Reinvent K-12 Education System: Prepare Underrepresented Students for STEM

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Abstract

Purdue Polytechnic High School (PPHS) is the first school initiated by Purdue University to achieve broader academic and workforce goals. The school's vision is twofold: reinvent or reimagine high school, and prepare students, especially underrepresented minorities for STEM fields. The school follows a competency-based model that provides students an environment to learn and explore their career passions through hands-on service projects. The school created a dynamic model for introducing projects that allow students to learn about different types of STEM-related fields, such as manufacturing, architecture, construction, engineering, science, technology, and more. The competency-based model provides an opportunity for educators to introduce projects to students at an early stage in their careers in an effort to help them develop a passion for a particular field. These projects can also help students make early choices and decisions about their future career aspirations. The research shows that the competency-based model supports students in learning and developing valuable skills such as collaboration, creative thinking and critical analysis, problem solving, teamwork, and networking. Students who earn a 3.4 GPA and a 1050 on the SAT or a 20 on the ACT are guaranteed direct admittance into the Purdue Polytechnic Institute at Purdue University.

Introduction

According to the Pew Research Center, Black and Latinx workers remain underrepresented in the STEM workforce [1]. To increase diversity in the STEM workforce, Purdue Polytechnic High School (PPHS), a charter school based in Indianapolis, IN, was established to achieve broader academic and workforce goals. The school uses a competency-based model to engage students in the classroom. PPHS fosters a sense of community for students by cultivating diversity in teachers, focusing on project-based learning, and providing students with a constructive and collaborative space to explore their passions. To support career readiness, the school personalizes student learning and focuses on enhancing student problem-solving skills through hands-on projects. Learning is integrated into projects to support students in acquiring skills and knowledge in math, science, technology, social sciences, etc.

Students' relationships with teachers are fundamental to their success in school [5], [6], [7]. A supportive and strong relationship with teachers allows students to feel more competent, make more positive connections with peers, and achieve greater academic gains [2]. Teachers' personal values drive their goals and behaviors at school [3]. Furthermore, motivation is important for teachers to persists and succeed in the profession [4], and teachers play a vital role in the success of a student's career. Several studies [5], [6], [7] report that teachers play integral and essential roles in enhancing students' learning through motivational support. This research evaluates the components of the school in an effort to understand student motivation towards learning in a project-driven learning environment. In the current study, students viewed their teachers as conversational, down-to-earth, relatable, and genuine. Teachers, who are referred to as coaches at the school, are motivated to teach students, and value the mission of the school to increase the diversity and career-readiness of underrepresented students in STEM fields.

The American Community Survey (ACS) defines the dropout rate as "the percentage of 16- to 24-year-olds who are not enrolled in school and have not earned a high school credential (either a diploma or an equivalency credential such as a GED certificate)" [8]. The National Center for Education Statistics (NCES) reports that there were 2.0 million status dropouts between the ages of 16 and 24 in 2019 [8]. If we break down the percentage of those who dropped out, Latinx (7.7 percent) and Black (5.6 percent) student rates are higher than the White (4.1 percent) student rate [8]. The competency-model provides students opportunities to personalize their learning environment, based on their learning preferences, as well as the time and effort needed to master the core content of the coursework.

During typical years (i.e., non-COVID years), students were required to take standardized tests for many college admissions in the United States. The two widely accepted standardized tests for undergraduate admission were the American College Testing (ACT) and the Scholastic Assessment Test (SAT), which measure students' critical reading, writing, and mathematical

abilities. Many colleges and universities required students to submit either SAT or ACT scores as a part of the undergraduate application process. In 2020, nearly 1.67 million students took the ACT, and 26% of students met all four ACT College Readiness Benchmarks: English, reading, math and science. Over half of historically underserved students (low-income, underrepresented minority, and/or first-generation college students) met none of the four benchmarks [9]. The U.S. Bureau of Labor Statistics projects that STEM jobs will grow 8% by 2029 [10]. In an effort to combat this challenge, Purdue University introduced a model to increase their STEM program pipeline, with a focus on historically underrepresented groups [11]. The PPHS school system meets the academic requirements of the state while providing a meaningful and fun learning experience for students. PPHS students who took the Indiana Statewide Testing of Education Progress Plus (ISTEP+) have scored at or above the state average for passing rates in English, math, and science [12].

Wagner [13] proposes the Seven Survival Skills for the 21st century: critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurialism; effective oral and written communication, accessing and analyzing information; and curiosity and imagination. Anna [14] discusses how to teach 21st-century skills to students in nine lessons: make them relevant, teach through the disciplines, develop thinking skills, encourage learning transfer, teach students how to learn, address misunderstandings directly, treat teamwork like an outcome, exploit technology to support learning, and foster creativity. To prepare students to survive in the 21st century, the school focuses on 20 core competencies, including critical thinking, language conventions, speaking and listening, growth mindset, responsibility, and self-regulation.

