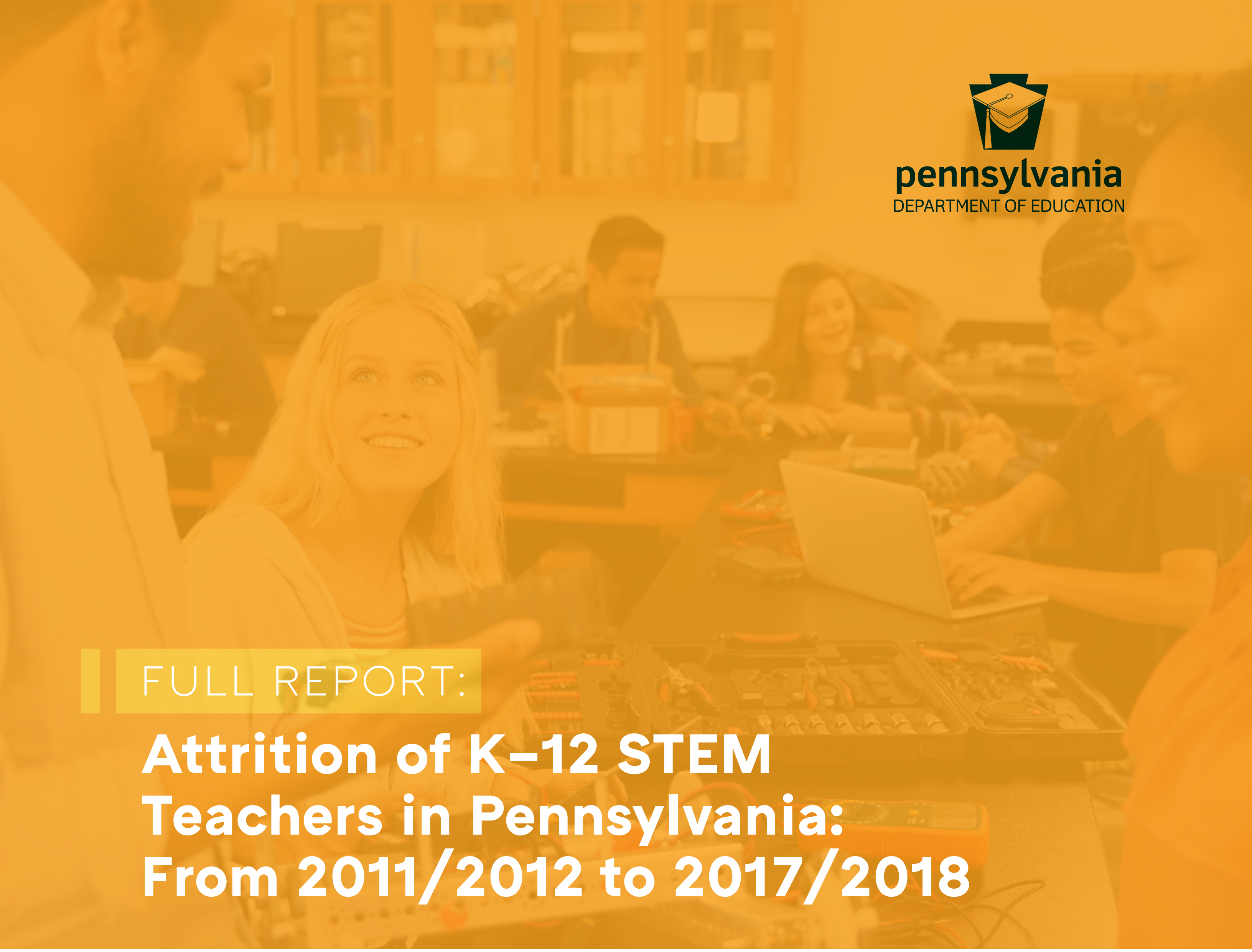

FULL REPORT:

Attrition of K–12 STEM Teachers in Pennsylvania: From 2011/2012 to 2017/2018

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Research and Evaluation

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Abstract

State education agencies seek to understand the stability of their teacher workforce, particularly in subjects considered difficult to staff, such as science and math. The present study uses survival analysis and longitudinal administrative records from the Pennsylvania Department of Education to investigate the retention of K-12 STEM teachers in the state's public schools, including charter schools. We calculate the average time a STEM teacher is employed in the school where they were first hired and use Cox proportional hazard models to identify risk and protective factors associated with attrition, in five subgroups of teaching assignments responsible for STEM content: Elementary All Subjects, Middle/Secondary Science, Middle/Secondary Math, Computer and Information Technologies, and Other Career and Technical Education. Half of newly hired STEM teachers left a full-time assignment at their school of hire after approximately four to six years of employment, depending on their STEM teaching assignment. The results of this study represent one aspect of understanding equitable access to STEM experiences for all students in Pennsylvania.

