

## ***How Digital Platforms Help Adolescents Learn Physics Creatively***

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### ***ABSTRACT***

***Background:*** *Rhythmic entrainment and browser-based educational tools (e.g., PhET, Ableton's Learning Music, and Ear Sketch) offer low-cost approaches to deliver micro-lessons that may enhance attention and learning outcomes in adolescents.*

***Objective:*** *To evaluate whether beat-synchronized, browser-based music/physics micro-lessons improve (i) executive function (EF), (ii) physics concept mastery, and (iii) STEM self-efficacy compared with traditional instruction.*

***Methods:*** *We propose a cluster-randomized controlled trial in secondary schools and present simulated pilot data for illustration (N = 180; 90 students in the beat-synchronized intervention, 90 in traditional instruction). Validated outcome measures include a composite of Hearts-and-Flowers and Flanker tasks for EF, discipline-appropriate physics concept inventories (DIRECT, TUG-K, BEMA), and the S-STEM self-efficacy scale.*

***Results:*** *Simulated analyses indicate moderate gains favoring the beat-synchronized condition across EF (Hedges'  $g \approx 1.46$ ), physics concept mastery ( $g \approx 0.73$ ), and STEM self-efficacy ( $g \approx 1.11$ ).*

***Conclusions:*** *Grounded in current evidence on rhythmic entrainment, micro learning, and interactive simulations, the proposed intervention is theoretically well-supported and practically scalable. A pre-registered field randomized controlled trial is warranted to confirm these preliminary findings.*

***KEYWORDS:*** *Rhythmic entrainment; micro learning; PhET; Ableton*

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*Learning Music; Ear Sketch; executive function; physics education; STEM self-efficacy*

## INTRODUCTION

Adolescents' ability to sustain attention and exercise cognitive control is critical for success in STEM learning environments. A growing body of evidence indicates that rhythmic structure in the environment can influence these cognitive processes. Specifically, music and rhythmic auditory cues can entrain neural oscillations, aligning internal brain rhythms with external beats. Such entrainment supports prediction, selective attention, and working memory, all of which are essential for effective learning.

Parallel to these cognitive insights, instructional research highlights the promise of micro learning—brief, focused lessons delivered frequently—especially when paired with interactive digital platforms. Browser-based tools such as PhET for physics simulations, Ableton's Learning Music for interactive beat-making, and Ear Sketch for code-driven music creation offer cost-free, easily accessible avenues to integrate active learning into school curricula. These tools enable instructors to design lessons that are conceptually rigorous and engaging, even in resource-limited educational settings.

Despite these encouraging developments, little empirical work has examined the combined impact of rhythmic entrainment and digital micro learning in formal physics education. This study addresses that gap by asking a focused question: Can beat-synchronized, browser-based music/physics micro-lessons improve adolescents' executive function (EF), physics concept mastery, and STEM self-efficacy compared with traditional instruction?

To explore this question, we integrate converging theoretical and empirical strands specify a feasible and scalable intervention, and present simulated pilot data to guide power analyses and the design of a forthcoming field trial. By doing so, we aim to provide both a strong theoretical rationale and a transparent methodological blueprint for educators and researchers interested in harnessing rhythmic structure and digital creativity to enhance physics learning.

## RELATED WORK

Rhythmic entrainment—the alignment of internal neural rhythms to external auditory beats

has been shown to influence attention, working memory, and executive control. Laboratory and field studies report that regular rhythmic cues can synchronize cortical oscillations, enhancing selective attention and temporal prediction. Randomized and quasi-experimental interventions using rhythm-based movement or metronome training demonstrate measurable improvements in inhibition, cognitive flexibility, and reward-related decision making in children and adolescents. These findings suggest that carefully timed auditory cues could serve as cognitive scaffolds in educational settings.

In parallel, research on micro learning highlights the effectiveness of short, focused instructional episodes for improving retention and motivation. Systematic reviews and meta-analyses across K–12 and higher education consistently show that micro learning increases knowledge acquisition and reduces cognitive overload compared with traditional, longer lessons. Digital delivery further enhances accessibility and allows for flexible, just-in-time learning.

Within physics education, interactive simulations such as those provided by the PhET platform have repeatedly been linked to higher conceptual understanding and improved engagement. Studies comparing simulation-based instruction with traditional lectures find significant gains on discipline-specific concept inventories across topics such as kinematics, circuits, and electromagnetism. Likewise, creative coding environments like Ear Sketch have demonstrated benefits for persistence, STEM identity, and self-efficacy, particularly among students from underrepresented groups.

