SUMMARY REPORT
2021 Comprehensive II Site Sustainability Evaluation Study

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With quantitative data visualization help from Alexandra Lau
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The full report includes detailed findings and evidence and is available at phystec.org.
Executive Summary

This study focused on the sustainability of 16 PhysTEC Comprehensive Grants funded from 2010-2015 ("Comprehensive II sites"). Evaluation questions included whether the number of physics teacher graduates increased, and sustained, what PhysTEC activities were sustained, and what factors contributed to sustainability. This period spans 5 different requests for proposals. Funding amounts were typically $300,000 over 3 years, plus a recommended 3-year institutional match; UTeach replication sites were funded at a lower level. Data gathered included archival documents, graduation data, a written survey, and a series of interviews, including completion of the Physics Teacher Education Program Analysis (PTEPA) Rubric. The desired outcomes included:

- Institutional capacity and culture for physics teacher education (PTE), such as leadership, resources, structure, and policy, and
- Sustained PTE program outcomes, such as graduation and an effective PTE program.

Sites were rated as "unsustained," "mixed," "sustained," or "grew."

The full report includes a diverse and rich data on outcomes across institutions, as does the full report summary. This executive summary provides only a very brief overview of the study.

Comprehensive II legacy sites often sustain their outcomes -- all but two sustained their outcomes to some degree, with meaningful outcomes and lasting impacts of the grant. All have a functional PTE program. More than half (9 institutions) are rated with high sustainability.

Comprehensive II legacy sites grow and sustain their graduation rates on average.

Teacher graduation increased by 1/year on average and this increase was sustained on average (1.3 teachers/year pre-funding, 2.2 teachers/year during-funding, 2.4 teachers/year during the sustainability period). For those sites which experienced an overall gain in graduation rate (N=11 sites) the average increase is 2 teachers/year. Gains and graduation rates were also overall higher for sites rated as sustained. Future teachers represented about 10% of undergraduate majors, on average, and about half of future teachers were certified through post-baccalaureate pathways.

Graduation rates by sustainability level
PhysTEC supported strong culture, norms, and capacity for PTE and created strong PTE programs. In many cases, the most important outcome was stated as being the supportive culture for teacher education. Site leaders were overall proud of the results of the grants, and the quality of education provided for teacher graduates. Based on the PTEPA Rubric, PhysTEC supported many improvements in PTE programs, such that Comprehensive II sites rival the strength of thriving programs in terms of program structure and practices. LA programs, curricular changes, and recruitment practices were commonly mentioned durable outcomes, and institutionalization of LA programs was somewhat common. Students at former PhysTEC sites also receive quality preparation regardless of site sustainability: All sites including “unsustained” sites) were found to have strong ratings in the PTEPA “Knowledge and Skills" standard -- this standard includes physics content and pedagogy, and field experiences. Additionally, nearly all sites experienced growth in PTEPA ratings during PhysTEC funding, regardless of sustainability level, showing that Comprehensive grant funding improved PTE programs.

Successes promote a positive feedback loop and provide “proof of concept.” Often, success bred success; the PhysTEC grant enabled site leaders to establish “proof of concept” that PTE was viable: There was interest among students, demand for courses, graduation numbers could increase, and Teachers in Residence (TIRs) and Learning Assistant (LA) programs could be valuable for the department. LA programs supported a strong culture for teacher education, which then supported the LA program. The institutional match period helped establish the value of these program elements and create funding and routine to support them.
Most activities were maintained for most sites, especially LA programs. Overall, it is remarkable how many activities and structures were maintained across sites. Sustainability plans from the grant were upheld and in all but two cases the institutional match commitment was upheld. For most areas of the PTEPA Rubric, activity maintained or increased since PhysTEC for at least 80% of sites. LA programs were maintained at 13 out of 15 sites with an LA program; PhysTEC created or helped to maintain all these programs. External funding and human resources (e.g., full time equivalent, number in the team, TIR) were often reduced. The TIR position was maintained for over half of institutions (N=9), usually in a regular departmental position (such as lecturer or lab coordinator). About half of current TIRs were part-time. Most TIRs who were sustained included coordinating an LA program as part of their duties, demonstrating that LA programs can be an effective part of a sustainability plan, even if only indirectly related to PTE.

Human and financial resources are related to sustainability. Unsustained sites lacked champions, resources, and capacity for PTE. The two unsustained sites did not have a champion, and there were also very few resources allocated to PTE (e.g., funding, people, and FTE). Sites with greater levels of sustainability had generally higher levels of internal and external funding, greater numbers of PTE leaders and team members, and greater FTE spent by faculty. Local teacher salaries were not related to sustainability level, nor was the year of funding. UTeach replication sites experienced mixed sustainability results, with the Master Teacher not typically serving as a good replacement for a PhysTEC TIR.

Sustainability increased with the number of majors and with postbac pathways. Department size was higher for the 9 more well-sustained sites (average 33 majors/year) compared to the less sustained sites (average 21 majors/year), and these sites also grew more (+15-16 majors/year on average compared to +8 majors/year). The percentage of majors choosing to become teachers also increased with the sustainability level (8-9% for lower sustainability compared to 10-11% for well-sustained sites). Well-sustained sites tended to include a post-baccalaureate pathway as one of the main ways in which students achieved certification, and more students graduated through these pathways than through undergraduate-only routes.

