# Developing an Understanding of the Implementation and Impacts of High School pre-Engineering Programs: Making the Case for a Benefit-Cost Analysis

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***Abstract*— With the ongoing demand for improved K-12 STEM education, a push for dual-credit courses, and the goal of college and career-ready high school graduates, schools have implemented numerous STEM programs including those focused on engineering. Curricular programs, such Engineering by Design, Project Lead the Way (PLTW), and EPICS High are being executed by schools across the country with varied amounts of success as measured by student-level outcomes. Exploring costs of these program implementations and their associated outcomes is vital in deciding the best means for preparing our future engineering workforce. This paper utilizes cost analysis to provide initial insights into the relative impact of one of the most common high school engineering program, PLTW. Specifically, by relying on data reported in select literature, we investigate the impacts versus the costs of implementing PLTW in high schools. Cost data includes select variables such as student section size, school size, and school type. These findings will provide a baseline for understanding cost variations of the PLTW curriculum across contexts, as well as what impact cost variations may have on student outcomes.**

***Keywords—cost analysis, pre-engineering education, STEM Education, Project Lead the Way***

## I. Introduction

Throughout the United States, science, technology, engineering, and mathematics (STEM) occupations are frequently difficult to fill. These challenges are often described as a risk to the nation's global competitiveness [1, 2]. Rothwell found that the median duration of STEM vacancy postings was more than twice that of non-STEM vacancies [3]. From positions that require associate degrees to those requiring PhDs, companies continue to face challenges in finding personnel with the adequate STEM literacy or competency to meet their workforce needs. Despite the ongoing national initiatives which highlight the importance of STEM and STEM careers to the economy (which lead directly to large sums of money spent towards new K-12 programs and curricula in STEM education [4]), U.S. students continue to perform at rates comparable to or beneath those of their international peers [5-7]. Theoretically, this (under) performance has a causal connection with the U.S. STEM workforce vacancies. The pressing question then is, "What can educators, administrators, industry, and policy makers do to encourage more students to pursue majors in STEM disciplines and careers in the STEM workforce?" Identifying responses to this question have been at the forefront of STEM educational research, educational policy implementation research, and the nation's educational agenda [1].

Despite the ongoing challenge of promoting K-12 students' STEM interests, research on educational policy implementation has found many education programs have been successful, particularly when implemented with fidelity. Hence, given the successes of select policy implementations, we theorize that the problem may be partly attributed to the variability in how the same program is implemented across contexts or locations. Subtle variations in the implementation, as well as nuances inherent to the contexts of implementation, can largely moderate the resulting outcomes of any program. In the following sections, we (i) provide a brief history of U.S. national expenditures in STEM education, (ii) describe the current state of pre-college engineering across the U.S., and (iii) describe the motivation of this study's focus on Project Lead the Way, one of the most common U.S. high school pre-college engineering curriculum.

### *A. Overview of U.S. Pre-College Engineering Programs*

In recent years, numerous programs have been developed to address STEM skills through engineering integration within or alongside other STEM content domains. In 2009, schools across the U.S. had integrated more than 20 programs to promote students' STEM attitudes, interests, or skills through something akin to engineering integration [8]. Today, there are several curricula available for use in K-12 schools including Engineering is Elementary (EiE), Project Lead the Way (PLTW), Engineering by Design (EbD), and Design Quest. Of these programs taught at the high school level, PLTW is one of the most widely used curricula. As of the start of the 2016-2017 academic year, PLTW was offered in over 6500 schools across the nation [9].

Perhaps due to the novelty of these programs, comparative analyses on the relative impacts of programs do not exist. Given a lack of studies comparing programmatic outcomes, it is challenging to indicate which program is "best" with respect to which ends. Add to this the variability of evaluation techniques used by researchers across studies within a single program, a cross-comparison of programs (e.g., comparing EDD with PLTW) through a synthesis of scholarly literature would require an unreliable amount of inference.

