PBL BRIEF #8

WPI

PBL & Demonstrating Mastery

Kimberly LeChasseur, PhD • Center for Project-Based Learning • November 2022

Briefer Brief

- Project-based learning (PBL) is perhaps best known for developing skills and mindsets. However, PBL can also be a useful tool for scaffolding mastery as students encounter new ways of thinking and doing through common intellectual experiences, capstone courses and projects, and ePortfolios (Kuh, 2008).
- PBL offers a means of bridging tensions facing higher education: appeals to better serve as vocational preparation (Hart, 2019; Stolk & Martello, 2015) and calls to ensure continued access to a classical liberal arts tradition (see LeChasseur, 2020).
- PBL is often the pedagogy chosen for capstone experiences (Pembridge & Paretti, 2010), with many top-ranked engineering universities, in particular, offering a sequences of PBL experiences to scaffold capstone projects (Ward, 2013).
- International studies have provided evidence of the additional value of using e-portfolios during PBL teaching and learning, such as boosting students' higher-order thinking skills, decreasing students' stress during project work, and increasing their self-confidence in new skills (Lukitasari, Hanhika, & Murtafiah, 2018; Gülbahar & Tinmaz, 2006).

Introduction

This brief outlines and critiques scholarship on whether and how project-based learning (PBL) enhances opportunities to develop and demonstrate mastery in three high-impact practices (HIPs): common intellectual experiences, capstone courses and projects, and ePortfolios. The concept of mastery learning decouples competence in an area of knowledge or skill from time-to-completion to acknowledge that different learners require different lengths of time and, often, different educational experiences to learn.[1] Some students may demonstrate mastery early in their college careers while others may need multiple experiences with something new to fully grasp how it fits into or changes their current thinking or abilities. These three high-impact practices have been empirically demonstrated to engage students and heighten learning.[2]

In mastery-based approaches, the emphasis is on achieving high-level outcomes. PBL can enhance mastery-based HIPs as a method of attending to the importance of process; doing so can keep mastery-based approaches from becoming superficially centered on attaining outcomes without attention to transferability of skills and the role of context. The quality of implementation in high-impact practices is also critical to their impact on students[3] and PBL can improve implementation.

This brief begins by describing and synthesizing the empirical literature on each of the three HIPs. Within this synthesis, the trends across the existing scholarship are described and the weaknesses in what we know are assessed. Also within each section is a summary of the empirical support around using PBL to realize the potential of the practice. The brief concludes with recommendations for future scholarship and suggestions for further reading.

Common Intellectual Experiences

The idea of providing common intellectual experiences is described by Kuh, O'Donnell, and Schneider (2017) as a means of crafting intellectual coherence for students across what might otherwise seem like disconnected learning experiences. Furthering this idea of general education's promise, Boning (2007) points out that "these connections should occur within disciplines, among disciplines, to real life and the world, and to majors and careers" (p. 1). Coherence might come in the form of a set of required common courses,[4] a vertically integrated general education program,[5] or a set of themed projects completed by all students.[6] Common intellectual experiences can be thought of as a way of ensuring that all college graduates have mastery over a core set of skills and knowledge.

Common intellectual experiences have their roots in the original forms of college education offered in the US, in which all students were expected to complete the same classical course of study.[7] For this reason, it is often appealing to conservative educators who view this tradition as particularly meaningful. Over the centuries, however, the pendulum has regularly swung between specialization and general education.[8] PBL may offer a means of bridging the two, allowing for the development of skills that satisfy the most sought-after 21st century job qualifications[9] while ensuring all students have access to a meaningful liberal arts community.[10]

Some universities use PBL as the means to orchestrate common intellectual experiences (see Table 1). Since 1970, Worcester Polytechnic Institute has centered its curriculum on distinctive PBL degree requirements. All students complete three common requirements, including the equivalent of a minor in a student-selected area of the humanities and the arts; an interdisciplinary team-based project at the intersection of technology and society, completed in the third year—often at an international project center; and a capstone project in the student's major area of study.[11] While these project experiences take place in widely varied contexts with unique, unstructured objectives, all students participate and a distinct culture around PBL, authentic learning, and connections between theory and practice—the university's's motto—permeates campus.[12]

Starting with its first class in 2002, Olin College of Engineering has employed a PBL-based curriculum to build common intellectual experiences among small cohorts of engineering students.[13] Aalborg University in Denmark infuses its curriculum with a variation of PBL that poses theoretical and practical problems to students to solve, typically through projects.[14] In these cases and many others, PBL is being used as the vehicle of a different type of coherence, one focused on the skills needed to address wicked problems[15] and grand challenges,[16] rather than the more classical studies of traditional general education requirements.

