

Augmenting Upper and Early-Learning STEM Lessons Through Phenomenon-Based Learning Projects

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Phenomenon-based Learning (PhBL) utilizes cross-curricular materials covering topics in science, technology, engineering, and mathematics (STEM) presented through an inquiry structure in which students design, plan, and carry out an extended project that produces a publicly exhibited output. Students learn 21st Century Skills through plurilingual methodologies, key curriculum learning areas, and essential social cues. Particularly suited to building bridges between subject and language teachers, the PhBL structure has also been used by teachers of single subjects, in either majority or minority languages, and particularly in STEM subjects where the inclusion of real-life issues augments student engagement. The emphasis on co- and student-agency is a way of developing the necessary skills enabling students to be successful in the professional sphere in this age of advanced cyber technology. PhBL structures focus on critical thinking techniques, a growth mindset mentality, strengthening the affective domain, and creating a classroom culture of trust and excellence. Continual and deliberate scaffolding strategies and the CLIL (Content and Language Integrated Learning) approach to promote STEM education are described.

Keywords: artificial intelligence (AI), Content and Language Integrated Learning (CLIL), STEM education, instructional scaffolding, Phenomenon-based Learning (PhBL), plurilingual methodologies, 21st Century Skills (21CS)

INTRODUCTION

What if our classrooms produced students who were masters of collaboration, taught with the work ethic of excellence, versed on global perspectives, critical thinkers with a top-quality toolbox of strategies, comfortable expressing themselves in public in different languages, and most importantly, in this age of the Fourth Industrial Revolution, had the emotional intelligence and empathetic qualities that rendered them more qualified than machines? Phenomenon-based Learning (PhBL) has shown the potential to extend these elements and help develop students who are positioned to learn on their own and who will be prepared to solve the problems that we will inevitably face in the future.

Strengthening the dynamic of co- and student-agency in the classroom is key to combatting the realities of the increasing efficiency of cyber technology in this epoch of the Fourth Industrial Revolution. A World Bank 2016 report found that the implementation of artificial intelligence has been destroying some five million jobs in 15 industrialized and developing countries over the recent years (World Economic Forum,

2016a). One of the most viable solutions to this abyss in the human workforce is to provide an extensive and varied compilation of skills in education. In effect, the jobs eliminated by new technologies require routine and physical tasks, while the types of jobs being created tend to require higher levels of education and specialized study (World Economic Forum, 2016b). As educators, our job is to provide our students agency over their learning and to help them become highly skilled critical thinkers who know how to work collaboratively and cooperatively and who can be more adept than machines in the fast-changing environments this merging technology is creating.

Arai et al. (2017), have been studying the limits of artificial intelligence in their aim to further the understanding of human thought. After analyzing the results of exams given to both university students and robots, they became fascinated and disturbed by the results: robots, which rely on logic and mathematics to answer questions, performed higher than their human counterparts, not only in multiple choice questions but on those requiring inferencing—the linking together of information from multiple sources with critical gaps. Determined to uncover the reason for this incongruity, they discovered that most curriculums they examined were not designed to teach critical thinking or inferencing within the development of comprehension skills and postulated that this leaves students at a great disadvantage in an age in which machines are already able to outperform humans not only in physical labor but in office jobs as well. Upon considering the ramifications of these findings, they concluded it is essential that educators take steps to make sure their students are more intelligent than artificial intelligence, namely by helping them to develop analytic thinking, to become adept at extracting meaning, and at cultivating interpersonal skills.

Artificial intelligence does have its limits, currently that is, and to keep the human advantage, it is incumbent on educators to provide the schooling that helps students to think in ways that machines that rely on mathematic algorithms to reach conclusions never can. After all, “What is unique about AI is also what is most feared and celebrated: its ability to match some of our own skills, and then to go further, accomplishing what humans cannot” (Jacobs, 2023, p. 6). Patrick Gelsinger, CEO of Intel, explained, “while generative AI is in the spotlight now, it’s just a sliver of what AI can and will do” (Sibley, 2023, p. 8).

