INSIGHTS

POLICY FORUM

PHOTO: SAHAR COSTON-HARDY

EDUCATION

Active learning: "Hands-on" meets "minds-on"

Widespread disruptions to schooling spurred by COVID-19 have amplified long-standing discussions about what high-quality teaching and learning can be. Growing bodies of research and practice, from early childhood to university classrooms and beyond, demonstrate the benefits of moving beyond traditional lecture-driven approaches in favor of "active learning." Such approaches put students more in the driver's seat through discussions, in-class questions, and feedback; interactive technologies; and other strategies to engage learners and deepen understanding. Beyond cognitive and academic benefits, active-learning approaches can also provide socioemotional support, particularly for students who may not feel at home in or supported by traditional passive learning. But there is no single active-learning approach. Instead, as the experts below describe, we see a rich and developing portfolio of methods and ideas supporting different ways to produce more effective learning. **—Brad Wible**

AI from the screen into the physical world

By **Nesra Yannier[1], Scott E. Hudson[1], Kenneth R. Koedinger[1]**

Improving science, technology, engineering, and mathematics (STEM) teaching is crucial for improving STEM learning. Yet teacher training improvements progress slowly. And even the best teachers are challenged to maintain the attention of new cohorts of "digital natives" and feel the need to find innovative ways to engage them. Less focus on scientific facts and more experiences with scientific inquiry better engage the natural curiosity of children. But many elementary teachers typically do not have the background or curriculum materials to teach science from an inquiry perspective.

Addressing these challenges, we have been developing mixed-reality Intelligent Science Stations (see norilla.org) to engage children in active, inquiry-based experimentation and learning experiences in the physical world while providing interactive guidance that supports teachers as well as students. Children perform and interpret real-world experiments in a given physical apparatus (e.g., an earthquake table, ramps, a balance scale). Artificial intelligence (AI) computer vision algorithms reconstruct the physical scene and


A child jumps from icon to icon to tell a story as part of the Urban Thinkscape in Philadelphia.

provide input to pedagogical algorithms that track the children's progress and provide adaptive, automated feedback to guide them in scientific inquiry, producing a powerful form of active-learning support. An engaging virtual helper can "see" what children are doing and provide assistance accordingly, as they work collaboratively.

In one station, children experiment with physical towers on an earthquake table, predict which of two minimally contrasting towers will fall first, and explain why, all with interactive feedback from the virtual helper. Replicated random assignment experiments demonstrate that students learn more with these AI-supported physical interactions than from tightly matched screen-based interactions using the same pedagogical algorithms (*1*, *2*). Children also prefer these AI-supported physical interactions over screen interactions, as confirmed by enjoyment surveys and enthusiastic student comments.

Not just any active learning works. When we turn off the system's intelligent guidance such that students are freely performing tower-building activities on their own (similar to most current museum exhibits and maker spaces), they still enjoy it, but they learn far less (*3*). Thus, we can more precisely define this effective form of active learning as engaging students in inquiry tasks where they predict and explain, prompted by contrasting cases associated with learning goals and supported by varied repetition with feedback.

These intelligent stations support more equitable access to high-quality learning by being available to children from diverse backgrounds in museums, schools, Head Start programs, and Boys and Girls Clubs, providing adaptive support to children even if they do not have a knowledgeable parent, teacher, or museum staffer to guide them. In addition to direct active-learning support, these stations also provide an example of effective active-learning techniques that teachers and mentors can use in other contexts.

Active learning in the community

By **Kathy Hirsh-Pasek[2,3]** *and* **Roberta Michnick Golinkoff[4]**

Growing consensus suggests that humans learn best when they are active (not passive) and engaged (not distracted), when material to be learned is meaningful (not disjointed), and when it occurs in a socially interactive context that is iterative (not merely repetitive) and fun (*4*). These characteristics can be used to design playful learning environments in schools, educational apps, and community spaces. With only 20% of a child's waking time spent in school, the transformation of public spaces into playful learning spaces can heighten educational opportunities beyond the classroom while being accessible, equitable, and culturally sensitive for all.

