Samuel Neaman Institute
for National Policy Research

Project-Based Learning: How Great Schools Motivate & Inspire

A Survey of Recent Research [i]

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This essay surveys research published in the past four years or so, on how innovative schools employ project-based learning to motivate and inspire children

"Youth, regardless of age or place, live parallel lives as learners. The ongoing technological revolution that has changed dramatically the way we relate to our environment, the way we perceive the world, the way we socially relate and even the way we know about ourselves, has not moved the educational system from its traditional essence.

"The paradox is that this is the system society created as The Learning Place. We send kids to spend most of their days in a system that is currently inconsistent and almost irrelevant to their learning needs.

"What message are we really sending them? Generation Z is so aware of this that they engaged in what I call, "The Silent Revolution" – they go through the system, knowing they will really learn only when they are outside (on their own computers/smart phones/ …), and they just switch off. We even give names to their "switching off" – attentional deficit, which I see as a healthy defense mechanism to deal with this parallel-inconsistent learning lives we impose to them!"

- Dr. Cecilia Waismann, VP R&D, MindCET [1]

Introduction: 3 Case Studies

1. 16 year old cures cancer

The first author recently returned from York University, in Toronto, Canada, where I observed how my friend Prof. Andrew Maxwell, Lassonde School of Engineering, led 19 creative high school students through an intensive startup boot camp in which teams of four developed innovative solutions to pressing social problems and then pitched their business plans to experts. These students all won science project contests throughout Canada.[2]

I spoke with Bhavya Mohan, an incredible 16-year-old from Ottawa, Canada, going into Grade 11, who made a breakthrough discovery for treatment of cancer. It won him first prize in Canada's high school science project competition. He will head to Bulgaria in the Fall to represent Canada at a European science fair contest.

[1] S. Maital. "Rethinking Our Schools: The Diagnosis." Jerusalem Report, Sept. 23, 2019, pp. 30-32

[2] Canadian Broadcasting Corporation, "Science fair phenom takes 1st place at national competition: Ottawa high school student develops treatment strategy to help fight cancer cells naturally" (website)

Bhavya's project was called "Taking ABiTE out of Cancer: A Novel Aptamer based BiTE for Cancer Immunotherapy". Perhaps it is hard to believe, but Bhavya's breakthrough finding is real, and in his research, he really was the Principal Investigator. Press accounts stated: "Mohan's project introduces a novel platform that will improve the human body's ability to naturally detect and eliminate cancerous cells and be an affordable alternative to current immunotherapies." Bhavya found a way to use the body's own DNA, avoiding a severe immune reaction to cancer drugs that can kill patients.

Bhavya Mohan's parents were born in India. His father was born and raised in New Delhi, and his mother, in the state of Behar. They emigrated to the US, initially, then to Canada. They work for the government, in Ottawa.

As press accounts affirm (and I can, too): "In most ways, Bhavya Mohan is like any other 16-year-old high school kid. He likes to spend time with friends. He plays guitar and basketball. Except when he isn't doing those things, he's winning science fairs and making breakthrough discoveries in cancer research."

How did it all start? Bhavya told me that in Grade 5, when he was only 11 (!), he reached out by email to biology professors. Most did not respond. One did -- Professor William Willmore, at Ottawa's Carleton University. He gave Bhavya tough reading assignments – and Bhavya eventually won his spurs and became Principle Investigator in a very difficult research project. Kudos to Professor Willmore!

What is the one thing you would change, I asked the 19 youths, if you could, at your school? There was a strong response. Fewer tests (especially, brain-destroying multiple choice, beloved by lazy teachers), and far more projects.

2. This school is a no-test zone

Touchstone School [K-8, in Grafton MA.] was founded in 1982 by concerned parents, long before magnet schools and charter schools became fashionable. Our visit at Touchstone began on October 1 with a "community meeting," with all the children sitting on the carpet in a half circle. As the children greeted us, I read carefully the school's mission statement on the wall: To cultivate a joy of lifelong learning through transformational intellectual social and emotional growth.[3]

Empty words? We soon learned they were not. The children love to come to school, love to learn, and radiate energy from the joy of discovery.

We joined a class as the teacher, Dave, led it on a nearby nature trail, to "tag" four varieties of trees and plants, typifying Touchstone's "discovery" approach. Dave told us he had taught at a school in a poor South Bronx community in New York, where the playground was a slab of hard concrete.