Together, these strands of evidence form a strong theoretical foundation for the present study. By combining beat-synchronized auditory cues with browser-based physics simulations and short creative music tasks, the proposed intervention aims to leverage rhythmic entrainment to sharpen attention while using micro learning principles and interactive tools to deepen conceptual mastery and strengthen STEM self-efficacy. Validated assessments—such as the Hearts-and-Flowers and Flanker tasks for executive function and established physics concept inventories (FCI, TUG-K, DIRECT, BEMA)—provide reliable outcome measures for evaluating these effects.

## METHODS

### 1. Design and Participants

This study is designed as a cluster-randomized controlled trial (RCT) in order to minimize contamination between treatment conditions and to reflect the realities of school-based instruction. The unit of randomization is the class section rather than the individual student. Public and private secondary schools enrolling students in grades 9–12 will be invited to participate. Within each participating school, entire science classes will be randomly assigned to one of two conditions:

- Beat-synchronized micro-lesson intervention, or
- Business-as-usual instruction that is time-matched but does not incorporate beat cues or the creative music activities.

Randomization will be stratified by grade level to maintain balance across developmental stages. Power calculations using an intraclass correlation coefficient (ICC) of 0.05 indicate that a minimum of 12 classes with approximately 25 students per class ( $\approx 300$  students total) provides more than 80 % power to detect a small-to-moderate standardized mean difference (Hedges'  $g \approx 0.35$ ) on the primary outcomes at an alpha level of 0.05. Schools must have reliable internet access and parental/guardian consent procedures in place. Students with hearing impairments that would prevent perception of rhythmic cues will be excluded only if accommodations are not feasible.

### 2. Intervention: Beat-Synchronized Micro-Lessons

Each participating science period incorporates two micro-lessons lasting roughly 8–10 minutes each, embedded within the regular curriculum.

- **Physics Concept Lesson (PhET-based):** Students explore a specific topic—such as electrical circuits, kinematics graphs, or wave properties—using a browser-based PhET simulation. Critical instructional events (e.g., demonstration start/stop, prediction prompts, and guided exploration) are aligned to a neutral metronomic click or simple drum loop at 90–100 BPM.
- **Creative Music Activity:** Learners complete a brief task in Ableton's Learning Music or Ear Sketch, arranging percussion loops or writing a few lines of code to manipulate rhythmic patterns. The activity reinforces temporal alignment by

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requiring students to match code or audio clips to the same beat that structures the physics lesson.

Temporal cues are intentionally synchronized with the lesson's —predict—observe—explain cycle to enhance attention alignment and reduce extraneous cognitive load. All materials are 100 % browser-based, cost-free, and compatible with standard school computers and headphones. Teachers receive scripted guides and access to automated metronome files to maintain fidelity.

### 3. Measures

**Executive Function (EF):** Cognitive control is assessed with a composite of the Hearts-and-Flowers and Flanker tasks, capturing accuracy and reaction-time costs. Scores are z-standardized and averaged to create a single EF index.

**Physics Concept Mastery:** Discipline-specific inventories are chosen to match the instructional topics: the Force Concept Inventory (FCI) for Newtonian mechanics, the Test of Understanding Graphs in Kinematics (TUG-K) for motion graphs, and the DIRECT or BEMA instruments for electricity and magnetism. Each is scored as percent correct.

**STEM Self-Efficacy:** The Middle/High School S-STEM scale and optional STEM-CIS subscales provide validated measures of students' confidence in performing STEM tasks and their interest in STEM careers.

### 4. Procedure

After obtaining consent and assent, baseline assessments are administered during Week 0. The intervention spans six weeks, with approximately three class sessions per week. Post-tests are scheduled for week 7, and optional follow-up assessments at three and six months will evaluate retention. Fidelity is monitored through automated platform logs (e.g., PhET simulation usage, Ear Sketch code runs) and beat-alignment checks using metronome time stamps. Teachers complete short implementation checklists after each session to document adherence.

