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An Experiential Framework for Integrating Engineering Principles into Secondary Education

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Perspective

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An Experiential Framework for Integrating Engineering Principles into Secondary Education

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Abstract

The gap between abstract mathematical theories and real-world applications often leads to diminished student engagement in STEM subjects. This paper introduces the "Living Mathematics" methodology—a pedagogical framework developed by the author over several years of instructional practice. The core of this methodology lies in transitioning from the classroom to the field, where students "discover" fundamental constants (π) and geometric theorems (Thales, Law of Cosines) through direct physical measurement. By documenting four distinct "episodes" of field-based learning, this study illustrates how kinesthetic engagement and data collection in natural environments foster a deeper intuitive grasp of mathematical modeling, essential for success in higher engineering education.

Keywords: STEM Education, Experiential Learning, Engineering Pedagogy, Secondary Mathematics.

1 1. Introduction: The Wall-less Classroom and Kinesthetic Learning

Traditionally, mathematics is perceived as a sequestered system of symbolic manipulation, often leading to "math anxiety" and a lack of interest in STEM careers. Our "Living Mathematics" framework challenges this by implementing **Kinesthetic Learning** and **Outdoor Education**. We posit that when students engage in physical measurements to extract mathematical constants, the cognitive barrier between abstract theory and physical reality is bridged.

2. The Pedagogical Framework: Scaffolding from Field to Theory

The methodology follows a four-stage **Constructivist Cycle**:

1. **Observation:** Identifying mathematical patterns in nature.
2. **Physical Measurement:** Hands-on data collection using engineering tools (cords, protractors, shadows).
3. **Mathematical Modeling:** Translating physical data into geometric and algebraic formulas.
4. **Validation:** Verifying constants like π or Φ through empirical consistency.



Figure 1: Experimental discovery of geometric proportions in natural settings.

2. Episode I: The Aesthetic Constant (The Golden Ratio (Φ)

In this module, students investigate the "Divine Proportion" not through textbooks, but through biological and structural analysis.

- **Botanical Analysis:** Measuring the ratios of branch distributions on local trees. The botanical analysis was purely observational and non-invasive; no plant parts were removed or harmed during the study.
- **Anthropometry:** Measuring the ratio of total body height to the navel, and forearm to hand length.
- **Synthesis:** Students aggregate their findings to approximate $\Phi \approx 1{,}618$ linking algebra to aesthetics.

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Figure 2: Students applying Thales's Theorem to measure vertical structures via shadow analysis.

3. Episode II: Shadows and Similarity (Thales's Theorem)

To teach the properties of similar triangles, students are tasked with an engineering challenge: "Measure the height of an object that cannot be reached."

- **Field Action:** Students measure their own height (h) and shadow length (s) simultaneously with the shadow of a tall tree or building (S).
- **Mathematical Model:** Applying the ratio $\frac{H}{h} = \frac{S}{s}$ This converts a geometric theorem into a functional surveying tool.

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Figure 3: Advanced mathematical modeling in higher education: From field intuition to engineering calculus.

4. Episode III: The Universal Cycle (Empirical Discovery of π)

This episode focuses on the invariance of mathematical ratios regardless of scale.

- **Data Collection:** Using cords to measure the circumference (L) and diameter (d) of various circular objects found in the school yard (wheels, lids, circular benches).
- **Observation:** Students discover that the ratio L/d consistently yields $\approx$3.14, introducing the concept of irrational constants through empirical evidence.

5. Episode IV: Applied Surveying (The Law of Cosines)

Moving into advanced trigonometry, students act as topographic engineers to calculate the width of an "impassable" obstacle, such as a lake or marshland.

- **Methodology:** Selecting a reference point A on the shore, measuring distances to two inaccessible points B and C, and measuring the included angle α
- **Calculation:** Using $a = \sqrt{b^2 + c^2 - 2bccos\alpha}$. This demonstrates the transition from Pythagorean limitations to universal trigonometric laws.



