

Drawing on our cross-country teaching experiences and published research, we offer educators a range of suggestions for adopting effective technology in their classrooms, empowering students to learn more effectively.

Implementing Blended Learning and Active Learning Strategies

- Leveraging insights from COVID-era online teaching

The COVID-19 pandemic, while disruptive, offered a unique opportunity to reimagine education. It propelled a global shift towards online learning, yielding valuable insights that can now fuel pedagogical advancements. Educators worldwide witnessed the transformative power of technology in boosting student engagement and learning outcomes. Tools like Zoom, Teams, Miro, and Google Meet facilitated not only remote learning but also fostered seamless global collaboration.³ Teachers, adapting to the online environment, embraced multimedia resources, interactive quizzes (not just for exams!), and videos/virtual simulations to inject dynamism into lessons. These valuable experiences are now ripe for application in traditional classrooms, paving the way for a blended learning approach. This synergy of in-person and online instruction promises a more versatile and effective educational experience.

While quizzes (even those designed for exams) can spur interactivity in traditional settings, and word clouds find their place as informal polls, the true power lies in leveraging technology to facilitate deeper engagement and the development of critical thinking. In a Singaporean freshmen organic chemistry course, the pandemic presented an opportunity to refine the Flipped Classroom model.⁴ With in-person teaching limited, the instructors established a vibrant Discord channel as an asynchronous learning community for students to connect, learn, and engage outside of class, combating isolation and fostering a sense of belonging.⁵ This, along with growing evidence of the benefits of peer-to-peer learning techniques,⁶ underscores the potential of technology to enrich the learning process beyond the confines of traditional methods.

Technology to aid 3D visualization

Visualizing molecules in three dimensions can be a daunting hurdle for students of pharmacology and organic chemistry. This spatial challenge is particularly significant in pharmacology or toxicology, where a molecule's 3D structure dictates its interaction with biological targets. Imagine two keys trying to unlock the same door; slight variations in their shape can render one completely ineffective. Similarly, a seemingly minor tweak in a molecule's structure can dramatically alter its pharmacological properties: take hexachlorocyclodecane (HCH), for instance. This seemingly simple molecule exists in different forms, each with its own unique personality. Alpha-HCH, an impurity in the organochlorine family, resembles its notorious cousin lindane (γ -HCH) in every way except one – the orientation of a single chlorine atom. This seemingly insignificant twist alters the molecule's 3D shape; if both molecules are persistent organic pollutant (POP), one was an insecticide (lindane) which has been intensively used (and now banned in many countries), the alpha isoform was only considered as an impurity.

This example highlights the crucial role of spatial awareness in understanding how molecules interact with the world around them. Fortunately, we are not limited to textbooks and 2D static diagrams. Mobile apps equipped with augmented reality (AR) offer a powerful tool to bridge the gap between theory and visualization. Imagine holding a molecule in your hand, rotating it, and observing how its shape influences its potential interactions. AR technology can bring these concepts to life, fostering a deeper understanding of the molecular ballet that governs pharmacology and organic chemistry (Figure 1).⁷

Sparkling curiosity via Game-based learning and Gamification

- Online and offline games for interactive learning

Games and gamified experiences not only help students grasp the intricate 3D dance of molecules and their reactions, but also foster a positive connection with the material. This interactive approach infuses the study of complex structures and reactions with a stimulating dimension, making organic chemistry more engaging than ever. Universities around the world are also joining the movement, with initiatives like France's Chem'Sc@pe,⁸ an escape game activity for first- and second-year undergraduate students, covering various organic chemistry topics and Singapore's ChemPOV platform.⁹

- Gamified elements to enhance motivation and engagement

The power of gamification extends beyond pharmacology and organic chemistry education itself. Take language learning: apps like Duolingo use points, level unlocks, and friendly competition to turn word memorization into a game. Students earn intrinsic motivation as they progress, making

learning a more rewarding experience. Likewise, math games like Prodigy transform intimidating concepts into virtual battles,¹⁰ making it fun to conquer equations. This playful approach doesn't just revamp the learning process; it also nurtures essential skills like problem-solving, collaboration, and creativity in learners.