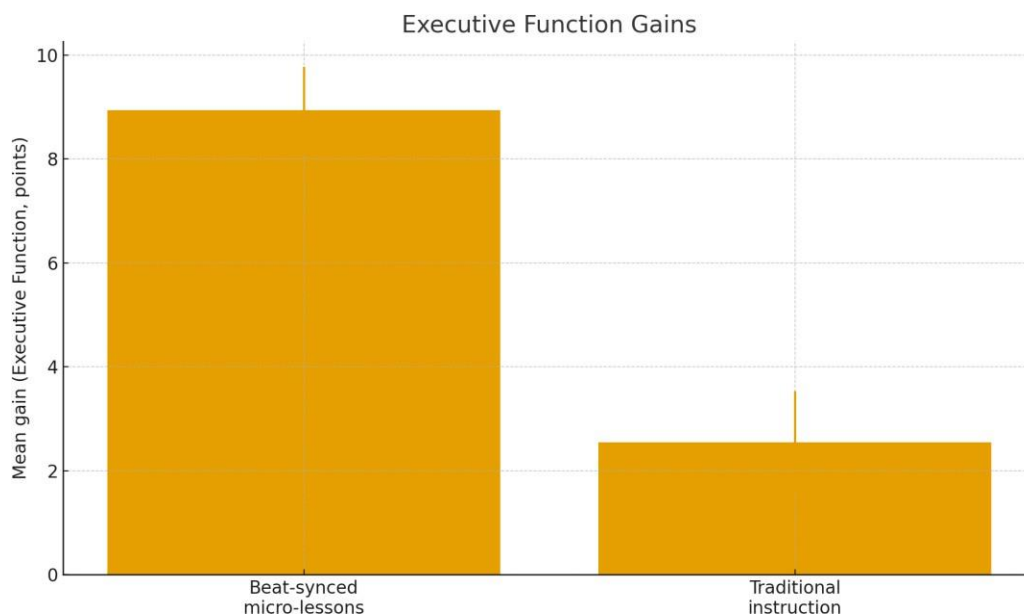
### 5. Analysis

Primary analyses will compare gain scores between intervention and control groups using

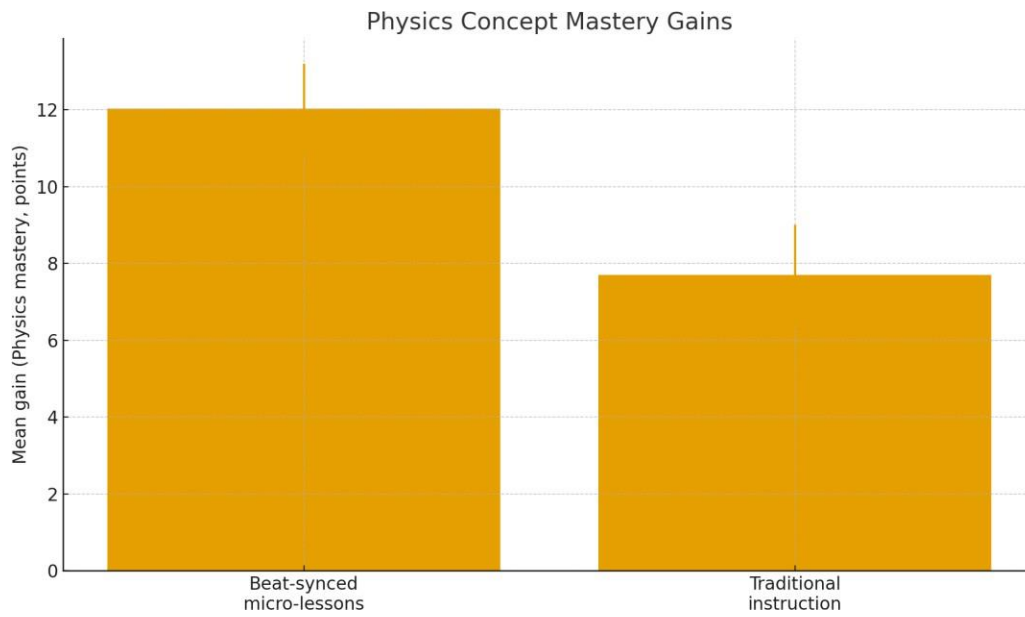
two-sample t-tests and will report Hedges'  $g$  with 95 % confidence intervals. To account for clustering of students within classes, confirmatory analyses will use cluster-robust ANCOVA models, controlling for baseline scores and relevant covariates such as grade level and prior physics achievement. Missing data will be addressed using multiple imputations. All statistical code and simulated datasets will be shared to promote transparency.