Site capacity is necessary but not sufficient for sustained outcomes; the addition of institutional culture is a hallmark of the exemplary institutions. Each site was rated on their capacity and culture for PTE based on their leadership, institutional culture, and resources. All those rated as sustained were at least “medium” capacity. Thus, “medium capacity” may be a threshold for good results. Among the 9 sites that were rated as sustained, 4 were identified as truly exemplary; these were marked by stronger institutional climate and program collaboration and rated as “high capacity.” Sites that were sustained but not exemplary appear to have maintained their programs and outcomes as a result of the efforts of champions, rather than due to broader commitment to the cause. Thus, “high capacity” including a strong institutional
climate may be needed for exemplary results. Five sites had strong capacity and strong PTE programs, but low graduation rates; these were denoted as “mixed.” Mixed sites (5 institutions) had generally good PTE programs but reduced graduation rates. These sites were typified by engaged champions but lacked supportive structure and institutional culture. When asked what helps keep things going at the site, we found that drivers of sustainability include people, money, structure, culture, and routine: The effort of champions, money, formalized structures, and culture change are critical. In many cases, having enough time to establish programmatic success enabled the establishment of value, and routines, to support continuity.

I thus conclude that:

- PhysTEC Comprehensive Sites achieve meaningful results for institutions, and the nation.
- PhysTEC supports organizational capital and a healthy ecosystem for PTE at institutions.
- It is difficult to maintain leadership, time, and effort, leading to fragility.
- Culture, including structure and routine, can help with sustainability.
- Motivated people, site capacity, and institutional culture are important, but insufficient on their own. Exemplary results require all elements of the model below to be exemplary: Motivated people, structure, and culture, likely with good connection to structures which support undergraduate education broadly.

About this study

This study was commissioned to assess sustainability of the latest round of PhysTEC Comprehensive sites. This was an intensive mixed-methods study requiring over 30 days of person-effort on the part of the evaluator alone. The findings are thus quite robust and rich.

Evaluation questions

1. Did the number of physics teacher graduates increase? Was this increase sustained?
2. What factors contributed to success in sustainability? What challenges to sustainability were encountered?
3. Which of the activities initiated by the PhysTEC grant are being sustained?
4. What is the future outlook for sustaining PhysTEC activities longer term?

Evaluation methods

Multiple data collection methods allowed the evaluator to gain a rich understanding of each site, while minimizing site leader time as much as possible. However, each site leader was still required to contribute at least 4 hours of time to the effort. We are all grateful for their effort.

<table>
<thead>
<tr>
<th>Evaluation method</th>
<th>Detail</th>
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<tbody>
<tr>
<td><strong>Document review</strong></td>
<td>Reviewed RFPs, MOUs, annual reports, proposals, etc.</td>
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<tr>
<td><strong>Graduation data</strong></td>
<td>PhysTEC-collected graduation data was analyzed for each site and across sites.</td>
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<tr>
<td><strong>Written survey</strong></td>
<td>Each site leader was asked to identify some quantitative and qualitative data about their site,</td>
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<td></td>
<td>including listing outcomes resulting from the grant in an “outcomes harvesting” approach.</td>
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<tr>
<td><strong>Orienting interview</strong></td>
<td>1+ hour interview with site leader(s) to learn the story of their site, about teacher graduates</td>
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<td>over time, and hear the factors they believe are important in their site’s success (or lack</td>
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<td></td>
<td>thereof)..</td>
</tr>
<tr>
<td><strong>PTEPA interview</strong></td>
<td>2+ hour interview to complete the PTEPA instrument, including rating change during, and since,</td>
</tr>
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<td>PhysTEC in key areas.</td>
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<tr>
<td><strong>Stakeholder interviews</strong></td>
<td>1 hour interview with 2-3 additional stakeholders to validate findings and collect additional</td>
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<td>information. Typically, these included the physics chair and the education partner.</td>
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</tbody>
</table>
This information was collected within a “Dashboard” which collected information across all 16 sites.

Created products

The products created from this effort are:
1. This internal PhysTEC analysis report
2. An external, public version of this report with site names removed.
3. Individual “internal site reports” for each site, with key outcomes, a site narrative, and evaluative recommendations. Provided in PDF and Word format for ease of sharing.

Confidentiality

Confidentiality within PhysTEC was not promised for participating sites. All interviewees were told that information they shared would be viewable by (1) the site leaders and (2) the PhysTEC PMT. The site leaders are provided the “internal site report” and can decide what, if anything, to share further among stakeholders at their site. The PhysTEC PMT can view a private analysis report, and internal site reports, with sites identified. This public version of this report has all identifying information removed.

Which institutions participated?

This study focused on the 16 sites which were funded during the 2nd NSF PhysTEC grant, plus the Campaign Funds funded sites. Funding initiated from 2010-2015, and typically lasted 3 years. Funding amounts were typically $300,000 in total, except at UTeach replication sites (typically half that amount). Sites included are listed below.