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The mission of the Department of Education is to ensure that every learner has access to a world-class education system that academically prepares children and adults to succeed as productive citizens. Further, the Department seeks to establish a culture that is committed to improving opportunities throughout the commonwealth by ensuring that technical support, resources, and optimal learning environments are available for all students, whether children or adults.

> Research suggests that the presence of a teacher is not enough to guarantee successful learning and that learning outcomes in any subject are positively associated with the annual stability of the teacher workforce.

Introduction

In 2017, the Policy Committees of the House of Representatives of Pennsylvania held a hearing on the state's "STEM learning ecosystem," the nexus of schools, after-school programs, community settings, museums, employers, and informal experiences that serve as students' learning environments for science, technology, engineering, and math (STEM) content (Traphagen & Traill, 2014). The hearing opened with the following remarks:

> Pennsylvania's future rests on [the] capacity of our young people to become the next 'solutioneers' to society's greatest challenges. Building the capacity of every learner to be resilient problem solvers with the ability to communicate, collaborate with a diverse range of people, and deploy a broad range of STEM skills from design thinking to computational thinking will ensure Pennsylvania is prepared for the needs of the STEM workforce.
>
> … In Pennsylvania, there will be approximately 300,000 jobs that require STEM skills or content by 2018; and over the next decade, 71 percent of new jobs will require computer science skills. … By 2025, more than 60 percent of jobs in Pennsylvania will require some form of postsecondary education or training …
>
> These projected opportunities … make the imperative for ensuring pathways for equitable access to STEM experiences for all students in Pennsylvania even more urgent (House of Representatives of Pennsylvania, 2017, p. 9).

One pathway to equitable STEM education is students' equal access to teachers who engage them in science, engineering, and math practices (National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Research Council, 2012). Research suggests that the presence of a teacher is not enough to guarantee successful learning and that learning outcomes in any subject are positively associated with the annual stability of the teacher workforce.

Some proportion of teachers leave their schools each year, and the departure might be to another school, district, or state, or to another profession altogether. Instability in the form of annual teacher turnover can disrupt curriculum coherence and the quality of instruction, adversely affect student achievement on standardized tests, and cost districts time and money, particularly for recruitment efforts in hard-to-staff subjects like secondary mathematics and science (Blazar, 2015; Carver-Thomas & Darling-Hammond, 2017; Goldhaber, Grout, et al., 2015; Loeb et al., 2005; Papay & Kraft, 2016; Ronfeldt et al., 2013; Synar & Maiden, 2012). STEM teachers are particularly vulnerable to turnover because their specialized skill sets can make available jobs in other, higher-paying industries (Carver-Thomas & Darling-Hammond, 2017; Goldhaber, Krieg, et al., 2015; Walsh, 2014). Science and math are subject areas with some of the highest K-12 teacher turnover rates nationally (Carver-Thomas & Darling-Hammond, 2017; R. M. Ingersoll, 2003) and are notoriously difficult positions for schools to staff. Shortages in the supply of science and math teachers have been associated with American students' underperformance on international assessments and with concerns that these students will not develop into an economically competitive workforce capable of technological innovations (R. Ingersoll & Perda, 2009; Kuenzi, 2008; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Science and Technology Council, 2018).

The following study investigates the retention of K-12 STEM teachers in public schools in Pennsylvania by identifying, over a seven-year period, the proportion of teachers who no longer teach full-time in the school where they were first hired. The study employs survival analysis, a statistical method used to analyze factors associated with a higher or lower risk of an event happening (Allison, 2010). In this case, the "event" is a teacher ceasing to teach full-time in the school where they were first hired. The results of this study represent one aspect of understanding equitable access to STEM experiences for all students in Pennsylvania. The following analysis clarifies the extent to which the state's STEM educators remain in their roles and risk factors associated with higher attrition rates in these critical subjects.

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(Carver-Thomas & Darling-Hammond, 2017; Goldhaber, Krieg, et al., 2015; Walsh, 2014)

Literature

Defining STEM education and the STEM teacher workforce

In the last two decades, science, technology, engineering, and math (STEM) education has emerged as a national learning priority (National Research Council, 2012) but eluded a precise definition or list of courses or school subjects. For example, the Pennsylvania STEM Coalition defines STEM education as "an integrated, interdisciplinary, and student-centered approach to learning that encourages curiosity, creativity, artistic expression, collaboration, computational thinking, communication, problem solving, critical thinking, and design thinking" (Pennsylvania Department of Education, 2020d). National frameworks for STEM education focus on the cross-cutting nature of STEM skills and content and STEM subjects' role in preparing students for high-skill careers. For example, the National Research Council's (2012) framework for STEM education charged schools with "[ensuring] that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology" (p. 1). More recently, the National Science and Technology Council (2018) Committee on STEM Education added the goals of digital literacy for all Americans, and increased diversity, equity, and inclusion in STEM fields and employment, to existing frameworks. Students' coursework and experiential learning in science, technology, engineering, and mathematics is meant to accomplish many outcomes.

