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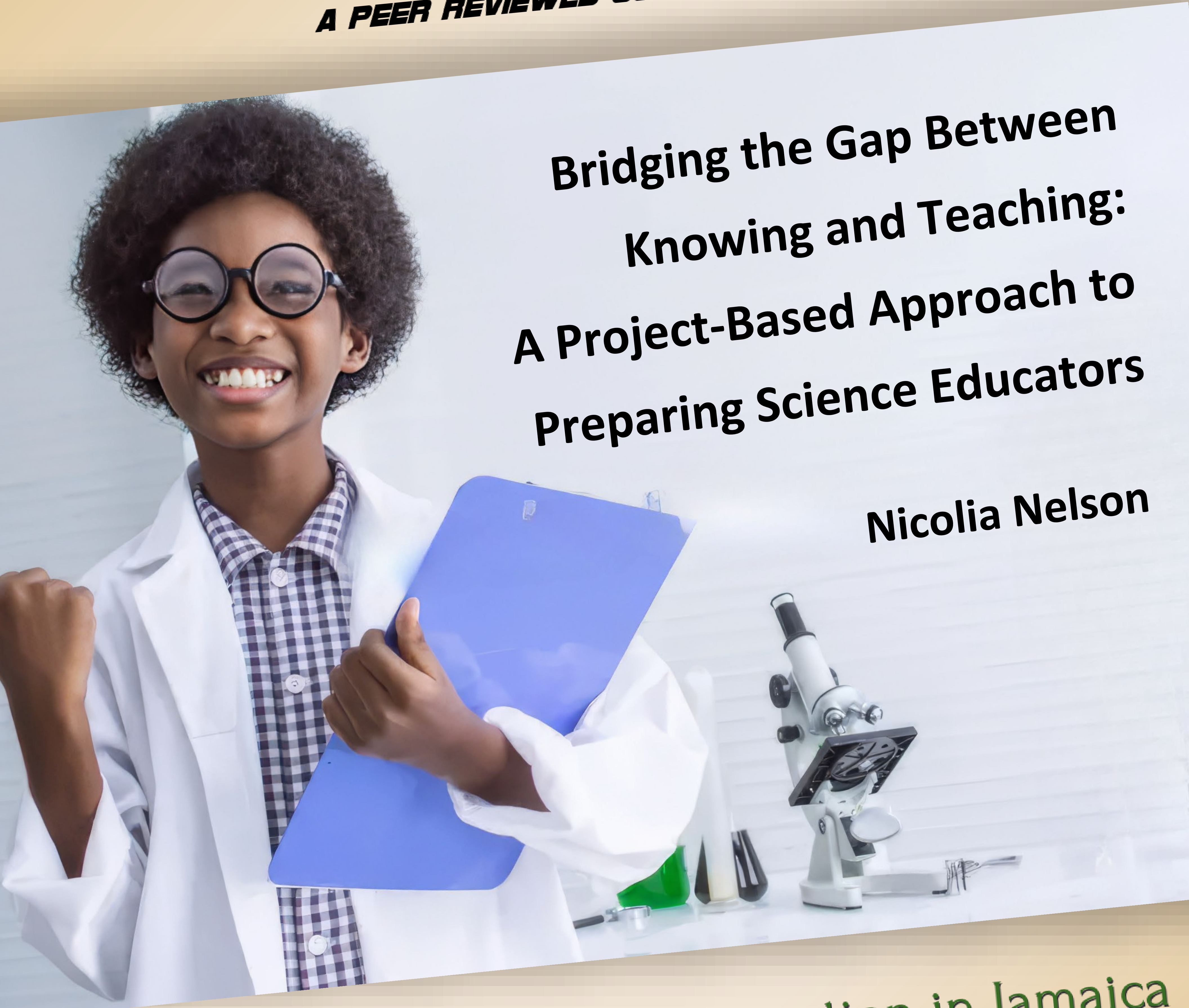