For example, in a review of the PLTW literature, Hess, Sorge, and Feldhaus [10] found a great deal of variation across the research techniques, lenses, contexts, and participants involved as scholars explored the efficacy of PLTW. In an attempt to synthesize this disparate literature, they identified a few apparent strengths and weaknesses of PLTW. Strengths included PLTW's influence in facilitating student STEM interest and motivation to pursue STEM degrees. Weaknesses included minimal or conflicting evidence related to improving students' mathematics or science skills. Additionally, some schools faced issues around implementing PLTW due to costs and space. While these studies elucidated some positive and negative aspects of PLTW implementation, these articles alone are insufficient for identifying which pre-college curriculum is best, their relative costs, and the relationship between costs and benefits.

### *B. Study Motivation*

Hess, Sorge, and Feldhaus' findings encouraged us to consider the variability across PLTW implementation within the context of costs versus benefits. Specifically, we questioned what factors of PLTW implementation contributed to which outcomes. Further, we hoped that this analysis would serve as a baseline for comparing PLTW with other pre-college engineering programs in the future.

This study was further motivated by the large expenditures put toward STEM programs, the identified weakness regarding the cost of PLTW implementation, and the fact that nearly all of the literature synthesized by Hess, Sorge, and Feldhaus focused on PLTW's effectiveness in obtaining some goal (e.g., improving test scores, motivating STEM interest) but neglected to mention costs for achieving those foals. We aspire to utilize cost-benefit effectiveness to explore PLTW programs within Indiana. Cost-benefit analysis identifies both the ability of a program to achieve the espoused goals along with the relative costs associated with reaching various levels of achievement. More specifically, cost-benefit analysis evaluates alternatives based upon their costs and effects in relationship to some produced outcome [11].

For example, increasing the number of students who major in a STEM field might be of importance, or enhancing student performance on a standardized test, or increasing the number of students completing a STEM degree. Each of these separate outcomes has an associated costs for achieving it based upon the intervention selected, how the intervention is implemented, and the total dollar expenditures. Notably, several studies have found a variation in outcomes across PLTW implementation. For example, note the conflicting evidence regarding math and science gains in PLTW delivery [12, 13]. As outcomes vary, costs vary as well. This study serves as an initial attempt to synthesize the variation in select costs based simply on student enrollment.

## II. METHODS

### *A. Cost Analysis*

There are four primary approaches of cost analysis: cost-effectiveness, cost-benefit, cost-utility, and cost-feasibility. Cost-effectiveness analysis analyzes alternative approaches based upon their costs and their effects in relationship to the desired outcome. When conducting a cost effectiveness analysis, programs being compared should have very similar or identical goals and a common effectiveness standard should be used for the comparison [14]. A cost-benefit analysis also analyzes alternative options, but comparisons are done based upon costs and benefits measured monetarily. Because cost-benefit analysis uses monetary values, it allows the evaluator to determine if the value of benefits exceed the costs, including what option has the highest ratio of return at varying levels (education, health, governmental, etc.). One issue that can arise with a cost-benefit analysis is assigning accurate monetary values to some benefits [15]. Cost-utility analysis is similar to cost-effectiveness except instead of effectiveness it analyzes economic utility, or the satisfaction of individuals with the associated outcomes. Finally, a cost-feasibility analysis looks solely at the costs to determine if it is feasible to implement a program [11].

For the purpose of this cost-analysis we used the ingredients method [11]. The primary concept is that behind every intervention there is a list of ingredients, each with its own respective value or cost. By identifying all of these ingredients and placing a cost on them, the total cost and per unit cost can be deduced. Additionally, by utilizing the ingredients method, one can distribute costs among the various agencies that may be sponsoring an intervention.