Competency-based Education Model

In the United States, the mastery-based learning model was proposed in the 1920s, developed by Ralph Tyler in the 1940s, and further developed by Benjamin Bloom [15], [16], and others [17], [18], [19] between 1960 and 1970. Proponents contended that the majority of students were able to master the skills; however, the time and method for each student to attain mastery varied.

The focus of the mastery-based learning model is to provide students with enough time and useful material to master the skill. The main challenge with the model was to determine how to assess a student's mastery of a skill. Bloom [15], [16] proposed an outcome-based learning model in which student mastery was measured using standard processes and timeframes established by the institution. Identifying student progress and outcomes for learning and teaching has long been a source of contention. Outcome-based education models emphasize student learning through actions that reflect competencies in the use of skills, content, ideas, information, and tools [18], [20]. This model differed from the traditional model in that it was more focused on students than on teaching methods and delivery systems. For example, in an

outcome-based model, teaching methods change dynamically in response to the student's skill and abilities rather than a fixed timeframe and schedule.

Competency-based Education (CBE) Model is the next step in this movement [18]. CBE is defined in a variety of ways by various researchers. Le Wolfe and Steinberg, for example, define CBE as "a growing field with no universal definition" [19]. Spady [21] defines CBE as "an adaptive and data-oriented education model having a collection of processes that measure the performance through set rules and learning outcomes within flexible time frame." The current research uses the definition from Gervais [22]: "CBE is defined as an extension of an outcome-based education model which is an amalgamation of instructional delivery method and assessment modules carefully designed to evaluate student learning through demonstration of skills, attitude, knowledge, and behaviors required for the degree".

Several studies [18], [19], [20], [21], [22] reported on how the CBE has been implemented globally, and specifically in the United States. For example, Kelchen [23] identified 34 colleges in the process of implementing CBE and 18 in the development phase. Inside Higher Education reported that 200 institutions were either planning or were in the process of implementing CBE [24]. In fact, in the United States, 600 postsecondary institutes are designing or implementing CBE programs.

Steele and colleagues [25] described the implementation of CBE in pilot programs within a school district in Colorado, four schools affiliated with Asia Society, a non-profit organization, and a school district in Pennsylvania. The number of students enrolled in the schools ranged from 2,000 to 10,000. They evaluated the model in these schools by interviewing leaders of the program and curricular developers, surveying students, and observing classrooms.

Each school site created unique content to implement a CBE model at the school site. For example, Steele and colleagues [27] developed four operational space wolf games focusing on difficult math concepts such as geometry and recorded flipped classroom lectures. They also developed outcome-based rubrics for grades 8 and 10 and established five Educurious units that took over the grade 9 curriculum in project mastery classes, in addition to developing digital film-making courses.

Steele and colleagues surveyed 1,500 students from all three regions to assess student performance. According to the findings, 80-90% of students believed that school teaches them a valuable skill. A majority of the students reported that they enjoyed their learning. Almost 80% of students across all sites had access to technology and materials. Over half of all students agreed that they were able to track their progress using learning management systems (LMS), given the opportunity to work at their own pace, able to get help when needed, and able to speak up and share their ideas.

Competency-based Model Components

The PPHS model is nontraditional and comprised of four components labeled as Personal Learning Communities (PLC), Personal Learning Time (PLT), Dojos, and Projects. The first component, the PLC, is the daily check-in for students with their coaches, where they are provided support with grades, scheduling school and extracurricular activities, and one-on-one coaching, if necessary. Coaches believe that students are to take an active role in their learning and coaches provide learning opportunities and support to learn the required material. The second component, the PLT, is the designated time for students to work independently on their core academic content. Students are given access to an online system to learn the contents of a course at their own pace, independently. The school system uses an online learning system called Edmentum [26] which delivers the academic content to students. For example, if a student is interested in learning Spanish language, a coach will release the course content to the student to learn the dialect of the Spanish language by accessing the online system. The student can then work independently to complete the course. This is an example of personalized learning that helps students to organize their time based on their personal learning habits and effort needed in a particular subject area. It may take a few days for a native Spanish speaker and a few weeks for a non-native speaker to complete the course and earn the required credits toward graduation, with the goal being that all students complete the course by the end of the term. With this system, the students are responsible for their own learning at their own pace, independently. The students may personalize the learning environment, according to their learning preferences and the time and effort needed to master the core content of a course.