Bridging the Gap Between Knowing and Teaching: A Project-Based Approach to Preparing Science Educators

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Each year, when I teach Applications of Genetics to fourth-year pre-service biology teachers, I am reminded that understanding science and teaching it are not the same. As we explore techniques such as polymerase chain reaction (PCR) and fluorescence in situ hybridization (FISH), a familiar pattern emerges: students can often define these techniques and explain their purpose, yet many struggle to describe how they work or, more importantly, how to teach them effectively to future secondary school students. Their struggle is understandable. Biotechnology involves molecular processes that cannot be directly observed, and limited access to advanced laboratory equipment in many teacher education institutions, including my own in Jamaica, often leaves students relying on textbooks, animations, lectures, and videos. As a result, these abstract concepts can seem intimidating, reducing students' confidence and increasing anxiety.

I wanted to do more than help students pass examinations. My goal was to prepare future teachers to explain complex scientific ideas confidently, adapt to resource-constrained classrooms, and inspire curiosity. This led to a central question:

> ***How could I make invisible molecular processes visible and, more importantly, teachable without access to sophisticated biotechnology laboratories?***

That question became the foundation of one of the most rewarding teaching experiences of my career.

Knowing Is Not the Same as Teaching

One of the greatest misconceptions in teacher education is that mastering content automatically prepares someone to teach it. My experience has shown otherwise. Although I studied biological sciences at both undergraduate and postgraduate levels, it was as a biochemistry laboratory demonstrator that the concepts truly came to life. Explaining procedures, answering questions, and connecting theory to practice deepened my own understanding, reinforcing that I learned the content more fully by teaching it.

That experience shaped my philosophy as a teacher educator. I believe that teaching is one of the most powerful ways of making content practical. When we teach, knowledge stops being something we simply possess and becomes something we actively use, question, reshape and communicate. It forces us to organize our thinking, identify misconceptions, and make abstract ideas meaningful for others. A student may understand a concept well enough to answer examination questions yet still struggle to explain that same concept to someone encountering it for the first time. It is this gap between knowing and teaching that I continually seek to address in my own practice.

Biotechnology illustrates this challenge well. Techniques such as PCR and FISH require students to visualize complex molecular processes that cannot be directly observed. Without hands-on experiences, many rely on memorization rather than conceptual understanding, making it difficult to explain these techniques or teach them effectively. This challenge is especially important in teacher education. My students are preparing to become science teachers, not laboratory scientists. They need both a strong understanding of biotechnology and the pedagogical skills to make it meaningful for secondary students.

While lectures provide essential foundations, they were insufficient to bridge the gap between knowing and teaching biotechnology. Students needed opportunities to discuss, simplify, and represent concepts as teachers would. Many of them will eventually teach in schools where laboratory equipment is scarce or unavailable. So I also wanted to demonstrate that limited resources need not limit learning, and that creativity and student-centered pedagogy can make complex science accessible in resource-constrained classrooms.

Why I Chose a Project-Based Approach

I chose project-based learning not because it was popular, but because it addressed a practical teaching challenge. As I reflected on the difficulties my students were experiencing, I realized that asking them to prepare another presentation or write another report would produce the same outcome. They might memorize the content well enough to complete the assignment, but they would still miss the deeper challenge of translating scientific knowledge into effective teaching. Instead, I decided to reverse the process. Instead of asking students to demonstrate what they knew, I challenged them to create something that would help others learn.

The assignment required students to work collaboratively to design a non-digital educational game that accurately represented either PCR or FISH. They could adapt familiar games such as Ludo, Monopoly, Scrabble, card games, or they could invent entirely new ones. Regardless of the format they chose, every rule, challenge, movement, and reward within the game had to represent some aspect of the biotechnology technique. Figures 1 and 2 illustrate two of the student-designed games developed during the project, demonstrating how complex molecular processes were transformed into engaging, interactive learning experiences.