The ingredients method has five main categories: 1) personnel, 2) facilities, 3) equipment and materials, 4) other program inputs, and 5) required client inputs. Personnel includes not only full-time employees (in this case the teachers) but also part-time, partial-time, volunteers, and consultants who may be involved in the intervention. Costs for personnel are based upon the role that they serve and the amount of time spent in delivering the intervention. Facilities are the physical space required for the intervention to take place. Equipment and materials include the instructional equipment, materials, and furnishings used for the intervention. When conducting a comprehensive cost-analysis, facilities, equipment, and materials should be included even if direct payments are not made by the organization or individuals who deliver the intervention. Other inputs include items which do not directly fit in the first three categories (e.g., additional insurance, lawyer fees). The final category, required client inputs, are the added costs incurred by participants, such as the costs to parents transporting their students to a program [11].

Within the realm of pre-engineering programs there have been few cost-analyses. Extensive searches have only produced one cost-analysis. This analysis, conducted by the Washington State Institute for Public Policy (WSIPP) [16], was recently updated in 2016. Their costing assumed that a school offers four sections of PLTW per year with no more than 20 students per class. They also estimated that students would participate, on average, for two years. Their findings were that the costs per student were $887 per year. Using findings from four research publications on PLTW, they estimated the benefits to the individual and society to be $12,970.

Within the educational research community, cost analysis has been used in two categories. The first involves attributing a direct cost to a program. This is most commonly done when the study has been initiated by the implementing institution. The second, which is done here, is a conceptual analysis. This analysis is not done to directly impact a decision but instead is meant to influence the thinking of key stakeholders [11].

### *B. Study Context*

To understand the potential variation in PLTW costs, a cost-analysis was run on several simulated PLTW curricular implementations. Introduction to Engineering Design (IED), an introductory course within the PLTW high-school curriculum, was selected as the unit of analysis for this study. IED is generally the first course taken by in the high school series of pre-engineering courses and is thus more likely to have more students enrolled than other PLTW courses. It is also offered more widely than other PLTW courses (e.g., Digital Electronics) or specialized content areas (e.g., Biomedical Engineering). In essence, while IED represents but one piece of the PLTW curriculum, it represents a piece that may have the broadest impact.

This cost analysis provides an overview of the potential cost differences in the implementation of IED based upon the number of students enrolled in the course. For the purpose of this cost-analysis we focused only on costs related to personnel, equipment, and materials. This was because this was not meant to be all-inclusive but to demonstrate to what extent there may be variations in per-student costs in relation to programmatic costs. This analysis involved a series of non-linear steps, each of which included notable assumptions and potential limitations.

### *C. Assumptions and Limitations*

This study’s steps and assumptions included:

1. The simulation included equipment costs as specified on the PLTW website for the course, the prorated cost of teacher’s Professional Development, and the teacher’s salary. This ignores numerous costs such as space and extraneous materials. We feel that this assumption is justified as these costs are highly variable across PLTW implementation. For example, many schools may already have the needed computer hardware whereas for others it is an added cost. We assumed that each classroom was equipped with or had access to the required number of computers, but notably, in many instances this may not be the case.
2. We modeled per-teacher PLTW sections from one to five. While there are schools where teachers may teach six sections, this tends to be uncommon and therefore we did not exceed a teacher teaching five sections of IED.
3. The number of teachers’ students across sections can vary dramatically. For the sake of the analysis, it was assumed that course sections were relatively equal. While this is not always the case, schools often use automated scheduling systems in order to balance section size.
4. The smallest IED teaching load used for this analysis was 12 students per section. Incremental class sizes and section numbers were changed to provide a broadened view of potential costs.

### *D. Data Variables*

Once the number of students and sections were determined, standardized costs were calculated [11] and then input into a spreadsheet to calculate all costs. Table 1 contains data as it relates to these calculations.