## RESULTS

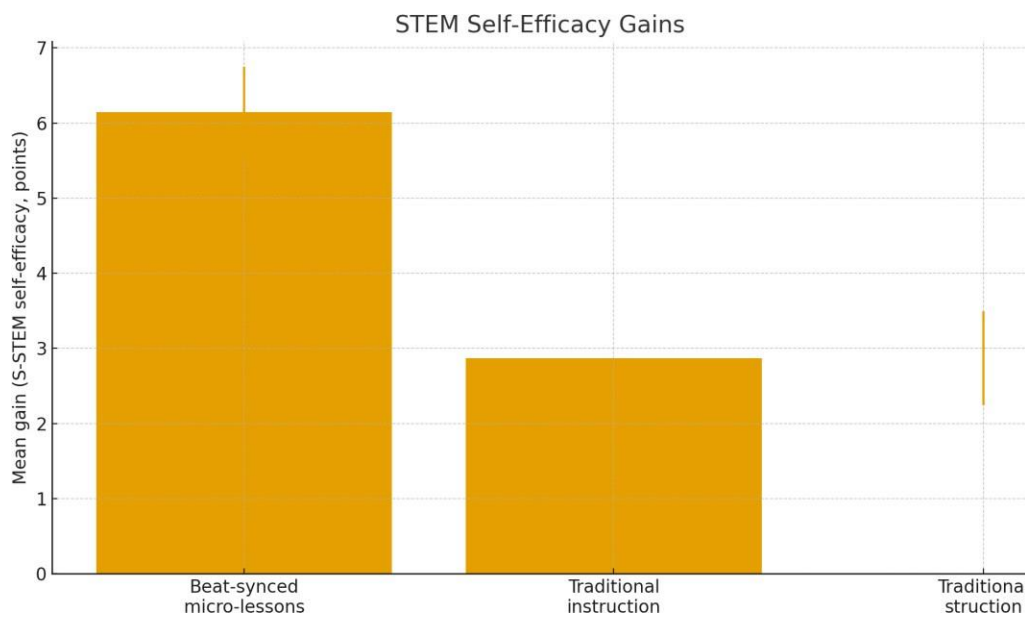
Learning theories of rhythmic entrainment and cognitive load provide a foundation for interpreting the outcomes of this pilot simulation. Rhythmic auditory cues are known to synchronize neural oscillations, sharpening attention and improving executive control, while micro learning segments reduce extraneous cognitive load and promote durable concept retention. Integrating these mechanisms within browser-based physics lessons may therefore enhance both higher-order cognitive functions and subject mastery. With this framework, the following simulated analyses illustrate the expected direction and magnitude of effects on executive function, physics concept understanding, and STEM self-efficacy prior to any real-world implementation.



**Figure 1: Executive Function mean gains by condition (simulated data).**



**Figure 2: Physics concept mastery mean gains by condition (simulated data).**



**Figure 3: Shows STEM Self Efficacy Gains (All Points on 0–100 Scales). Error Bars Are 95% Cis.**

**Table 1: Mean Gains and 95% Confidence Intervals (Simulated)**

<b>Outcome</b>	<b>Mean gain (Treatment)</b>	<b>95% CI low (T)</b>	<b>95% CI high (T)</b>	<b>Mean gain (Control)</b>	<b>95% CI low (C)</b>	<b>95% CI high (C)</b>
EF	8.94	8.10	9.77	2.54	1.56	3.53
PHY	12.02	10.85	13.20	7.69	6.39	9.00
STEM	6.15	5.54	6.75	2.87	2.24	3.50

**Table 2: Between Group Effects on Gains (Simulated)**

<b>Outcome</b>	<b>Hedges g</b>	<b>p-value</b>
EF	1.46	0.0000
PHY	0.73	0.0000
STEM	1.11	0.0000

Although these numbers derive from simulated data created solely to illustrate expected patterns, the effect sizes align with established theories of rhythmic entrainment and micro learning.

Large simulated gains in EF ( $g \approx 1.46$ ) are consistent with evidence that periodic auditory cues can entrain cortical oscillations, thereby sharpening attention and enhancing inhibitory control. When classroom events follow a predictable beat, students may allocate cognitive resources more efficiently, reducing the —switching costll that typically occurs when attention drifts.