This shift transformed the task. Instead of asking, “What is PCR?”, students began asking, “How can DNA amplification become a game?” or “How can players experience the steps of FISH through movement and decision-making?” Answering these questions required a deeper understanding of the science. The project also modelled the student-centered pedagogy I hope my pre-service teachers will use in their own classrooms. Rather than applying Project-Based Learning as a prescribed method, I adapted its principles of inquiry, collaboration, creativity, and authentic problem-solving to our context. Looking back, the project was never really about making games—they were simply the vehicle. The real goal was to help future science teachers ask the essential question: How can I help someone else understand this? For me, that question represents the true bridge between knowing science and teaching science.

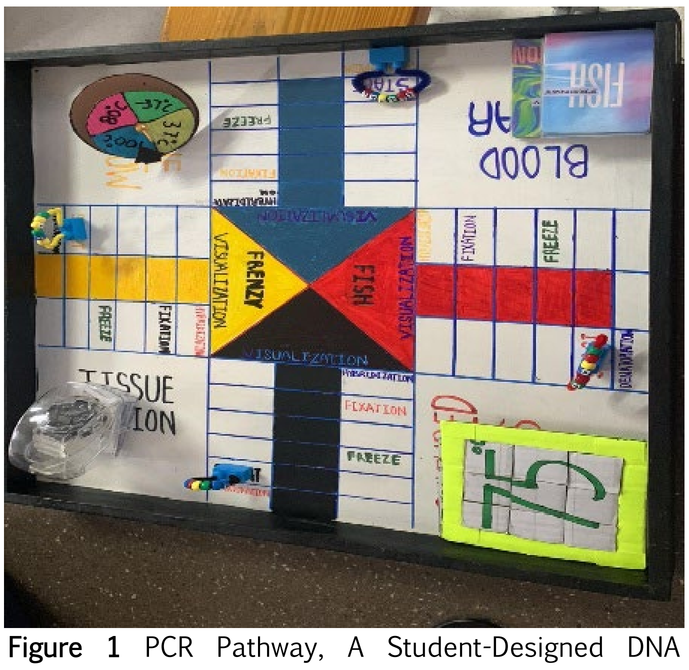

Figure 1 PCR Pathway, A Student-Designed DNA Amplification Board Game that simulates the polymerase chain reaction (PCR) using instruction and action cards to reinforce key concepts.

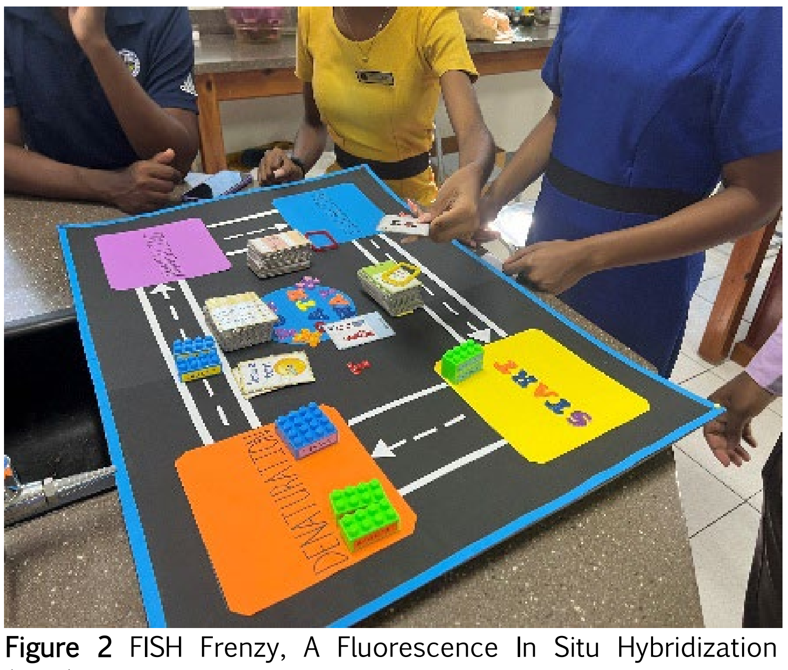

Figure 2 FISH Frenzy, A Fluorescence In Situ Hybridization (FISH) Ludo-inspired Student-developed Board Game in which players apply their understanding by navigating discipline-specific challenges and obstacles to reach the finish.