Coaches monitor student progress through the PLC. If students need additional support to succeed in their coursework or in a project, the content area expert coaches will design and offer a Dojo session for students. Students are responsible for signing up for Dojo sessions to acquire the required knowledge and increase the likelihood of success in their coursework and in their projects. The third component is the Dojo sessions, which serve two purposes: 1) to provide additional support to students who are struggling with a specific topic, and 2) to help students develop specialized skills that increase the likelihood of their success when they participate in projects or participate in standardized tests, such as ISTEP+. An example of a Dojo session would be to provide additional support in preparing them for the SAT or ACT exam.

The fourth component of the model is the project, which is divided into two types of projects: the design challenge, and the passion project. The school has partnerships with local businesses. These partnerships create opportunities for students to visit industry partners' sites, and work with businesses to solve real-world challenges that are tied to competency skills. Students work with industry partners to pitch design challenge ideas. A few examples of these projects are:
1- How might we optimize a machine?
2- How might we revitalize urban neighborhoods in our community?

3- How might we create or enhance products or service to help community members lead healthier lives?
4- How might we create new and better food sources to feed nine billion people by 2050?
5- How might we extend the healthy human lifespan worldwide?

Design challenge projects provide students the opportunity to work in teams to solve real-world challenges, and at the conclusion of the projects, students present them to the industry partners and teachers. Design challenge projects are mainly for 9th and 10th grade students who partner with industry partners to pitch a new idea in every 6-week cycle. Students are required to complete two years of design challenge projects.

On the other hand, the passion projects are created and offered by coaches, and students in grades 9 to 12 work in small groups to learn and complete these projects. A few examples of passion projects are photography, music production, robotics, writing a story for a movie, managing money, and building a tiny house. Each project is aligned to achieve core competencies identified by colleges, employers, and the community. For example, when students work on a passion project to build a tiny house, they are expected to develop core competencies such as how to use appropriate tools strategically and learn the critical structural elements of a house.

The 20 core competencies that the school focuses on are to develop and use models, analyze and interpret data, make sense of problems and persevere in solving them, reason abstractly and quantitatively, use appropriate tools strategically, attend to precision, historical thinking, understand diverse perspectives, engage in personal or collaborative, action key ideas and textual support, analyze, integrate and evaluate sources, structural elements and organization, synthesis and connection of ideas, the iterative process, the research process, language conventions, speaking and listening, growth mindset, responsibility, and self-regulation.

PPHS Grading System

The school follows a non-traditional grading system, 50% of the students' grades come from Edmentum, an online learning system that students use to learn the course content, and the 50% of the remaining grades come from projects that students complete in a project cycle. For example, a student may enroll in a course labeled as Biology 1 and sign up for one project that directly correlates with biology. Fifty percent of the grade is based on completion of the course material that the student completes through Edmentum, and 50% of the grade will come from appropriate project completion. Each competency will have up to five pieces of evidence and average of all competencies will make up the competency grade. Competency grades can be improved by demonstrating new evidence. After five evidence, sixth evidence will replace the evidence with the lowest score. Students can monitor the progress of their enrolled courses in Edmentum, which allows them to check the "Current Grade", which is the snapshot of the

student's current progress, and "Course Grade", which is the students' progress towards completing the course. Competencies are tracked through Alma. Students and parents are notified whenever competency or Edmentum grades deviates from the threshold of 50%.

Competency-based Model Implementation

Students start their day with a PLC session (first component of the model); this is an opportunity for students to check-in with their coaches. They are provided support with grades, scheduling school and extracurricular activities, and one-on-one coaching, if necessary. The PLC coaches are the first point of contact for their parents. The first session lasts for approximately 45 minutes followed by another 45-minutes session where students work on an industry project (fourth component of the model).

The third session is the personal learning time, which lasts for one and a half hour. This implements the second component of the model allowing students to learn and adapt at their own pace. In the fourth session, students work on their passion project for one hour. This session is followed by a Dojo (third component of the model) session for one hour. Students continue working on the passion project after the Dojo session. A dojo session is an opportunity for students to ask questions related to the project or topics to complete the project. The day ends with a second PLC, which is the first component of the model.

Method and Results

Participants selected for this study were PPHS stakeholders, including 7 parents, 10 students, 10 teachers, 3 board of directors, 2 industry partners, and 1 school administrator. One-on-one interviews and focus groups were used for collecting data for this study. Focus groups were conducted with teachers, students, and parents, and one-on-one interviews were conducted with the rest of the stakeholders. The participants were interviewed to capture their perspectives on the least and most effective components of, and the best practices associated with, the model.