1. First RFP (2009)
   a. California State University, Long Beach
   b. Middle Tennessee State Un.
   c. Towson University II
   a. Boston University
   b. Virginia Tech
3. Third RFP\(^1\) (2011)
   a. Alabama, University of
   b. Arizona State University
   c. University of Missouri - Columbia
   a. Georgia State University
   b. James Madison University
   c. University of Central Florida
   d. University of Cincinnati
5. Fifth RFP (2014)
   a. Rowan
   b. Texas State
   c. UNC/Mines
   d. West Virginia U

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\(^1\) The third RFP is when the RFP was in its near final form, with a clearly defined period of sustainability.
What is a sustained PhysTEC site?

To understand what “success” would look like for site sustainability, I did some work to define this construct more specifically for PhysTEC sites. I sought guidance from the international development community. USAID defines sustainability as: “The ability of a local system to produce desired outcomes over time. Discrete USAID-funded interventions contribute to sustainability when they strengthen the capacity of the system to produce valued results and be both resilient and adaptive in the face of changing circumstances” (ADS 201, see Definitions). They identified categories of both Learning, and Sustainability, with sustainability split into individual, organizational, and institutional sustainability.

Valued outcomes

From this definition and our evaluation questions, I arrived at two main valued outcomes related to physics teacher education (PTE), resulting from PhysTEC grants: Capacity, and Sustained Outcomes. These are defined below, and each site was rated globally on this outcome, taking all factors into account holistically.

<table>
<thead>
<tr>
<th>Capacity &amp; culture for PTE</th>
<th>Sustained PTE Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Institutional capacity &amp; culture for PTE</strong> should be strong now, regardless of where it was immediately after the grant.</td>
<td><strong>PTE program outcomes should be at least as strong now as they were post-grant.</strong></td>
</tr>
<tr>
<td><strong>Includes:</strong></td>
<td><strong>Includes:</strong></td>
</tr>
<tr>
<td>- Institutional culture and commitment.</td>
<td>- PTE program strength.</td>
</tr>
<tr>
<td>- Leadership and resources</td>
<td>- PTE program growth and resilience.</td>
</tr>
<tr>
<td>- Structure and policy</td>
<td>- Number of future physics teachers.</td>
</tr>
<tr>
<td><strong>Measured by:</strong></td>
<td><strong>Measured by:</strong></td>
</tr>
<tr>
<td>- PTEPA standards 1 and 2.</td>
<td>- PTEPA standards 3-6.</td>
</tr>
<tr>
<td>- Number and FTE of leaders, existence of champion, funding.</td>
<td>- Changes in PTEPA since the grant.</td>
</tr>
<tr>
<td>- Stated outcomes.</td>
<td>- Stated outcomes.</td>
</tr>
<tr>
<td>- Interviews across all stakeholders.</td>
<td>- Activities sustained.</td>
</tr>
<tr>
<td>- Department size</td>
<td>- What keeps things going / resilience.</td>
</tr>
<tr>
<td><strong>Global rating:</strong></td>
<td><strong>Global rating:</strong></td>
</tr>
<tr>
<td>- Low / medium / high (3 levels)</td>
<td>- Unsustained / mixed / sustained/ grew</td>
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While both are valued outcomes, I decided that “sustained PTE outcomes” were the primary dependent variable by which I would examine results, treating “capacity” as a dependent variable.
Theoretical model

I have found that the findings from this study dovetail well with a model developed by Allie Lau and collaborators\(^2\) to identify factors which contribute to high use of active learning in introductory courses. They find that motivated people with knowledge and opportunities are necessary but insufficient to generate high use of active learning; these people must operate within (and develop) a supportive culture for active learning. They find that people and culture develop iteratively in high active-learning departments. They also find that establishing high use of active learning takes intentional effort over a sustained period.

I have adapted their model of factors contributing to “active learning” instead for factors contributing to “PTE” within departments. Their model, adapted for PTE, is shown below. I suggest that all items in the grey box represent “capacity,” and the desired result is the “sustained PTE outcomes” -- which includes both the quality of the PTE program and the number of graduates it maintains. Based on my recommendation (from the results of this PhysTEC study), Lau et al added an indicator arrow showing that this positive outcome further reinforces the culture in a positive feedback loop. I will return to this model again in the conclusions section.

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Full Report Summary

This study was commissioned to assess sustainability of the latest round of PhysTEC Comprehensive sites. This study focused on the 16 sites which were funded during the 2nd NSF PhysTEC grant, plus the Campaign Funds funded sites. Funding initiated from 2010-2015, and typically lasted 3 years. Funding amounts were typically $300,000 in total, except at UTeach replication sites (typically half that amount). This was an intensive mixed-methods study requiring many person-days of effort. The findings are thus quite robust and rich.

Evaluation questions include:
1. Did the number of physics teacher graduates increase? Was this increase sustained?
2. What factors contributed to success in sustainability? What challenges to sustainability were encountered?
3. Which of the activities initiated by the PhysTEC grant are being sustained?
4. What is the future outlook for sustaining PhysTEC activities longer term?

Evaluation methods included document review, graduation data, a written survey, an orienting interview, a PTEPA Rubric interview, and stakeholder interviews. We are very grateful for the site leaders’ effort in enabling this data collection.

