



THE VALUE OF PROJECT-BASED LEARNING IN STEM EDUCATION

Education is changing. No longer can students afford to sit passively in classrooms memorizing facts and data. Instead, to succeed in today's increasingly complex world, they must develop both foundational competencies (such as literacy and basic mathematics) and 21st-century skills (including problem solving, collaboration and creativity) to overcome challenges that have no clear solution.

Project-based learning (PBL) is an educational approach focused on assigning and guiding students through self-directed projects toward clear learning outcomes.¹ Grounded in the proven benefits of hands-on learning,² PBL's effectiveness has to do with the increased levels of student engagement and interest thanks to a newfound sense of agency.

Joshua Block, a humanities teacher

at Science Leadership Academy in Philadelphia, agrees, and in an article for Edutopia, applauds PBL's ability to turn students into active learners.³

"Project-based learning transforms the roles of students and teachers in ways that benefit all. This de-centering of the classroom and knowledge helps students develop a sense of agency as learners and as people. If teachers maintain traditional notions of students as information recipients, teaching and learning become a pointless game where, instead of connection and engagement, the main challenge for students is

to read the teacher's mind while producing a product in which they don't feel invested."

Block's observations speak to the dangers of disengagement within the classroom. Without the ability to relate to what they're learning, students are more likely to feel habitually unmotivated and uninterested.⁴ PBL addresses this problem by subverting traditional classroom dynamics, transforming teachers into facilitators and students into active learners. While this pedagogy has become more popular within the teaching community in recent years,⁵ this type of education is grounded in two primary philosophical traditions: pragmatism and constructivism.

On Aug. 26, 1898, the American philosopher and psychiatrist William James delivered a lecture at the University of California, Berkeley where he first promoted "the principle of pragmatism in a public setting:"

"To attain perfect clearness in our thoughts of an object ... we need only consider what effects of a conceivably practical kind the object may involve – what sensations we are to expect from it, and what reactions we must prepare. Our conception of these effects, then, is for us the whole of our conception of the object, so far as that conception has positive significance at all."⁶

In other words, for James, the merit of an idea or action is determined by its utility. First developed by philosopher Charles Peirce,⁷ pragmatism "stresses the priority of action over doctrine, of experience



A Camp Invention participant builds an invention prototype.

1. Thomas, J. (2000, March). A Review of Research on Project-Based Learning. Retrieved from <https://www.asec.purdue.edu/ict/HBCU/documents/AReviewofResearchofProject-BasedLearning.pdf>

2. Daniels, N. (2006). The Effectiveness of Hands-On Activities Compared to Paper and Pencil Activities When Teaching Reading to First through Fifth Grade Students. Retrieved from <https://pdfs.semanticscholar.org/c005/72153204be879d6902355ba3ace1048dd561.pdf>

3. Block, J. (2015, February 26). 5 PBL Best Practices for Redefining the Teacher's Role. Retrieved from <https://www.edutopia.org/blog/pbl-practices-redefining-teachers-role-josh-block>

over fixed principles, and it holds that ideas borrow their meanings from their consequences and their truths from their verification.”⁸

The immediacy of pragmatism’s approach caught the attention of philosopher and psychologist John Dewey, who immediately saw the benefits of applying its principles to American education. Specifically, he believed that the most effective way for a student to learn was through a hands-on approach that embraced interacting within an environment. In line with pragmatism’s conviction that personal experience is the most effective teacher, Dewey believed that students receive little value from passive forms of education that involve a higher authority lecturing to a captive audience. Instead, those who learn best, learn by doing.⁹

Dewey would go on to develop these ideas even further in his seminal article, “The Reflex Arc Concept in Psychology.” In it, he introduces the concept that human experience builds on itself and is not composed of unrelated smaller parts. The implications of this insight would prove profound, causing a paradigm shift in the fields of psychology and education. Instead of viewing the individual as a passive recipient of stimuli, here Dewey describes experience as an active endeavor, where people learn by building upon their past activities to form a more complete understanding of the world around them.¹⁰