The Project in Action

The project was implemented over three academic years with fourth-year pre-service biology teachers enrolled in *Applications of Genetics*. I focused on two biotechnology techniques—polymerase chain reaction (PCR) and fluorescence in situ hybridization (FISH)—because they consistently pose learning challenges for students. Although PCR and FISH are fundamental biotechnology techniques, their molecular processes are highly abstract and cannot be directly observed. However, because both follow clear, logical sequences, they were well suited for translation into educational games.

The project aimed not only to strengthen students' understanding of biotechnology but also to help them think like future teachers by transforming scientific knowledge into meaningful learning experiences. It formed a major coursework assessment and was introduced at the start of the semester, with design work beginning a few weeks later.

I deliberately began with the science rather than game construction. Students first researched PCR and FISH independently before exploring the concepts through lectures and discussions. nce they had a solid foundation, we shifted to game design, focusing on what makes an educational game effective: clear objectives, meaningful challenges, simple but engaging rules, opportunities for feedback, and an element of fun. More importantly, we discussed that every aspect of the game should accurately represent the scientific process. This was where the deepest learning would occur, through deciding how a biological process could be represented through gameplay.

Students then formed groups and entered what quickly became my favourite stage of the project: the brainstorming sessions. The classroom transformed into a design studio as students sketched ideas on the whiteboard, debated game mechanics, and received feedback from their classmates. Together, we questioned whether the rules accurately reflected the biology, challenged one another's assumptions, and refined ideas before anyone began constructing a final product.

One of the most rewarding moments came when a student who had previously struggled to explain scientific concepts presented “FISHpoly,” an adaptation of *Monopoly*. As she explained how the game's spaces, movement, and challenges represented fluorescence *in situ* hybridization, it became clear that she was no longer just learning the concept she was thinking carefully about how another learner could understand the concept, and in so doing improving her understanding of the concept. Figure 3 illustrates the initial brainstorming session for the development of FISHpoly**.**