We watched closely as another teacher, Emily, taught a class how to analyze a literary text, with eighth graders working in pairs, marking up flipchart pages and mapping stories. Emily, we learned, also teaches at a university. Her students matched her high energy. Like many of the teachers, she got involved with Touchstone when

[3] S. Maital, "Still in First Grade", Marketplace, Jerusalem Report, Sept. 13, 2015, pp. 30-33

her own daughter was a pupil there. We chatted with another teacher, Kim, whose mother has taught at Touchstone for some 25 years; Kim herself was a Touchstone student. Tamara, who teaches first and second grade, has also taught there for a quarter century.

Later, we spoke at length with Susan Diller, Touchstone Head of School for the past five years. She told us her school is not afraid of the label "progressive or transformative," that is at times applied when parents claim that "discovery is not learning." I asked her if Touchstone children felt maladjusted when they graduate from eighth grade and go on to conventional high schools.

"They love it," she told me. "They love the fact they are self-motivated and self-directed learners and that they can influence other kids. They love their ability to enlighten other students about what is possible when learning is welcomed and embraced instead of being a burden. And teachers love our kids! Our children know who they are, and know how to talk to teachers. They connect easily with others. Children in public schools [and, I interjected, in universities] ask, when given an assignment, how many pages? How long? What size font shall we use? Touchstone kids? They ask, can we extend this project? Can we try a different way? Can you recommend some books? And they do not need tests to know how they are doing. They know if their work is living up to their abilities and the work assigned. And they strive to do their best, always, without the lure of a grade which only temporarily influences and rewards."

So, why do so many schools, all over the world, look like, and feel like, prisons or factories? Why is Touchstone School such a rare exception? In his book *Out of Our Minds*[4], educator Sir Kenneth Robinson explains that "mass public education systems… were built after the [19th century] Industrial Revolution." Schools were designed to supply literate workers to man assembly lines. Compulsory public education was perhaps the greatest social invention of all time but educational systems have not adapted to today's knowledge economy. They are obsolete.

"The challenge," Robinson writes, "is to implement innovation on a wide scale, to meet the challenges of life and work in the 21st century."

But schools are still stuck in the 19th century. They teach kids old stuff they could learn today on their own. Schools also should be teaching how to dream up new things.

3. First-hand Evidence N=2

My grandson, O, is 12 years old. He is musical, creative and athletic. He goes to a highly-rated school. At the start of the school year, I asked him if he was learning anything interesting.

"No!" he shot back. "Did you expect a different answer?"

The sad fact is, I did not. He and 2.3 million other Israeli schoolchildren are bored.

[4] Kenneth Robinson. Out of Our Minds. Tantor Media, Incorporated

And in contrast: This past August, my wife and I toured the Canadian Rockies with our son, daughter-in-law and two grandchildren, ages 4 and 7. I had long talks with E., the 7-year-old, about dinosaurs. She spoke for hours with passion about dinosaurs, their habits, food, and why they disappeared. *All this, she learned in a school project at a private NYC Jewish school*. We talked about paleontologists and what they do for a living. And once, we found what looked like a fossil – and her face lit up with happiness.

Project-Based Learning (PBL): What Is It?

Definition: "Students work on a project over an extended period of time – from a week up to a semester – that engages them in solving a real-world problem or answering a complex question. They demonstrate their knowledge and skills by creating a public product or presentation for a real audience. As a result, students develop deep content knowledge as well as critical thinking, collaboration, creativity, and communication skills. Project Based Learning unleashes a contagious, creative energy among students and teachers".

There are several key elements to a true, authentic PBL methodology: ♦ A challenging, meaningful problem to solve, or a question to answer, at a level that is appropriate for the participants; ♦ Students engage in a rigorous, extended process of asking questions, finding resources and applying what they learn; ♦ The project speaks to personal concerns, interests and issues in the students' lives, and involves real-world context, tasks and tools; ♦ Students make key decisions about the proj ect, including how they work, what they create and, often , how well they have succeeded; ♦ Students and their teachers reflect on the effectiveness of their inquiry and project activities, the obstacles they faced and how they overcame them; ♦ Students all give, receive and rigorously apply feedback to improve both their process and their products; ♦ Students make their project work public by explaining, displaying and presenting it to audiences beyond the classroom."[5] [See Figure 1 and Figure 2 for two alternate graphic presentations of the key elements of PBL].