I focus on two main desired outcomes from the grants, which are bidirectional in their causality. Each site was rated globally on each outcome based on all data.

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Overall, were PhysTEC site activities and outcomes sustained?

**Comprehensive II legacy sites often sustain their outcomes** -- all but two sustained their outcomes to some degree, with meaningful outcomes and lasting impacts of the grant. All have a functional PTE program. More than half (9 institutions) are truly thriving, rated with high sustainability, and 4 of these growing further since the grant. The 5 programs that were not fully sustained did typically maintain their program structures but not graduation rates. The majority (12) are rated as having at least medium capacity in their PTE program, and most report continued effort and resources dedicated to PTE. The average current internal funding spent on PTE is approximately $100,000, with 2 PTE leaders and 2 PTE non-leaders, spending about 0.5 faculty FTE and 0.3 TIR FTE. Thus, most former PhysTEC-funded sites have functional PTE programs, many of which are truly thriving -- more than can be said for most departments.
Did the number of physics teacher graduates increase? Was this increase sustained?

Comprehensive II legacy sites grow and sustain their graduation rates on average. Teacher graduation increased by 1/year on average, and this increase was sustained on average. The data, however, is messy and idiosyncratic. Teacher graduation rates increased from 1.3 teachers/year pre-funding to 2.2 during funding and 2.4 during the sustainability period. For those sites which experienced an overall gain in graduation rate (N=11 sites) the average increase is 2 teachers/year. These increases contribute significantly to addressing the national physics teacher shortage.

Well-sustained sites experience sustained graduation rates of 3-4 teachers/year. Well-sustained sites (those which “sustained” or “grew”) had overall higher teacher graduation rates: 2.5 teachers/year for “sustained”, and 3.8 teachers/year for “grew” sites. Growth in teacher graduation rates was also higher at these well-sustained sites, with overall pre-post growth of 1.1 and 2.1 teachers/year at “sustained” and “grew” sites, respectively. Only “unsustained” sites experienced no average growth from pre-to-post funding, though both “unsustained” and “mixed” sites experienced a decrease in graduation rates, on average, after funding ended.
Future teachers represent about 10% of the undergraduate majors at departments. The number of majors, and the fraction of majors who choose teaching, increases for more successfully sustained sites.

About half of teachers at an institution are certified through a postbac pathway, on average. On average, 42% of students at these sites received an undergraduate certification, compared to 47% receiving postbac certification as a standalone program or add-on to an undergraduate program (see right).

What were the outcomes of the PhysTEC grants?

Site leaders are overall proud of the results of PhysTEC, and feel it was a success. Site leaders feel the grant was a success due to sustaining activities and positions, changes in culture, and laying the groundwork for future grants. In many cases, PhysTEC offered the chance to institutionalize changes by creating a “proof of concept” and allowing time for changes to become entrenched. Site leaders were proud of their PTE programs, including the quality of education they can provide to future teachers, and the number of teacher graduates.

I posit that institutional capacity and culture support sustained PTE outcomes, and vice versa.

PhysTEC supported institutional capacity and culture for PTE -- especially norms. This statement is supported by multiple strands of evidence. Most site leaders (N=9) mentioned a supportive culture for teaching (or for teacher education) as the most significant outcome of the grant. The other common significant outcome was the entrenchment of key programs (usually an LA program) into institutional culture and practice. Site leaders were also able to name 4-5 outcomes for each of 3 areas related to institutional capacity and culture, with about half of those outcomes identified as key outcomes. They were able to name even more outcomes (5 compared to 3-4) in “capacity and commitment,” due to changes such as faculty and administrative support and changing norms. Thus, PhysTEC supports changes in culture and norms supporting PTE (compared to structures, policy, or collaborations).

Sites have strong PTE programs which were enhanced during the PhysTEC grant. Based on PTEPA rubric results, Comprehensive II sites approach the “thriving” physics teacher education programs, with 73% of PTEPA items rated at least Benchmark (compared to 78% for thriving programs). Comp II results also rival those of the thriving programs at the standard and component level. Most sites reported increases in each area of the PTEPA, showing across-the-
board enhancement of PTE, with some exceptions. LA programs, curricular changes, and recruitment practices, were the most commonly mentioned durable outcomes.

\[ \text{PTEPA results: Comp II sites (% of items at least Benchmark)} \]

Institutionalization of LA programs can support both the culture and quality of PTE. LA programs were often institutionalized during PhysTEC, indicating a culture of support for physics education and/or teacher education. Those same LA programs enhanced the quality of PTE, and of undergraduate physics education. The strength of those LA programs then further enhanced the cultural support for physics teaching and/or physics teacher education in a positive feedback loop. This is evidenced by the fact that LA programs were named both as important cultural outcomes for sites (average of 2 outcomes/site) and as enhancements to the PTE program (average of 0.6 outcomes/site). LA programs were named by 5 as the most significant outcome.
The most common challenge is effort and personnel, followed by licensing requirements. Many champions indicated that it’s hard to keep PTE going, requiring great effort and engagement of faculty. While best if done as part of a dedicated position, usually this isn’t anybody’s “real” job. Many also mentioned that licensing requirements and time to degree, including students choosing late to pursue teaching, is a challenge.