One such Playful Learning Landscape project, Urban Thinkscape (*5*) (see photo), transformed a bus stop in West Philadelphia by designing activities that children can do while they and their families wait for the bus. The goal was to spark parent-child interactions, which are known to promote better language skills. Puzzle walls, hidden figure designs, a story-building installation, and a hopscotch crafted from the happy-sad test (*6*) for executive function became catalysts for the study of spatial language, rich conversations, and impulse control. Observational data suggest that language conversations between parents and children, question asking, and spatial language known to build STEM scores were greater at Urban Thinkscape than at a control playground site in the same area.

With Parkopolis (*7*), the human-sized board game, active-learning techniques engaged families with fraction dice and a card deck filled with challenges from the psychological literature. Both children and caregivers used more STEM language and engaged in more STEM interaction in Parkopolis than they did in a control exhibit focused on rocket launching.

Thus far, 10 installations have been studied in cities such as Philadelphia, Chicago, and Santa Ana (see playfullearninglandscapes.com). In each city, scientists co-design the installations with architects and with members of the community to ensure cultural sensitivity and accessibility. This exemplifies how scientists can use active learning—socially and physically co-constructed learning with a clear learning goal—to enhance educational opportunities for young children and their families. The work enhances equity and neighborhood rejuvenation through community-based participatory research, thus serving as a model of how research in the learning sciences can benefit from community input.

Developing executive functioning through less-structured time

By **Yuko Munakata[5]** *and* **Sabine Doebel[6]**

Children's learning and achievement are tied to their executive functioning, a collection of cognitive skills that develop across childhood and support a wide range of goal-directed behaviors, including planning ahead, focusing amid distractors, adaptively shifting from one activity to another, and inhibiting impulses. Active learning, where children practice or explore rather than just listen or watch, is critical to the development of executive functioning. But how structured should those activities be? Many attempts to boost executive functioning focus on structured practice of putative executive processes on targeted tasks. Working memory training, for example, requires participants to hold in mind progressively longer sequences of information. Such training shows limited benefits beyond practiced tasks (*8*). An alternative is to develop executive function skills during less-structured activities such as play, outings, and reading—activities that have long been available for many children but that have been displaced in recent times by more-structured activities. Less-structured activities give children opportunities to explore, engage curiosity, make choices, and set goals, where adults may provide guidance and feedback but not explicit structured direction. Less-structured time can also provide opportunities to observe, learn from, and engage with others.

Children who spend more time in less-structured activities show better executive function, after controlling for socioeconomic factors. For example, 6-year-old children who spent more of their leisure time in less-structured activities showed better self-directed executive functioning (*9*). Preliminary evidence from a longitudinal twin sample suggests that children who experienced more structured environments (e.g., formal lessons) at age 4 showed worse self-directed executive functioning at age 7; this link was mediated by nonshared environmental factors rather than genetic factors, highlighting the causal influence of how children spend time (*10*). For 3- to 5-year-old children at home during the COVID-19 pandemic, preliminary evidence suggests that more time and variety in less-structured activities was associated with better externally cued executive function, and they were able to flexibly switch to new rules when instructed (*11*). Further evidence comes from existing school curricula. In studies using randomized lottery-based admission (*12*), children in Montessori schools—who have ample opportunities to make choices, follow interests, and engage in exploratory play within a prepared environment—show some evidence of better executive function than peers in more conventional preschool settings. Less-structured time that permits choice, playful exploration, and interaction with others may promote the development of executive functioning and learning at home and in school by allowing children a more active role in goal-directed behavior and knowledge acquisition.

PHOTO: MEDIANEWS GROUP/BAY AREA NEWS/GETTY IMAGES

Physically active learning

By **Daniel L. Schwartz**[7]

There are likely many pathways by which physical activity affects thoughts and feelings. Relevant to school, physically active learning can support the ability of students to model the world, discover patterns, and generate creative ideas. Yet far too often, particularly during remote schooling during a pandemic, students are expected to sit still and quietly listen.

There are rich neural connections that project between the motor and visual system, including the spatial imagination. These connections are arguably why people can design and use multipart tools. When people use their hands to help model physical systems, they can solve problems that they cannot do verbally or by sight alone, such as explaining the behavior of imagined gears or water in a tilting glass (*13*, *14*). By asking students to use their hands to model physical phenomena, it may help them build a mental model of how the world works.

