

## **The Efficacy of Project Lead the Way: A Systematic Literature Review**

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# **The Efficacy of Project Lead the Way: A Systematic Literature Review**

## **Abstract**

Project Lead the Way (PLTW) is a non-profit organization offering project-based STEM education curricula for K-12 students. As of 2015, PLTW was by far the largest pre-engineering program implemented throughout the United States with a presence in over 6500 schools. Since its conception in 1997, PLTW rapidly expanded and today covers all 50 states and the District of Columbia. The PLTW Engineering curriculum offers a sequence of courses that students may take over the course of high school, and many university programs allow students who complete this sequence the opportunity to earn college credit. The PLTW Gateway curriculum targets students in Grades 6-8 and the PLTW Launch curriculum targets K-5 students. See the PLTW website for current program titles. They now simply use PLTW Engineering, PLTW Gateway, and PLTW Launch.

This study investigates the efficacy of PLTW efforts through a systematic literature review process. Specifically, we explored the following research questions:

- To what extent has PLTW been an area of scholarly investigation and what has been the nature of these investigations?
- What primary strengths and weaknesses of PLTW does this literature identify?
- What gaps in PLTW literature exist and what future research is needed?

After an initial data collection and literature reduction processes, we synthesized 31 articles that collected and analyzed empirical data related to PLTW. Our gathered literature included 16 journal articles, 11 dissertations, and 4 theses. Using an emergent coding process, we found that primary strengths of PLTW curricula include facilitating student interest in STEM (namely, engineering), motivating students to pursue STEM degrees, and providing teachers with effective professional development opportunities and support. However, weaknesses of PLTW include minimal evidence supporting PLTW participation as improving students' mathematics and science abilities, scheduling and space issues, and moderate financial costs for schools to participate in PLTW. Altogether, the literature collected varied widely and, as a result, each of these strengths and weaknesses requires further investigation. This study concludes with an identification of gaps in PLTW literature that scholars might utilize to focus future PLTW-related investigations, which will in turn improve future PLTW and PLTW-related interventions.

## 1. Introduction

There is a growing consensus across the United States that we need more science, technology, engineering, and mathematics (STEM) degree recipients, particularly if the U.S. aspires to remain economically competitive in the global marketplace.<sup>1-3</sup> Part of the difficulty in motivating large quantities of U.S. students to pursue STEM degrees likely corresponds with the decreasing performance of U.S. students in mathematics and science on standardized tests<sup>4</sup> and their below average performance on some standardized tests when compared internationally,<sup>5,6</sup> although recent TIMSS results are less dismal.<sup>7,8</sup> Nonetheless, as a result of a decline in the percentage of U.S. students pursuing STEM degrees, improving STEM education throughout K-12 has become a national focus.<sup>1</sup> In theory, integrating pre-college engineering and technology curriculum throughout STEM ought to motivate students to engage with STEM and, in turn, this enhanced interest ought to improve their math and science abilities.<sup>9</sup>

Project Lead the Way (PLTW) is a non-profit organization that has developed a project-based pre-college engineering and technology curriculum for K-12 students. As of 2015, PLTW was by far the largest pre-engineering curriculum throughout the United States with a presence in over 6500 schools nationally.<sup>10</sup> Since its conception in 1997, PLTW rapidly expanded and grew, to the point where it now covers all states and the District of Columbia. One of the core claims from PLTW is that by including real-world STEM problems into the pre-college curriculum, these disciplinary topics will become interesting to students. As they wrote in a recent brochure:

PLTW Engineering™ is more than just another high school engineering program. It is about applying science, technology, engineering, and math through a project-based, hands-on approach to solve complex, open-ended problems in a real-world context. Students focus on the process of defining and solving a problem, not on getting the “right” answer. They learn how to apply STEM knowledge, skills, and habits of mind to make the world a better place through innovation.

PLTW students say that PLTW Engineering influenced their post-secondary decisions and helped shape their future. PLTW students are shown to study engineering and other STEM disciplines at a rate significantly higher than their non-PLTW peers. Even for students who do not plan to pursue engineering after high school, the PLTW Engineering program provides opportunities to develop highly transferable skills in critical thinking, collaboration, and problem solving, which are relevant for any coursework or career.<sup>11</sup>

PLTW’s “Pathway to Engineering” curriculum offers a sequence of courses that students may take over the course of high school, and many university programs allow students who complete this curriculum the opportunity to earn college credit. PLTW also offers tracks for students to specialize in Biomedical Science or Computer Science. Prior to high school, PLTW also offers a “Gateway” curriculum targeted at middle school students and a “Launch” curriculum targeted at elementary students.

While PLTW is but one of many pre-college engineering programs,<sup>12,13</sup> it is the largest throughout the United States.<sup>14</sup> As a result, the impact and effectiveness of PLTW efforts ought to be grounded in scholarly research, particularly if PLTW is nationally adopted as the “model” for improving K-12 students’ mathematics and science abilities throughout the United States.<sup>1</sup>

## 2. Research Purpose

The purpose of this study was to investigate the current status of scholarly literature on Project Lead the Way (PLTW) through a systematic literature review and to use this collected literature to determine the effectiveness of PLTW (howsoever explored in the gathered literature). We did not limit our search to specific components of PLTW (e.g., Pathway to Engineering, Gateway). After collecting scholarly literature pertaining to PLTW, including peer-reviewed journal articles, dissertations, and theses, we analyzed this literature to identify where PLTW has proved to be the most and least effective, and where gaps in PLTW literature might exist. While PLTW's claims regarding the impact of PLTW curriculum<sup>11</sup> on students are encouraging and extremely important for a "Nation at Risk", we explore to what extent scholarly findings support PLTW's assertions. As such, the guiding research questions for this study included:

- To what extent has PLTW been an area of scholarly investigation and what has been the nature of these investigations?
- What primary strengths and weaknesses of PLTW does this literature identify?
- What gaps in PLTW literature exist and what future research is needed?

## 3. Data Collection

To begin this study, we collected literature available within several academic databases, including Academic Search Premier, Compendex, Inspec, OmniFile, and ProQuest Dissertations and Theses. We conducted this search during September and October of 2015. We only retained peer-reviewed journal articles, dissertations, and theses which used "Project Lead the Way" in the Abstract or Title. Table 1 provides an overview of our literature retention process. In sum, we initially retained 36 articles, including 19 journals, 13 dissertations, and 4 theses.

**Table 1:** Initial Literature Search and Retention Process Overview

| Database                | Hits | Retained | Number of and Reason for Omission of Articles   |
|-------------------------|------|----------|---|
| Academic Search Premier | 15   | 10       | -5 articles that were one- or two-page reports  |
| OmniFile                | 15   | 7        | -6 articles that were duplicates from Academic Search Premier<br>-2 articles that were short reports  |
| Engineering Village     | 19   | 2        | -3 articles that were internal duplicates<br>-6 articles that were duplicates from previous searches<br>-8 articles that were short reports |
| ProQuest Dissertations  | 19   | 17       | -2 articles, as the results were published in journals already collected from the above databases   |

Next, we removed articles using the criterion shown in Table 2. Through this process, we removed five articles, decreasing the total articles that we retained to 31. These removed articles included an overview of how the University of Louisville was building a "STEM pipeline",<sup>15</sup> an overview of the supply and demand of K-12 technology education instructors throughout the U.S.,<sup>14</sup> and an overview of how universities can partner with high schools to deliver pre-

engineering curricular programs such as PLTW.<sup>16</sup> The fourth article we removed referenced PLTW in the abstract but did not include PLTW students in their investigation.<sup>17</sup> The last article identified relevant constructs for assessing the impact of PLTW on students' design processes but did not utilize these to evaluate PLTW.<sup>18</sup>

**Table 2:** Criteria for Retaining Literature for Data Analysis

| <b>Criteria</b>   | <b>Operationalization</b>                                     |
|-------------------|---|
| Publication Focus | Project Lead the Way was one of the primary foci of the paper |
| Data Collection   | There was some form of empirical data collected in the study  |
| Data Analysis     | The authors explicitly stated how they analyzed their dataset |
| Applicability     | Results provided insights to improve Project Lead the Way     |

In each of the 31 articles we retained, PLTW was not necessarily the focus of the paper, but was a core focus. For example, in a few articles, PLTW students acted as a comparison or control group.<sup>19-21</sup> Likewise, some manuscripts (primarily the dissertations) focused on several pre-engineering curricula.<sup>18,22</sup> Nonetheless, each of the articles that we retained included specific research, data collection, and data analysis approaches, along with results and suggestions for improving PLTW.