Which of the activities initiated by the PhysTEC grant are being sustained?

Most activities were maintained for the majority of sites. Overall, it is remarkable how many activities and structures were maintained across sites. Sustainability plans from the grant were upheld and in all but two cases the institutional match commitment was upheld. For most areas of the PTEPA, activity maintained or increased since PhysTEC for at least 80% of sites. Institutional climate, team attributes, and collaboration were elements of culture which often increased since PhysTEC. In the PTE program, recruitment activities often increased since the end of the grant. Many institutional resources were maintained on average, including internal funding, the number of PTE leaders, faculty and non-faculty FTE were maintained for at least 10 out of 16 sites.

![Bar chart showing most sites maintained or increased most PTEPA areas since PhysTEC](image)

External funding often was not maintained. The most common area that was not maintained was external funding. While internal funding was maintained for 13 out of 16 sites, external funding was only maintained for 6. On the PTEPA, over 30% of sites reported decreases in “resources,” which includes funding, personnel, and space.
Human resources are often reduced since PhysTEC. Several measures of human resources were often reduced -- on the PTEPA, about 50% of sites report a reduction in the number of people on the PTE team (as evidenced both by the PTEPA data and quantitative resource data). Faculty FTE was only maintained for 10 sites, and TIR FTE was only maintained for 6 sites. Thus, while the number of PTE leaders is generally maintained, the amount of time they have to spend on PTE is often reduced, and the number in their support team is also reduced. This is often due to the loss of the TIR.
The TIR position and/or duties are often eliminated or reduced -- but this is not always a problem. A total of 9 sites maintained the TIR, and 7 eliminated the TIR position. Only 5 out of the 9 maintaining the TIR maintained them as the original job described; the other 4 reduced their FTE or had other primary job duties. Additionally, 4 were maintained as part-time TIRs, most of whom had been part-time during PhysTEC. However, in some cases losing the TIR was not a drastic loss, and sites which sustained their PhysTEC activities were only slightly more likely to have sustained their TIR as well. Thus, a TIR may be valuable, but not necessary. Additionally, well-sustained sites were more likely to have part-time TIRs, showing that even a part-time position can be very valuable.

TIRs are often maintained through a regular departmental position. Most maintained TIRs were in regular positions such as lecturer, instructor, or lab coordinator, with a portion of their duties dedicated to TIR-like jobs.

TIR sustainability may be helped by including LA programs within their duties. In most cases the TIR’s current job included directing or coordinating the LA program, and/or teaching the pedagogy course. During PhysTEC, half of TIRs worked with the LA program, usually recruiting LAs, mentoring them, and teaching the pedagogy course. Such duties may help maintain the TIR position for some sites -- 66% of maintained TIRs worked with the LA program, in contrast to only 28% of discontinued TIRs.

LA programs were almost always maintained; broad support for the LA program helped enable many elements of PTE to maintain. Only 2 sites studied did not maintain their LA program; all other 13 sites with an LA program maintained that program. Not all these programs were created by PhysTEC (8 new programs were created), but PhysTEC helped to institutionalize or maintain most of the existing programs. Qualitatively, I heard that institutional support for the LA program created an internal drive to keep the LA program going, often leading to finding a way to hire the TIR to run it and/or to teach the pedagogy course. A wide range of funding strategies were used to support the LA program, from soft money requests,
federal work study, provost funding, course fees, and an external gift. While the LA program was often only indirectly related to PTE, having such a program created many benefits supporting PTE, such as hiring a TIR, teaching a pedagogy course, and providing a community for future teachers.

**What factors contributed to success in sustainability? What is the outlook for sustaining PhysTEC activities longer term?**

**Unsustained sites lacked champions, resources, and capacity for PTE.** Recalling that only 2 sites did not sustain their activities, what characterized these two outliers? Notably, they did not have a champion, and there were also very few resources allocated to PTE (e.g., funding, people, and FTE). These unsustained sites also reported reduction in all these areas since the end of PhysTEC. Unsustained sites also had very low PTEPA ratings, were rated as “low” capacity for PTE based on leadership, institutional climate, and resources, and tended to be at smaller departments.

**While external factors were not clearly related to sustainability, sustainability increased with the number of majors and with postbac pathways.** Local teacher salaries were not related to levels of sustainability, nor was the year of funding (i.e., year of PhysTEC RFP). However, the department size did increase for more well-sustained sites compared to “unsustained” or “mixed” (42 majors graduated/year for “grew”, versus 25, 22, and 20 for “sustained”, “mixed” and “unsustained” respectively). “Sustained” and “grew” sites also experienced greater growth in their major since funding ended (+15-16 majors/year on average compared to +8 majors/year). The percentage of majors choosing to become teachers also increased with the sustainability level, at 8%, 9%, 10% and 11% for each increasing level of sustainability, respectively. Well-sustained sites (those which “sustained” or “grew”) tended to include a post-baccalaureate pathway as one of the main ways in which students achieved certification, and more students were graduated through these pathways than through undergraduate-only routes.
Site capacity and culture is necessary but not sufficient for sustained outcomes. Each site was rated on their capacity and culture for PTE based on their leadership strength, institutional culture, and resources. All “grew” sites were rated as “high capacity,” most “sustained” and “mixed” sites were rated medium or high capacity and all “unsustained” sites were rated low capacity. Thus, “medium capacity” may be a threshold for good results, but “high capacity” is necessary but insufficient for exemplary results.