All recorded interviews were transcribed, and a thematic analysis was used to analyze the collected data. The research shows that the competency-based model supports students in learning and developing valuable skills such as collaboration, creative thinking, problem solving, teamwork, and networking. PPHS meets the standards set by the State of Indiana by allowing students to complete the curriculum through Edmentum and provide direct instructions through small groups and with hands-on projects. Indiana Statewide Testing for Educational Progress-Plus (ISTEP+) is an annual test designed by the Indiana Department of Education to measure the student's achievement in reading, writing, and mathematics. PPHS students have scored at or above the state average for passing rates in English, math, and on both tests [27].

Students reported the success and motivation factors associated with the school model, which are 1) school atmosphere that encourages them to manage schedule schoolwork and extracurricular activities on their own, 2) teachers who are referred to as coaches are helpful, conversational, down-to-earth, relatable, and genuine, 3) group projects, such as design challenges and passion projects where teachers serve as facilitators, focus on real-world issues, 4) students feel better prepared to solve challenging projects in the future, and 4) students enjoy the hands-on and interactive nature of the projects.

Barni [3] reports that "teachers' personal values drive their goals and behaviors at school". Teachers plan a vital role in the success of a student career. This research shows that teachers play a key role in creating an environment that can empower and motivate students to learn and thrive. This research indicates that teachers discuss the success and motivation factors associated with the school model are 1) the mission of the school which includes increasing diversity and career-readiness for underrepresented students, 2) strong bonding with students 3) teacher opinions are valued by the school administrators, and 4) project-based learning which helps teachers create an environment for students to learn and grow.

Parents reported the success and motivation factors associated with the school model are: 1) school provides opportunities for students to work on projects and build relationship with the community members, 2) students have the opportunity to interact with other students from different origins and ethnic groups, 3) students are guided to become independent thinkers 4) students are passionate about their projects and feel confident and successful in the school.

The board of directors reported that students will have necessary skills upon graduating from PPHS, which include but are not limited to presentation skills, confidence to engage in a new field of study, built-in curiosity, time management, maturity, collaboration, teamwork, and ability to create networks within the community.

Conclusion

The current study focused on the assessment and evaluation of a project-driven learning model at a STEM school in the midwestern United States. Researchers at Purdue University's Polytechnic Institute and the College of Education studied the components of the school to understand student motivation towards learning in a project-driven learning environment. Research reports the success and motivation factors, and best practices associated with the model. Teachers report that they have strong bonding with their students, their opinions are valued by the school administrators, and they love the concept of project-based learning. Parents chose this school because it provides opportunities for students to work on projects and build relationships with community members, and students can interact with other students from different origins and ethnic groups. Students reported that school atmosphere encourages them to manage their

schoolwork and extracurricular activities on their own, coaches are helpful, conversational, down-to-earth, relatable, and genuine, and they feel better prepared to solve challenging projects in the future.

The results indicate that the competency-based model supports students in learning and developing valuable skills such as collaboration, creative thinking, problem solving, teamwork, and networking. Furthermore, the school meets the academic requirements of the state and students scored at or above the state average for passing rates in English and math on the ISTEP+ [12].

References

[1] C. Funk and K. Parker, "Diversity in the STEM workforce varies widely across jobs*"*, *Pew Research Center's Social & Demographic Trends Project*, 2022. [online]. Available: https://www.pewresearch.org/social-trends/2018/01/09/diversity-in-the-stem-workforce-varies-widely-across-jobs [Accessed 9 February 2022].

[2] B. K. Hamre, and R. Pianta, "Student-Teacher Relationships", National Association of School Psychologists, In G. G. Bear & K. M. Minke (Eds.), Children's needs III: Development, prevention, and intervention (pp. 59–71), 2006. https://psycnet.apa.org/record/2006-03571-005 (accessed Feb. 10, 2022).

[3] D. Barni, F. Danioni, and P. Benevene, "Teachers' self-efficacy: The role of personal values and motivations for teaching," Frontiers, 01-Jan-1AD. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01645/full. [Accessed: 02-Feb-2022].

[4] A. Wigfield and J. S. Eccles, "Expectancy–Value Theory of Achievement Motivation," *Contemporary Educational Psychology*, vol. 25, no. 1, pp. 68–81, Jan. 2000, doi: 10.1006/ceps.1999.1015.

[5] J. Schuitema, T. Peetsma, and I. van der Veen, "Longitudinal relations between perceived autonomy and social support from teachers and students' self-regulated learning and achievement," *Learning and Individual Differences*, vol. 49, pp. 32–45, Jul. 2016, doi: 10.1016/j.lindif.2016.05.006.