Some games, like the collaborative board game "CheMakers" developed by educators and students, even bridge the digital divide. These physical iterations offer a different dimension: less immersive but more interactive, they facilitate real-time discussions with teachers, enriching the learning experience further.¹¹

Fostering International Partnerships

Learning from Best Practices in Science Diplomacy

- Collaborating with institutions across borders, such as Singapore-France partnerships
- Sharing and adopting effective teaching methodologies

The scientific partnership between Université Paris Cité and the National University of Singapore (NUS) presents significant opportunities for research and education through mobility programs.^{12–16} The partnership promotes large-scale international collaborations through annual joint calls for projects, resulting in around 35 funded projects across disciplines. One of these projects was dedicated to organic chemistry in which we used immersive virtual reality to conduct a field trip¹⁷ and asked third- and fourth-year undergraduate students to answer environmental chemistry questions. The use of immersive VR allows circumventing logistical and cost problems, on top of proven educational benefits.¹⁸ Université Paris Cité also participates in NUS's Global Experience Paris

program,¹⁹ offering NUS students immersive experiences in Paris through lectures, masterclasses, and cultural activities. These international collaborations strengthen bilateral exchange of best pedagogical practices.²⁰

The Role of Generative AI in Future Pedagogy:

Harnessing AI for Personalized Learning:

- Tailoring instruction to individual student needs and learning styles
- Providing adaptive feedback and support

AI, in particular, GenAI, uses large language models (LLMs) that synthesize a stock of data. The role of generative AI (GenAI) in future pedagogy is poised to revolutionize the way we approach education, ushering in an era of personalized and adaptive learning experiences. GenAI, with its capacity to understand, generate, and respond to human-like text,²¹ enables the creation of tailored educational content that caters to individual learning styles and paces.²² This technology has the potential to design dynamic and interactive lesson plans, adapting in real-time to students' progress and addressing their specific needs. Moreover, generative AI can facilitate the development of virtual tutors that provide instant feedback, fostering a more engaging and supportive learning environment. By automating routine tasks like grading and assessment, educators can redirect their focus towards fostering critical thinking, creativity, and complex problem-solving skills. As GenAI continues to evolve, it holds the promise of democratizing access to quality education globally, breaking down barriers and ensuring that learners of all backgrounds receive personalized and effective instruction.

Training Teachers and Students in AI Utilization:

- Equipping educators with AI-based teaching tools and strategies

- Empowering students to leverage AI for self-directed learning

Training teachers and students in AI utilization is becoming increasingly crucial in preparing individuals for the evolving landscape of education and the workforce. Educators must be equipped with the knowledge and skills to integrate AI tools effectively into their teaching methods, adapting to a tech-enhanced learning environment. Professional development programs can empower teachers with insights into incorporating AI for personalized lesson planning, automated assessment, and data-driven decision-making. Simultaneously, students benefit from AI education by gaining proficiency in utilizing GenAI technologies, fostering digital literacy and problem-solving skills essential for the future job market. Encouraging a curriculum that includes AI concepts ensures that students are not just consumers but active contributors to the AI-driven world. Instead of amplifying the potential negatives of GenAI and banning it in courses, we opined that teachers can reimagine their assessment better so that students can apply AI more deliberated via critical thinking. Students will inadvertently need to apply the skills in working alongside AI. With open-science platform becoming more advanced in development,²³ we argue that learners can potentially harness the chemistry data lake for enhanced learning transfer. This holistic approach to AI education for both teachers and students establishes a foundation for a technologically adept and innovative educational landscape.

Conclusion

Embracing digital tools offers educators a powerful ally in tackling the complexities of pharmacology and organic chemistry. Engaging platforms, infused with game-based elements, can transform opaque mechanisms into vivid visualizations and interactive practice. This dynamic approach promises not just understanding, but also excitement, fostering a deeper appreciation for

these crucial disciplines. We encourage educators to explore the diverse landscape of learning technologies, informed by our insights and research, to craft engaging and effective environments where every student can feel the magical interactions of molecules.

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