Exemplary sites have overall strong programs, as judged by the PTEPA. “Mixed” sites have overall intact PTE programs but experience other difficulties. Sites which “grew” have higher overall PTEPA ratings (86% rated at least Benchmark) than “Sustained,” “mixed,” or “unsustained” sites. However, ratings between “sustained” and “mixed” were similar in this metric. “Mixed” sites have PTEPA results which rival or exceed those of stronger programs (e.g., “thriving,” “sustained,” or “grew” programs). This suggests that the PTE programs at “mixed” sites are structurally strong, but they are not achieving high graduation rates or there is some other noted dysfunction from the evaluation keeping them from reaching “sustained” status. This also suggests that PTEPA ratings can only differentiate at the edges of the scale (exemplary versus non-functional programs); the PTEPA alone cannot differentiate solid and weaker programs, and neither can graduation rates or site leaders’ self-ratings. However, when taken as a whole, these measures can help distinguish institutions.

Institutional climate seems to differentiate sustained sites from truly thriving ones. Several points of evidence support this statement. First, the sites which “grew” were very strong in “institutional climate and support” (PTEPA 1A) and “program collaboration” (PTEPA 2C) with over 90% of items rated at least Benchmark. “Program evaluation” was also highly rated at these sites. In addition, more of the “grew” sites reported further improvement in PTEPA 1A since PhysTEC ended. In comparison, at “sustained” sites, the components in the PTEPA standard “Institutional commitment” were rated at similar levels as “sustained” and “unsustained” sites. Thus, “sustained” sites may have maintained their programs and outcomes because of the efforts of champions, rather than due to broader commitment to the cause. Truly exemplary sites may be differentiated by enhanced institutional commitment.
Sustainability may be enhanced by structural outcomes, and overall resiliency. Among the written outcomes, sites which “sustained” or “grew” named more outcomes in structure and policy compared to less well-sustained sites and named more of these outcomes as key. These structural outcomes were often the same things that kept things going, such as certification pathways, advising policies, and putting a course on the books. Additionally, those at “sustained” or “grew” sites were typically able to name a wide array of things that keep the PTE program going (from culture, to structure, to champions), showing more overall resiliency than “mixed” or “unsustained” sites.

Well-sustained sites maintain the PTE program structures and practices; recruitment and mentoring often fall away at less maintained sites. None of the sites rated as “sustained” or “grew” reported any decrease in PTEPA ratings since PhysTEC ended in standards 3-6 (assessing recruitment, coursework and preparation, mentoring, community, and assessment). Sites which “grew” had particularly strong ratings in “recruitment opportunities,” “recruitment activities,” and “early teaching experiences.” Less well-sustained sites (“mixed” and “unsustained”) reported more across-the-board decreases on the PTEPA since PhysTEC, but especially in recruitment activities (component 3B) and mentoring (standard 5).

Well-sustained sites maintain greater human and financial resources, including the number of leaders and a PTE team. Sites with greater levels of sustainability had generally higher levels of internal and external funding, greater numbers of PTE leaders and team members, and greater FTE spent by faculty. Many of these metrics maintained or grew since PhysTEC for “sustained” and “grew” sites, and often decreased at the other sites. On the PTEPA, the program team members and team attributes components (2A and 2B) decreased at 67% of “unsustained” or “mixed” sites compared to 44% of well-sustained sites. “Sustained” and
“grew” sites are more often part of a team focused on PTE. Leader turnover, champion positional power, or having a TIR, was not clearly related to sustainability levels.

Students at former PhysTEC sites receive quality preparation regardless of site sustainability. All sites including “unsustained” sites were found to have ratings in the PTEPA “Knowledge and Skills” standard which rivalled those of thriving programs -- this standard includes physics content and pedagogy, and field experiences. Additionally, nearly all sites experienced growth in PTEPA ratings during PhysTEC funding, regardless of sustainability level, showing that Comprehensive grant funding improved PTE programs.

UTeach is not necessarily a good sustainability plan. With only 3 UTeach replication sites, it is difficult to make strong statements. However, all UTeach replication sites were in the “unsustained” or “mixed” groups, and I observed that physics department ownership, and TIR connection, was often reduced in UTeach sites. UTeach Master Teachers did not offer a good replacement for a PhysTEC TIR, typically, because they have less connection to the physics department and engage in less recruitment. A UTeach Master Teacher also would not typically be engaged with an LA program which, as reported earlier, can be an important part of a healthy PTE ecosystem.

Drivers of sustainability include people, money, structure, culture, and routine. When asked what keeps a particular outcome going, there were some common themes, listed here in order of decreasing frequency. One was the effort of champions, and often the institutionalization of a position for that champion (such as a TIR or including PTE courses within a faculty course-load). Money, including grant funding, were named as useful. Structures were commonly named, such as formalized PTE program structures, LA programs, or certification pathways. Lastly, culture change kept things going, such as support for teaching careers, or inertia and routine. Several people mentioned that the length of the PhysTEC grant, and the 3-year institutional match period, was critical for establishing the culture and routine necessary to argue successfully for the structures, people, and money needed to maintain the program.
What was PhysTEC’s contribution to success?