[5] Source: PBLWorks website (link)

Figure 1: Project-Based Learning - Key Elements

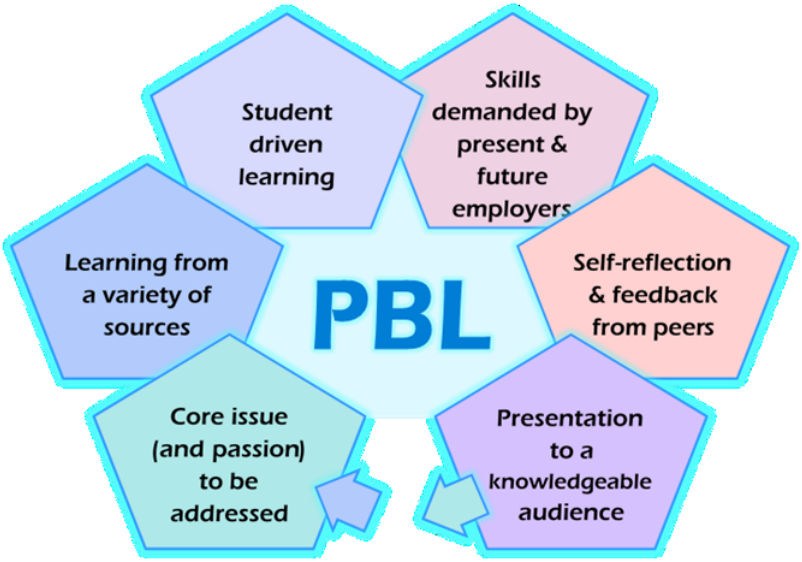
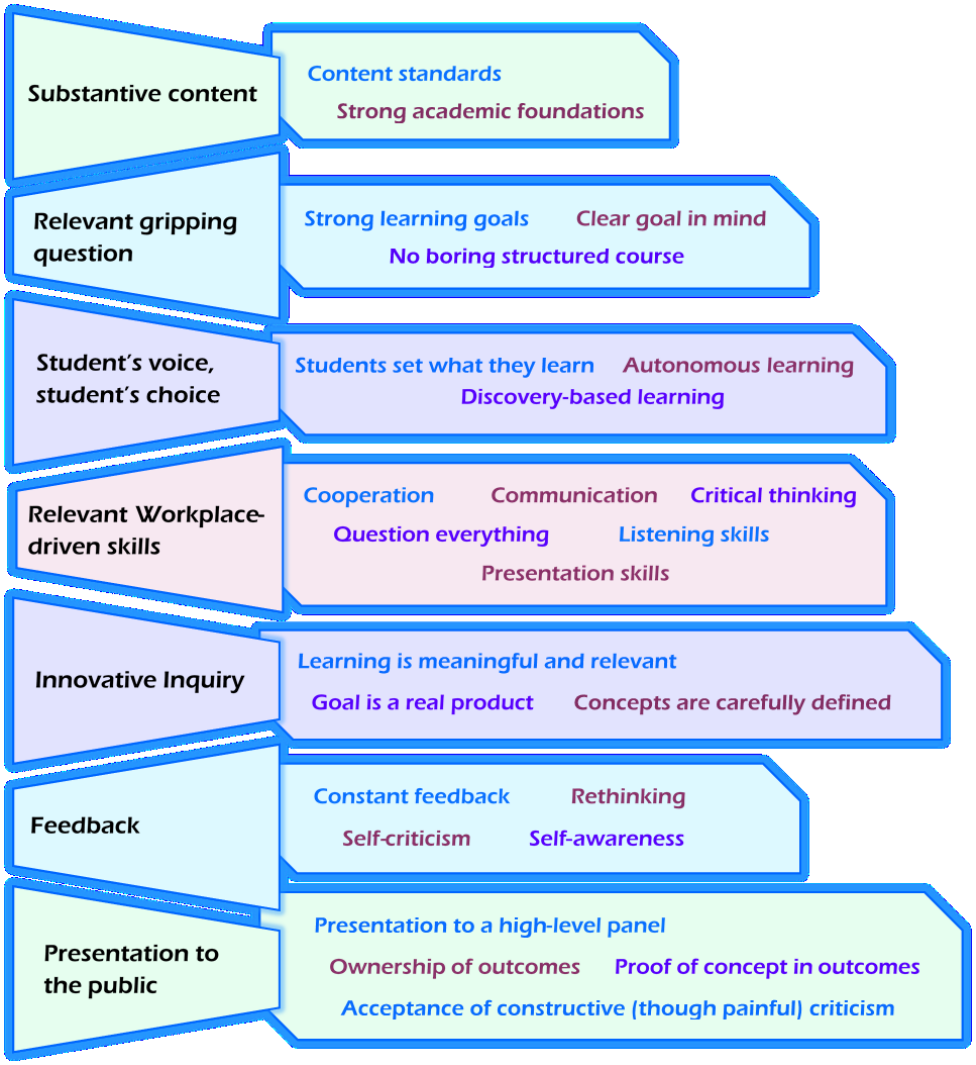