A second application of physically active learning involves providing students with the opportunity to move visible objects, which harnesses the visual system to help them see patterns and new structures in the objects that they move. For instance, by moving small plastic pieces, children are more likely to figure out how to solve 1/4 of 12 pieces than if they only look at the pieces, even if those pieces are preorganized into four groups of three pieces each. The children are also more likely to generalize their learning than if they simply rely on verbal solutions (*15*). Asking students to manipulate objects will be most effective when there is latitude in how they can move the objects and there are clear problem statements that guide their search for patterns, such as using miniature tracks and cars to build a road system that minimizes congestion.

A third application of physical activity is to improve creativity. Walking at a comfortable pace increases people's ability to generate more creative uses for objects and more creative and well-structured analogies (*16*). There are many candidate mechanisms to explain this effect on creativity, which range from positive mood enhancement to the relaxation of cognitive filtering. Pending the ultimate explanation, it appears that setting oneself a problem to think about and then taking a simple walk unleashes one's ability to think of new alternatives that may not reveal themselves when sitting.

[1]Human-Computer Interaction Institute, Carnegie Mellon University, Pittsburgh, PA, USA; nyannier@andrew.cmu.edu. [2]Department of Psychology, Temple University, Philadelphia, PA, USA. [3]Brookings Institution, Washington, DC, USA; kathryn.hirsh-pasek@temple.edu. [4]School of Education, University of Delaware, Newark, DE, USA. [5]Department of Psychology and Center for Mind and Brain, University of California, Davis, Davis, CA, USA; ymunakata@ucdavis.edu. [6]Department of Psychology, George Mason University, Fairfax, VA, USA. [7]Graduate School of Education, Stanford University, Stanford, CA, USA; daniel.schwartz@stanford.edu. [8]Department of Physics, Harvard University, Cambridge, MA, USA; louis@physics.harvard.edu. [9]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA, USA. [10]Department of Physics, University of California, Merced, Merced, CA, USA. [11]Department of Biology, University of Washington, Seattle, WA, USA; ellij@uw.edu. [12]Research for Inclusive STEM Education Center, School of Life Sciences, Arizona State University, Tempe, AZ, USA; katelyn.cooper@asu.edu.

Experimentation and interaction can engage learners and deepen understanding.

the same experiment twice in different courses, and the results were the same: Students learned significantly more with active learning (as expected), and they also felt that they learned from it—but their feeling of learning was more pronounced with the well-presented traditional lectures.

These misperceptions have broad implications for STEM education. Course evaluations based on students' perceptions of learning could inadvertently promote inferior methods of instruction—a superstar lecturer can explain things in such a way as to make students feel like they are learning more than they actually are. By contrast, the cognitive effort involved in active learning is a sign of effective learning, even if students may not always perceive it that way. Moreover, these perceptions of learning may also play a role with popular active-learning methods that rely heavily on instructor feedback (*17*, *20*). We recommend that instructors intervene early in the semester to discuss notions of learning versus the feeling of learning and persuade students that they are in fact benefiting from the sustained mental efforts associated with active learning (*19*). This mismatch between actual learning and the feeling of learning must be addressed and understood by faculty and students for these proven instructional strategies to be more effective and to become widespread.

Students may learn more than they think

By **Louis Deslauriers[8], Logan McCarty[8,9], Kristina Callaghan[8,10]**

Despite strong evidence that active learning based on the principles of deliberate practice produces better educational outcomes (*17*), traditional lecturing remains the dominant mode of instruction in college STEM courses (*18*). Why are students and faculty slow to embrace active learning, which seeks to cognitively engage students and to promote peer interactions? In large part, the effortlessness associated with listening to a well-presented lecture can mislead students (and instructors) into thinking that they are learning a lot.

We compared students' perception of learning with their actual learning in college physics classrooms (*19*). During one class session, half the students were randomly assigned to a class that used active learning (experimental treatment) consisting of students working in small groups on carefully designed in-class activities, followed by instructor feedback tailored to student comments and questions during group work. The other half of the students attended a well-presented lecture (control treatment). The roles were reversed in the subsequent class session. Both experimental and control groups used identical course materials and only the students' active engagement with the material was toggled on and off. We repeated