PhysTEC provided resources to start the program, enabling proof-of-concept to maintain it. Site leaders indicated that the funding from PhysTEC was essential, allowing them to hire TIRs, establish an LA program, and/or develop coursework. It also created impetus and accountability for moving things forward, both for champions and their education counterparts. Through this activity, PTE was legitimized, generating credibility, creating a critical mass of students in the program, allowing leaders to demonstrate success and argue for continued support. In many cases (N=5) PhysTEC funding paved the way for future funding from the NSF.

Site leaders request post-funding engagement, and less management. Site leaders would like to continue their connection to PhysTEC and to have opportunities to continue to grow their work. Many also requested less management during the grant, including allowing them to choose whether to rotate a TIR. They also suggest emphasizing the importance of the TIR, and helping leaders strategically leverage the institutional match period.

Site leaders also request focusing on other externalities. Other areas site leaders would like PhysTEC to focus on are in-service teachers, state requirements, and state advocacy.
Conclusions and discussion

In this section I will discuss the meaning and interpretation of these findings.

**PhysTEC Comprehensive Sites achieve meaningful results for institutions, and the nation.**
I would like to emphasize the strength of formerly funded PhysTEC Comprehensive sites; all but two were rated as sustained to some degree, and about half are truly thriving. These sites spend time and money on PTE and have functional PTE programs -- more than can be said for most physics departments. On average these sites also grew and sustained their graduation rates by 1.3 teachers/year, and those which did increase their graduation rates did so by 2 teachers/year on average. Even at sites without enhanced graduation rates, their capacity for effective PTE is much higher than it was before the grant; they are poised for success. The PTE programs are, overall, stronger at all these institutions than it was before the grant. In the cases of the most exemplary sites, their PTE programs and institutional commitment is off the charts. The outcomes which were observed align quite well with PhysTEC’s values -- e.g., institutional commitment, leadership, culture, and structure. This suggests that the PhysTEC model is overall working. Site leaders, PhysTEC, and its funders, should be very proud of these achievements.

**PhysTEC supports organizational capital and a healthy ecosystem for PTE at institutions.**
I found evidence for across-the-board improvements to PTE, including institutional capacity and culture, resources, leadership, collaboration, recruitment, mentoring, and assessment. The majority of activities were maintained for most sites. Many sites institutionalized LA programs which provided a recruitment cool and community for future teachers in many cases, and in other cases supported a strong undergraduate physics program and enabled support of a TIR and/or pedagogy course. PhysTEC thus created intellectual and organizational capital that is important for PTE, as well as activities that provide a supportive ecosystem for PTE to thrive, now or in the future.

**It is difficult to maintain leadership, time, and effort, leading to fragility.**
The most common areas that fell away were the time and personnel to focus on PTE. TIRs were maintained at 9 out of 16 sites, but 4 of these 9 were in a reduced capacity. Many leaders spoke of the difficulty of continuing to work hard to support PTE, including continuing to onboard faculty, without it being their “real job.” PER faculty were sometimes valuable for this effort, but not every PER faculty has time or interest to focus on PTE. Focused time and effort was often difficult, and without it, the work either languished or weakened. Unsustained sites were typified by a lack of leadership, resources, and institutional support. The need for champion efforts can lead to fragility of PTE programs. When a “hero effort” is required, things can also fall apart. Structural supports can help; see below.

**Culture, including structure and routine, can help with sustainability.**
These challenges can and were overcome by culture, including structure, policy, routine, and institutional support. Dedicated funding, positions, including PTE in formal duties, LA programs, policies, and routine were helpful in maintaining activities, as were strong institutional climate and collaboration. Many of these structural supports are part of the normative supports for undergraduate education. These supports, when present, can help reduce the “hero effort” required of PTE.

**Motivated people, site capacity, and institutional culture are important, but insufficient on their own. Exemplary results require all elements of the model to be exemplary.**

I return to the theoretical model described earlier. Across this evaluation I found strong support for this model. Motivated people are important, but not sufficient for site sustainability; without a champion, efforts languished. If people can generate structures and begin to establish cultures that support PTE, the success and proof of concept of the PTE program can feed back into the program’s continued success and cultural support. I have also added threats to the model below. Both unsustained and mixed sites were hampered by severe threats, such as budget cuts and personnel loss. All sites experience threats, and some are able to mitigate those threats, and some are not. These threats are often outside the control of motivated people and are often unable to be mitigated despite best efforts and strategy. I place it within the “opportunities” bubble since opportunities and threats are often two sides of the same coin (e.g., a retirement might be an opportunity if it eliminates an intransigent faculty, or it might be a threat if it eliminates a willing champion).