[6] M. A. Theobald, *Increasing student motivation: strategies for middle and high school teachers*. Thousand Oaks, Calif: Corwin Press, 2006.

[7] E. E. J. Thoonen, P. J. C. Sleegers, T. T. D. Peetsma, and F. J. Oort, "Can teachers motivate students to learn?," *Educational Studies*, vol. 37, no. 3, pp. 345–360, Sep. 2010, doi: 10.1080/03055698.2010.507008.

[8] "Status Dropout Rates," American Community Survey (ACS), May 2021. Accessed: Feb. 10, 2022. [Online]. Available: https://nces.ed.gov/programs/coe/indicator/coj#fn1.

[9] "U.S. High School Graduates, Underserved Students Will Face Significant Challenges in College According to New ACT Achievement Data," *ACT Newsroom & Blog*, Oct. 14, 2020. https://leadershipblog.act.org/2020/10/act-grad-class-2020-achievement-data.html (accessed Feb. 10, 2022).

[10] "Employment in STEM occupations: U.S. Bureau of Labor Statistics," *U.S. Bureau of Labor Statistics*, Sep. 08, 2021. https://www.bls.gov/emp/tables/stem-employment.htm (accessed Feb. 10, 2022).

[11] S. Associates, "Design Crossover: Filling the Higher Ed STEM Pipeline Starting in K-12," *Schmidt Associates*, Dec. 14, 2020. https://schmidt-arch.com/design-crossover-filling-higher-ed-stem-pipeline-starting-k-12/ (accessed Feb. 10, 2022).
015.

[12] "Purdue Polytechnic High School Ind (4271) | Indiana," inview.doe.in.gov, 2019. https://inview.doe.in.gov/schools/1090154271/proficiency?lang=en#chart-grid (accessed Feb. 10, 2022).

[13] T. Wagner, "The global achievement gap: why even our best schools don't teach the new survival skills our children need--and what we can do about it". New York: Basic Books, 2008, pp. 19–100.

[14] A. R. Saavedra and V. D. Opfer, "Learning 21st-Century Skills Requires 21st-Century Teaching," Phi Delta Kappan, vol. 94, no. 2, pp. 8–13, Oct. 2012, doi: 10.1177/003172171209400203.

[15] R. J. Marzano and J. S. Kendall, "The new taxonomy of educational objectives". Corwin Press, 2006.

[16] B. S. Bloom, "Learning for Mastery. Instruction and Curriculum. Regional Education Laboratory for the Carolinas and Virginia, Topical Papers and Reprints, Number 1," Evaluation Comment, vol. 1, no. 2, 1968, [Online]. Available: https://eric.ed.gov/?id=ED053419

[17] K. Ford, "Competency-based education: History, opportunities, and challenges," UMUC Center for Innovation in Learning and Student Success, vol. 10, p. 24, 2014.

[18] S. P. T. Malan, "The'new paradigm'of outcomes-based education in perspective," Journal of Family Ecology and Consumer Sciences= Tydskrif vir Gesinsekologie en Verbruikerswetenskappe, vol. 28, no. 1, pp. 22–28, 2000.

[19] C. Le, R. E. Wolfe, and A. Steinberg, "The past and the promise: Today's competency education movement". Jobs for the Future, 2014.

[20] W. G. Spady, Outcome-Based Education: Critical Issues and Answers. ERIC, 1994.

[21] W. G. Spady, "Competency based education: A bandwagon in search of a definition," Educational researcher, vol. 6, no. 1, pp. 9–14, 1977.

[22] J. Gervais, "The operational definition of competency-based education," The Journal of Competency-Based Education, vol. 1, no. 2, pp. 98–106, 2016.

[23] R. Kelchen, "The landscape of competency-based education: Enrollments, demographics, and affordability," American Enterprise Institute, 2

[24] T. Nodine and S. M. Johnstone, "Competency-based education: Leadership challenges," Change: The Magazine of Higher Learning, vol. 47, no. 4, pp. 61–66, 2015.

[25] J. L. Steele et al., "Competency-Based Education in Three Pilot Programs: Examining Implementation and Outcomes". ERIC, 2014.

[26] "Make Personalized Learning an Achievable Reality in Every Classroom," edmentum. https://www.edmentum.com/ (accessed Feb. 10, 2022).

[27] A. Sorrells, "How one school is building a STEM pipeline for minority students with a direct pathway to college," EducationNC, Sep. 18, 2019. https://www.ednc.org/how-one-school-is-building-a-stem-pipeline-for-minority-students-with-a-direct-pathway-to-college/ (accessed Feb. 10, 2022).2