Equity requires heads and hearts

By **Elli J. Theobald[11]** *and* **Scott Freeman[11]**

Educational inequities are pervasive from pre-K through college (*21*), but active learning—a suite of pedagogical approaches that engage students in the construction of knowledge through activities and discussion in class, as opposed to passively listening to an expert—reduces performance differences in undergraduate STEM courses. Recent meta-analyses show that active learning benefits all college STEM students, on average (*22*), and has disproportionate benefits for students from groups that are historically and currently marginalized in STEM (*23*). Specifically, by meta-analyzing 9238 student exam scores from 15 studies and pass-fail data on 44,606 students from 26 studies, we found that on average, after controlling for exam, student, and instructor characteristics, differences in exam scores and passing rates between students from "majoritized" groups and students from low-income or racially and ethnically minoritized groups were smaller in active-learning classes compared with courses dominated by lecturing. Classes that used active learning to engage students for two-thirds or more of the total instructional time had a 42% reduction in the between-student difference on exam scores and a 76% reduction in the between-student difference in passing rate compared with classes that did not use active learning (*23*).

Why does active learning promote equity in higher education STEM classes? Early work on this question focused on how structuring the course experience with preclass readings, in-class activities, and mock exams creates opportunities for deliberate practice (*24*). This is, in essence, a "heads hypothesis." However, a growing body of evidence suggests that these features are necessary, but not sufficient, to eliminate inequities. Minoritized students also gain disproportionate benefits from a culture of inclusion and belonging in STEM—classes where instructors demonstrate respect for students as learners and a commitment to their success and where group work creates a sense of shared purpose and community (*25*). Taken together, the data support a "heads and hearts" approach, where instructors combine deliberate practice and psychosocial safety.

Researchers should continue to interrogate educational inequities by disaggregating outcomes by student identity. Educators should continue to answer calls to abandon teaching traditions based on expert exposition. As we transition back to in-person teaching and learning after the COVID-19 pandemic, faculty can create positive change with courses that activate students' minds, in classrooms where their hearts are safe.

Instructor decisions and student anxiety

By **Katelyn M. Cooper**[1,2] *and* **Sara E. Brownell**[1,2]

A common characteristic of active learning is increased interactions among students (e.g., group work) and between a student and the instructor (e.g., instructor asking questions). These interactions can change classroom dynamics and create stressful situations that would not exist in traditional lecture courses. Thus, instructors may be reluctant to implement active learning because it has been shown to increase students' anxiety in undergraduate science classrooms (*26*, *27*). However, it is not as widely recognized that certain ways in which active learning can be implemented have also been found to decrease student anxiety, compared with both traditional lecture courses and other types of active learning (*26*, *27*). Whereas low amounts of anxiety can be motivating for students, high anxiety is detrimental, including for students' academic performance (*28*).

Active-learning activities can be implemented in many different ways, and we have found that how it is implemented matters—for example, whether the activity is collaborative, whether students can choose their own groups, or whether an activity is associated with points. Using interview studies with students from a research institution (*26*) and from community colleges (*27*) to probe science students' feelings of anxiety, students reported that how active learning is implemented affects their anxiety. Compared with traditional lecture courses, students often see active learning as an opportunity to practice solving problems before high-stakes assessments, which decreases their anxiety. Explaining the purpose of active learning to students can help them recognize this benefit. Additionally, in traditional lectures, students sometimes describe feeling as though they are the only person in the room who does not understand the content. Conversely, in active learning, students find it useful to work with peers, who can help them realize that they are not the only ones struggling to grasp a scientific concept. However, if students are assigned to work with students that they do not know or are asked to speak out in front of the whole class, their "fear of negative evaluation" in these social situations can result in higher anxiety (*26*, *27*). As such, it is important to design active learning in ways that minimize student fear of negative evaluation, with the intent to maximize the benefits that students reap. For example, we recently reconsidered why we ask students to share in front of the class and suggested that learning gains may be achievable without the sometimes anxiety-inducing element of the share (*29*). Engaging students in their own learning while also reducing anxiety requires instructors to thoughtfully consider each aspect of active learning and how their decisions can affect students.

In active learning, students find it useful to work with peers.