Adding perspective to these statements, when asked whether or not it is possible to train students to keep up with generative AI, GPT-3.5 generally agreed with Arai et al, responding, “Yes, it is possible to train students to keep up with generative AI, but it requires a structured and comprehensive approach to education and skill development,” listing tasks students should be involved in including building foundational knowledge (math, computer science and machine learning); engaging in practical and hands-on projects (involving generative AI, such as experimenting with and building new AI models), collaborating with peers, mentors and experts, making a commitment to continuous/life-long learning, among other recommendations that build awareness of AI and its potential (OpenAI, 2023, see Appendix A for the full transcript). Students must be immersed in experiences that promote content-area expertise, collaboration and analytical skills encompassing common sense reasoning, including communication and language skills (both oral and technical), as well as competence in understanding the world and phenomena holistically occurring around them.

PhBL provides students with this education, offering opportunities for both scholastic and social development since the PhBL structure emphasizes co- and student-agency in both social and academic contexts. Interdisciplinary and multilingual factors can be addressed through the Content and Language Integrated Learning (CLIL) approach which focuses on teaching through a language that is not the majority communication vehicle of the school as the medium of instruction and learning. Techniques included under the CLIL umbrella of methodologies, such as scaffolding and thinking frames, provide teachers with a platform for implementing holistic education, competence-based learning, learner autonomy, fostering creativity and critical thinking, and ultimately changing the curricular framework to the notion of *how* to learn instead of on *what* to learn, while recognizing the relevance and impact technology has on the lives of students today.

METHODOLOGY

Curricula integrating subjects such as science, technology, engineering, and mathematics (STEM) through projects focusing on the PhBL structure, and taught through the CLIL approach, generate spontaneous and autonomous environments that help ignite students' interests and prepare them for the skills they will need in the emerging work force. Plurilingual methodologists recognize their students' content and language abilities, and value the multiple language skills and competencies their students bring to the learning environment. They reinforce task-based learning and language awareness, allowing their students to choose which language(s) to use depending upon the situation, and ensure that multilingual resources are readily available. Multiple modes of communication encompassing all four language domains (listening, speaking, reading, and writing) are supported across different languages through gestures, visuals, and multimedia to promote usage of each student's linguistic resources and ultimately facilitate comprehension and communication through translanguaging.

Combined with Phenomenon-based Learning (PhBL), an educational movement initiated by Finland's educational system in 2016, students are immersed deeper into contextual situations aligned with real-life issues while applying knowledge and skills from multiple disciplines. Teachers increase student engagement in authentic STEM research through participation in Project-based Learning (PBL) and Problem-based Learning (PrBL) activities that facilitate students to create their own questions, perform their own research, and communicate their results widely (Odell & Pedersen, 2020). Similar to PBL and PrBL scenarios (see Kennedy & Odell, 2014; Odell, Kennedy, & Stocks, 2019; and Kennedy & Odell, 2023), PhBL fosters engagement in learning new knowledge and skills as students investigate phenomenon-related topics of personal interest and concern while making connections across subject areas in a global context. PhBL is deeply rooted in constructivist learning theory and socio-constructionist and socio-cultural learning theories.

PBL, PrBL and PhBL tend to engage students in inquiry-based learning through the 5E Model of instruction (Engage, Explore, Explain, Elaborate, and Evaluate), following the natural learning process (Bybee, 2015, p. ix). Figure 1 shows the 5E's in circular action.