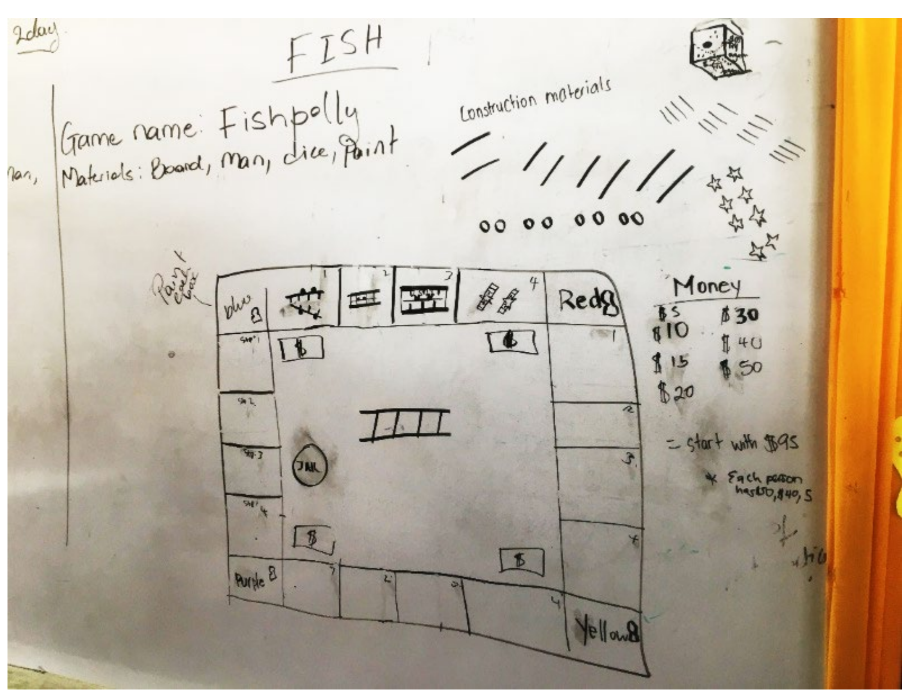

Figure 3 Brainstorming Session for the Development of Fishpoly

Students were free to invent entirely new games or adapt existing ones, provided the science remained accurate. Many groups chose to adapt familiar games that would already be recognized in Jamaican classrooms. Ludo proved especially popular, while others transformed Monopoly, Scrabble, and other traditional card games, into engaging biotechnology learning experiences. Some designed entirely original games. I intentionally limited the project to non-digital games because I wanted students to create resources that could realistically be reproduced in classrooms where there were limited technological access.

Once the game mechanics were finalized, each group identified the materials needed for construction. Students were encouraged to use recycled and low-cost materials, and I contributed toward essential supplies to demonstrate my commitment to the project and support its successful implementation. Construction took place both at home and during scheduled class sessions. These sessions became more than opportunities to assemble game boards. They allowed students to exercise creativity, solve practical problems together, and occasionally step away from the intensity of traditional lectures. Alongside the games, each group was required to produce an instruction booklet explaining the objective of the game, the rules, and how each component represented the biotechnology technique being taught.

Presentation Day

Presentation day was one of the highlights of the course. Students introduced their games, explained the underlying science, and invited classmates to play. The classroom buzzed with discussion, laughter, and friendly competition as students explained PCR and FISH, corrected misconceptions, and justified the biological reasoning behind their game designs. One detail that particularly stood out to me was how students incorporated local culture into their designs. The Ludo adaptations made use of familiar Jamaican expressions. In Jamaican Ludo, when a playing piece first enters the board, players often say that the piece has been "born." Some groups cleverly linked this idea to stages within PCR and FISH, allowing the game's language to reinforce the biology while remaining culturally familiar. These small touches reminded me that meaningful science teaching does not always require sophisticated technology. Sometimes it simply requires creativity, contextualization, and the willingness to see familiar resources through a different lens.

> ***By the end of the project, I realized that the games themselves were never the greatest achievement. The real success was watching my students move beyond learning biotechnology to thinking critically about how they would teach it.***

Figures 4 and 5 below showcase additional student-designed board games that reflect this shift from content acquisition to pedagogical thinking, demonstrating how complex biotechnology concepts were transformed into engaging learning tools.

Figure 4 PCR Roll, An Environmental-Themed Ludo-inspired PCR Student-created Board Game that integrates PCR concepts into an environmental science context. Players collect and replicate DNA samples while navigating different ecosystems.

Figure 5 Completed Fishpoly Board Game Prototype, a student-developed board game that reinforces fluorescence *in situ* hybridization (FISH) concepts through handcrafted components, including custom-made dice.

Challenges Along the Way

Although the project was a rewarding learning experience, it was not without challenges. Like many ambitious classroom innovations, it required continuous guidance, flexibility, and patience. The first challenge emerged early. Because the project carried significant coursework weight and extended over approximately eight weeks, many students initially felt overwhelmed. They were expected not only to learn two complex biotechnology techniques, PCR and FISH, but also to transform them into educational games.

At first, many struggled to see how designing a game could deepen their understanding of molecular processes. However, this uncertainty became part of the learning process. Research suggests that the process of designing educational games encourages learners to actively construct knowledge, engage in higher-order thinking, and develop deeper conceptual understanding than simply playing games alone (Kurt & Çetin Dindar, 2025).

Maintaining momentum was another challenge. Although weekly milestones were established, students were balancing multiple courses, assignments, and practicum responsibilities. It quickly became clear that timelines alone were insufficient. Regular in-class reminders, progress checks, and structured opportunities to discuss challenges were essential in keeping students on track.