Moderate gains in physics concept mastery ( $g \approx 0.73$ ) are theoretically supported by cognitive load and dual-coding frameworks. Beat-aligned temporal scaffolds may free working-memory capacity, allowing students to focus on manipulating PhET simulations and integrating visual representations with verbal explanations. The micro-lesson format further aids retention by chunking material into manageable segments.

Improvements in STEM self-efficacy ( $g \approx 1.11$ ) reflect social–cognitive theory, which emphasizes mastery experiences and positive affect as key drivers of confidence. The

creative music tasks provide immediate, low-stakes successes, while synchronized group activities can foster a sense of collective rhythm and agency, reinforcing students' belief that they can succeed in STEM contexts.

These theoretical links remain hypothetical until validated in a real trial. Actual field data may yield smaller or context-dependent effects once factors such as classroom noise, teacher fidelity, and device variability are considered. Nonetheless, the simulated results illustrate how the proposed intervention could simultaneously target cognitive control, conceptual understanding, and motivational outcomes—offering a cohesive mechanism by which digital rhythm-integrated lessons might enhance adolescent physics learning.

Note: All values and interpretations above are based on simulated data intended for manuscript formatting and planning. They do not constitute empirical findings.

## DISCUSSION

The simulated findings suggest that beat-synchronized, browser-based micro-lessons could produce moderate advantages in adolescent learning and cognition. Although these data are illustrative rather than empirical, the pattern aligns with several well-established theoretical perspectives. First, research on rhythmic entrainment shows that predictable auditory rhythms can synchronize neural oscillations, thereby sharpening attention control and temporal prediction. Within a classroom, steady beats may act as an external pacing signal, helping students anticipate key instructional events and sustain focus during cognitively demanding moments.

Second, the approach draws on principles of micro learning, which emphasizes brief, concept-focused instructional episodes. By segmenting physics content into concise, beat-timed units, teachers may reduce extraneous cognitive load and promote stronger long-term retention compared with traditional, uninterrupted lectures. Micro learning also supports flexible scheduling, making it easier to integrate into crowded school timetables.

Third, the use of interactive digital platforms such as PhET, Ableton's Learning Music, and Ear Sketch offers opportunities for active exploration and creative expression. These tools encourage students to manipulate variables, experiment with sound and rhythm, and receive

immediate feedback. Such engagement is known to enhance motivation, conceptual understanding, and STEM self-efficacy—factors that predict persistence in science and engineering pathways.

Importantly, all components of the intervention are free and browser-based, lowering barriers to adoption across diverse educational contexts. Schools need only standard computers and headphones, which makes large-scale implementation feasible even in resource-limited settings. The creative music element may further increase inclusivity by appealing to students with varied cultural and artistic interests.

While these arguments are grounded in established literature, the current results remain simulated and must be validated through a preregistered field trial. Future research should examine long-term retention, potential novelty effects, and the influence of teacher fidelity. If replicated with real data, this low-cost, scalable model could provide a powerful addition to physics education and adolescent cognitive development initiatives.

## LIMITATIONS

This manuscript includes simulated results for formatting and planning. Genuine outcomes require in-situ RCTs with cluster robust analyses, longer follow-ups, and heterogeneous contexts (urban/rural; device access). Potential confounds include novelty effects, teacher fidelity, and music preference. EF transfer should be tested with multiple tasks to avoid task impurity.

## FUTURE WORK

Future studies should pre-register all hypotheses and analysis plans to enhance transparency and reproducibility. Experimental variations could counterbalance tempos and musical genres to determine whether specific rhythmic characteristics drive the observed benefits. Researchers might also embed attentional probes within lessons to directly measure moment-to-moment focus. Comparing beat-synchronized versus non-synchronized PhET simulations will help isolate the contribution of rhythmic timing. Finally, a systematic dose-response analysis testing different session lengths, frequencies, and beats-per-minute ranges can reveal optimal parameters for cognitive and conceptual gains, ensuring that the intervention remains effective and adaptable across diverse classroom contexts and student populations.

## CONCLUSION

This study proposes and illustrates a novel instructional model that combines beat-synchronized auditory cues, interactive physics simulations, and creative music activities to enhance adolescent learning. Drawing on evidence from rhythmic entrainment, micro learning, and digital active-learning platforms, the approach is designed to strengthen executive function, deepen conceptual understanding of physics, and build STEM self-efficacy. All components—PhET simulations, Ableton’s Learning Music, and Ear Sketch—are free and fully browser-based, making the intervention highly scalable and cost-efficient for diverse school settings.