#### 4. Data Analysis

To begin the coding process, we cursorily read each of the 31 scholarly papers we had retained (note that this search did not include conference papers). Throughout this process, we developed an emergent coding process by creating higher-level categories with underlying codes. In the database we compiled, we continually commented on a study's methods, findings, and limitations. At the end of this process, we developed 10 categories with a few sub-categories that we felt could be meaningfully compared across the wide span of PLTW literature we had collected. Table 3 provides an overview of our final coding framework used to guide the analyses throughout this paper.

**Table 3:** Overview of the Coding Framework

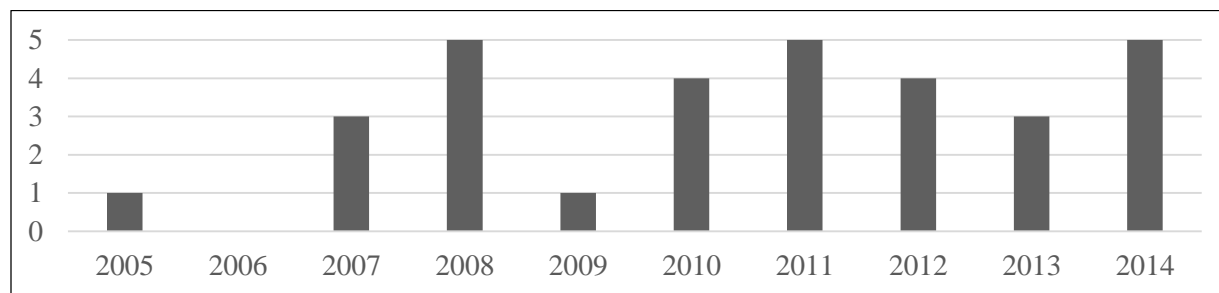
| <b>Categories</b>   | <b>Description/Coding</b>  |
|---------------------|--|
| Publication Type    | Journal, Dissertation, or Thesis                                       |
| Year                | Year of publication (as opposed to the year of data collection)        |
| State(s)            | State(s) where data was collected from                                 |
| Participants        | Participants involved in the study                                     |
| Research Focus      | Focus of the research study (e.g., abilities, motivations)             |
| Focus (narrowed)    | A finer categorization than above (e.g., <i>students'</i> abilities)   |
| Research Methods    | The type of research conducted (e.g., Quantitative, Qualitative, Both) |
| Sample Size         | Total sample size of PLTW-affiliated participants                      |
| Internal Comparison | Whether the study compared PLTW internally (e.g., by demographics)     |
| If so, what?        | What were the comparative variables used (e.g., gender, age)?          |
| External Comparison | Whether the study compared PLTW to non-PLTW participants               |
| If so, what?        | What were the comparative variables used (e.g., math ability)?         |
| PLTW Support        | Whether the results supported Project Lead the Way Curriculum          |

## 5. Results

In total, we collected, retained, and analyzed 31 articles pertaining to PLTW. Appendix A shows an overview of these articles. In this section, we explore (a) the year of publication, (b) the states included, (c) the participants investigated, (d) the research foci, (e) the research methods utilized, and (f) the sample sizes within and across the studies. Next, this section explores each article as grouped according to three variations: (a) studies that included an internal or “within-PLTW” comparison by specific factors or variables, (b) studies that included an external or “outside-PLTW” comparison with non-PLTW-affiliated participants, and (c) studies that did not involve any explicit form of comparison. A few studies included both an internal and external comparison; therefore, we included these studies’ findings within each of the aligned sections.

### 5.1 By Year

All of the articles we collected and retained for analysis were published in 2005 or later. As Figure 1 shows, the first article was published in 2005 whereas more than two out of three articles were published in 2010 or later.



**Figure 1:** Frequency Count of Articles by Year

### 5.2 By State

By far, the state most commonly represented throughout the collected literature was Indiana ( $n = 9$ ). This is likely because Indiana is one of the largest PLTW providers<sup>23</sup> and Indiana has been the home of PLTW headquarters since 2011. Two studies explored PLTW-affiliated participants within Iowa<sup>24,25</sup> and North Carolina<sup>20,26</sup>, and other states included within these 31 articles included Connecticut,<sup>27</sup> Minnesota,<sup>28</sup> Missouri,<sup>29</sup> South Carolina,<sup>30</sup> Tennessee,<sup>19</sup> and Utah.<sup>31</sup> Many authors identified their participants by region, whereas in several more articles the participants’ location was not identified whatsoever. In other words, only nine of the 50 states that offer PLTW programs were explicitly included in the PLTW literature we analyzed. This is likely because these states were primarily early adopters of the PLTW curriculum.

### 5.3 Participants

The majority of participants included in these studies ( $n = 14$ ) were current PLTW students (note that 2 of these articles focused on middle school PLTW students<sup>27,28</sup>). The second most common participants were teachers ( $n = 11$ ); 7 studies focused solely on high school teachers, whereas 2 included teacher groups that spanned middle and high school.<sup>32,33</sup> The next most salient distinction was *former* PLTW students; most of these studies focused on the post-secondary

pathways of PLTW high school graduates in comparison to non-PLTW high school graduates. The remaining studies we grouped into a category that we called “other”; these studies included PLTW students’ parents,<sup>34</sup> PLTW-school-affiliated principals,<sup>35</sup> principals at middle and high schools that did not offer PLTW,<sup>36</sup> PLTW program managers and partnership teams,<sup>37</sup> and lastly (all in one study) College and Technology Education Directors, PLTW Counselors, and PLTW Administrators<sup>31</sup>. Table 4 provides an overview of the participant breakdown. As a single article could include multiple samples, the cumulative number of participants is more than 31.