Although "STEM education has been evolving from a convenient clustering of four overlapping disciplines toward a more cohesive knowledge base and skill set critical for the economy of the 21st century" (National Science and Technology Council, 2018, p. 1), studies of STEM teacher retention must identify the relevant workforce by some criteria, such as a roster of school subjects or areas of teacher licensure. Literature on STEM education suggests that the coursework comprising K-12 STEM learning has evolved significantly over time. According to Salinger & Zuga (2009), students primarily learned STEM content through departmentalized math and science courses (such as elementary and middle school general science or high school algebra, biology, chemistry, earth science, and physics) from the 1950s through the 1990s, at which point the National Science Foundation (NSF) and others began integrating technology into school curricula and states began adopting technology standards. The place in current curricula for technology, engineering, or integrated STEM content is not always clear, and technology education "has been in flux for decades" (Dugger, 2007; National Academies of Sciences, Engineering, and Medicine, 2020, p. 78). Pre-college teaching of engineering has been limited, primarily appearing in "career and technical education" (CTE) high school coursework (National Academies of Sciences, Engineering, and Medicine, 2020; Salinger & Zuga, 2009). "CTE" replaced the term "vocational education" in the early 2000s to reflect the goals of teaching cross-industry technical skills and credentialing students for high-skill jobs, updated from vocational education's traditional focus on agriculture, trades, and industry (Association for Career and Technical Education, 2020). Brown et al. (2011) note that there is not consensus among researchers or practitioners on how to define STEM – "Which sciences are included, and does the level of math matter, and how is technology defined?" – nor consensus on its implementation – "Is it STEM education when all four concepts are taught in separate classes? ... Or does a student only receive a STEM education when the four areas are integrated in one or more courses?" (p. 6). A concern in the literature is that technology and engineering education are overlooked or taught only in service to science and math (Daugherty, 2009; National Academies of Sciences, Engineering, and Medicine, 2020).

> Literature on STEM education suggests that the coursework comprising K-12 STEM learning has evolved significantly over time. There is not consensus among researchers or practitioners on how to define STEM.

Studies of STEM teacher retention employ a wide range of criteria to identify the target population of STEM teachers. Many studies focus on science and/or math exclusively, such as Rinke (2014), whose analytic sample is limited to secondary teachers assigned to Biology, Chemistry, and Environmental Science; Goodpaster et al. (2012), whose analytic sample comprises high school teachers of biology, earth science, chemistry, mathematics, and physics; Carver-Thomas & Darling-Hammond (2017), who calculate retention for teachers whose self-reported main teaching subject is mathematics or science; or Murnane & Olsen (1990), whose analytic sample contains teachers of elementary all-subjects and secondary biology, mathematics, chemistry, and physics. Ingersoll & Perda (2009, 2010) conducted an empirical investigation of teacher shortages in math and science, following teachers with an in-field undergraduate major (a major in mathematics, statistics, engineering, math education, biology, physics, chemistry, geology, another natural science, or science education), regardless of the teacher's assignment once hired. Fewer studies include engineering, computer science, or other technology teaching assignments alongside science and math; Hutchison's (2012) case study is one exception. A small literature is dedicated specifically to the retention

CTE teachers, but studies typically group the wide range of CTE endorsements or specialties into one combined sample (e.g., Briggs, 2008; Hasselquist & Graves, 2020; McCaslin & Parks, 2002; Mordan, 2012; Song et al., 2011; Walter & Pellock, 2004). Concerns about teacher supply shortages and high attrition rates are common across all definitions of the STEM teacher workforce.

In Pennsylvania, two methods of identifying STEM teachers are through a teacher's certification area(s) or a teaching assignment. Certificates are the requisite credential for classroom teachers, and certificates appropriate for teaching STEM content include middle/secondary grades general science; middle/secondary grades mathematics; elementary K-6 (all subjects); biology; chemistry; physics; earth and space science; environmental science; business, computer, and information technology; technology education; and a range of relevant vocational specialties, including engineering, health-related technology, agriculture, electronics and electro-mechanical technology, automotive technology, and biological technology (Pennsylvania Department of Education, 2020a, 2020c). The state also offers Endorsements, credentials obtained through short programs that enhance a certification area with specialized training. Teachers wishing to better integrate science, technology, engineering, and math learning experiences and understand the role of STEM in workforce preparation can obtain an optional Endorsement in "Integrative STEM PK-12" from 24 participating universities across the state, but it is neither required to teach STEM nor a standalone credential (Pennsylvania Department of Education, 2014).