FIGURE 1
EVIDENCE-BASED PRACTICES: THE 5E MODEL OF INSTRUCTION

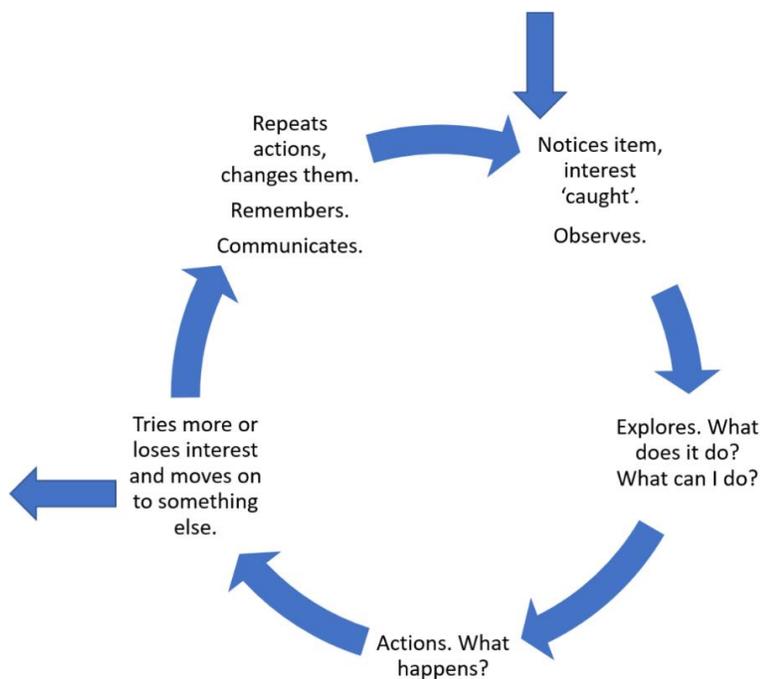


Note: Graphic used with permission from the San Diego County Office of Education, 2018. <https://ngss.sdcoe.net/Evidence-Based-Practices/5E-Model-of-Instruction>

Inquiry questions are typically centered around topics that begin with either a “how”, “why”, or “what if” scenario. Students acquire an understanding of new information through the process of solving the problem associated with the phenomenon they personally identified with and become more responsible and independent as they seek practical relevance to everyday life, regardless of age.

According to McClure (2017), “young children are capable of engaging in, at developmentally appropriate levels, the scientific practices that high school students carry out” (2017, p. 2). STEM capabilities begin in the initial early years through developing manipulative skills, planning and identifying solutions to basic problems, creating designs, evaluating outcomes, changing paths as needed, and learning about safety and following safety rules and instructions (Kennedy & Tunnicliffe, 2022). The STEM Play Cycle, as shown in Figure 2 (Tunnicliffe & Kennedy, 2021), promotes creativity, observation, questioning, exploration, investigation, and constructing meaning through problem-solving and applying knowledge gained from previous experiences. This continuous cycle involves different variations of inquiry as problems are solved, or the child loses interest and moves on to something completely new to investigate.

**FIGURE 2
THE STEM PLAY CYCLE**



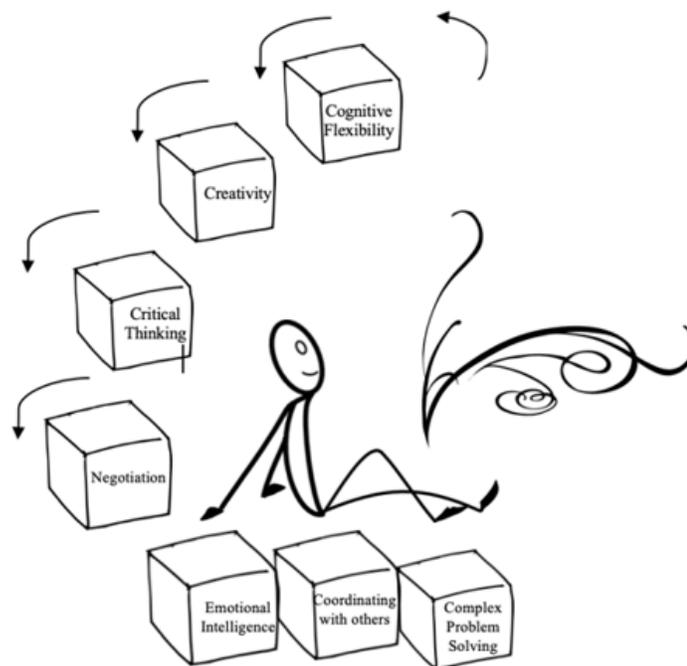
Phenomena should be relevant to the students’ environment and elicit curiosity. Phenomena are “occurrences in the natural and human-made world that can be observed and cause one to wonder and ask questions...requires students to use the science and engineering practices (SEPs), crosscutting concepts (CCCs), and disciplinary core ideas (DCIs) in concert to explore, investigate and explain how and why phenomena occur” (Cerwin et al, 2018, p. 9). The basic criteria educators must consider when determining appropriate phenomena to build and expand students’ knowledge and understanding in STEM education should answer the following six questions (NGSS@NSTA, 2017; Penuel & Bell, 2017).