**Table 4:** Overview of Participants Included in the 31 PLTW Articles Reviewed in this Study

| Description           | Count | % of Articles |
|-----------------------|-------|---------------|
| Current PLTW Students | 14    | 45.2%         |
| PLTW Teachers         | 10    | 32.3%         |
| Former PLTW Students  | 4     | 12.9%         |
| Other                 | 5     | 16.1%         |

#### 5.4 Research Focus

Eight articles focused on students’ abilities, such as students’ math or science achievement,<sup>27,29,38</sup> cognitive processes,<sup>20,39</sup> conceptual understanding or “cohesion”,<sup>40</sup> ideation,<sup>21</sup> and problem-solving, teamwork, or communication skills.<sup>28</sup> The literature that we grouped as “attitudes” entailed a behavioral link. For example, this literature focused on students’ interests in mathematics or science,<sup>27,30</sup> self-efficacy,<sup>32,41</sup> and motivational constructs such as task value, goal orientation, or effort.<sup>24,42,43</sup> Conversely, literature which focused on perceptions mostly involved participants’ perceptions of the importance or the impact of PLTW, such as parents’ views regarding the impact of PLTW on their children’s abilities<sup>34</sup> or teachers’ perceptions of barriers to student learning of science or math.<sup>22</sup> Literature pertaining to pathways generally focused on factors that influenced students to pursue STEM degrees or persist in college,<sup>19,23,25,44</sup> although one of these articles focused on what motivated teachers to pursue technology education degrees.<sup>45</sup> The final three articles pertaining to PLTW Implementation varied widely: one was a curriculum analysis of PLTW and the alignment of PLTW curricula with national and Minnesota state standards,<sup>28</sup> a second was on lessons learned from effective PLTW partnership teams,<sup>37</sup> and a third was on the extent of PLTW service-learning integration.<sup>46</sup>

Table 5 presents an overview of the research foci throughout the 31 manuscripts we collected. As Table 5 indicates, these foci varied widely. As a single article may have included multiple foci, the cumulative percentage of research foci was greater than 100%.

**Table 5:** Overview of the Research Focus throughout the 31 PLTW Articles Reviewed

| Research Focus      | Participants Sampled |          |       | Totals |              |
|---------------------|----------------------|----------|-------|--------|--------------|
|                     | Students             | Teachers | Other | Sum    | % (Sum / 31) |
| Abilities           | 8                    | 0        | 0     | 8      | 25.8%        |
| Attitudes           | 6                    | 2        | 0     | 8      | 25.8%        |
| Pathways            | 4                    | 1        | 0     | 5      | 16.1%        |
| Perceptions         | 2                    | 6        | 3     | 11     | 35.5%        |
| PLTW Implementation | -                    | -        | -     | 3      | 9.7%         |

## 5.5 Research Methods

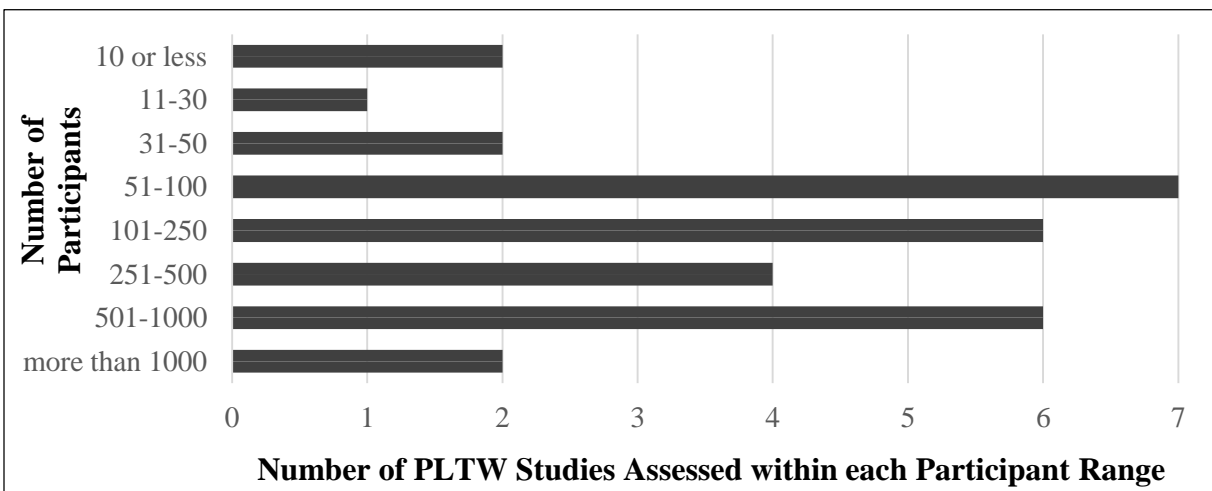
Next, we distinguished between the types of methods utilized throughout the collected literature. As Table 6 shows, 23 articles used quantitative research methods (this included studies where qualitative data was “quantized” and these quantized results were all that was presented, such as in Kelley<sup>20</sup> and Kelly et al.<sup>39</sup>). Conversely, three articles (less than 10%) included qualitative research methods. These results indicate there is a strong focus and even a bias in favor of quantitative studies when researchers explore the efficacy of PLTW. Furthermore, five of the 31 articles used both qualitative and quantitative methods (e.g., a quantitative study followed by a qualitative study, or vice versa). For these, we coded the research type as “both” indicating that quantitative and qualitative methods were pursued, but not that the study was “mixed methods.”

**Table 6:** Overview of the Research Type throughout the 31 PLTW Articles Reviewed

| Research Type | Count | % of Articles | Examples   |
|---------------|-------|---------------|--|
| Quantitative  | 23    | 74.2%         | T-tests, Regression, ANOVA, Descriptive analysis |
| Qualitative   | 3     | 9.7%          | Classroom observations, interviews, videos       |
| Both          | 5     | 16.1%         | Surveys combined with interviews or observations |

## 5.6 Sample Size

Several manuscripts included multiple groups of participants (e.g., both directors and teachers), and as a result, the “sample size” may have shifted throughout an individual paper. The sample size we recorded was the cumulative number of PLTW-affiliated participants included within the study (e.g., if the groups in the study were distinct, we added the total number together, whereas if the qualitative group was a subset of the quantitative group, we only coded the number associated with the quantitative group). We did not include comparison groups or “missing data” in the sample sizes (e.g., some authors would indicate that X amount of students participated in PLTW, but only Y amount completed pre-post surveys). Because of this process, the 31 articles we analyzed included a cumulative number of 8042 PLTW-affiliated participants. Figure 2 provides an overview of the distribution of sample sizes throughout the 31 analyzed articles.



**Figure 2:** Distribution of Sample Size across the 31 Analyzed PLTW Articles



## 5.7 Within-PLTW Comparisons

In this section, we provide an overview of the studies that included some form of an internal comparison as well as the outcomes of these investigations. 12 of the 31 articles, or just over 38%, included an internal comparison of some kind. We grouped these comparisons into three categories: (a) comparisons of the impact of PLTW by demographic variables such as race, class, or gender, (b) comparisons of perceptions of the efficacy of PLTW by select factors, and (c) controlled interventions aimed at improving specific aspects of PLTW curricula.

### *5.7.1 Demographics*

The first group of articles that included “internal” comparisons used demographic variables to compare PLTW teachers’ or students’ experiences with or abilities resulting from PLTW participation. Taken together, these results identified a need to provide more experiences for individuals from underrepresented STEM populations to not only participate in, but teach PLTW curriculum. In the future, this change could inspire more underrepresented students to develop an interest in mathematics and science, as well as to pursue STEM careers.

The most recent study in this category was a dissertation from Purdue University by Sorge<sup>23</sup> who explored the influence of PLTW participation on Indiana collegiate students’ academic pathways. While Sorge’s sole focus was not on demographic variables, part of his investigation explored the moderating effect of gender and race on PLTW high school graduates’ post-secondary academic pursuits. Sorge found that both non-White and female PLTW students were less likely to pursue STEM degrees than White or male students in general, but that this trend did not hold for PLTW graduates. In other words, Sorge indicated that PLTW courses appear to “attract and/or encourage both females and non-white students to major in STEM.”