Pennsylvania first adopted K-12 academic standards for Mathematics in the 1990s; for Science and Technology, Geography, Environment and Ecology, and Career Education and Work in 2002; and for Computer Science in 2018 (Pennsylvania Department of Education, 2013, 2020b). Teaching assignments within these broad STEM-related areas, as recorded in the Pennsylvania Information Management System (PIMS), include Elementary Primary (grades 1-3) or Intermediate (grades 4-6); Middle Level Mathematics (grades 7-9); Middle Level Science (grades 7-9); Secondary Mathematics (grades 10-12); General Science (grades 10-12); Biology; Life Science; Chemistry; Physical Science; Physics; Earth and Space Science; Environmental Education; and a range of assignments related to computer, data processing, audio-visual, and information technologies, as well as job-specific technologies (e.g., automotive, electronic, or health-related). This is consistent with national evidence that STEM education during the school day primarily occurs through general math and science coursework in elementary grades, departmentalized math and science coursework in middle and secondary grades, engineering coursework in secondary career and technical settings, and technology coursework as a mix of standalone classes and integrated with other subjects.

> However the STEM workforce is identified, literature on national supply and demand finds that teachers in STEM roles are more difficult to recruit and hire and more likely to depart for other schools, districts, or jobs than teachers in most other subjects.
>
> (Carver-Thomas & Darling-Hammond, 2017; Hutchison, 2012; R. M. Ingersoll, 2003; R. Ingersoll & Perda, 2010; Rinke, 2014)

Given the decisions of prior researchers in the STEM teacher retention literature and available data from the PIMS system, this study used teaching assignment to identify a base cohort of STEM teachers in Pennsylvania. The study broadly defined STEM as any coursework with science-, technology-, engineering-, or math-related content. The researchers defined five broad "STEM categories" and classified individual teaching assignments as members of a relevant category. The full list of PIMS teaching assignments considered "STEM" for the purposes of this study appear in Table 1.

National STEM teacher recruitment, staffing, and retention

However the STEM workforce is identified, literature on national supply and demand finds that teachers in STEM roles are more difficult to recruit and hire and more likely to depart for other schools, districts, or jobs than teachers in most other subjects (Carver-Thomas & Darling-Hammond, 2017; Hutchison, 2012; R. M. Ingersoll, 2003; R. Ingersoll & Perda, 2010; Rinke, 2014). The national supply of STEM teachers is a matter of concern for school districts, state and federal policymakers, and researchers (e.g., National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Science and Technology Council, 2018; House of Representatives of Pennsylvania, 2017). Science and math teacher vacancies are consistently described in policy and research as difficult to staff (Aragon, 2016; Clark et al., 2013; R. Ingersoll & Perda, 2010; Malkus et al., 2015). Regional shortages of technology educators are also reported (National Academies of Sciences, Engineering, and Medicine, 2020). The No Child Left Behind Act of 2001 acknowledged staffing difficulties for STEM teacher roles by allowing states to use Title II funds for "carrying out programs that establish, expand, or improve alternative routes for state certification of teachers and principals, especially in the areas of mathematics and science" (NCLB, 2001, qtd. in Clark et al., 2013), and President George W. Bush promised to enlist 30,000 new math and science teachers in the national workforce during the 2006 State of the Union Address (R. Ingersoll & Perda, 2010).

STEM teacher shortages and attrition are most acute in urban and rural schools, as compared to suburbs and large towns.

The demand for STEM teachers is also high, a function of the turnover rates in these subject areas. Annual turnover rates for science and math teachers nationwide are estimated between 13 and 16 percent, lower only than ESL and special education (Carver-Thomas & Darling-Hammond, 2017; R. M. Ingersoll, 2003). These general trends have persisted for decades; for example, statewide studies from the late 1980s in Michigan and North Carolina found that high school chemistry and physics teachers reported the shortest median stay at the school in which they were first hired, versus other subjects (Murnane & Olsen, 1990). Turnover rates of technology, engineering, and other STEM-relevant CTE endorsements are more difficult to locate in the literature. Mordan (2012) used the federal Beginning Teacher Longitudinal Study (BTLS) to estimate that 16.1% of CTE teachers leave the teaching profession after one year, higher than the 10.3% attrition rate for the entire BTLS sample.

Evidence suggests that high STEM teacher turnover rates are not common to all schools, though, and national turnover rates mask variation in staffing and retention at the school level (Aragon, 2016; Borman & Dowling, 2008; Cowan et al., 2016; R. M. Ingersoll & May, 2012; R. Ingersoll & Perda, 2010). Ingersoll & Perda (2010) concluded from surveys conducted by the National Center for Education Statistics that "the production of new [math and science] teachers through teacher preparation programs and hiring problems are not evenly distributed across different locations … the largest source of difference in hiring problems is … between schools, even within the same district" (p. 585). STEM teacher shortages and attrition are most acute in urban and rural schools, as compared to suburbs and large towns. Nationwide, Ingersoll & Perda (2010) concluded that "there is a large, annual, asymmetric reshuffling of a significant portion of the math science teaching force, with a net loss on the part of poor, minority, rural and urban schools and a net gain to nonpoor, nonminority suburban schools" (588). Goodpaster et al. (2012, p. 9) emphasized the "major challenge" rural schools face in filling vacancies and retaining teachers, particularly in the physical sciences and in computer science. Across locales, schools with a significant proportion of students in poverty also report higher rates of science and math teacher turnover (Carver-Thomas & Darling-Hammond, 2017; R. M. Ingersoll & May, 2012). A study by Carver-Thomas and Darling-Hammond (2017) used nationally representative survey data to calculate an annual science and math teacher turnover rate of 17.8% in Title I schools versus a rate of 10.5% in non-Title I schools.