I found evidence that site sustainability increased overall as more elements from the model were added. Without a motivated person, the site was unsustained. If there were motivated
people, and adequate PTE programs, but local structures or lack of opportunities keep them from achieving better results, results were “mixed”. Sites were “sustained” when capacity and culture were overall strong, including motivated people, good opportunities, and supportive structures for PTE -- in other words, good intellectual and organizational capital. However, truly exemplary results (“grew” sites) were observed when the institutional climate was exceedingly strong and leaders mediated opportunities strategically to generate that structure and culture. For well-sustained sites, the PTE outcomes (number of graduates, and the quality of preparation of those graduates) did appear to feed back into the culture and structure for PTE by demonstrating success and establishing proof-of-concept and value.

In other words:

1. Few elements of this mode + threats → Unsustained site with low capacity
2. Mostly motivated people → Mixed results, but good PTE program
3. Mostly motivated people + structure → Sustained results with many graduates
4. Motivated people + structure + culture → Exemplary (“grew”) results

Or in graphical form:

This model represents merely a hypothesis. While it is supported by the data, this is in correlational form only, and we cannot infer the causality suggested by this diagram.

Based on this study, here are some examples of each of these key elements:
<table>
<thead>
<tr>
<th>Motivated people</th>
<th>Opportunities/Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Champions</td>
<td>● Funding (internal and external), including Noyce and existing funding streams (e.g., for SIs or grad students)</td>
</tr>
<tr>
<td>● PTE team</td>
<td>● 3-year institutional match period</td>
</tr>
<tr>
<td>● TIR (may be part-time)</td>
<td>● Retirement/hiring/turnover in department or administration</td>
</tr>
<tr>
<td>● PER faculty</td>
<td>● Champion power</td>
</tr>
<tr>
<td>● Advisors</td>
<td>● Global pandemics</td>
</tr>
<tr>
<td>● Instructors, especially of intro course</td>
<td>● State-level certification requirements</td>
</tr>
<tr>
<td>● Education partners, especially with physics backgrounds, including teacher of Methods course, university supervisor, advisor, UTeach director</td>
<td>● Department needs (students, TAs)</td>
</tr>
<tr>
<td>● Local K12 partners, including district science coordinator</td>
<td>● Size of major</td>
</tr>
<tr>
<td>● Program alumni</td>
<td>● Grants (e.g., Noyce, S-STEM, GFO)</td>
</tr>
<tr>
<td>● Department chair</td>
<td>● Recognition from APS or others</td>
</tr>
<tr>
<td>● Administrators, especially with education backgrounds</td>
<td>● Local need for physics teachers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
<th>Culture</th>
</tr>
</thead>
<tbody>
<tr>
<td>● LA program</td>
<td>● Funding decisions, resource allocation, hiring decisions</td>
</tr>
<tr>
<td>● Positions (for TIR, instructor, etc.)</td>
<td>● Faculty awareness of need for PTE</td>
</tr>
<tr>
<td>● Courses “on the books”, and listed</td>
<td>● Perceptions of teaching among students/faculty</td>
</tr>
<tr>
<td>● Teaching assignments</td>
<td>● Faculty or admin support* in physics and/or education</td>
</tr>
<tr>
<td>● Certification pathways, including dual certification and post-bac</td>
<td>● Use of active learning in physics</td>
</tr>
<tr>
<td>● Counting education credits in physics</td>
<td>● Routine and norms</td>
</tr>
<tr>
<td>● Teaching concentration in physics</td>
<td>● “Proof of concept” for PTE program</td>
</tr>
<tr>
<td>● BA in physics</td>
<td>● Collaboration between education and physics</td>
</tr>
<tr>
<td>● Graduate assistantships</td>
<td>● Community for pre-service physics teachers</td>
</tr>
<tr>
<td>● Noyce grants</td>
<td>● Community for in-service physics teachers</td>
</tr>
<tr>
<td>● UTeach</td>
<td>● Institutional mission / history of teacher education</td>
</tr>
<tr>
<td>● Advising structure</td>
<td>● Student demand for courses / interest in teaching</td>
</tr>
<tr>
<td>● Active learning in physics curriculum</td>
<td>● “For reformed teaching, PTE, disciplinary teacher preparation, and/or LA program.”</td>
</tr>
<tr>
<td>● Intro physics reforms</td>
<td></td>
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</tbody>
</table>
In the best cases, PhysTEC “lifts all boats” in the department. PhysTEC often helped the department support teaching excellence, through using the TIR as an instructional coach for faculty, supporting a thriving LA program, using PTE candidates as well-trained TAs in undergraduate courses, and generating conversations about educational outcomes. There are many institutional mechanisms to support active learning (such as teaching evaluations and course assignments), but fewer available to support PTE specifically; thus, it may be valuable for PTE to “hook onto” the existing institutional mechanisms supporting teaching excellence and a thriving undergraduate program. For example, rather than generating a conversation about how to support an undergraduate pathway to teaching certification only, a broader conversation about career pathways and concentrations in the major might be easier. This suggests a broadened model, below, showing PTE as part of the ecosystem of undergraduate education within the department.

Recommendations were made to PhysTEC based on these results, including in areas of PhysTEC strategy, support for funded and legacy sites, and data collection and evaluation. Key recommendations include continuing to offer Comprehensive grants, determining how to support the common postbac pathways, strategically supporting undergraduate improvement within physics departments, and engaging legacy sites. Recommendations for supporting sustainability among funded sites are also provided.