Figure 2: An Alternate Graphic Presentation of PBL – Key Elements



A strong example of PBL is found in Porat and Kapon[6]. They taught high school students a sense of the nature and role of physical measurement, “in a fun and engaging way”. A series of projects involved “the design, building and calibration of a measurement device for a basic physical quantity (time, length and mass). Each measurement device is made up of recycled materials and simple pieces of equipment available in any high school physics laboratory. The students build the device, calibrate it, and write a detailed documentation that explains how it works, its specifications and instructions for use. The students also present their work to peers and visitors.” Recalling my own boring high school physics class, I deeply regret not experiencing this imaginative PBL approach.

Problem-Solving & Creative, Critical Thinking

Can schools teach children how to think critically and creatively? Is this in fact their mandate?

L. Mutakinati et al.[7] observe that critical thinking “is one of the most important real-life skills.” It is defined as “an ability to analyze information, determine its relevance and then interpret it in solving problems.” In this study, 160 first-grade Japanese students from four classes were given filter paper, beaker glass, plastic bottles, litmus paper and other tools, and challenged to think how to use the materials in order to show how to clean up wastewater. They filled out worksheets and designed tools. The projects were conducted during six separate lessons. Critical thinking skills were quantified. Nearly three students out of four attained ‘advanced’ or ‘practicing thinker’ skills, implying the ability to critique their own plans and powers of thought. Recall that first-grade students are generally aged 6 or 7. This study suggests that PBL can be implemented from the outset of children’s school experiences.

Indonesia, a huge developing nation of some 270 million people, should be closely followed, for its pioneering experiments in modernizing its educational system, with especial emphasis on skill-building and PBL. It is an emerging-market country that has acted effectively to modernize its educational system.

Anifaza et al.[8] studied the new so-called Indonesia 2013 curriculum, which includes PBL. They studied 102 11th-grade math and science students, and compared the impact of three different learning models: PBL, problem-based learning and discovery learning. They find that PBL and problem-based learning both improve students’ creativity and critical thinking skills, while PBL is best at enhancing creativity.

In the case study about Touchstone School that opened this paper, it was asserted that students who complete eight years under a ‘pure’ PBL curriculum, with no experience in conventional tests, perform well when faced with multiple-choice tests.

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[6] Porat, G., & Kapon, S. (2018). Building Measurement Devices with Students–From Hands-on to Minds-on. The Physics Teacher, 56(7), 461-465

[7] Mutakinati, L., Anwari, I., & Kumano, Y. (2018). Analysis of students’ critical thinking skill of middle school through stem education project-based learning. Jurnal Pendidikan IPA Indonesia, 7(1), 54-65

[8] Anazifa, R. D., & Djukri, D. (2017). Project-Based Learning and Problem-Based Learning: Are They Effective to Improve Student's Thinking Skills?. Jurnal Pendidikan IPA Indonesia, 6(2), 346-355

In Craig et al.[9] this issue is addressed in a long detailed paper. The authors find that students taught through PBL, as a group, matched performance of conventionally-taught students, in the TAKS (state-mandated Texas multiple-choice test, required for graduating high school), for 11th grade Science, and for 9th, 10th and 11th grade math, and exceeded their performance for 10th grade Science. For parents concerned that innovative pedagogy, such as PBL, could damage their children's ability to excel at crucial career-critical multiple-choice exams, this suggests that PBL does not harm their test-taking skills, but, other research asserts, enhances crucial life skills like creative thinking and critical thinking.

Assessing PBL Authentically

Authentic assessment is the measurement of "intellectual accomplishments that are worthwhile, significant, and meaningful," as contrasted to multiple choice standardized tests. Authentic assessment can be devised by the teacher, or in collaboration with the student by engaging student voice. When applying authentic assessment to student learning and achievement, a teacher applies criteria related to "construction of knowledge, disciplined inquiry, and the value of achievement beyond the school." Authentic assessment means enabling students to demonstrate their competency in a more real-world setting. For example: Actually performing a skill, or showing use of a particular knowledge. Authentic learning mirrors the problem solving that takes place outside of school.

Authentic assessment has been shown to be crucial in effectively applying PBL.

Suastra et al.[10] studied 60 9th-grade students of public high schools in Singaraja, Indonesia. The focus was on the impact of "authentic assessment".

They compared two groups who were taught through PBL: one with authentic assessment, the second without it. Their finding: "Authentic assessment is effective in enhancing critical thinking, scientific attitude, and self-efficacy" in science teaching.