Prior research provides several explanations for the high attrition rates of STEM teachers, on average. Retirements account for less than one-quarter of math and science teacher turnover (R. Ingersoll & Perda, 2010). Job dissatisfaction, or "a desire to obtain a better job or career," is the primary reason cited by science and math teachers on surveys administered by the National Center for Education Statistics, followed by family or personal reasons, or staffing decisions on the part of the school (R. M. Ingersoll & May, 2012, p. 449). Two in-depth case studies of high school STEM teachers found that the quality of mentoring and professional development during a teacher's first year contributed to job satisfaction and intentions to stay (Goodpaster et al., 2012; Hutchison, 2012). Hasselquist & Graves' (2020) small case study of factors related to CTE teacher retention reiterated the importance of professional support and space to innovate on the job.

> Job dissatisfaction is the primary reason [reason for turnover] cited by science and math teachers on surveys administered by the National Center for Education Statistics.
>
> (Ingersoll & May, 2012)

As job opportunities for people with skills in technology, data processing, mathematics, and other STEM skills expand in industries outside of education, and whole careers become multipart, many educators may view teaching as "temporary work in building a varied career" (Rinke, 2014, p. 19). Rinke (2014) suggests this is particularly relevant for the STEM workforce. Survey data from the National Center for Education Statistics report that early-career math and science teachers are more likely than other teachers to hold noneducation academic degrees than education ones (e.g., more likely to hold a bachelor's degree in biology or chemistry than a bachelor's degree in science education) and also more likely to possess a master's or doctoral-level degree (R. Ingersoll et al., 2012). STEM teachers' specialized skill sets often qualify them for attractive, higher-paying jobs in other industries (Carver-Thomas & Darling-Hammond, 2017; Goldhaber, Krieg, et al., 2015; Murnane & Olsen, 1990; Walsh, 2014). Since the early 1960s, researchers have argued that "the insensitivity of teachers' compensation to differences in opportunity cost" explains some of the recruitment and retention difficulties in STEM subject areas (Murnane & Olsen, 1990, p. 107). Some states have implemented strategic compensation policies to incentivize STEM teacher retention, such as targeted bonuses for STEM and special education teachers in North Carolina, or loan forgiveness for teachers in high-needs licensure areas in Florida, which subsequently improved retention (Cowan et al., 2016).

Educator preparation programs are also a factor in STEM teacher retention (Carver-Thomas & Darling-Hammond, 2017; R. Ingersoll et al., 2012). Alternative certification pathways to teaching often result in early-career educators' shorter-term engagements with the teaching profession, and more science and math teachers are alternatively certified than other subject-area teachers (R. Ingersoll et al., 2012). More than 40 percent of all teachers enter the profession through "nontraditional or alternative routes" (R. Ingersoll et al., 2012), and high-profile alternative certification programs, such as Teach for America, place candidates in hard-to-staff schools and subject areas by design (Clark et al., 2013; Heilig & Jez, 2010). Although these dynamics are problematic for retention, "short-term" teachers can bring advanced proficiency in high-needs subjects, even if their tenure in the profession is unclear (Raue & Gray, 2015).

The rates at which STEM teachers leave their school assignment is a policy concern to state education agencies because of the many adverse effects of high teacher attrition. Across all subject areas, teacher workforce instability is associated with reduced student achievement; instability includes hiring teachers after the start of the school year (Papay & Kraft, 2016); reassigning teachers to a different grade, subject, or school (Atteberry et al., 2017; Blazar, 2015); or teachers departing from the school in which they work (Ronfeldt et al., 2013). Recruitment and staffing activities cost districts both money and time, especially when replacing teachers in hard-to-staff subjects like math and science. One estimate suggests that urban districts spend in excess of $20,000 for each teacher they replace (Carver-Thomas & Darling-

Hammond, 2017; Papay & Kraft, 2016). Teacher departures can have a destabilizing effect on a school's climate and community for both teachers and learners (Carver-Thomas & Darling-Hammond, 2017; Ronfeldt et al., 2013). As states and districts strive to make evidence-based decisions, and as STEM education seeks to be workforce-relevant and technologically current, turnover can undermine knowledge about what works with respect to programs, products, and policies.