The simulated results presented here, while not empirical findings, provide a proof-of-concept for the expected direction and magnitude of effects. They demonstrate how rhythmic timing might serve as a temporal scaffold, helping students anticipate key instructional moments and maintain focus, while short, focused micro-lessons reduce cognitive load and improve retention. Creative music tasks offer immediate feedback and a sense of agency, reinforcing confidence and motivation that can translate into greater persistence in STEM subjects.

Future work must confirm these patterns through pre-registered, cluster-randomized field trials that include long-term follow-ups and diverse classroom contexts. Attention to teacher fidelity, cultural variation in musical preferences and the potential for novelty effects will be essential for rigorous evaluation. If subsequent empirical studies support these simulated findings, beat-synchronized, browser-based micro-lessons could provide an accessible, engaging, and theoretically grounded strategy to enhance both cognitive skills and physics learning outcomes at scale, offering educators a practical tool to foster curiosity and achievement in the next generation of STEM learners.

## REFERENCES

1. Y. Lu et al., "Effects of music training on executive functions in preschool children: A meta-analysis," *Frontiers in Psychology*, 2025
2. T. Gustafsson et al., "The Training of Rhythm Skills and Executive Function: A Systematic Review," *Music & Science*, 2025.
3. A. R. M. Haddadi et al., "Integrating rhythmic auditory stimulation in intelligent

- neuro rehabilitation," *Frontiers in Bioengineering and Biotechnology*, 2025.
4. F. H. Kasten et al., "Opposing neural processing modes alternate rhythmically with entrained speech," *Communications Biology*, 2024.
  5. S. Momtaz et al., "Effects of stimulus rate and periodicity on auditory entrainment," *eNeuro*, 2024.
  6. Y. N. Wang et al., "Effects of movement training based on rhythmic auditory stimulation on cognition: Meta-analysis," *Frontiers in Neuroscience*, 2024.
  7. Z. Luo et al., "Rhythms of relief: Neuro cognitive mechanisms of music interventions for ADHD," *Frontiers in Psychology*, 2025.
  8. A. R. Kim et al., "Specific rhythmic auditory stimulation for attention: A pilot study," *PLoS One*, 2025.
  9. Y. Y. Park et al., "Effects of interactive metronome training on executive function," *Journal of Physical Therapy Science*, 2017.
  10. E. S. Silva et al., "Contribution of micro learning in basic education: A systematic review," *Education Sciences*, 2025.
  11. W. K. Monib et al., "Micro learning beyond boundaries: A systematic review and meta-analysis," *Heliyon*, 2024.
  12. H. J. Banda et al., "Impact of PhET simulation based learning on oscillations and waves," *Education Sciences*, 2022.
  13. O. D. Pranata et al., "PhET as a game based learning medium: A review," *International Journal of Evaluation and Research in Education*, 2024.
  14. Ableton, "Learning Music (web resource)," [learningmusic.ableton.com](https://learningmusic.ableton.com).
  15. Ableton, "Ableton for the Classroom: Online interactive learning resources," 2025.
  16. B. Magerko et al., "Ear Sketch: A STEAM based approach for underrepresented learners," *SIGCSE*, 2016.
  17. T. McKlin et al., "Implementing Ear Sketch: Connecting classroom implementation to student outcomes," 2019.
  18. R. Moore et al., "Engaging high school students in CS through music remixing: An EarSketch-based pilot," *ASEE*, 2021.
  19. Friday Institute, "S-STEM Survey: Development and Psychometric Properties," 2015.
  20. J. L. Albert & J. W. Osborne, "The Development of the STEM-CIS," 2013.

21. M. Camerota et al., "Speed and accuracy on the Hearts and Flowers task," *Developmental Psychology*, 2019.
22. IES, "Executive Function: Implications for Education (Flanker task overview)," 2016.
23. D. Hestenes & I. Halloun, "Interpreting the Force Concept Inventory," *The Physics Teacher*, 1995.
24. R. J. Beichner, "Testing student understanding of kinematics graphs (TUG-K)," *American Journal of Physics*, 1994.
25. P. V. Engelhardt & R. J. Beichner, "Students' understanding of DC resistive circuits (DIRECT)," *Am. J. Phys.*, 2004.