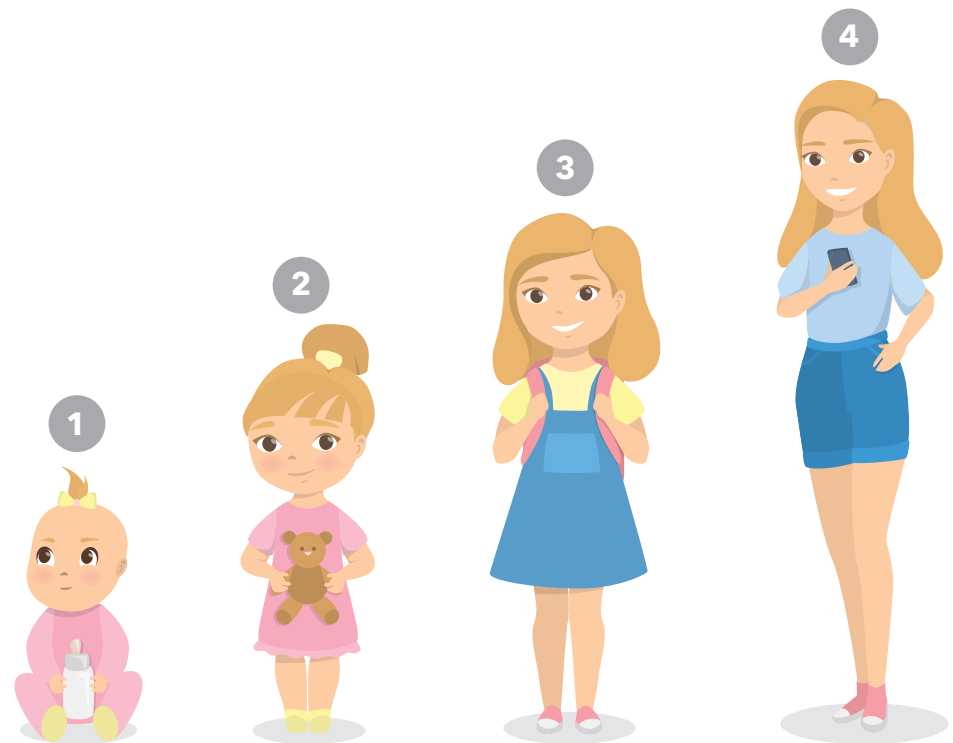
CONSTRUCTIVISM AND THE IMPORTANCE OF LEARNING THROUGH EXPERIENCE

Dewey’s mission to apply the essential tenets of pragmatism to improve the effectiveness of education led to a renewed belief and interest in how philosophy and psychology could be applied in a practical way. Swiss psychologist Jean Piaget took these ideas a step further and immersed himself in the study of human development. Years of work and research led to the development of constructivism – the philosophical belief that human learning is constructed, and that new knowledge is built on the foundation of previous learning and

experience.¹¹ In line with Dewey’s own views regarding effective education and his ideas in “The Reflex Arc Concept in Psychology,” constructivists see learning as an active process. In contrast to the belief that people are empty hard drives that continuously download information, they instead believe that current experience is continuously compared to past events. This constant modification of knowledge in response to new information is how we learn.¹²

Piaget’s crowning achievement was his

theory of cognitive development that he published in his 1936 book “The Origins of Intelligence in Children.” Not only did this work represent the first major systematic study of cognitive development in the field of psychology, but it challenged the prevailing assumption at the time that children were simply less competent thinkers than adults. Instead, he argued that young children think in categorically different ways compared to their adult counterparts. For Piaget, he saw these differences as a series of stages.¹³



PIAGET'S FOUR STAGES OF COGNITIVE DEVELOPMENT

- 1 Sensorimotor Stage: Birth to Age 2**
A child develops the conception of object permanence – the knowledge that an object still exists despite being temporarily hidden.
- 2 Pre-Operational Stage: Age 2 to 7**
Children in this stage begin to think symbolically. Words and objects begin to represent other things. Understanding the viewpoint of others remains difficult during this time and thinking remains egocentric.
- 3 Concrete Operational Stage: Age 7 to 11**
This stage represents a fundamental turning point in a child’s development, and marks the start of organized and rational thinking. Children begin solving problems in their head without needing to physically try things in the real world.
- 4 Formal Operational Stage: Age 11 into Adulthood**
In this final stage, children gain the ability to think about abstract concepts and logically test a hypothesis.¹⁴