As STEM education seeks to be workforce-relevant and technologically current, turnover can undermine knowledge about what works with respect to programs, products, and policies.

Although this body of evidence suggests that much about teacher turnover is detrimental, it is important to note that some degree of turnover is to be expected or even desired. Retirement, for example, is a standard and reasonably forecastable phenomenon (Carver-Thomas & Darling-Hammond, 2017; Steinberg et al., 2018). Some preretirement departures are "necessary and beneficial" (R. M. Ingersoll, 2003, p. 12; Steinberg et al., 2018), and several studies report that less effective teachers are more likely to leave their jobs than highly effective teachers (Goldhaber et al., 2011; Hanushek et al., 2016; Redding & Henry, 2018). At least one study has demonstrated that districts are able to replace leavers with more effective teachers, particularly when the leaver is induced to exit on poor performance grounds (Adnot et al., 2017), although it is not known if this holds true for STEM teachers specifically. Further research is necessary to understand the net effects of teacher turnover, especially at the high magnitudes documented for the STEM teacher workforce.

Recognizing the Pennsylvania Department of Education (PDE)'s need to estimate STEM teacher turnover more accurately, the following study uses administrative records to describe and analyze attrition among STEM teachers in K-12 public schools (including charter schools) in Pennsylvania. Specifically, the study addresses the following question:

1. What is the average length of time a teacher *currently teaching* a science, technology, engineering, or math subject is employed in the same school or district?[1]

This analysis initially sought to answer a second, related research question concerning the retention of in-field STEM teachers:

2. What is the average length of time a teacher *certified* to teach a science, technology, engineering, or math subject is employed in the same school or district?

However, limitations in the data on teacher certification prevented an answer to this question as designed, so a descriptive analysis of in-field and out-of-field STEM teachers in Pennsylvania is presented instead. The supplementary analysis and additional detail on the data limitations are available in the Annex.

1 The average is computed as the median in this study. This is because the maximum survival time was capped at seven years (the period of time covered by the data), so calculating the mean survival time of teachers in the base cohort would be meaningless.

Data

Teacher-level data

Data source. Teacher-level data were obtained from various databases maintained by PDE. Information on teachers' background characteristics as well as details on their contract were obtained from the Pennsylvania Information Management System (PIMS) Staff dataset; information on teachers' assignments was obtained from the PIMS Assignment dataset; and information on teachers' professional development was obtained from the Professional Education Record Management System (PERMS).[2] Each teacher had a unique ID number, making it possible to link their data across the different datasets as well as across the different academic years. These datasets were updated on June 30 of each year, and data from the 2011-2012 academic year to the 2017-2018 academic year were included in the analysis.[3]

Teachers included in the base cohort. The base cohort included teachers who were newly hired by a K-12 public school (including charter schools) in Pennsylvania during the 2011-2012 academic year and had one teaching assignment and taught full-time in only one school that year. Teachers in the dataset who had been hired before the 2011-2012 academic year were not included in the study, because this would have over-estimated the overall survival times of teachers, because the analysis would not have taken into account the survival times of the teachers who had left the teaching profession before the beginning of the 2011-2012 academic year. In other words, the analysis would have excluded teachers whose survival times were shorter than the survival times of teachers that were still teaching in the 2011-2012 academic year.

To define the base cohort of teachers, first, staff whose contract started during the 2011-2012 academic year (i.e., between July 1, 2011 and June 30, 2012) and working full-time in the 2011-2012 PIMS Staff dataset were identified. Staff hired by private schools were excluded. For each individual in this subset, all teaching assignments (excluding any assignments in special education programs or administrative assignments) in the 2011-2012 PIMS Assignment dataset were identified, and the proportion of time assigned (PTA) to these teaching assignments were summed for each school that the individual worked in. Lastly, only the individuals whose summed PTA for the *teaching assignments* was at least 100 in a school were included in the final subset of teachers. Thus, individuals who worked full-time in one school but did not teach full-time for that school (e.g., the individual's responsibilities were split between teaching and administrative assignments) were not included in the base cohort. The resulting base cohort included 3,947 teachers.

Identification of STEM teachers. In order to identify STEM teachers in the base cohort, the authors reviewed all unique teaching assignment values in the PIMS Assignment dataset and developed five broad STEM categories to classify teachers of science, math, technology, or engineering subjects (Table 1): Elementary All Subjects, Middle/Secondary Science, Middle/Secondary Math, Computer and Information Technology, and Other Career and Technical Education. A sixth category, Non-STEM, was used to classify full-time teachers in the base cohort in all other subjects for comparison (e.g., English, History). A STEM category was assigned to each teacher in the base cohort.

Descriptive statistics of the base cohort. Table 2 and Table 3 report the descriptive statistics of teachers in the base cohort.

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2 Since the datasets included teachers' personal information, in order to receive the datasets, the research team had to receive Institutional Review Board (IRB) approval from PDE as well as sign a data use agreement and a data access agreement with them. After receiving the datasets, the research team was required to keep the datasets on the University of Pennsylvania's secure server at all times.