The second most recent article fitting this category was a thesis by Green<sup>30</sup> from South Carolina State University. Green focused on the experiences of African American PLTW students. Specifically, she compared students’ Likert-type scale responses to measures such as math and science confidence and interest, as well as students’ career aspirations, and grouped participants’ responses by gender. Green’s sample included 116 males and 38 females, and her results indicated that for these female students, PLTW participation had a greater influence on their math and science expectations and interests than their male peers. Conversely, she did not find significant differences in school factors, ethnic identity, math/science confidence, career decision-making, or family relations between these two groups of students.

The third article was a dissertation by Holt from the Virginia Polytechnic Institute.<sup>32</sup> Holt’s focus was on experiences that influenced PLTW teachers’ self-efficacy beliefs. Specifically, Holt used an instrument called the *Teachers’ Self-Efficacy Belief System-Self (TEBS-S)*<sup>47</sup> and compared participants’ responses with respect to a wide range of demographic variables. Holt identified several factors that contributed to PLTW teachers’ self-efficacy, including “pre-PLTW teaching experience, PLTW teaching experience, post-secondary course hours completed, teacher licensure process, and current and past teaching schedules.”

The fourth article was a dissertation by Tolan from Andrews University.<sup>45</sup> Tolan compared PLTW teachers’ career paths, along with their perceived importance of career needs, daily career

experiences, and usefulness of PLTW. The variables she compared included gender and participants' teaching entry point. One of her findings indicated that females were more likely to enter teaching for altruistic purposes when compared to males. One surprising insight from her study was that *none* of her female participants indicated that they entered technology education due to a particular role model. Tolan explained that this finding was likely due to the limited number of technology education teachers throughout the U.S. who are currently female.

The fifth article in this category was a dissertation by Paslov from Southern Connecticut State University.<sup>27</sup> While Paslov's primary focus was on the experiences and perceptions of eighth grade female PLTW students, one of her eight research sub-questions compared between male and female students' experiences. Paslov's results indicated that both males and females displayed positive attitudes towards mathematics as a result of participating in PLTW. Further, both groups performed better in mathematics as a result of PLTW. However, females outperformed males on four of the 11 Blue Ribbon Testing categories at the end of the year compared to *no females* outperforming males at the start of the year. According to Paslov, another surprising insight was that PLTW participation significantly increased female "students' perceptions of [their] teachers' attitudes towards them as learners of mathematics." Notably, although male students responded more favorably than female PLTW students along this measure post-course, PLTW did not show any influence on these male students' responses.

Lastly, in a 2007 journal article, Rogers<sup>35</sup> explored the perceptions of PLTW high school principals using the *Principals and Inclusion Survey* or PIS<sup>48</sup>. Rogers' findings indicated that principals perceived PLTW to have a very positive effect on students (specifically, students' motivation/enthusiasm, critical-thinking skills, and problem solving skills) as well as on teachers (namely, teachers' perceptions of the relevance of the curriculum and their motivation and enthusiasm). However, female principals tended to respond more favorably to the PIS items than male principals. Principals at schools that had implemented PLTW for three or more years responded more positively to questions on the influence of PLTW on students' math and science abilities when compared to principals at schools who had implemented PLTW for less than three years. According to Rogers, qualitative responses confirmed these general survey findings.

### 5.7.2 *PLTW Perceptions*

This second set of internal comparisons focused on teachers', parents', or other PLTW affiliates' perceptions of either the impact of PLTW participation on student performance or their general perceptions of the importance of PLTW curriculum. Taken together, these studies suggested that successful PLTW implementation is contingent upon administrative support and collective effort, that professional development increases teachers' perceived support, and that students' parents' perceptions of PLTW vary by gender and socio-economic class.

The most recent article in this group was from McMullin and Reeve.<sup>31</sup> These authors identified critical factors for PLTW initiation or evaluation by (a) exploring College and Technology Education Directors' PLTW perceptions and (b) comparing PLTW teachers', administrators', and counselors' perceived importance of PLTW curricula in the state of Utah. Results from this latter goal indicated that each group perceived support from administrators, counselors, and teachers (e.g., one another) to be the most critical factor for successful PLTW implementation,

whereas these groups perceived university support as least important. Counselors unanimously agreed that students needed more time in their schedules in order to participate in PLTW.

The second most recent article in this group was a dissertation from Purdue University by Kaluf.<sup>33</sup> Kaluf compared responses to four survey constructs by variables such as teaching experience and years of professional development. The survey constructs included Structural Features of Professional Development, Core Features of Professional Development, Reflection on Professional Development, and Post-Professional Development Support. Kaluf only found one significant variable. Specifically, a greater number of professional development sessions led to more favorable responses to the Post-Professional Development Support scale.

The final article in this groups was by Werner, Kelley, and Rogers.<sup>34</sup> These authors compared PLTW students' parents' perceptions of the benefits of PLTW on their children. They divided their analyses by gender (their sample included 26 male parents and 53 female parents) and income level. Their results indicated that male parents perceived PLTW as having a slightly more positive effect on their children than female parents. Further, parents with less annual income were less favorable towards PLTW than parents of higher annual incomes.

### 5.7.3 *Controlled Interventions*

This last set of internal comparative studies matched traditional PLTW students with PLTW students exposed to another intervention or who completed distinct tasks. What these studies had in common was a focus on improving PLTW curricula. While two of these articles focused on improving PLTW students' design processes, one focused on heightening students' perceptions of STEM (with the theory that this may relate to student motivation to pursue STEM careers).

The most recent article fitting this category was a thesis by Farrington from Purdue University.<sup>21</sup> Farrington compared the ideation process of students who enrolled in a traditional ideation lecture to students who were exposed to IDEO's (a design and innovation consulting firm) ideation process. Farrington's study consisted of two control groups and two treatment groups. The results indicated that one of the treatment groups developed significantly more ideas than the control groups during a 30-minute team ideation task; the second treatment group did not.

The second most recent article that we mapped to this category was a journal publication by Lawanto and Stewardson.<sup>42</sup> These authors compared the motivation of PLTW students when engaging in a "creative" design task (marble sorter design) versus a "predictive" design task (bridge design). Their results indicated that students' interests and expectancies for success did not vary across the two design tasks. However, students engaged in predictive design showed higher Intrinsic Goal Orientation. Lawanto and Stewardson explained that this indicates "students are more intrinsically motivated working on a design task that requires analysis over creative thinking." For both design processes, Lawanto and Stewardson found Intrinsic Goal Orientation and Task Value to be good predictors of expectancy for success.

The third article was from Boynton and Hossain<sup>19</sup> who explored two research objectives, the second of which was to compare two groups of students' perceptions of STEM; the first group consisted of rural Tennessee students enrolled in Principles of Engineering who did not have an added lesson, whereas the second PLTW group had an added "hands-on" three-hour lesson on

risk analysis related to the Wolk Creek Dam, a “real-world” and upstream dam that was familiar to students. Boynton and Hossain found that the latter group of students’ perceptions of STEM became more positive as a result of the intervention. They suggested that infusing real-world infrastructure problems into pre-college engineering programs can motivate students to pursue STEM careers.

## 5.8 Outside-PLTW Comparisons

In this section, we provide an overview of the studies that included some form of an external comparison, along with the outcomes of these investigations. Of the 31 articles we collected, 13 articles were of this sort. 10 of these articles included a comparison between PLTW students and non-PLTW students; we further categorized these as comparing between students’ abilities, pathways, and attitudes or perceptions. The remaining articles compared PLTW and non-PLTW teachers’ perceptions.