1. Is the phenomena observable or able to be investigated through firsthand experiences (e.g., in a classroom, lab, or outdoor environment) or through teacher-led experiences (e.g., demonstrations, videos, or analyzing patterns in data)?
2. Is the phenomena grade-level appropriate (e.g., would student explanations be grade-level appropriate)?

3. Is the phenomena going to build understandings supporting the grade level performance expectations (e.g., do students understand and incorporate core ideas, science and engineering practices, and crosscutting concepts to explain how and why the phenomena occurs)?
4. Is the phenomena relevant to the students' environment or real-world issues the student is aware of or learning about?
5. Is the phenomena interesting and important to society (e.g., will students find making sense of the phenomenon valuable)?
6. Is the phenomena justifiable in terms of financial cost and instructional time?

Most STEM learning experiences seek to provide opportunities to remove the artificial boundaries between STEM disciplines, help students better understand the connected nature of knowledge using critical skills, and lead to success in the 21st-century economy through applying the skills and knowledge that they have learned or are in the process of learning (Kennedy & Sundberg, 2020, p. 479). Learning through PhBL projects creates opportunities to construct the building blocks of key 21st Century Skills (21CS) as depicted in Figure 3 (Fields, 2017), allowing students to implement strategies that create an armory of critical thinking skills. PhBL projects encourage students to think deeply and laterally about issues, opening windows to a vision of the future.

**FIGURE 3
BUILDING BLOCKS THAT EMERGE FROM PHBL PROJECTS**



The six basic steps involved in helping students to develop the knowledge necessary for understanding, explaining, and predicting phenomena include:

1. Encouraging students to identify “phenomena” that have a global context and can be related to real life issues or events.
2. Asking students to develop inquiry-based questions around the phenomena that begin with either a “how”, “why”, or “what if” scenario?
3. Identifying the skills and knowledge students will need to acquire to answer their questions.
4. Teaching the basic concepts surrounding the students’ chosen questions and encouraging them to try to solve the problems they have identified.

5. Providing a learning environment that supports an open structure of time allowing students to engage in the necessary research and problem-solving required.
6. Facilitating and guiding students through their research and problem-solving processes in a manner that helps them develop their own way of solving the problem.

For STEM and other subject-area teachers, participating in learning around explaining phenomena and designing solutions to problems allows students to build general science ideas into deeper, more transferable knowledge. The six overarching tenants of PhBL are as follows:

1. Phenomenon-based Learning contradicts direct, teacher-centered learning by placing emphasis on student participation and *learning* instead of on *teaching*.
2. All students, including English Language Learners (ELLs) and students from culturally underrepresented populations in STEM fields, should be supported to investigate phenomena that are engaging and meaningful to them.
3. Projects should engage students in inquiry-based learning through the 5E Model of instruction (Engage, Explore, Explain, Elaborate, and Evaluate), allowing students to continuously revisit, reflect, and expand on their thinking.
4. Projects should include developing a growth mindset, in grade-appropriate learning contexts, augmenting the affective domain filter, creating a culture of trust and excellence, targeting language acquisition methods, extending the 5Cs of language learning (communication, cultures, connections, comparisons, communities) in every aspect of planning, crossing interdisciplinary boundaries, recognizing multi-cultural similarities and differences, designing age-relevant topics, and extending relevance in global issues.
5. Scaffolding techniques are employed, focusing on strategies and activities as a means of helping students to learn new material and to balance out diversity in the classroom.
6. Team-building activities and techniques are embedded into work sessions to engender a culture of trust in the learning environment and to consciously teach students how to problem-solve social issues.

Learning environments should be designed to foster the ethic of excellence (Berger, 2003), in which students are provided with opportunities to present multiple revisions, with periodic peer and/or teacher assessments to ensure that the final task represents students' *best* work. Two types of phenomena, anchoring and investigative, are generally incorporated into classroom instruction.