Table 1. Examples of PBL in Common Intellectual Experiences

University	Common Intellectual Experiences	Further Reading
Worcester Polytechnic Institute	*Humanities & Arts Sequence:* 6-course requirement, including a final project demonstrating mastery in a focus area. *Interactive Qualifying Project:* 9-credit-hour requirement that involves students working in teams with students not in their major to tackle an issue that relates science, engineering, and technology to society sponsored by a project partner (e.g., in government, industry, non-profit organization). *Major Qualifying Project:* 9-credit-hour requirement in a student's major completed at entry level professional quality.	Vaz, R. F. (2000). Connected Learning: Interdisciplinary Projects in International Settings. *Liberal education, 86*(1), 24-31. Heinricher, A. C., Quinn, P., Vaz, R. F., & Rissmiller, K. J. (2013, June). Long-term impacts of project-based learning in science and engineering. In *2013 ASEE Annual Conference & Exposition* (pp. 23-874).
Olin College of Engineering	*Design Stream:* course sequence introducing a studio environment through authentic design projects. *Technical Self-Study Requirement:* a student-identified technical area in which students develop mastery independently. Capstone Project: a year-long interdisciplinary, team-based project completed in the fourth year. *Culminating Project:* a final project either focused on the arts or on entrepreneurship; may or may not be connected to the capstone.	Somerville, M., Anderson, D., Berbeco, H., Bourne, J. R., Crisman, J., Dabby, D., ... & Zastavker, Y. (2005). The Olin curriculum: Thinking toward the future. *IEEE Transactions on Education, 48*(1), 198-205. Ribeiro, J., Silva, G., Santos, J., & Rauch, M. J. (2018). Designing Student Centered Learning Methodologies in Applied Sciences Engineering Education. In *International Conference The Future of Education* (p. 217).
Aalborg University	*Projects:* Each semester includes 15-credit-hours of team-based project work, alongside courses (which may themselves include PBL).	Kolmos, A., & Fink, F. K. (2004). *The Aalborg PBL model: progress, diversity and challenges*. L. Krogh (Ed.). Aalborg: Aalborg University Press. Hernandez, C., Ravn, O., & Valero, P. (2015). The Aalborg university PO-PBL model from a socio-cultural learning perspective. *Journal of problem based learning in higher education, 3*(2).

Capstone Courses and Projects

Capstones serve as a final demonstration of mastery that typically build upon a set of learning experiences either as a final course or a culminating project. They may be multidisciplinary in nature[17] and often involve 21st century skills alongside the application of core content knowledge.[18] Some colleges and universities allow for team-based capstone projects as a means of demonstrating the ability to work through group dynamics, make compromises, and draw on peers' assets to develop a successful end product.[19]

According to the National Survey of Student Engagement, 44% of seniors in 2018 experienced a culminating senior experience, which may have included a capstone course, senior project or thesis, portfolio or other demonstration of mastery. Students in smaller schools were more likely to complete a culminating senior experience – 60% of seniors in schools with fewer than 2,500 undergraduate students compared to 40% in schools with 10,000 undergraduate students or more. Seventy-six percent of seniors at baccalaureate colleges with an arts and sciences focus reported having completed a culminating senior experience.