### *5.8.1 Students’ Abilities*

The first group of studies that compared between PLTW and non-PLTW students focused on the achievement or abilities of students across these two groups. Generally, these studies focused on students’ mathematics or science abilities and cognitive processes. Taken together, these studies indicated that high school PLTW interventions have little influence on students’ mathematics abilities (although these results were not unanimous), and that the cognitive processes utilized by PLTW students throughout their design processes may be unique from other student populations.

The first article in this group was a 2010 journal publication from Tran and Nathan.<sup>38</sup> These authors compared 70 PLTW students’ mathematics and science abilities (54 of these students were in Introduction to Engineering Design, 1 was in Principles of Engineering, 3 were in Digital Electronics, and 12 were enrolled in 2 or more of these courses) with 70 hand-picked non-PLTW students that were comparable (as indicated by propensity score matching) to the PLTW students (namely, in their scores on a “core math” category). Their primary finding was that PLTW did not influence students’ math or science scores. Rather, their results indicated that PLTW may have been detrimental to PLTW students’ math gains on these state tests.

The second most recent article fitting this category was a 2010 journal publication from Kelley, Brenner, and Pieper.<sup>39</sup> These authors compared the experiences and cognitive processes used by Indiana EPICS-High students with those of PLTW students participating in a Principles of Engineering course. They used classroom observations and interviews, along with a verbal protocol analysis, to compare the design processes of six PLTW students with six EPICS-High students. By using a deductive coding process (they utilized a computer program called OPTEMP, which was developed in alignment with Halfin’s<sup>49</sup> cognitive processes), they found that EPICS High students utilized a greater variety of cognitive processes than PLTW students throughout the verbal protocol, although both groups spent the majority of the time “designing” and “analyzing.” Kelley et al. indicated that both groups applied little mathematics, as evident by their limited use of the “computing” process.

The third article in this category was a 2008 publication by Kelley<sup>20</sup> that used a similar methodology as Kelley et al.’s previous study<sup>39</sup> discussed above. However, instead of comparing

cognitive processes of PLTW students with EPICS-High students, here the comparison group was four students enrolled in a pre-college engineering course offered by teachers who partnered with the National Center for Engineering and Technology Education (NCETE). Kelley's analysis focused on the "problem framing" component of students' design processes, again using a verbal protocol methodology where students' time-on-task was limited to 30 minutes. Kelley's results indicated that NCETE students were more "solution driven" than PLTW students.

The fourth article was a 2008 dissertation by Wheeler from the University of Kansas.<sup>29</sup> Wheeler compared PLTW Principles of Engineering students' scores on the Missouri state mathematics test with a control group of 50 randomly selected non-PLTW students. Wheelers' results indicated that PLTW did not have an impact on students' mathematics abilities; while PLTW Principles of Engineering students' scored higher on math than a control group, the students' eighth-grade mathematics state testing score accounted for a much larger proportion of the variance in an ANOVA model than did PLTW enrollment.

Lastly, Paslov<sup>27</sup> (whose dissertation also included an internal comparison between male and female PLTW students, as discussed above) compared changes in eighth grade PLTW students' attitudes towards and achievement in mathematics against the same changes among eighth grade students who did not participate in PLTW. Paslov's results indicated that PLTW significantly increased PLTW students' mathematics performance (as measured by Blue Ribbons Testing for both male and female students) when compared to the control group. Specifically, PLTW students increased along the outcome measures called Operations, Probability and Statistics, Patterns, and Integrated Understanding. Further, focus group interviews with each group of students "indicated either a like or love of mathematics at a two-to-one ratio" when comparing PLTW students with the control group.

### 5.8.2 *Students' Pathways*

Each of the studies in this category focused on former PLTW students. Specifically, these studies compared the impact of PLTW participation on students' collegiate pursuits. Taken together, these studies indicated that participating in PLTW has a strong positive influence on students' motivation to pursue STEM degrees, especially engineering.

The most recent study in this group was a dissertation from Purdue University by Sorge<sup>23</sup> (this study also included an internal comparison, as described above). Sorge explored the influence of PLTW participation on Indiana collegiate students' academic pathways. His investigation included the largest sample size of all studies we analyzed. Specifically, his sample included 4032 PLTW high school graduates, 37,774 graduates who attended a high school that offered PLTW but did not take PLTW themselves, and 13,806 graduate students who attended a high school that did not offer PLTW. Using a multi-level analysis, Sorge found that PLTW graduates, in general, were more likely to major in STEM when compared to both their non-PLTW peers as well as graduates from non-PLTW schools. Additionally, Sorge found no differences in students' likelihood to pursue a STEM degree when comparing non-PLTW graduates from schools that did offer PLTW with graduates from schools that did not offer PLTW.

Next, a 2013 journal publication by Starobin and colleagues<sup>25</sup> compared the academic pathways of spring 2009 Iowa high school graduates who participated in PLTW (n = 702) with students

who did not ( $n = 11,218$ ). Of the PLTW students, 263 went directly to a 4-year college, whereas 231 went directly to community college. Using pathway analysis, their results indicated that 25% of PLTW students had enrolled in a STEM field in comparison to 10% of their non-PLTW peers.

Lastly, in a 2011 dissertation out of Clemson University, Porter<sup>44</sup> compared the impact of PLTW participation (among other variables) on student pursuit of an engineering academic degree versus a physical science degree. Porter found four statistically significant variables that influenced a student's decision to enroll in an engineering undergraduate program rather than a physical science program. Among these, PLTW was the strongest predictor, as PLTW high school graduates were 8.9 times more likely to enter engineering than physical science.

### 5.8.3 *Students' Attitudes or Perceptions*

The next two studies compared PLTW and non-PLTW students' attitudes or perceptions. The limited number of studies in this category identify a need to study PLTW students' STEM-related perceptions and attitudes with respect to non-PLTW peers in greater detail.

The first of these studies was a 2014 journal article from Starobin and colleagues.<sup>24</sup> These authors compared PLTW's impact on Iowa community college freshman students' self-regulatory efficacy when compared to their peers who did not participate in PLTW. Their findings indicated that PLTW students reported significantly lower self-regulatory efficacy along three constructs (effort, initiative, and time management) than their peers.

The second study was a dissertation by Harrison from Old Dominion University.<sup>26</sup> Harrison compared the perceptions of technology as well as the technological literacy of 23 PLTW students enrolled in Principles of Engineering with 58 students participating in a "standards based education" course, 70 students participating in a "general education" course, and the "general public." Harrison's results indicated that adults in the general public held more positive perceptions of the importance of technology education than all groups of students. Further, PLTW students held a more limited definition of technology than the other student groups (e.g., PLTW students were more likely to perceive technology as "computers and the internet" rather than "changing the natural world to satisfy our needs").

### 5.8.4 *Teachers' Perceptions*

The literature mapped to this category explored PLTW teachers' perceptions of the importance or impact of PLTW in comparison to non-PLTW teachers. Taken together, the results indicated that PLTW teachers perceive the integration of pre-engineering curriculum into high schools to be important, although they perceive math and science to be less essential factors for students to pursue engineering degrees than their high school STEM education counterparts do.

The most recent study in this category was a 2012 dissertation out of Purdue University by Rogers.<sup>50</sup> Rogers' objective was to compare PLTW teachers' and non-PLTW Engineering and Technology Education (ETE) teachers' perceptions of technology education in Indiana using the *Characteristics of Technology Education Survey* created by Hill and colleagues<sup>51</sup>. Rogers did not find any significant differences in the perceptions of technology education when comparing

between ETE teachers who were and who were not teaching PLTW. Rogers suggested that this indicates that the goals and outlook of these two groups of teachers are similar.