1. Anchoring phenomena generally connect student learning across multiple weeks of instruction and often require a significant or in-depth understanding of several science ideas as well as incorporate multiple lenses of evidence and reasoning to adequately explain the phenomena. Due to the size or scale of an anchoring phenomena, students may only be able to explain certain aspects involved.
2. Investigative phenomena are generally implemented across several lessons through instructional sequences and provide students personal experience with observable events where an evidence-based explanation can be constructed. They often require understanding or use of a fewer number of connected science ideas to explain the phenomena. Students begin to communicate aspects of an anchoring phenomena by explaining investigative phenomena.

According to Mehisto, Marsh, and Frigols (2008), CLIL plays a critical role as the substructure of the PhBL model implemented. This can be understood through its six major components and focused interventions provided by the teacher:

1. Content (specific content taken from learning standards and learning objectives).
2. Communication (scaffolding of vocabulary; grammatical structures; functional and academic language).
3. Cognition (critical thinking and the utilization of thinking frameworks).
4. Competences (developing subject and language knowledge; planning and building cooperation skills through interaction).
5. Community (building connections to local, national, and global community; developing cultural awareness).

6. Pedagogical interventions (addressing learner needs, guiding student learning and collaboration; implementing ongoing evaluation measures).

Breaking down new knowledge and pre-teaching key ideas ensures that academic language and concepts are filtered through dynamic scaffolding techniques and strategies. Closely aligned to the concept of the Zone of Proximal Development (Vygotsky, 1978), scaffolding is a powerful tool for learning. It introduces new material in ways that respect cognitive load by chunking material into understandable blocks, thus helping students lower their anxiety levels, become more open and engaged in learning, and move forward more confidently.

Plurilingual Methodologies and PhBL

Scaffolding techniques are numerous and varied. They can include different types of decoding devices and mnemonic strategies and combine visuals and text, graphic organizers, and other commonly used classroom learning strategies. Scaffolding techniques are any activity that supports learning, learning about languages, and learning through languages (Canney, Kennedy, Shroeder & Miles, 1999; Fields, 2018; Kennedy, Abbitt, & Odell, 2010).

PhBL projects stand apart from traditional project-based learning as they include additional elements designed to develop social and academic skills not normally addressed in more traditional models. Designing a PhBL project is not linear, and this in itself can confuse first-time users. However, this brings with it a certain amount of liberty as the teacher can begin wherever desired in the structure and then circle back, filling in gaps, and amending criteria whenever necessary.

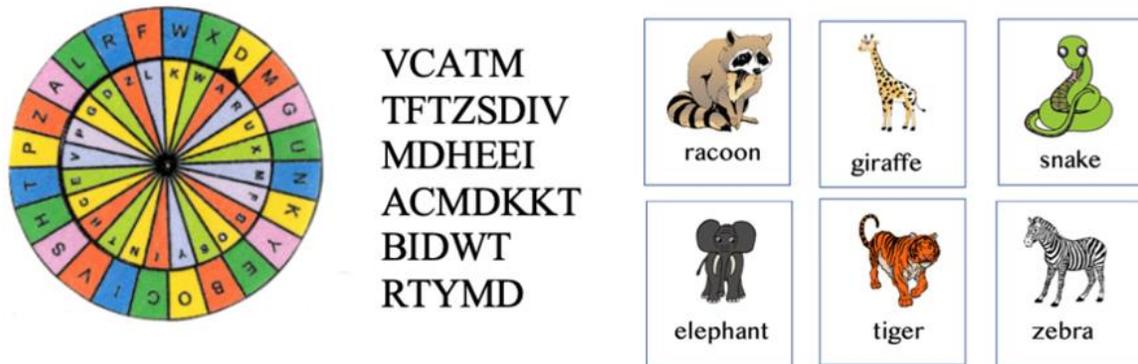
Some teachers, for instance, approach a project by defining learning objectives (sometimes synonymous with ‘learning outcomes’). Others need to establish the final task – the exhibition mode, or how the students will make learning visible. Because learning standards must be the basis of all tasks, some teachers feel the need to begin by establishing these points. However, all can be amended, augmented, adapted, or removed depending on the final skills expected to be mastered in the final output.

