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# Innovating Wireless Education: Visualization as a Catalyst for Student Engagement

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**Innovating Wireless Education: Visualization as a Catalyst for Student Engagement**


## Abstract

Wireless communications underpin many modern technologies and national priorities, yet student interest and enrollment in wireless engineering have declined as emerging fields such as robotics, autonomy, and artificial intelligence gain prominence. This decline persists despite the critical reliance of these fields on wireless technologies for sensing, control, and connectivity, and despite growing industry demand for skilled wireless engineers. This project addresses the disconnect between educational pathways and workforce needs by redesigning how introductory wireless communications concepts are taught. Guided by experiential learning theory, an NSF Improving Undergraduate STEM Education (IUSE) project (DUE 2417446) introduces a problem- and project-based learning (PBL/PjBL) approach that emphasizes engagement, visualization, and real-world relevance. Central to the course redesign is an interactive simulation tool that enables students to visualize and manipulate otherwise abstract radio frequency and communication concepts. Early feedback from surveys and focus groups indicates improved conceptual understanding, increased engagement, and meaningful connections to real-world wireless systems. These results suggest that experiential, visualization-driven approaches can revitalize wireless communications education and strengthen the pipeline to wireless engineering careers.


## 1. Introduction and Motivation

Wireless communication technologies are foundational to modern society, supporting applications ranging from mobile connectivity and sensing to cyber-physical systems, autonomous platforms, and artificial intelligence–enabled decision making. Advances in 5G/6G, the Internet of Things (IoT), and software-defined radios have further elevated the importance of wireless expertise across engineering disciplines. At the same time, workforce reports consistently point to a growing demand for engineers with strong backgrounds in wireless and RF systems.

Despite this importance, undergraduate interest in wireless communications has steadily declined. Many students gravitate toward fields perceived as more tangible or immediately impactful, such as robotics, autonomy, and machine learning. Ironically, these domains depend critically on robust wireless links for sensing, coordination, control, and data exchange. A key contributor to this disconnect is the way wireless communications is traditionally introduced in the curriculum: early emphasis on abstract mathematics, signal models, and derivations can obscure relevance and discourage persistence before students develop intuition or see applications. While this traditional approach may lead to learning gains for some students, research on sustained conceptual understanding suggests multiple representations of concepts tend to have more lasting effects on students.

Educational research has long shown that student motivation and retention are strongly influenced by perceived relevance, early success, and opportunities for active engagement. When learners encounter material primarily through passive or abstract representations, they may struggle to form mental models that support transfer and long-term understanding. This project responds to these challenges by rethinking both *what* is taught in introductory wireless courses and *how* it is taught, with the goal of creating a learning experience that is engaging, intuitive, and closely connected to real-world systems.

**2. Pedagogical Framework**

The planned course redesign is grounded in experiential learning theory, which conceptualizes learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). Rather than positioning theory as a prerequisite to meaningful engagement, experiential learning emphasizes that experience and inquiry can motivate and deepen conceptual understanding.

Building on this framework, the project seeks to adopt a combined PBL/PjBL approach. Problem-based learning engages students with open-ended, authentic problems that require investigation and self-directed learning, while project-based learning emphasizes extended design or implementation tasks culminating in concrete artifacts. Both approaches have been shown to improve student engagement, conceptual understanding, and retention in engineering education when compared to purely lecture-based instruction (Prince & Felder, 2006; Hmelo-Silver, 2004).

In the planned redesigned wireless communications course, students encounter motivating problems early, for example, how modulation choices affect robustness in noisy channels or how bandwidth constraints shape system performance. These problems will create a need-to-know context that drives engagement with mathematical models and analytical tools. In addition, these early hands-on activities expose students to real-world operating regimes and parameter ranges, helping them better appreciate the practical implications of key theoretical developments introduced later in the course. The proposed learning objective matrix maps core wireless topics (e.g., modulation, channel effects, spectral analysis) to specific PBL/PjBL activities, ensuring alignment between experiential tasks and conceptual goals.

Storyboard-guided learning paths further support students as they navigate complex materials. These storyboards explicitly connect problems, simulations, theory, and reflection, helping students understand not only *what* they are doing, but *why* it matters in realistic wireless scenarios.

**3. Instructional Tools and Course Design**

A key contribution of the project thus far is the development of an interactive simulation tool designed to “make the invisible visible” and “make the abstract tangible.” Wireless phenomena such as radio frequency waveforms, modulation effects, and channel impairments are inherently difficult to observe directly. Visualization has been shown to play a critical role in helping students build intuition for such abstract processes, particularly in signal processing and communications contexts (Mayer, 2009).

Introduction to Communication Systems at Virgina Tech is a junior-level undergraduate course designed to provide students with a foundational understanding of electrical communication systems. The course begins with connecting signals and systems concepts to analog communications like amplitude modulation (AM) and frequency modulation (FM) radio, followed by an extended focus on digital communication systems. Throughout the course, students analyze signals in both the time and frequency domains and are introduced to core concepts including signal-to-noise ratio (SNR), energy per bit, noise power spectral density, bit error rate, and basic transmitter and receiver design. Students also complete multiple projects that involve modeling communication systems using MATLAB.

The current version of the simulation tool allows students to manipulate system parameters such as modulation type, noise power spectral density, or energy per symbol and immediately observe the resulting changes in error rate, signal space representation and signal to noise ratio (SNR). By linking parameter changes to visual outcomes, the tool supports active experimentation and hypothesis testing, key elements of experiential learning.