1. **Equipment/Supplies Cost per Student:** The first costs calculated were equipment supplies, and. This was done using the PLTW website that provides standardize costs for equipment and supplies based upon the total number of students and the largest section size [17]. In total, 32 different configurations of students were used in calculating equipment and supply costs.
2. **Teacher Professional Development (PD) Costs per Student:** We calculated PD costs by using the same PLTW website [17]. These costs were prorated over 5 years. To do this, it was assumed that the value of the professional development will be the same during each of the 5 years. While an argument can be made against this, for the basis of a one-year analysis of costs keeping these costs consistent made sense. Additionally, the length of 5 years was selected based upon the changes made to the PLTW curriculum over time and the need to acquire additional training. Each year schools pay an annual fee to PLTW for the course, this fee is $3000 and the cost was distributed over all the students. Next teacher salary was calculated.
3. **Teacher Salary:** Teacher salary was calculated based upon data from the Bureau of Labor Statistics [18]. The salary used was the May 2016 national estimates for a secondary school career and technical education teacher. The national average was used to align with the PLTW estimation based upon national average costs. Teacher salary was then broken down under the assumption that teachers taught six total sections per day and each section was 1/6 of their total salary and benefits. This was then multiplied by the total number of sections and divided by the total number of students to get the per student teacher salary costs.
4. **Annual Fee per Student:** Annual fee per student is calculated by the overall school fee for the course divided by the number of students.
5. **Total Cost per Student:** Each per student cost was summed to provide an estimated total student cost. Table 1 provides an overview of these results

TABLE I. ESTIMATED COST PER STUDENT

| Students, Sections, Largest Section | Equip/ Supplies Cost per Student | Teacher PD per Student (USD) | Annual Fee per Student (USD) | Teacher Salary per Student (USD) | Total Cost per Student (USD) |
|---|---|---|---|---|---|
| 12, 1, 12 | 183.20 | 40.00 | 250.00 | 826.11 | 1,299.31 |
| 14, 1, 14 | 166.10 | 34.29 | 214.29 | 708.10 | 1,122.77 |
| 20, 1, 20 | 132.00 | 24.00 | 150.00 | 495.67 | 801.67 |
| 22, 1, 22 | 155.20 | 21.82 | 136.36 | 450.61 | 763.99 |
| 28, 1, 28 | 134.91 | 17.14 | 107.14 | 354.05 | 613.24 |
| 30, 1, 30 | 129.81 | 16.00 | 100.00 | 330.44 | 576.26 |
| 30, 2, 15 | 89.61 | 16.00 | 100.00 | 660.89 | 866.50 |
| 32, 1, 32 | 133.65 | 15.00 | 93.75 | 309.79 | 552.19 |
| 32, 2, 16 | 87.52 | 15.00 | 93.75 | 619.58 | 815.86 |
| 40, 2, 20 | 76.25 | 12.00 | 75.00 | 495.67 | 658.92 |
| 42, 2, 21 | 90.57 | 11.43 | 71.43 | 472.06 | 645.49 |
| 50, 2, 25 | 81.38 | 9.60 | 60.00 | 396.53 | 547.51 |
| 50, 2, 26 | 82.14 | 9.60 | 60.00 | 396.53 | 548.27 |
| 50, 2, 27 | 83.19 | 9.60 | 60.00 | 396.53 | 549.32 |
| 50, 3, 17 | 63.26 | 9.60 | 60.00 | 594.80 | 727.66 |
| 60, 2, 30 | 73.80 | 8.00 | 50.00 | 330.44 | 462.25 |
| 60, 3, 20 | 57.03 | 8.00 | 50.00 | 495.67 | 610.69 |
| 60, 4, 15 | 53.70 | 8.00 | 50.00 | 660.89 | 772.59 |
| 80, 3, 27 | 59.11 | 6.00 | 37.50 | 371.75 | 474.36 |
| 80, 4, 20 | 47.89 | 6.00 | 37.50 | 495.67 | 587.06 |
| 90, 3, 30 | 56.07 | 5.33 | 33.33 | 330.44 | 425.18 |
| 90, 4, 23 | 52.77 | 5.33 | 33.33 | 440.59 | 532.03 |
| 100, 4, 25 | 50.13 | 4.80 | 30.00 | 396.53 | 481.46 |
| 100, 4, 26 | 50.51 | 4.80 | 30.00 | 396.53 | 481.84 |
| 100, 4, 27 | 51.03 | 4.80 | 30.00 | 396.53 | 482.37 |
| 110, 4, 28 | 49.69 | 4.36 | 27.27 | 360.48 | 441.81 |
| 110, 5, 22 | 47.29 | 4.36 | 27.27 | 450.61 | 529.53 |
| 110, 5, 23 | 47.77 | 4.36 | 27.27 | 450.61 | 530.01 |
| 110, 5, 24 | 47.98 | 4.36 | 27.27 | 450.61 | 530.22 |
| 120, 4, 30 | 47.22 | 4.00 | 25.00 | 330.44 | 406.67 |
| 120, 5, 24 | 44.94 | 4.00 | 25.00 | 413.06 | 487.00 |
| 120, 5, 25 | 45.56 | 4.00 | 25.00 | 413.06 | 487.62 |