Like all parts of the structure, the inquiry question can be crafted at any point. The essential component of these key questions is to understand that they may not ostensibly reflect all elements of the final task since their function is aimed at exciting learners about the topic. Their role serves to launch the project and establish an environment of inquiry and engagement. For example, primary students in Argentina studied aerosols in the atmosphere resulting from eruptions of the Puyehue and Calbuco Volcanos. They also engaged in long-term data collection and analyses through GLOBE Program atmosphere protocols (Prieto & Kennedy, 2022). And, on an international scale, the COVID-19 Engineering Design Challenge (Kennedy, 2021) focused on a global issue inspiring over 1,000 students spanning 14 countries over a period of two and a half years to create innovations to address the pandemic and share their research designs with their schools and communities.

The most effective inquiry questions are those that open the door to research, have multiple possible answers, seek to address a problem (intellectual, theoretical, or philosophical), are connected to the real world, and encourage students to become intellectually engaged. One way to facilitate this outcome is using the question continuum of lower- and higher-order thinking questions.

Most questions presented in educational settings are designed for lower-order thinking skills. However, PhBL inquiry questions encourage deeper thinking by using higher-order thinking questions, thus changing the educational paradigm. Figure 4 (Fields, 2017) provides an example of how the forward movement up the question continuum changes learners’ personal engagement expectations.

FIGURE 5
SCAFFOLDING THROUGH CRITICAL THINKING



Research has shown the benefits of implementing pedagogical strategies that provide students with various opportunities to apply contextual and linguistic supports (Xu et al., 2016). These experiences encourage active student participation and help instructors confirm student understanding of new vocabulary and the contexts for using it.

EVALUATION

PhBL, as described by *Phenomenal Education: Rethinking from Finland* (Silander, 2015), focuses on learning holistically, providing motivating starting points to provide an authentic context for interdisciplinary study that can be assessed based on the *Phenomenon Based Learning Rubric*. This evaluation resource is intended to be used by educators to ensure they provide students with a holistic view of real-world phenomena, within a real and global context while crossing many disciplines.

Alternative assessments are also encouraged so that more skills are honored than just the usual linguistic-logical learning styles. The key purpose of formative assessments in the PhBL structure is to support learning content and language, foster critical thinking about both, and help teachers and learners become synchronized and verify or negate progress. Summative assessments (in this case the final task), are used to demonstrate to others that students are achieving intended learning outcomes, and ultimately to improve learning practices (Mehisto, 2017). Deep thinking is supported through a variety of thinking frameworks suggested by the PhBL structure. Thinking frameworks can help students become better thinkers by deliberately providing them with tactics and strategies to organize their thinking (Perkins, 1986).

Developing interpersonal skills is an important outcome of PhBL project implementation; a skill that is indispensable at a management level and may be unlikely to be touched by machines soon. When excellence is demanded, learners adopt this expectation as a personal credo that will translate into all aspects of their lives and ultimately distinguish them from the other candidates in the work force. Finally, students working to communicate from a wide variety of perspectives and in diverse situations, all in a bilingual/multi-lingual environment, will gain the skills needed to become viable and desirable candidates in our current and future global market.

The U.S. Next Generation Science Standards (NGSS) are goals that reflect what a student should know and be able to do. These standards outline three dimensions essential to providing students with a high-quality science education: practices, crosscutting concepts, and disciplinary core ideas. These dimensions provide context for the scientific content covered in the classroom, delve into how science knowledge is acquired and understood, and show connections through the integrated nature of science across the disciplines. NGSS (2016) summarized the guiding principles involved when implementing phenomena into lesson and unit planning (see Figure 6).