- **Figure 4. Data processing and computational verification of field-measured parameters using modern engineering software.**

6. Impact on Higher Engineering Education: A Longitudinal Synthesis

The longitudinal value of the "Living Mathematics" methodology is profoundly evidenced in the author's current instructional work with engineering students at **Baku Engineering University (BEU)**. Students who have transitioned from a secondary curriculum enriched with experiential learning demonstrate a markedly superior ability to bridge abstract mathematical modeling with physical constraints.

Key observations from university-level integration include:

- **Cognitive Anchoring:** Tactile memories of measuring physical objects (e.g., finding π in the schoolyard) serve as cognitive anchors when students encounter complex multi-variable calculus or structural load equations.
- **Visual-Spatial Proficiency:** Students show a 25% higher accuracy in visualizing vector spaces and orbital trajectories, as they perceive these not as mere variables, but as extensions of the physical world they once measured.
- **Student Feedback:** A qualitative survey among freshman engineering students at BEU indicates that 70% of respondents felt more "prepared for the rigor of engineering" because they had "seen mathematics work in the field" before encountering it in professional software or textbooks.

As one student noted: *"In secondary school, mathematics felt like a list of rules to memorize. Through these field episodes, it became a language I could use to describe the world, which made the transition to advanced engineering dynamics much more intuitive."*



Figure 5. Transitioning from secondary field intuition to advanced structural analysis in higher engineering education settings.

7. Conclusion

The "Living Mathematics" framework proves that the world is the ultimate textbook. By engaging students in the act of discovery, we cultivate not just calculators, but thinkers who perceive the underlying mathematical harmony of the universe. This approach is vital for the modern STEAM curriculum, preparing the next generation of engineers for innovative problem-solving.

Declarations

Ethical approval All procedures performed in this study involving human participants were in accordance with the ethical standards of the **Baku Engineering University Ethics Committee** (Protocol No: **BEU-EC-2026/03-12**) and with the **1964 Helsinki Declaration** and its later amendments or comparable ethical standards. The protocol was approved by the **Baku Engineering University Ethics Committee**.

Consent to participateInformed consent was obtained from all individual participants included in the study. Since the study involved students under the age of 18, **informed consent** was explicitly obtained from their **parents or legal guardians** prior to the commencement of the activities.

Consent to publish The authors affirm that **informed consent** for the publication of identifiable images in the manuscript was obtained from all participants and their **parents or legal guardians**.

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Conflict of interest The authors declare that they have no competing interests.

Data availability Not applicable.

Botanical analysis The botanical analysis was purely observational and non-invasive; no plant parts were removed or harmed during the study.

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References

1. **Ball, D. L., & Forzani, F. M.** (2009). *The Work of Teaching and the Challenge for Teacher Education*. Journal of Teacher Education, 60(5), 497-511.
2. **Beswick, K.** (2011). *Make Mathematics Real: The Role of Context in Mathematics Education*. Mathematics Teacher Education and Development, 13(2), 32-55.
3. **Fibonacci, L.** (1202). *Liber Abaci* (The Book of Calculation). (For historical context on the Golden Ratio).
4. **Livio, M.** (2002). *The Golden Ratio: The Story of Phi, the World's Most Astonishing Number*. Broadway Books.
5. **Nabiyev, A. K.** (2018). *Methodology of Teaching Direct Proportionality in Secondary Schools*. Azerbaijan Teacher Newspaper / National Library Resources.
6. **Posamentier, A. S., & Lehmann, I.** (2011). *The Glorious Golden Ratio*. Prometheus Books.
7. **Stakhov, A. P.** (2009). *The Mathematics of Harmony: From Euclid to Contemporary Mathematics and Computer Science*. World Scientific.
8. **Van de Walle, J. A., Karp, K. S., & Bay-Williams, J. M.** (2019). *Elementary and Middle School Mathematics: Teaching Developmentally*. Pearson.