PHOTO: FAT CAMERA/GETTY IMAGES

REFERENCES AND NOTES

1. N. Yannier, S. E. Hudson, E. S. Wiese, K. R. Koedinger, *ACM Trans. Comput. Hum. Interact.* **23**, 1 (2016).
2. N. Yannier, K. R. Koedinger, S. E. Hudson, in *CHI '15: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Association for Computing Machinery, 2015), pp. 1045–1054.
3. N. Yannier, S. E. Hudson, K. R. Koedinger, *Int. J. Artif. Intell. Educ.* **30**, 74 (2020).
4. J. M. Zosh *et al.*, *Front. Psychol.* **9**, 1124 (2018).
5. B. Hassinger-Das, I. Palti, R. M. Golinkoff, K. Hirsh-Pasek, *J. Cogn. Dev.* **21**, 125 (2019).
6. K. H. Lagattuta, L. Sayfan, M. Monsour, *Dev. Sci.* **14**, 481 (2011).
7. A. S. Bustamante *et al.*, *Dev. Psychol.* **56**, 1041 (2020).
8. R. Kassai, J. Futo, Z. Demetrovics, Z. K. Takacs, *Psychol. Bull.* **145**, 165 (2019).
9. J. E. Barker *et al.*, *Front. Psychol.* **5**, 593 (2014).
10. J. E. Barker, K. van Deusen, N. P. Friedman, Y. Munakata, PsyArXiv 10.31234/osf.io/hytwu (2021).
11. N. Stucke, G. Stoet, S. Doebel, PsyArXiv 10.31234/osf.io/nw3qa (2021).
12. A. S. Lillard *et al.*, *Front. Psychol.* **8**, 1783 (2017).
13. D. L. Schwartz, J. B. Black, *Cogn. Sci.* **20**, 457 (1996).
14. D. L. Schwartz, T. Black, *J. Exp. Psychol. Learn. Mem. Cogn.* **25**, 116 (1999).
15. T. Martin, D. L. Schwartz, *Cogn. Sci.* **29**, 587 (2005).
16. M. Oppezzo, D. L. Schwartz, *J. Exp. Psychol. Learn. Mem. Cogn.* **40**, 1142 (2014).
17. L. Deslauriers, E. Schelew, C. Wieman, *Science* **332**, 862 (2011).
18. M. Stains *et al.*, *Science* **359**, 1468 (2018).
19. L. Deslauriers, L. S. McCarty, K. Miller, K. Callaghan, G. Kestin, *Proc. Natl. Acad. Sci. U.S.A.* **116**, 19251 (2019).
20. M. K. Smith, W. B. Wood, K. Krauter, J. K. Knight, *CBE Life Sci. Educ.* **10**, 55 (2011).
21. R. B. Harris, M. R. Mack, J. Bryant, E. J. Theobald, S. Freeman, *Sci. Adv.* **6**, eaaz5687 (2020).
22. S. Freeman *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **111**, 8410 (2014).
23. E. J. Theobald *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **117**, 6476 (2020).
24. D. C. Haak, *Science* **332**, 1213 (2011).
25. M. A. Kraft, *J. Hum. Resour.* **54**, 1 (2019).
26. K. M. Cooper, V. R. Downing, S. E. Brownell, *Int. J. STEM Educ.* **5**, 23 (2018).
27. V. R. Downing, K. M. Cooper, J. M. Cala, L. E. Gin, S. E. Brownell, *CBE Life Sci. Educ.* **19**, ar20 (2020).
28. B. Seipp, *Anxiety Res.* **4**, 27 (1991).
29. K. M. Cooper, J. N. Schinske, K. D. Tanner, *CBE Life Sci. Educ.* **20**, fe1 (2021).

ACKNOWLEDGMENTS

N.Y., S.E.H., and K.R.K. were supported by National Science Foundation (NSF) grant 2005966. K.H.-P. was supported by NSF grant 2005776 and by the William Penn Foundation. Y.M. was supported by National Institute of Child Health and Human Development grant R01HD086184. D.L.S. was supported by NSF grant 0214549. L.D., L.M., and K.C. were supported by Harvard University through the Division of Science in the Faculty of Arts and Sciences.

10.1126/science.abj9957

Active learning: “Hands-on” meets “minds-on”

Nesra YannierScott E. HudsonKenneth R. KoedingerKathy Hirsh-PasekRoberta Michnick GolinkoffYuko MunakataSabine DoebelDaniel L. SchwartzLouis DeslauriersLogan McCartyKristina CallaghanElli J. TheobaldScott FreemanKatelyn M. CooperSara E. Brownell

Science, 374 (6563),