4. Murray, S., Mitchell, J., Gale, T., Edwards, J., & Zyngier, D. (2004). Student disengagement from primary schooling: a review of research and practice. Student disengagement from primary schooling: a review of research and practice. CASS Foundation. Retrieved from <http://www.cassfoundation.org/2016/wp-content/uploads/2016/07/StudentDisengagement.pdf>

5. Brown University. Teacher as Facilitator. Retrieved from <https://www.brown.edu/academics/education-alliance/teaching-diverse-learners/teacher-facilitator>

6. James, W. Philosophical Conceptions and Practical Results. University Chronicle. Retrieved from https://archive.org/stream/philosophicalcon00jameuoft/philosophicalcon00jameuoft_djvu.txt

7. Atkin, A. Charles Sanders Peirce: Pragmatism. Retrieved from <https://www.iep.utm.edu/peircepr/>

8. Rosenthal, S. B., & Thayer, H. S. Pragmatism. Retrieved from <https://www.britannica.com/topic/pragmatism-philosophy>

9. PBS. Only a Teacher - Schoolhouse Pioneers - John Dewey. Retrieved from <https://www.pbs.org/onlyateacher/john.html>

Piaget’s stages of development revolutionized education around the world and made educators aware of how important it is to cater teaching styles to fit a student’s cognitive level. While criticisms regarding Piaget’s unsystematic methodology and the questionable “one size fits all” application of the stages themselves have become common topics of discussion for academics, the psychologist’s contributions to curriculum design and to the field of education are impossible to ignore.¹⁵

PBL uses ideas from both pragmatism and constructivism by encouraging students to learn through their own actions and experiences. By embracing this process of trial and error, children can improve their ideas over time by testing them out in the real world.

APPLYING PHILOSOPHY TO PROJECT-BASED LEARNING

In recent years, both Dewey’s pragmatic approach and Piaget’s constructivist principles have seen a growth in popularity due to their usefulness in STEM education. Because understanding these innovative subjects requires the type of active learning promoted by both thinkers, many STEM educators have relied heavily on techniques inspired by both approaches.

The difference between a traditional classroom and one that embraces constructivism is drastic. In a 2015 article for the International Organization of Scientific Research Journal of Research & Method in Education (IOSR-JRME), Dr. Steve Olusegun provides a helpful chart comparing a traditional classroom to ones that use constructivist principles:



A Camp Invention participant embraces hands-on learning.

TRADITIONAL CLASSROOM	CONSTRUCTIVIST CLASSROOM
<ul style="list-style-type: none">• Curriculum begins with the parts of the whole and emphasizes basic skills.• Strict adherence to fixed curriculum is highly valued.• Materials are primarily textbooks and workbooks.• Learning is based on repetition.• Teachers disseminate information to students; students are recipients of knowledge.• A teacher’s role is directive, rooted in authority.	<ul style="list-style-type: none">• Curriculum emphasizes big concepts, beginning with the whole and expanding to include the parts.• Pursuit of student questions and interests is valued.• Materials include primary sources of material and manipulative materials.• Learning is interactive, building on what the student already knows.• Teachers have a dialogue with students, helping them construct their own knowledge.• A teacher’s role is interactive, rooted in negotiation.

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Olusegun’s chart makes it clear that to successfully enable the type of active learning promoted by Dewey and Piaget, teachers must adopt the role of a facilitator. Because students are expected to build on what they learn through experience and action, teachers in turn must make every effort to promote agency and engagement in the classroom.