As with many collaborative projects, participation levels varied. Some students arrived with well-developed ideas, while others contributed minimally and relied heavily on peers. Rather than viewing this only as a limitation, I came to see it as an opportunity to explicitly teach collaboration as a professional skill. Like teaching itself, effective teamwork requires modelling, guidance, and practice.

Time constraints were the most significant limitation. While students had sufficient time to design and construct their games, I would have preferred to dedicate more class time to playing and refining them. One of my original goals was for repeated gameplay to reinforce biotechnology concepts. However, competing academic demands limited the extent to which this aspect could be fully realized. In future iterations, I would deliberately allocate structured sessions for gameplay, reflection, and refinement.

What Changed?

Student reflections confirmed that designing games deepened their understanding of PCR and FISH in ways that lectures alone did not. Translating biotechnology concepts into game mechanics required them to simplify complex ideas, organize them logically, and think critically about scientific processes, reflecting experiential learning (Ranken et al., 2024).

Collaboration further strengthened learning as students justified their reasoning, challenged misconceptions, and refined their designs. Many also reported intending to use similar strategies during their teaching practicum, demonstrating a shift from content mastery to pedagogical thinking.

Over three years, students created eight educational games, including adaptations of Ludo, Monopoly, Scrabble, and original designs that represented PCR, FISH, and biotechnology applications. Notably, students who initially struggled with the concepts often produced the most thoughtful games, highlighting the value of creativity and collaboration as alternative ways of demonstrating understanding.

Assessment outcomes also improved. Most students attempted the optional examination question on PCR and FISH, and approximately 60% passed, suggesting greater confidence and conceptual understanding of these challenging topics.

Lessons for My Practice

This experience continues to shape my approach to teacher education in four ways. First, students develop deeper understanding when required to teach or represent a concept rather than simply learn it. Designing games forced them to think about how others would engage with scientific ideas, an approach consistent with research on learning by teaching, which demonstrates that preparing to teach promotes deeper understanding and knowledge retention (Fiorella & Mayer, 2015).

Second, resource limitations should not be viewed only as constraints. While laboratory tools enhance biotechnology teaching, creative pedagogical approaches can produce equally meaningful learning experiences.

Third, teacher educators must model the pedagogies they expect future teachers to use. If we want graduates to create student-centered classrooms, they must first experience these approaches themselves, a principle consistently highlighted in recent teacher education research (Darling-Hammond et al., 2024).

Finally, learning can be both rigorous and enjoyable. Throughout the project, collaboration, fun, and competition coexisted with scientific reasoning and critical thinking, strengthening rather than reducing engagement.

For educators considering a similar approach, several lessons emerged. Start with one complex concept rather than an entire unit, adapt familiar games to increase relevance, and incorporate regular feedback and brainstorming sessions. Require students to develop instruction manuals linking gameplay to scientific concepts, and provide time for peer play and reflection, where some of the richest learning occurs.

Conclusion

When I first introduced this project, my goal was to improve students' understanding of PCR and FISH. However, the most significant transformation was not in the games themselves, but in students' thinking. This shift captures the essence of science teacher education. Our responsibility is not only to develop scientific knowledge, but to prepare educators who can transform that knowledge into meaningful learning experiences. In resource-constrained contexts, this capacity is especially vital. Creativity, intentional pedagogy, and a willingness to reimagine traditional approaches remain among the most powerful tools in science education.

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Nicolia Nelson is a biology lecturer and teacher educator, specializing in microbiology, environmental biotechnology, and genetics-based content, helping to prepare pre-service science teachers. Her teaching and professional interests centre on innovative, student-centered pedagogies that enhance conceptual understanding in science, particularly in resource-constrained contexts, and how complex biological processes can be made accessible through creative instructional approaches. Nicolia's recent practice-based work explores the use of educational game design and problem-based learning strategies to support both scientific understanding and pedagogical development among pre-service teachers. She encourages learners to move beyond content acquisition and develop reflective practice by considering how scientific concepts can be effectively taught in real classroom contexts.

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