The second study in this group was a journal article by Nathan and colleagues.<sup>52</sup> These authors' primary objective was to develop a survey instrument "to document teachers' beliefs and expectations about pre-college engineering instruction, college preparation, and career success in engineering." They called this instrument the *Engineering Education Beliefs and Expectations Instrument*, or EEBEII. Upon validating this instrument, Nathan et al. compared non-PLTW teachers (specifically, 100 Mid-western STEM teachers) versus 43 PLTW teachers' responses (among other variables) to the EEBEII constructs. Their results indicated that PLTW teachers responded higher to the constructs called Environmental and Structural Support (which included items like "My school provides resources for students interested in engineering...") and Teaching for Engineering: Academic Course (which included items like, "The science and math content taught in my course is explicitly connected to engineering."). Conversely, non-PLTW STEM teachers responded higher to the construct called Careers in Engineering: Academic Achievement (which included items like "To be an engineer a student must have high academic achievement in math, science, and technology courses.").

The last study in this group, and the first study found in this literature review, was a 2005 journal article by Rogers.<sup>53</sup> Using Likert-type scale survey responses, Rogers compared Indiana PLTW (n = 34) and non-PLTW technology education (n = 28) teachers' perceptions of the importance of "pre-engineering" curricula. Rogers' analyses revealed that both PLTW and technology education teachers were generally favorable to pre-engineering curricula, although PLTW teachers tended to be more favorable than non-PLTW teachers.

## 5.9 PLTW Potpourri

In this section, we explore the remaining eight articles that did not include an external or internal comparison. In essence, these studies investigated the impact of or perceptions towards PLTW in manners similar to those already described, but did not include any form of comparison. Four of these articles focused on students and four focused on teachers or administrators.

### *5.9.1 Student Influence*

The first of these studies, a 2013 journal publication by Nathan et al.,<sup>40</sup> used classroom videos, curricular artifacts, verbal transcripts, and interviews with classroom teachers to explore how PLTW students build and maintain cohesion across STEM representations within the classroom. More specifically, these authors sought to identify and determine methods for alleviating challenges teachers and students face in building cohesion. Their primary insights were that instructors could develop cohesion and STEM integration through strategies such as identification, coordination, forward projection, and backward projection. As they wrote, "Our novel claim is that one key mechanism of STEM integration is producing and maintaining cohesion of central concepts across the range of representations, objects, activities, and social structures in the engineering classroom."

The second article we grouped to this category was by Lawanto, Santoso, and Yang.<sup>43</sup> These authors explored 113 PLTW students' responses to the *Motivated Strategies for Learning*

*Questionnaire* or MSLQ<sup>54</sup> (a survey that measures intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, and self-efficacy). This study was similar to Lawanto and colleagues' study<sup>42</sup> described above, but here the authors did not compare student motivations when engaging in two distinct design tasks. Rather, they built a regression model to predict success expectancy. Their results indicated that "students' intrinsic goal orientation and task value were significant predictors [...] to students' expectancy for success."

The next article, a 2011 dissertation from Capella University by Martin,<sup>41</sup> explored the variables that influenced black PLTW students' self-efficacy using the MSLQ<sup>54</sup>. Using the casual comparative method, Martin found that (a) engineering exposure was a good predictor of engineering self-efficacy, (b) "middle/high school classes" and parents were the most significant contributors in terms of motivating students to study engineering, (c) students who experienced engineering workshops, had engineering hobbies, or experienced engineering environments were marginally more likely to intend to pursue engineering as a degree, and (d) Principles of Engineering was the most impactful PLTW course in motivating students to pursue engineering.

The last article in this category was a 2011 journal publication from Stohlmann and colleagues.<sup>28</sup> Alongside weekly informal conversations with teachers and classroom observations, these authors used curriculum analysis to identify the strengths and weaknesses of PLTW's middle school program, "Gateway to Technology," at Johnson Middle School in the state of Minnesota. Their analyses indicated that, in general, PLTW implementation faces burdensome scheduling issues and middle/high school curriculum constraints. Further, they suggested that PLTW curriculum needs to be improved to better align with Minnesota's state mathematics and science standards. Nonetheless, their observations suggested that PLTW student benefited in terms of teamwork, critical-thinking, communication, questioning, and problem-solving skills. Altogether, these authors questioned the ultimate impact of PLTW participation on students' achievement gains in math and science. They suggested more research is needed in this domain.

### 5.9.2 *Teachers and Administrators*

The first study in this category was a 2012 thesis from Purdue University by Smiley.<sup>46</sup> In this study, Smiley explored the extent to which Engineering, Design, and Development (EDD) PLTW teachers had incorporated service learning into their courses. For this analysis, Smiley developed a Likert-type survey with metrics that identified which "core components of service-learning [...] were being implemented" in each curriculum. Smiley found that only two of the 15 EDD teachers surveyed met the criteria to be accurately described as "service-learning" courses. Hence, Smiley indicated that service learning is only a peripheral component of PLTW.

The second study in this category was a 2008 University of Illinois dissertation by Daugherty.<sup>22</sup> Daugherty examined five professional development programs: Engineering the Future, Project Lead the Way, Mathematics across the Middle School MST Curriculum, The Infinity Project, and INSPIRES. Her study sought to explore the nature of the professional development programs within each program by using direct observations, interviews, and a questionnaire. Daugherty identified several challenges to PLTW implementation from the PLTW teachers, including their students' generally low level of mathematics abilities, their students' lack of motivation, the teachers' difficulty in learning the software and the technological skills, the overall requirements to implement the curriculum, and a lack of the school's and teacher's money/time. While the



focus of Daugherty's investigation was not comparative, her analysis revealed two interesting distinctions between PLTW and the other programs: (a) PLTW tended to be led by "technology educators" whereas the other programs tended to be led by engineers and (b) PLTW was the only program that required that the teachers must become certified to teach the curriculum.

Third, in a 2008 thesis from Utah State University, Reutzel<sup>37</sup> identified "effective practices in the development and utilization of partnership teams in successful Project Lead the Way programs." Using a Delphi technique, Reutzel developed and had Program Managers from top PLTW programs rank 22 items pertaining to "Effective Practices That Partnership Teams Do to Make PLTW Programs Successful" and 27 items pertaining to "Effective Practices That Partnership Team Coordinators Do to Make PLTW Partnership Teams Successful." Through this investigation, Reutzel indicated that "practices related to achieving program success are primary, while the practices utilized by partnership team coordinators are secondary, existing in the aid of the primary purpose."

Lastly, Shields<sup>36</sup> explored non-PLTW principals' responses to a survey measuring perceptions of the value of PLTW for Technical Education by variables including age, level of experience, and gender (this study was not grouped as "within-PLTW" since the participants were not affiliated with PLTW). Shields' analysis revealed that, while these principals perceived PLTW to be a "valid part of the TE [technology education] curriculum," PLTW implementation faces major cost barriers. Shields suggested that principals need to have funding provided (e.g., through grants), and that PLTW, as a program, needs to improve their processes for distributing knowledge of opportunities to obtain funding for PLTW implementation.