Similarly, Andanawarih et al.[11] studied 40 10th-grade students in Bandung, Indonesia. They too found that 'authentic assessment' was highly effective in enhancing problem-solving ability and concept mastery.

[9] Craig, T. T., & Marshall, J. (2019). Effect of project-based learning on high school Students' state-mandated, standardized math and science exam performance. Journal of Research in Science Teaching

[10] Suastra, I. W., & Ristiati, N. P. (2019, June). Developing Critical Thinking, Scientific Attitude, and Self-efficacy in Students through Project Based Learning and Authentic Assessment in Science Teaching at Junior High School. In Journal of Physics: Conference Series (Vol. 1233, No. 1, p. 012087). IOP Publishing

[11] Andanawarih, M., Diana, S., & Amprasto, A. (2019, February). The implementation of authentic assessment through project-based learning to improve student's problem solving ability and concept mastery of environmental pollution topic. In Journal of Physics: Conference Series (Vol. 1157, No. 2, p. 022116). IOP Publishing

In Garner et al.[12], a study was designed to "improve teachers' competence in assessing PBL, by teaching teachers how to create assessment blueprints based on classical test theory", as well as how to use assessment data to measure content mastery. Some 21 high school math teachers participated in a five-day workshop, focused on helping teachers apply PBL to their math courses. It is crucial that teachers in various disciplines receive quality training in implementing and designing PBL and especially, in assessing its impact.

An important field of educational research is known as EER – Educational Effectiveness Research. EER studies how best to evaluate educational innovations. Sasson et al.[13] studied an innovative PBL approach for 9th and 10th graders, where three teachers co-taught each lesson "to maximize development of high-order thinking skills". The authors' goal was to evaluate rigorously two key skills: critical thinking and question-posing (the ability to frame and ask strong productive questions). Over two years, the innovative class was compared to a traditional class learning the same material, at three points in time. There were a total of 71 students. Students in the innovative learning class had a "significant advantage" in critical thinking skills after two years, and in question-posing as well. The authors make the case for 'evidence-based education' based on rigorous evaluation of innovative approaches.

Digital Technology & Robotics

Many experts believe that digital technologies will be crucial, in reinventing 21st C. schools. Gomez-Pablos et al.[14] provide results of a study of 310 Spanish teachers who used PBL, in various projects that incorporated digital technologies. Their study offers many valuable insights. First, PBL benefits not only students but also teachers – a fact often forgotten or neglected. Second, according to the teachers, PBL "was an effective strategy for increasing student involvement, developing their creative abilities, encouraging active exploration, inquiry and discovery, and providing an opportunity to use technology and develop digital skills". [p. 509]. They assert strongly that it is "of the utmost importance that projects should be supported and led by the school's management team." In addition, teachers should help students learn to collaborate – a skill they may lack, because we are not born with it but acquire it. "What is important," they assert, "is not only to collaborate to learn [with PBL] but to learn to collaborate". They also stress the need to give adequate time for PBL – conventional classroom study can crowd out valuable PBL hours.

Robotics and robots universally capture young people's imagination and spark their desire to learn and to build, and, in addition, to engage in STEM studies (Science,

[12] C. Garner, K. E. Rambo-Hernandez, A. Naz, M. Lu, "Improving High School Math Teachers' Confidence and Skills in Assessment of Engineering Project Based Learning", American Society for Engineering Education, 2017

[13] Sasson, I., Yehuda, I., & Malkinson, N. (2018). Fostering the skills of critical thinking and question-posing in a project-based learning environment. Thinking Skills and Creativity, 29, 203-212

[14] Gómez-Pablos, V. B., del Pozo, M. M., & Muñoz-Repiso, A. G. V. (2017). Project-based learning (PBL) through the incorporation of digital technologies: An evaluation based on the experience of serving teachers. Computers in Human Behavior, 68, 501-512

Technology, Engineering, Math). MIT has developed a STEM program in robotics, known as MIT Beaver Works Summer Institute Robotics. Karaman et al.[15] describe the program's details and its results. The program focuses entirely on robotic software, not hardware, and is project-based. In each team, students design software for a robot operating system, including tracking tools. The four-week program was residential at MIT, during the summer of 2016. Some 46 students participated. It included an academic program of theoretical lectures, lab exercises, lectures on how to communicate and to collaborate, and technical seminars.

Karamant et al. note that students themselves assessed the program. Students found their programming skills improved, even for those who had considerable such skills at the onset; their understanding of advanced robotic concepts went from near-zero to substantial, in a very short time; and their communication and collaboration skills improved a great deal.