## III. RESULTS

By relying on the data shown in Table 1, these findings indicate that total student costs for the IED course can vary from a high of approximately $1,300 for one section of 12 students to a low of roughly $400 for 120 students taught in four equal sections of 30. Most often, teacher costs accounted for the largest contribution towards total per student cost. However, in some classroom configurations, equipment and supply costs had a greater impact. For example, a single section of 28 students showed a greater per student cost (~$135) for Equipment and Supplies than a single section of 20 (~$132). The per student cost of equipment and supplies was $40 less for a single section of thirty students when divided into two sections of 15 (~$90) than just one class of thirty (~$130). However, the teacher salary per student was twice as much for the two 15 student sections ($~660) than the single section with 30 students ($~330.44).

## IV. DISCUSSION

As one might surmise, there are different per student costs for implementing the same course depending upon the number of sections, number of students in a section, and the total number of students. Many variables impact the total per student cost and not all were included in this basic cost analysis. However, these costs likely represent a significant proportion of the overall incremental costs. While noting this caveat, the least expensive implementation is 4 sections of 30 students, which is approximately 1/3 the per student cost of the most expensive implementation of 12 students in 1 section.

These data do not identify the outcomes associated with the varied context of IED implementation. While there are other more comprehensive methods for cost analysis, it is important that these models take into account the varying implementations and their associated student outcomes. For schools looking to implement a STEM-focused program, identifying the associated costs and their associated benefits is essential. For example, a small rural school might have assessed implementing PLTW in their school and chose not to do so because their annual per-student cost would exceed $1300. A more thorough cost-effectiveness or cost-benefit analyses of multiple STEM programs would also provide schools with the opportunity to select a program which was affordable for their implementation type and grounded on the expected benefits based upon their program implementation.

The next step in this research will include an extensive cost analysis of the entire PLTW program and a broader array of implementations. This analysis will examine costs versus benefits given the varying implementation options. Outcome data in Indiana are available but the associated costs by school still need to be collected. However, further studies beyond PLTW should also be conducted on other pre-engineering programs, specifically examining their per-student costs and benefits/effectiveness. The findings from these studies can provide useful information as funders and schools seek to maximize the use of their limited resources. Additionally, these data can be valuable to university faculty working with school systems on pre-STEM programs. Helping administrators and teachers navigate the programs best suited to support their student learning will directly influence if and to what extent their students become interested in pursuing STEM-related academic pathways and careers.

While this study is simplistic in methods and scope, it provides evidence for the high variability associated with the costs of implementing the same program as well as how these factors might influence a wide array of outcomes across contexts. Despite this, the integration of costs and benefits/outcomes tend to be neglected in research on PLTW. In virtually every study explored by Hess, Sorge, and Feldhaus [10], the impact of cost factors was never modelled in any direct way. While some authors noted the challenges of PLTW implementation due to high costs [19], our future work aspires to ascertain the extent to which programs, costs, and fidelity of implementation are associated with the outcomes cultivated by PLTW and other pre-engineering curricula.

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