3 Although datasets for the 2010-2011 academic year were also available, they were not included in the analysis, because these data had been collected in January, while the data for the other years had been collected in June.

TABLE 1. Teaching assignments counted in researcher-defined STEM categories

STEM CATEGORY	TEACHING ASSIGNMENT IN PIMS
Elementary All Subjects	Elementary, Primary Grades 1-3, Elementary Elementary, Intermediate Grades 4-6, Elementary Kindergarten, age4(K4), Elementary Kindergarten, age5(K5), Elementary Alternate Education Program, K-6, Elementary
Middle/Secondary Science	Middle Level Science, 7-9, Secondary General Science, Intermediate, 10-12, Secondary General Science, Advanced, 10-12, Secondary Science, Interdisciplinary Advanced, 10-12, Secondary Biology, Secondary Life Science, Intermediate, 10-12 Chemistry, Secondary Physical Science, Advanced, 10-12, Secondary Physical Science, Intermediate, 10-12, Secondary Physics, 10-12, Secondary Earth and Space Science, Advanced, Secondary Earth and Space Science, Intermediate, Secondary Environmental Education, Secondary Alternate Education, Middle Level Science, 7-9, Secondary Alternate Education, Secondary Science, 10-12, Secondary English as Second Language, Middle Level Science, 7-9, Secondary
Middle/Secondary Math	Middle Level Mathematics, 7-9, Secondary Mathematics, 10-12, Secondary Title 1 /Remedial Math, Elementary, PreK-6 Title 1 /Remedial Math, Secondary, 7-12 Alternate Education, Secondary Math, 10-12, Secondary
Computer and Information Technology	Audio-visual Communications Technology, Secondary Business Education, Elementary Business Education, Secondary Computer Science, Elementary, PreK-6 Computer Science, Secondary, 7-12 Computer Technology, Secondary Data Processing, Secondary Digital Technology, Secondary Industrial Arts/Technology Education, Secondary Network Systems Technology, Secondary Office Technologies, Secondary Radio/Television, Secondary Technology Education, Elementary, PreK-6 Technology Education, Secondary, 7-12

STEM CATEGORY	TEACHING ASSIGNMENT IN PIMS
Other Career and Technical Education	Agriculture, Secondary Air Conditioning, Secondary Air Conditioning/Refrigeration, Secondary Allied Health Science Technology, Secondary Automotive Mechanics, Secondary Automotive Technician, Secondary Automotive Technology, Secondary Building Construction Trades, Secondary Building Trades Maintenance, Secondary Carpentry, Secondary Dental Assistant, Secondary Diesel Mechanic, Secondary Drafting-Mechanical, Secondary Electrical Occupations, Secondary Electrical Technology, Secondary Electrical, Construction/Maintenance, Secondary Electro-Mechanical Technology Electronics Technology, Secondary Engineering Related Technology, Secondary Health Assistant, Secondary Health Related Technology, Secondary Heating, Secondary Horticulture/Floriculture, Secondary Industrial Arts, Electricity Unit Shop, Secondary Industrial Arts, Metal Unit Shop, Secondary Industrial Arts, Wood Unit Shoop, Secondary Industrial Technology, Secondary Machine Shop, Secondary Maintenance Mechanic, Secondary Masonry Occupations, Secondary Masonry, Secondary Masonry/Bricklaying, Secondary Mechanical Design Technology, Secondary Mechanical Drawing (Vocational), Secondary Medical Assistant, Secondary Metalworking Occupations, Secondary Nurses' Aide, Secondary Plumbing, Secondary Sheet Metal, Secondary Small Engine Repair, Secondary Welding, Secondary

TABLE 2. Characteristics of Teachers in the Base Cohort – Categorical Variables (N = 3,513)

VARIABLE	%	FREQUENCY
STEM teaching assignment category[a]		
Elementary All Subjects	41	1,442
Middle/Secondary Science	7	242
Middle/Secondary Math	9	307
Computer and Information Technologies	3	97
Other Career and Technical Education	2	82
Non-STEM	38	1,343
Sex		
Male	28	986
Female	72	2,527
Race/ethnicity		
White	89	3,149
Black	7	229
Hispanic	2	58
Asian	1	48
Other (Native Hawaiian or Pacific Islanders, American Indian, and Multi-Racial)	1	29
Age (when hired)		
Age < 30	49	1,727
30 ≤ Age < 50	39	1,576
Age ≥ 50	12	410
Years of work experience (when hired)		
Experience < 3	48	1,696
3 ≤ Experience < 25	47	1,655
25 ≤ Experience	5	162
Highest degree earned (at the end of the 2011-2012 academic year)		
Below Bachelor's degree	2	72
Bachelor's degree	57	2,025
Master's degree	40	1,396
Doctoral / Specialist degree[b]	1	20

a. Teachers were classified in a STEM category based on their teaching assignment when hired. Refer to Table 1 for teaching assignments in each STEM category. If a teacher taught multiple STEM subjects, they were categorized into the subject with the most assigned time.
b. An educational specialist degree (e.g., Ed.S.) is a terminal professional degree for individuals who have already completed a master's degree in education.