A somewhat different program exists at Technion, in which teams of students from several faculties design and build an autonomous Formula 1 racing car, both software and hardware. The "Formula Technion" project involves 35 students from three faculties: Mechanical Engineering; Aerospace Engineering and Industrial Engineering and Management. The team is headed by student Tal Lifshitz of the Faculty of Aerospace Engineering. Formula Technion cars are designed and constructed by students as part of the "New Product Design" course held at the Faculty of Mechanical Engineering under the guidance of Prof. Reuven Katz. The Formula Project has been held at the Technion since 2013. Construction of the autonomous Formula car, which is expected to join the races in the summer of 2020, is underway.

Safitri et al.[16] describe a project-based e-learning program for 10th grade students, in which they built a rocket car and a magnetic car, in order to learn and understand Newton's laws of motion. According to the widely-used Torrance creativity test, students in the PBL program had improvements in their creative thinking, greater than that of a control group.

PBL in Elementary Schools

At what age can PBL be effectively applied in schools? Is it suitable for elementary schools?

[15] Karaman, S., Anders, A., Boulet, M., Connor, J., Gregson, K., Guerra, W., ... & Vivilecchia, J. (2017, March). Project-based, collaborative, algorithmic robotics for high school students: Programming self-driving race cars at MIT. In 2017 IEEE Integrated STEM Education Conference (ISEC) (pp. 195-203). IEEE

[16] Safitri, A. D. (2018, September). Enhancing senior high school students' creative thinking skills using project based e-learning. In Journal of Physics: Conference Series (Vol. 1097, No. 1, p. 012030). IOP Publishing

Yuliana et al.[17] use the four-D method (Define, Design, Develop, Disseminate) to develop “thematic learning sources for project-based learning for Grade 4 pupils in elementary schools in Indonesia, and then ask nine experts to evaluate their material.

Their material integrates the stages of scientific inquiry with the five stages of PBL (observing, asking a question, reasoning, attempting and presenting). With appropriate material, they conclude that PBL “is very suitable to be implemented in an elementary school.”

YI-Wen Lin et al.[18] developed a STEM-oriented PBL course “with hands-on projects” for the higher grades of Taiwan elementary schools. The goal was to “develop the students’ interest in explorative learning”. Teams of students built a Webduino robot car and controlled it by writing block programs. There was a final competition involving an oval circuit racing by the robot cars. They find performance improvement in the “3 C’s - Creativity, Collaboration and Communications capability”, according to the teachers, but participants’ scores do not show statistically significant gains. The authors note that that “students are willing to take a hands-on approach to learning”.

Tsybulsky[19] studied 17 Israeli science teachers in their practicum module conducted in elementary schools, engaged in team-teaching PBL. They find that student teachers appreciated being given autonomy, and “a dominant role in the process”, They “took price in their ability to manage the whole PBL process”. “I learned about myself as a teacher, that I am capable”, said one subject. In a sense, the team-based practicum itself was an example of PBL, as the student teachers worked to effectively apply PBL.

A key advantage of PBL, often insufficiently emphasized, is that it is necessarily multi-disciplinary, at a time when single-discipline thinking is proving less and less effective. Trisdiono et al.[20] study the effectiveness of multidisciplinary integrated project-based learning among 130 elementary-school students, half experimental and half control group. They find multidisciplinary PBL enhanced both collaboration and critical thinking.

[17] Yuliana, M., & Wiryawan, S. A. (2018, May). The development of thematic materials using project based learning for elementary school. In Journal of Physics: Conference Series (Vol. 1022, No. 1, p. 012018). IOP Publishing

[18] Lin, Y. W., & Wang, T. I. (2017, September). The Design of a STEM-Oriented Project-Based Course for the Higher Grades of Elementary Schools. In International Symposium on Emerging Technologies for Education (pp. 137-143). Springer, Cham

[19] Tsybulsky, D. (2019). The team teaching experiences of pre-service science teachers implementing PBL in elementary school. Journal of Education for Teaching, 45(3), 244-261

[20] Trisdiono, H., Siswandari, S., Suryani, N., & Joyoatmojo, S. (2019). Multidisciplinary Integrated Project-based Learning to Improve Critical Thinking Skills and Collaboration. International Journal of Learning, Teaching and Educational Research, 18(1).

PBL in Vocational Schools

Lubis et al.[21] show that key competences were enhanced when a highly-structured six-phase version of PBL was employed among twelfth-grade vocational school students. In their study they emphasize the key role of the ability of teachers "to fit the initial objectives and…oversee the ..work project".