#### 5.10 Support of the Literature Towards PLTW

The last item we coded asked whether the article was supportive of PLTW. We could not code many articles because either the authors were not clear on their stance to this question or the authors offered conflicting accounts. In total, nine articles (roughly 29%) clearly portrayed PLTW positively, whereas six articles indicated that non-PLTW comparative groups outperformed PLTW students (roughly 19%). Studies with a positive evaluation of PLTW ranged in foci from students' academic pathways,<sup>23,25,44</sup> middle school students' mathematics abilities and interests,<sup>27</sup> students' self-efficacy,<sup>41</sup> principals' perceptions,<sup>35</sup> parents' perceptions,<sup>34</sup> and PLTW's professional development and teacher training programs.<sup>22,32</sup> Studies that portrayed a negative evaluation of PLTW included either a focus on students' math and science abilities,<sup>29,38</sup> students' regulatory self-efficacy,<sup>24</sup> students' cognitive processes utilized during a design task,<sup>20,39</sup> or the (lack of) incorporation of service-learning-type pedagogy into PLTW.<sup>46</sup>

### **6. Discussion**

In this study, we collected and analyzed 31 peer-reviewed journal articles, dissertations, and theses on the pre-college engineering curriculum, Project Lead the Way (PLTW). Here, we have used the research questions to frame the discussion of our synthesis of these works. Specifically, the discussion proceeds in four sections: (a) the **nature** of the 31 PLTW articles we reviewed, (b) the apparent **strengths** of PLTW as a program as evident throughout these articles, (c) the apparent **weaknesses** of PLTW, and (d) potential **gaps** in scholarly PLTW literature where future investigators might focus their attention.

## 6.1 Nature of PLTW Scholarly Investigations

First, all of the articles we analyzed were published in 2005 or later, and nearly 70% of the articles were published in 2010 or later. While we recognize that PLTW curricula is constantly changing, we posit that the recentness of the publications we analyzed mitigates some (but not all) concerns regarding the dynamics of PLTW as a program.

Second, the participants sampled within these studies varied widely, but most prominently, these investigations included participants who were current PLTW students (n = 14; 45%), whereas the second most common participants were teachers (n = 10; 32%). Former PLTW students were the third most prominent group of participants (n = 4; 13%), and there was an assortment of “other” participants, including PLTW administrators, principals, and parents of PLTW students

Third, the foci of these investigations varied widely. We classified the studies as focusing on abilities (n = 8; 26%), attitudes (n = 8; 26%), pathways (n = 5; 16%), perceptions (n = 11; 36%), and implementation of PLTW, in general (n = 3; 10%; note that a single paper could include multiple foci so these cumulative percentages are greater than 100%). To explore these areas, the investigators showed a strong preference for quantitative methods (n = 32; 74%) over qualitative (n = 3; 10%) or some combination of both (n = 5; 16%). This is not to suggest these are the only areas of investigation or methodological pursuits that are important, but rather, it identifies the variety of research foci scholars have used to investigate PLTW curriculum thus far.

## 6.2 Apparent Strengths of PLTW

From this synthesis, three strengths of PLTW curriculum were most striking. First, PLTW participation facilitated student interest in STEM subjects, particularly math and engineering. Second, PLTW participation motivated students to pursue and persist in STEM degrees. Third, PLTW professional development facilitated teachers’ confidence in implementing PLTW curriculum. We describe these findings next.

For all students, especially students underrepresented in engineering, participating in PLTW fostered student interest in mathematics and engineering. For example, Martin found that participation in the Principles of Engineering PLTW course was the strongest predictor of students’ motivation to pursue engineering as a degree.<sup>41</sup> Likewise, Sorge found that both non-White and female PLTW students were less likely to pursue STEM degrees than White or male students in general, but that this trend did not hold for PLTW participants.<sup>23</sup> Green, who focused on the experiences of African American PLTW students, found that female students who participated in PLTW showed greater increases in their math and science expectations and interests than their male peers.<sup>30</sup> These findings were corroborated by Paslov, who found that participation in the Gateway PLTW curriculum facilitated both eighth grade male and female students’ positivity towards mathematics.<sup>27</sup>

Perhaps the greatest consensus throughout this literature (as evident by the lack of contradictory findings) was that PLTW served as a motivational impetus for students to pursue STEM degrees and even persist within them.<sup>23,25,44</sup> These findings were supported by at least two other studies not included in the literature review of which the authors were aware. For example, Pike and

Robbins<sup>55</sup> utilized propensity score matching to depict the causal effects of PLTW participation on college enrollment. While their results did not indicate PLTW students were more likely to persist through the first-year of college when compared to their non-PLTW peers, PLTW students in their study were more likely to major in STEM disciplines. Conversely, Van Overschelde found PLTW students, when compared to a matched set of students, were more likely to enroll in a Texas institution of higher education.<sup>56</sup>

Lastly, for teachers, PLTW's professional development was a marked strength. For example, Daugherty, who explored several pre-college engineering initiatives, found PLTW professional development was especially impactful as "technology educators" who had implemented the programs themselves generally led it. In essence, this setup made the training contextualized and relevant, at least from the teacher perspective.<sup>22</sup> Also, teachers had to become certified to teach PLTW, thus incentivizing the professional development itself. This finding was corroborated by Kaluf, who found that the number of attended professional development sessions was the only variable that contributed to teachers' responses along a "Post-Professional Development Support" scale.<sup>33</sup> Similarly, Holt explored factors that contributed to PLTW teachers' self-efficacy, and found PLTW teaching experience was one important variable in this respect.<sup>32</sup>

### 6.3 Apparent Weaknesses of PLTW

As with the strengths, a few potential weaknesses of PLTW were apparent from the literature we analyzed. First, evidence that PLTW participation facilitates improvements in students' math and science abilities was largely lacking. The few studies that did focus on this topic were at odds. Second, PLTW implementation faces scheduling and space issues that some schools may be unable to overcome. Third, PLTW costs are significant, and some school districts may have a general lack of (or potentially, a lack of awareness of) sources for meeting these costs.

First, while PLTW was quoted in *Rising Above the Gathering Storm*<sup>1</sup> as a model for "improving K-12 science and mathematics education", a few investigations contradicted this assertion. For example, Tran and Nathan found that PLTW was slightly detrimental to students' performances on state mathematics and science tests.<sup>38</sup> Similarly, Wheelers' results indicated that PLTW participation did not improve (although it did not inhibit) students' mathematics performance.<sup>29</sup> Nonetheless, whereas each of these studies focused on high school students, the one study that focused on math and middle school students suggested that PLTW students' mathematics performance and attitudes improved for both male and female students.<sup>27</sup>

Second, PLTW curriculum is often difficult to incorporate into high school and middle school students' schedules. For example, McMullin and Reeve indicated that high school counselors unanimously agreed that students needed more time in their schedules in order to participate in PLTW.<sup>31</sup> Similarly, Stohlmann et al. described "scheduling and space issues" as a key and noticeably discernable problem for the Gateway to Technology program.<sup>28</sup> These problems are likely not unique to PLTW, but similar to any pre-engineering curriculum.