FIGURE 6
NGSS: USING PHENOMENA IN NGSS-DESIGNED LESSONS AND UNITS

PRIOR THINKING ABOUT PHENOMENA	THINKING ABOUT PHENOMENA THROUGH THE NGSS
If it's something fun, flashy, or involves hands-on activities, it must be engaging.	Authentic engagement does not have to be fun or flashy; instead, engagement is determined more by how the students generate compelling lines of inquiry that create real opportunities for learning.
Anything students are interested in would make a good "engaging phenomenon"	Students need to be able to engage deeply with the material in order to generate an explanation of the phenomenon using target DCIs, CCCs, and SEPs.
Explanations (e.g., "electromagnetic radiation can damage cells") are examples of phenomena	Phenomena (e.g., a sunburn, vision loss) are specific examples of something in the world that is happening—an event or a specific example of a general process. <i>Phenomena are NOT the explanations or scientific terminology behind what is happening. They are what can be experienced or documented.</i>
Phenomena are just for the initial hook	Phenomena can drive the lesson, learning, and reflection/monitoring throughout. Using phenomena in these ways leads to deeper learning.
Phenomena are good to bring in after students develop the science ideas so they can apply what they learned	Teaching science ideas in general (e.g., teaching about the process of photosynthesis) may work for some students, but often leads to decontextualized knowledge that students are unable to apply when relevant. Anchoring the development of general science ideas in investigations of phenomena helps students build more usable and generative knowledge.
Engaging phenomena need to be questions	Phenomena are observable occurrences. Students need to <i>use the occurrence to help generate the science questions or design problems that drive learning.</i>
Student engagement is a nice optional feature of instruction, but is not required	Engagement is a crucial access and equity issue. Students who do not have access to the material in a way that makes sense and is relevant to them are disadvantaged. Selecting phenomena that students find interesting, relevant, and consequential helps support their engagement. A good phenomenon builds on everyday or family experiences: who students are, what they do, where they came from.

CONCLUSION

Studies highlighted in this paper showed that students perform equally, if not higher, on standardized exams after learning through PhBL projects than those taught through teacher-centered methods. The focus on the learner helps students become more active in their own process; the inclusion of global issues and multi-cultural recognition, along with the other elements of the PBL structure, activate student engagement, interest, and belief in their future possibilities.

PhBL breaks down the artificial barriers of STEM and general disciplines, enabling students to understand the connected nature of knowledge and utilize critical skills leading to success in the 21st century economy while combatting the realities of the increasing efficiency of cybertechnology of the Fourth Industrial Revolution. PhBL strategies that employ scaffolding strategies combined with the CLIL approach to focus on critical thinking techniques and growth mindset mentality, strengthen the affective domain and create a classroom culture of trust and excellence.

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APPENDIX

(GPT-3.5) 10/6/2023

Is it possible to train students to keep up with generative AI?

ChatGPT

Yes, it is possible to train students to keep up with generative AI, but it requires a structured and comprehensive approach to education and skill development. Generative AI, such as GPT-3 and its successors, represents a cutting-edge technology in the field of artificial intelligence, and staying current in this field can be challenging. Here are some steps that can help students keep up with generative AI:

1. **Foundational Knowledge:** Begin with a strong foundation in mathematics, computer science, and machine learning. Understanding concepts like linear algebra, calculus, probability, and deep learning is crucial.
2. **Online Courses and Tutorials:** Enroll in online courses and tutorials on platforms like Coursera, edX, Udacity, and Khan Academy. These platforms offer a wide range of courses on AI and machine learning topics.
3. **Academic Programs:** Consider pursuing formal education in AI and machine learning through bachelor's, master's, or doctoral programs at universities. Many universities offer specialized programs in AI.
4. **Stay Updated:** Subscribe to academic journals, blogs, and AI research publications to keep up with the latest developments in the field. Popular AI research conferences like NeurIPS, ICLR, and CVPR are good sources of cutting-edge research.
5. **Hands-On Projects:** Apply your knowledge by working on practical projects related to generative AI. Building your own AI models and experimenting with existing ones can be a valuable learning experience.
6. **Coding Skills:** Develop strong coding skills in programming languages commonly used in AI, such as Python and libraries like TensorFlow and PyTorch.
7. **Join AI Communities:** Join online AI communities, participate in forums, and engage in discussions with AI enthusiasts and professionals. Networking can provide valuable insights and collaboration opportunities.
8. **Ethical Considerations:** Understand the ethical implications of AI, especially generative AI, and the potential for misuse. Stay informed about responsible AI practices and guidelines.
9. **Specialization:** Depending on your interests, consider specializing in areas related to generative AI, such as natural language processing (NLP), computer vision, or reinforcement learning.
10. **Continuous Learning:** Recognize that the field of AI is constantly evolving. Make a commitment to lifelong learning, as new techniques and technologies emerge regularly.

It's important to note that keeping up with generative AI requires dedication, persistence, and a genuine interest in the field. Additionally, collaboration with peers, mentors, and experts can be highly beneficial in staying current and advancing in the rapidly changing landscape of AI.