Capstone projects are endemic in engineering programs as a means of having students exhibit readiness for industry responsibilities,[20] though their structure varies across colleges and universities. According to a 2015 national survey, 68% of engineering programs require students to complete a capstone project through enrollment in particular courses, 13% require a project only (without a corresponding course), 12% require a capstone course followed by a project, and no programs require a capstone course without a project; six percent have some other capstone experience.[21] Many capstone experiences are longer than a typical course. Approximately half (54%) of engineering programs indicated that their capstone courses span two semesters; an additional 4% of programs using the quarter schedule report capstones that span two quarters and 5% indicated capstones that span three quarters.[22]

With projects such an integral part of many capstone experiences, it is no surprise that PBL is often explicitly chosen as a pedagogy by faculty facilitating them.[23] In an analysis of capstone elements common to internationally top-ranked engineering programs, Ward (2013) found that many of the top-ranked engineering universities offer a sequence of PBL experiences to scaffold independent problem solving prior to the capstone (see Table 2). A national survey of faculty who teach engineering capstone courses found that the most commonly identified goal of capstones is to "provide opportunities for students to synthesize and apply prior coursework in an environment that simulates real-world experiences through open-ended projects" (Pembridge & Paretti, 2010, p. 8).

Beyond engineering, many interdisciplinary programs, such as digital humanities[24] and sustainability studies,[25] use capstone projects to allow students to demonstrate their ability to independently address open-ended problems or authentic challenges by applying what they have learned in their coursework. Although capstone projects are not as common beyond engineering, they can offer similar benefits to students, particularly those in applied fields.[26]

Table 2. Common Elements of Capstone Projects

Element of Capstones	Description	Further Reading
PBL Precursor Courses	Sequence of courses (i.e., cornerstone courses) that scaffold skills development and foundational content to culminate in a capstone	Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120. Cortázar, C. (2020, June). Teaching Human-centered Design to Engineers: Continuous Improvement in a Cornerstone Course. In 2020 *ASEE Virtual Annual Conference Content Access*.
Group Project Emphasis	Mandating or allowing students to work in teams to mimic collaborative work environments common in many industries	Yu, X., Cutler, S., & McFadden, D. (2020, June). Collaborative project-based learning approach to the enculturation of senior engineering students into professional engineer practice of teamwork. In *ASEE Annual Conference and Exposition, Conference Proceedings* (Vol. 2020, p. 343). Mostafapour, M., & Hurst, A. (2020). An exploratory study of teamwork processes and perceived team effectiveness in engineering capstone design teams. *Int. J. Eng. Educat, 36*, 436-449.
Design-Build-Test Model	Students not only design a solution to a problem, but also build a prototype to operationally test the design, and potentially identify improvements, to demonstrate the ability to meet industry-level design standards	Friess, W. A., & Goupee, A. J. (2019, October). Transformation of a mechanical engineering capstone experience. In *2019 IEEE Frontiers in Education Conference (FIE)* (pp. 1-4). IEEE. Qattawi, A., Alafaghani, A. A., Ablat, M. A., & Jaman, M. S. (2021). A multidisciplinary engineering capstone design course: A case study for design-based approach. *International Journal of Mechanical Engineering Education, 49*(3), 223-241.
Active Industry Involvement	Stakeholders from relevant prospective employers are involved in capstone topic nomination, formative feedback to students, and assessment	Krishnakumar, S., Berdanier, C., McComb, C., Parkinson, M., & Menold, J. (2020, August). Comparing Student and Sponsor Perceptions of Interdisciplinary Teams' Capstone Performance. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 83921, p. V003T03A007). American Society of Mechanical Engineers.
Sequential Assignments	Capstones are organized into a series of assignments which each contribute to the final product	Higbee, S., & Miller, S. (2020, October). Tracking Capstone Project Quality in an Engineering Curriculum Embedded with Design. In *2020 IEEE Frontiers in Education Conference (FIE)* (pp. 1-5). IEEE.

Note: Adapted from Ward (2013)

ePortfolios

An e-portfolio is a collection of artifacts, such as products created for projects or internships, demonstrations of technical knowledge or skill, and other accomplishments, which are made digitally available. In addition to these artifacts, an e-portfolio includes reflections about the work included or about how the artifacts serve as evidence of particular expertise, skills, and professional identity.[27] Pedagogically, e-portfolios can be used to prompt student reflection and connections between specific learning experiences and broader themes; to assess the knowledge and skills students have gained; and to communicate with instructors and other stakeholders in student learning.[28] Because they are hosted online, e-portfolios can be easily shared with potential employers as students transition from learning to joining the workforce.[29]

The use of ePortfolios has increased dramatically over the past decade. According to a national survey conducted by Educause, an advocate of technology use in education, 57% of US colleges and universities offer ePortfolios to students as of 2015.[30] More than half of college students report having used an ePortfolio at least once during their college career.[31] The rise in prevalence makes ePortfolios one of the more commonly practiced high-impact practices.