PBL for College Outreach

How can more high school students be encouraged to study science and engineering in college? Some colleges are implementing outreach programs for high school. In Dehipawala et al.[22], one such program implemented in a community college used projects from astronomy and bio-optics. The core of the program was to transform a conventional physics problem, to a design problem, stressing the three key principles of engineering education: design, science knowledge, and mindset. A PBL project on smartphone radiation and its impact on memory stressed this key fact: surveys show that only 12% of Gen Z (born after 2000) students learn effectively by listening, in a conventional classroom setting.

In Van Horne et al.[23], the authors developed "a year-long course to teach high school biology by engaging youth in interest-driven projects focused on contemporary projects. We explored how engaging youth in the epistemic practices of science in culturally expansive ways supported their science-linked identification." In short: PBL sought to encourage youth to see themselves as future scientists. The authors observe trenchantly, "science in school is often solely focused on learning content knowledge, but that goal can be attended to while also helping students participate in becoming scientists as well." (p. 472). That statement can be broadly generalized – help students learn content, but also to learn what people do when they are managers, economists, engineering, biologists, teachers, mathematicians or truck drivers. This paper is highly enlightening, as it focuses on two real students "Julie" and "Anthony" and their specific thought processes as they shape their future professional identities.

[21] Lubis, A.L. et al. Project-Based Entrepreneurship Education Model in Vocational High Schools, International Journal of Scientific & Technology Research (Vol. 6, no. 6, June 2019).

[22] Dehipawala, S., Sullivan, R., Armendariz, R., Shekoyan, V., Tremberger Jr, G., Lieberman, D., & Cheung, T. (2018, September). Assessment of high-school engineering education outreach program employing project-based learning in astronomy and bio-optics within a college setting. In Optics Education and Outreach V (Vol. 10741, p. 107410H). International Society for Optics and Photonics

[23] Van Horne, K., & Bell, P. (2017). Youth disciplinary identification during participation in contemporary project-based science investigations in school. Journal of the Learning Sciences, 26(3), 437-476

PBL for Enhancing Key Skills

There is a growing consensus that schools must do better in teaching children crucial skills. Mekaria et al.[24] compare "quantum learning" with PBL, in two Indonesian Grade 7 classes.[25] The main finding was "there is no difference in the effectiveness of learning between the methods of Project Based Learning and Quantum Learning, in terms of student's reasoning, achievement, and attitudes toward mathematics."

Mi Thant Mont et al.[26] studied a program that paired Ph.D. students with high school teachers, to develop STEM curricula. In this study, two graduate students with biomedical and mechanical engineering backgrounds worked with a high school engineering teacher, to optimize a new honors engineering series for grades 9-12. Several short modules spanning 2-3 classes each were implemented, supplementing long-term projects. The ambitious goal "envisions high school students to become confident, proactive individuals armed with the engineering mindset and capable of solving modern society's greatest problems", based on acquired skills of engineering design.

Susilawati et al.[27] compared two groups of high school students, both of which experienced PBL, but one had a special PBL program that included "multi-life skill-building" (collaborative skills and technology skills). The multi-life skills program proved most effective.

[24] Mekaria, T. Y., & Widjajanti, D. B. (2018, September). The effectiveness of quantum learning and project based learning viewed from the student's reasoning ability, achievement, and attitude toward mathematics. In AIP Conference Proceedings (Vol. 2014, No. 1, p. 020160). AIP Publishing

[25] Quantum learning is not easy to define; it is largely a way to design the educational experience, to enhance learning skills: quantum note-taking, memory, mind maps, quantum writing and reading techniques. Add to that lifelong learning skills -- creative problem solving techniques, leadership skills, self-confidence feeling, responsibility, motivation and effective communication. A key element: all students take active roles in quantum learning. Quantum writing is: clustering and quick writing. Quantum memory techniques consist of association, classification, animation, and basic memory systems. The term quantum learning comes from quantum physics, which assumes that new properties come out when ordinary existence combines or get in touch. Every quantum piece has the capacity to effect the world. According to the Heisenberg uncertainty principle, acquiring certain data is almost impossible. Relationships are non-linear and there is a mutual causality.