While there are different ways to apply constructivism and pragmatic active

learning to STEM education, PBL has emerged as a popular way to do so because of the technique’s ability to show students the relevance of what they’re learning. It does this by creating authentic activities focused on collaboratively solving real-world problems.¹⁷

10. Hildebrand, D. (2018, November 1). John Dewey. Retrieved from <https://plato.stanford.edu/entries/dewey/#PhilEduc>
11. Bada, S. O. (2015). Constructivism Learning Theory: A Paradigm for Teaching and Learning. Constructivism Learning Theory: A Paradigm for Teaching and Learning. Retrieved from <https://pdfs.semanticscholar.org/1c75/083a05630a663371136310a30060a2afe4b1.pdf>

12. Phillips, D. C. (1995). Correction: The Good, the Bad, and the Ugly: The Many Faces of Constructivism. Educational Researcher, 24(9), 5-12. doi: 10.2307/1177274
13. Mcleod, S. (2018, June 6). Jean Piaget’s Theory of Cognitive Development. Retrieved from <https://www.simplypsychology.org/piaget.html>

14. Ibid.
15. Hopkins, J. R. (12AD). The Enduring Influence of Jean Piaget. Retrieved from <https://www.psychologicalscience.org/observer/jean-piaget>

WHAT MAKES A PROJECT AUTHENTIC?

The concept of authenticity is a difficult one to agree upon. Because each person might have a varying opinion as to what is “genuine” or “real,” even an instructor’s best intention to introduce an authentic project into their classrooms might fall flat. Though an activity might contain clear real-world applications, not every student will show the same amount of interest. In line with the constructionist belief that each person brings with them a different set of experiences, a one-size-fits-all approach to PBL is simply not effective.

In an article for Edutopia, John Larmer, editor in chief at the Buck Institute for Education, agrees that there exists a sense of confusion around what separates “authentic” PBL from the unauthentic type. To simplify this, he puts forth a “sliding scale of authenticity”:

NOT AUTHENTIC:

These projects do not resemble the type of work done outside of school and are little more than academic exercises. Examples include writing an essay, creating a poster or developing a PowerPoint presentation. Beyond the teacher and their classmates, there exists no outside audience for the work they’ve produced.

SOMEWHAT AUTHENTIC:

Here students simulate what occurs in the world outside the classroom. A common activity in this category would involve each member of a class playing a specific role – a scientist, computer programmer, journalist, etc. – and being placed in a situation that mimics an event that might occur in the real world.

FULLY AUTHENTIC:

In this category, students conduct work that is real and authentic to their own lives, or work that has an impact on or use in the real world. From prototyping an invention to brainstorming ideas for a business, the key here is that these projects are their own, and they have agency over the projects’ direction.

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Larmer’s explanation of what constitutes an authentic PBL experience is helpful for any educator looking to implement this type of learning in their classroom. By giving students the responsibility to solve problems to advance projects they are invested in, educators can help them develop the ability and confidence to maneuver through whatever our increasingly complex world throws at them.

At the National Inventors Hall of Fame® (NIHF), we pride ourselves on weaving the principles of PBL throughout all our education programs. By inspiring students with stories and advice from NIHF Inductees, we can show this next generation of innovators what they too can achieve.

There is a famous John Dewey quote that emphasizes giving students, “...something to do, not something to learn,” highlighting how that process of meaningfully doing naturally results in discovery and learning. In our new Camp Invention® module for 2020, Design Thinking Project™, children build STEM skills as a result of their desire to make their invention prototypes to scale and give them moving or functional parts. They make discoveries about the advantages and disadvantages of various materials as they build and test their prototypes. The power of participants’ learning comes from their natural engagement with the rewarding process of solving a challenge that they have identified by following their own personal sense of curiosity.

- Jayme Cellitioci, Creativity and Innovation Strategist



16. Brooks, J. G., Brooks, M. G., & Brooks, J. G. (2000). The Case for Constructivist Classrooms: In Search of Understanding. Alexandria, VA: Assoc. for Supervision and Curriculum Development.

17. Jumaat, N. F., Tasir, Z., Halim, N. D. A., & Ashari, Z. M. (2017). Project-Based Learning from Constructivism Point of View. Advanced Science Letters, 23(8). doi: 10.1166/asl.2017.9605

18. Larmer, J. (2012, June 5). PBL: What Does It Take for a Project to Be “Authentic”? Retrieved from <https://www.edutopia.org/blog/authentic-project-based-learning-john-larmer>