The processes used in developing an e-portfolio borrow practices from multimedia development and portfolio development,[32] which share similarities with the pedagogical practices involved in PBL (see Table 3). Advocates often point to the utility of e-portfolios as an authentic assessment,[33] similar to common ways of thinking about assessment in PBL.[34] Beyond using e-portfolios as an appropriate assessment tool for PBL, this high-impact practice is particularly effective when intentionally combined with other elements of PBL. International studies have provided evidence of the additional value of using e-portfolios during PBL teaching and learning, such as boosting students' higher-order thinking skills,[35] decreasing students' stress during project work and increasing their self-confidence in new skills.[36]

Table 3. Comparison of Pedagogical Styles Related to ePortfolios

Project-Based Learning	Multimedia Development	Portfolio Development
Centrality of Projects: Central to the curriculum, it is an essential part of the teaching strategy.	*(no comparable requirement)*	*(no comparable requirement)*
Start with a Driving Question: The driving question encompasses every aspect of the learning; used to solve real-world problems.	**Decide/Assess:** Determine the needs, goals, & audience for the presentation	**Project:** Determine the purposes and uses of the portfolio Collect: Learn to save artifacts that represent particular goals, competencies, & achievements
Constructive Investigations: Student inquiry is an essential part of the learning process. Students observe, self-reflect, and reiterate as part of the process.	**Design/Plan:** Determine content, sequence for coherent presentation **Develop:** Gather and organize multimedia materials to include	**Select:** Review & evaluate the artifacts saved to determine which best demonstrate the narrative to be told through the portfolio **Reflect & Perfect:** Reflect on growth over time & gaps in development & self-assess goals
Student Autonomy: The process has no predetermined outcome. Students complete the process with the teacher's guidance, encouragement, and scaffolding.	**Implement:** Give the presentation	**Interject:** Add personal touches to the portfolio
Real Life: Students create solutions to problems and have a variety of different end products.	**Evaluate:** Determine the presentation's effectiveness in meeting the original goal with the intended audience	**Connect:** Conference with others on the impact of the portfolio **Respect:** Show pride in accomplishments

Note: Project-based learning criteria modified from "A review of research on project-based learning" by J. Thomas (2000), Autodesk Foundation; Multimedia development phases modified from "Multimedia projects in education: Designing, producing, and assessing" by K. S. Ivers & A. E. Barron (1998), Libraries Unlimited; Portfolio development phases modified from "The portfolio connection: Student work linked to standards" by S. Belgrad, K. Burke, & R. J. Fogarty (2008), Corwin Press.

Conclusions and Next Steps

Although PBL has gained a reputation as a means of developing students' skills for industry careers, it can also be used as a pedagogy of mastery. Embedding PBL into common intellectual experiences can support mastery over a breadth of foundational knowledge. Capstone courses that leverage PBL require students to develop mastery of a topic in depth, as well as industry-relevant professional skills. Using PBL to craft ePortfolios asks students to demonstrate mastery of reflection in addition to the breadth and depth displayed within the curated collection of learning outcomes and products.

There is still work to be done in assessing the elements of each of these high-impact practices that are most likely to support student growth. With wide variation in implementation and few empirical studies that look across individual institutional contexts, we do not yet know enough for evidence-based design of PBL to support mastery learning. To what extent does using PBL, compared to other pedagogical approaches, contribute to student success via these high-impact practices? Similarly, there is much to learn about who has access to high quality PBL teaching during common intellectual experiences, capstone courses and projects, and ePortfolios.

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Center for Project-Based Learning
100 Institute Road
Worcester, MA 01609
508-831-6836
wpi.edu/projectbasedlearning