[26] Mi Thant Mon (Thant) Soe, R. Schultz, J.M. Muscarella, J.S. Ward, A.K. Fontecchio, "A Project-Based Approach to Develop Engineering Design Process Skills among High School Students", (Work in Progress), 2018 ASEE Annual conference and Exposition, paper ID #23525

[27] Ardhyani, S., & Khoiri, N. (2017). Project Based Learning Multi Life Skill for Collaborative Skills and Technological Skills of Senior High School Students. In Journal of Physics: Conference Series (Vol. 824, No. 1, p. 012010). IOP Publishing

Impact of PBL on Teachers

A key PBL-related research question is: "what kinds of experiences lead student-teachers …to advocate and practice inquiry-based pedagogy?" (Tsybulsky et al[28]). The authors note that in Israel, since 2015, "educational reform...has promoted PBL as a core learning paradigm". They sought to "present the thoughts, feelings and emotions of student-teachers" as they participated in a PBL activity. Their main finding: "the practical experience of leading PBL in science classes in a team-teaching framework was perceived as significant by student-teachers" as it led to "meaningful processes of professional-identity construction". If we are to have cadres of teachers skilled in the PBL methodology, then we do need to train "constructivist teachers who advocate and practice inquiry-based pedagogy".

Tsybulsky and Oz[29], in a related study, had 17 Israeli student-teachers implement, in their first semester of the practicum, PBL, and in the second semester, any other conventional method. There was a great deal of frustration, and difficulties, with PBL, but ultimately, a sense of success and satisfaction. This led student science teachers to develop positive attitudes "towards student-centered inquiry-based learning" and to adopt elements of PBL in their pedagogy.

PBL vs. Discovery Learning

Project-based learning is based on solving problems chosen by the students. Discovery learning (DL) stresses learning through observations and experienced, closely guided by teachers. They are similar, but differ in the autonomy students have in their learning experiences. In Tumewu et al.[30], the effectiveness of PBL vs. DL was studied in two 7th grade classes. The context was the issue of global warming. The focus was students' "metacognitive strategies" – what, how and when individual learning strategies are applied, and how effective they are. It was found that PBL "improved students' metacognitive strategies more than using discovery learning".

Conclusion: Many Children Are Left Behind

In 2001, in his first major act as President, George W. Bush initiated the No Child Left Behind Act, which mandated a nation-wide system of objective tests, to evaluate school quality. The theory was largely based on the free-market capitalism model, in

[28] Tsybulsky, D., & Muchnik-Rozanov, Y. (2019). The development of student-teachers' professional identity while team-teaching science classes using a project-based learning approach: A multi-level analysis. Teaching and Teacher Education, 79, 48-59

[29] Tsybulsky, D., & Oz, A. (2019). From Frustration to Insights: Experiences, Attitudes, and Pedagogical Practices of Preservice Science Teachers Implementing PBL in Elementary School. Journal of Science Teacher Education, 30(3), 259-279

[30] Tumewu, W. A., Wulan, A. R., & Sanjaya, Y. (2017, May). Comparison between project-based learning and discovery learning toward students' metacognitive strategies on global warming concept. In AIP Conference Proceedings (Vol. 1848, No. 1, p. 060013). AIP Publishing

which share prices reflect measurable bottom-line results of competing businesses. It was reasoned, let schools be like businesses – rate them by their bottom line.

The result, copied by other countries such as Israel, was disastrous. Teachers understandably taught children how to excel at multiple-choice tests, rather than enjoy learning and pursue curiosity. As a result, many children were left behind, and still are. And many teachers simply detested what they had to do, for their schools to survive. After two decades, the immensity of this disaster has finally become apparent.

But an almost underground opposition has emerged – innovative schools that spark children's interest and love of learning, rather than bore them to death. For instance, La Prad and Hyde[31] describe IDEAS (Innovation through Design, Engineering, Arts and Sciences), a small public school in Sheboygan, Wisconsin, and a member of the Coalition of Essential Schools (CES). CES goals interweave "power, agency and joy". IDEAS uses PBL, with teachers leading small groups of students in projects. The underlying concept is "less is more -- curricular decisions should be guided by the aim of thorough student mastery and achievement rather than by an effort to merely cover content."

As La Prad and Hyde note, "there are thriving alternatives to many of the current textbook and test driven curriculum practices commonly found in today's schools". [e.g., see Dattiel[32], for an Israeli example].

What remains is only to ask: Why are educational systems in the US, Israel and elsewhere so disgracefully slow to learn from the many phenomenal educational experiments now underway, some underground, in Grafton, MA., Sheboygan, WI, northern Tel Aviv, and elsewhere? Why are we unable to reform and adapt our schools to the needs and personalities of Gen Z? And what is the price we will pay, when we finally wake up to realize that we have cheated a whole generation of young people out of the quality education they need and deserve?

[31] LaPrad, J. G., & Hyde, A. M. (2017). IDEAS: A qualitative inquiry into project-based learning. The Qualitative Report, 22(2), 479-498

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