Third, a major inhibitor of PLTW implementation relates to costs of the program. Implementing PLTW may be too expensive for schools, particularly those in economically disadvantaged districts. This difficulty may correlate with a problem of PLTW curriculum cited by Tolan,

specifically, a lack of role models for students from demographic populations that are underrepresented throughout STEM (namely, engineering).<sup>45</sup> Nonetheless, there is often opportunities for funding PLTW initiatives, but a separate barrier corresponds with a general lack of awareness of these funding opportunities.<sup>36</sup> Yet, even if administrators, principals, or teachers desire use of the curriculum and successfully obtain funding, physical space issues may still lead to indirect costs that are not directly attributed to PLTW implementation.<sup>28</sup>

#### 6.4 Gaps in PLTW Literature

Several populations of participants included within this analysis might be considered “fringe” participations, with only one a few of the 31 investigations cited herein oriented towards them (e.g., PLTW principals, PLTW high school graduates, High School Counselors, and Administrators). These populations represent a viable area for future PLTW investigations. The variety of research foci might be expanded upon with respect to each of these groups. For example, scholars might focus on parents’ attitudes towards PLTW, former PLTW students’ mathematics or science performance with respect to their peers’ in college courses, and improving teachers’ abilities to integrate math and science into PLTW coursework.

In addition, while the scholarly foci of these 31 articles tended to be on high school students, PLTW’s Biomedical Science and Computer Science curricula were never a focal point. A concerted focus on these curricula and their influence on student learning, perceptions, and attitudes would likely be valuable. Similarly, the Launch curriculum was not a focus of any of these articles, and the Gateway curriculum was the focus of only a few. It is likely that each of these offerings, occurring at different stages of students’ cognitive development, would have markedly distinct influences on students’ perceptions of, and interests in STEM.

Third, the majority of the articles we investigated were quantitative, which indicates that a range of qualitative foci would provide viable lines of investigation in the future, potentially identifying a range of other pertinent research foci. For example, future scholars might immerse themselves within varying PLTW curricula (from Launch, to Gateway, to Principles of Engineering, and to Capstone courses) and utilize ethnographic methods to add nuance to much of the findings investigators have derived from quantitative investigations already. These ethnographic investigations would likely lead to foci beyond those identified herein.

Lastly, many states that we know implement PLTW were not represented in the articles synthesized in this literature review. We posited that this was likely because “early adopters” provided a grounding for scholarly investigation that may not be available in states that were recent adopters. It is also likely that findings from these investigations have been captured in conference papers and proceedings. Nonetheless, future scholars might pursue large scale, cross-state investigations. Results from these macro-scale research studies could provide insights for PLTW “best practices” and significantly improve PLTW and related pre-engineering curricula.

### **7. Conclusion**

Despite the rapid and still ongoing growth of PLTW, these results indicate that scholarly literature pertaining to the efficacy of PLTW curriculum is rather sparse. Strengths of PLTW included sparking student interest in STEM subjects and careers along with the nature of PLTW

professional development for teachers. Weaknesses of PLTW included a lack of research supporting that PLTW promotes performance in math and science, curriculum space issues, and substantial costs of PLTW implementation. An outcome of this work was the identification of gaps where future researchers might focus their attention to investigate and improve the efficacy of PLTW. We posit that by addressing some of these gaps, scholars might uncover an inventory of best practices that could improve the implementation of not only PLTW, but also all pre-engineering and STEM education programs throughout K-12 education in the U.S. and beyond.

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## Appendix A: Overview of the Project Lead the Way Literature Analyzed in this Study

| Author(s)           | Year | Type         | State     | Type | Participant             | Focus                     | Within | Outside | Support |
|---------------------|------|--------------|-----------|------|-------------------------|---------------------------|--------|---------|---------|
| Boynton; Hossain    | 2010 | Journal      | TN        | QUAN | PLTW Students (current) | Pathways; Perceptions     | x      | -       | -       |
| Daugherty           | 2008 | Dissertation | N/a       | QUAL | PLTW Teachers           | Perceptions               | -      | -       | Yes     |
| Farrington          | 2014 | Thesis       | Midwest   | QUAN | PLTW Students (current) | Abilities                 | x      | -       | -       |
| Green               | 2012 | Thesis       | SC        | QUAN | PLTW Students (current) | Attitudes                 | x      | -       | -       |
| Harrison            | 2009 | Dissertation | NC        | QUAN | PLTW Students (current) | Perceptions               | -      | x       | -       |
| Holt                | 2011 | Dissertation | Multiple  | QUAN | PLTW Teachers           | Attitudes                 | x      | -       | -       |
| Kaluf               | 2014 | Dissertation | IN        | QUAN | PLTW Teachers           | Perceptions               | x      | -       | -       |
| Kelley              | 2008 | Journal      | NC        | QUAN | PLTW Students (current) | Abilities                 | -      | x       | No      |
| Kelley et al.       | 2010 | Journal      | IN        | QUAN | PLTW Students (current) | Abilities                 | -      | x       | No      |
| Lawanto et al.      | 2012 | Journal      | Multiple  | QUAN | PLTW Students (current) | Attitudes                 | -      | -       | -       |
| Lawanto; Stewardson | 2013 | Journal      | Multiple  | QUAN | PLTW Students (current) | Attitudes                 | x      | -       | -       |
| Martin              | 2011 | Dissertation | N/a       | QUAN | PLTW Students (current) | Attitudes                 | -      | -       | Yes     |
| McMullin; Reeve     | 2014 | Journal      | UT        | BOTH | PLTW Teachers; Other    | Perceptions               | x      | -       | -       |
| Nathan et al.       | 2013 | Journal      | N/a       | QUAL | PLTW Students; Teachers | Abilities                 | -      | -       | -       |
| Nathan et al.       | 2010 | Journal      | Midwest   | QUAN | PLTW Teachers           | Perceptions               | -      | x       | -       |
| Paslov              | 2007 | Dissertation | CT        | BOTH | PLTW Students (current) | Abilities                 | x      | x       | Yes     |
| Porter              | 2011 | Dissertation | Southeast | QUAN | PLTW Students (former)  | Pathways                  | -      | x       | Yes     |
| Reutzel             | 2008 | Thesis       | Multiple  | BOTH | Other                   | PLTW Implementation       | -      | -       | -       |
| Rogers (George)     | 2005 | Journal      | IN        | QUAN | PLTW Teachers           | Perceptions               | -      | x       | -       |
| Rogers (George)     | 2007 | Journal      | IN        | BOTH | Other                   | Perceptions               | x      | -       | Yes     |
| Rogers (Stevan)     | 2012 | Dissertation | IN        | QUAN | PLTW Teachers           | Perceptions               | -      | x       | -       |
| Shields             | 2007 | Journal      | IN        | QUAN | Other                   | Perceptions               | -      | -       | -       |
| Smiley              | 2012 | Thesis       | IN        | QUAN | PLTW Teachers           | PLTW Implementation       | -      | -       | No      |
| Sorge               | 2014 | Dissertation | IN        | QUAN | PLTW Students (former)  | Pathways                  | x      | x       | Yes     |
| Starobin et al.     | 2013 | Journal      | IA        | QUAN | PLTW Students (former)  | Pathways                  | -      | x       | Yes     |
| Starobin et al.     | 2014 | Journal      | IA        | QUAN | PLTW Students (former)  | Attitudes                 | -      | x       | No      |
| Stohlmann et al.    | 2011 | Journal      | MN        | QUAL | PLTW Students (current) | Abilities; Implementation | -      | -       | -       |
| Tolan               | 2008 | Dissertation | Multiple  | BOTH | PLTW Teachers           | Attitudes; Pathways       | x      | -       | -       |
| Tran; Nathan        | 2010 | Journal      | Midwest   | QUAN | PLTW Students (current) | Abilities                 | -      | x       | No      |
| Werner et al.       | 2011 | Journal      | IN        | QUAN | Other                   | Perceptions               | x      | -       | Yes     |
| Wheeler             | 2008 | Dissertation | MO        | QUAN | PLTW Students (current) | Abilities                 | -      | x       | No      |