Importantly, the tool is not intended to be treated as a one-time demonstration. Instead, the plan is to keep enhancing the tool and continue integrating it throughout the course in lectures, in-class activities, and homework assignments. This repeated, and varied use encourages students to revisit concepts, explore edge cases, and connect formal analysis with visual intuition. The design aligns with research suggesting that interactive simulations are most effective when embedded within a broader pedagogical strategy rather than used in isolation.

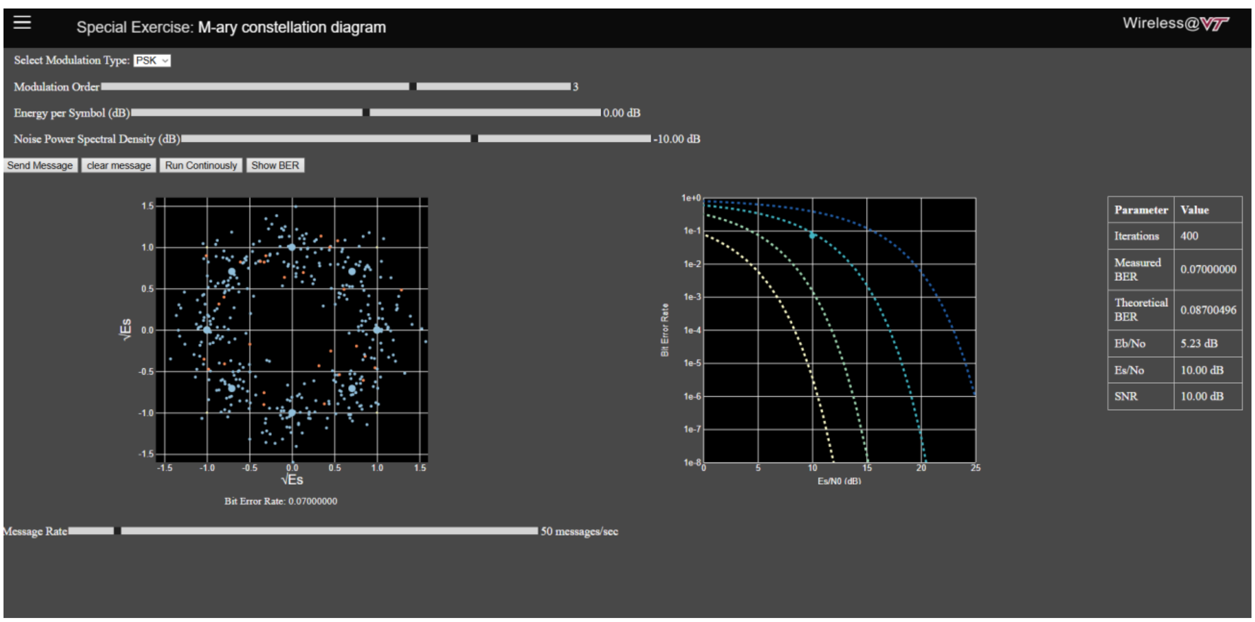


Figure 1: M-ary Simulation home page with 1 8-PSK sample tested

## 4. Preliminary Evaluation and Student Feedback

An Initial evaluation of the simulation tool has been conducted in Spring 2025 through end-of-course surveys and informal focus groups. While these data are primarily formative, they provide early insight into student perceptions and learning experiences.

Students consistently reported that the simulation tool improved their ability to understand abstract communication concepts. Visual representations were frequently cited as helping bridge the gap between mathematical expressions and system behavior. Many students highlighted the value of being able to adjust parameters and immediately observe effects, noting that this process helped them develop an intuitive understanding of topics such as modulation schemes and signal distortion.

Engagement was another recurring theme. Students reported returning to the simulation tool multiple times for homework, exam preparation, and concept review, suggesting that it functioned as an ongoing learning resource rather than a transient classroom activity. Several students also identified direct connections between the tool and real-world systems, including Wi-Fi and orthogonal frequency-division multiplexing (OFDM). Notably, some students described applying insights gained from the simulation to their senior design projects, indicating meaningful transfer beyond the course.

Although these findings are preliminary and largely qualitative, they align with prior research showing that active, visualization-rich learning environments can enhance both engagement and conceptual understanding in engineering education.

**5. Ongoing and Future Work**

Current efforts focus on iterative refinement of the simulation tool and course materials based on student feedback and instructional observations. Planned enhancements include expanding coverage of the tool to additional wireless topics, improving usability, and developing scaffolding features to support students with varying levels of prior knowledge. Also, hands-on hardware experiments have been designed for the course and with a plan for integrating them in future courses.

Future research will incorporate a more systematic assessment of learning outcomes, including pre/post concept inventories, performance-based measures, and comparisons with traditional instructional approaches. These data will support a more rigorous evaluation of the impact of experiential, PBL/PjBL-based instruction on student learning, motivation, and persistence in wireless engineering pathways.

**6. Conclusion**

This NSF IUSE project demonstrates the potential of experiential, problem- and project-based learning approaches to reinvigorate introductory wireless communications education. By emphasizing early engagement, visualization, and real-world relevance, the redesigned course will address longstanding barriers associated with abstraction and delayed application. Preliminary evidence suggests that making wireless concepts visible and interactive can enhance understanding, increase engagement, and strengthen connections to industry-relevant systems. Collectively, these results point toward a promising strategy for rebuilding the educational pipeline in wireless engineering and better aligning undergraduate education with evolving technological and workforce needs.

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