TABLE 3. Characteristics of Teachers in the Base Cohort – Continuous Variables

VARIABLE	MEAN	SD	*N*
Annual salary (before deductions, 2011-2012 academic year)	52,464	16,770	3,505
Hours of professional development (2011-2012 academic year)[a]	40	26	2,796

a. Only ACT 48 professional development courses were included.

School-level data

Data source. School-level data were obtained from two publicly available datasets. Information on students' academic achievement was obtained from datasets maintained by PDE which were available from the 2014-2015 academic year to the 2017-2018 academic year. Other school-level information was obtained from the Common Core of Data (CCD) database maintained by the National Center for Education Statistics (NCES), available from the 2011-2012 academic year to the 2016-2017 academic year. In all datasets, schools were identified with a unique school and Local Education Agency (LEA) numbers, making it possible to link data across the different sources, including the teacher-level datasets.

Explanatory variables. Table 4 and Table 5 present the characteristics of the schools in which the base cohort teachers taught.

TABLE 4. Characteristics of Schools in which the Base Cohort Teachers Taught – Categorical Variables (*N* = 968)

VARIABLE	%	FREQUENCY
Urbanicity		
Rural	24	229
Town	12	113
Suburb	48	468
City	16	158
School size[a]		
Less than 1,000 students	82	794
1,000 or more students	18	174
Title 1 eligibility[b]		
Eligible	69	646
Not eligible	31	285
School type		
Traditional public school	86	830
Public charter school	14	138
School level		
Primary school (pre K to grade 8)	46	448
Middle school (grades 4 to 9)	16	154
High school (grades 7 to 12)	32	308
Other (other configurations not falling into the categories above)	6	58

Note: Unless otherwise noted, information is from the 2011-2012 academic year.

a. School size was calculated by averaging number of students enrolled from the 2011-2012 academic year to the 2016-2017 academic year.

b. Information on Title 1 eligibility was available for only 1,010 schools (out of the 1,048 schools in which the base cohort teachers taught).

TABLE 5. Characteristics of Schools in which the Base Cohort Teachers Taught – Continuous Variables

VARIABLE	MEAN	SD	*N*
Race/ethnicity			
% of White students	68	31	932
% of Black students	16	26	932
% of Hispanic students	9	16	932
% of Other Race/Ethnicity students[a]	6	6	932
Student-teacher ratio	15	3	932
% of male students	51	4	932
% of students below basic level for PSSA[b]	17	13	662
% of students below basic level for Keystone[c]	12	12	319

Note: Unless otherwise noted, school characteristics were calculated by averaging information from the 2011-2012 academic year to the 2016-2017 academic year.

a. This category includes Asian, Native Hawaiian or Pacific Islander, American Indian, and Multi-racial students.

b. Schools with grades 3 to 8 had data on the PSSA assessment. Results were obtained from the 2014-2015 academic year to the 2017-2018 academic year.

c. Schools with grade 11 had data on the Keystone assessment. Results were obtained from the 2014-2015 academic year to the 2017-2018 academic year.

STEM teachers' characteristics

Descriptive statistics of STEM teachers in the base cohort. Table 6, Table 7 and Table 8 report the descriptive statistics of the STEM teachers in the base cohort.

TABLE 6. Characteristics of STEM Teachers in the Base Cohort – Categorical Variables (*N* = 2,170)

VARIABLE	%	FREQUENCY
STEM teaching assignment category[a]		
Elementary All Subjects	66	1,442
Middle/Secondary Science	11	242
Middle/Secondary Math	14	307
Computer and Information Technologies	5	97
Other Career and Technical Education	4	82
Sex		
Male	26	555
Female	74	1,615
Race/ethnicity		
White	89	1,942
Black	7	153
Hispanic	1	29
Asian	2	31
Other (Native Hawaiian or Pacific Islander, American Indian, and Multi-Racial)	1	15

VARIABLE	%	FREQUENCY
Age (when hired)		
Age < 30	48	1,040
30 ≤ Age < 50	40	876
50 ≤ Age	12	254
Years of work experience (when hired)		
Experience < 3	48	1,031
3 ≤ Experience < 25	48	1,044
25 ≤ Experience	4	95
Highest degree earned (at the end of the 2011-2012 academic year)		
Below Bachelor's degree	2	47
Bachelor's degree	58	1,259
Master's degree	39	855
Doctoral / Specialist degree[b]	1	9

a. Teachers were classified in a STEM category based on their teaching assignment when hired. Refer to Table 1 for teaching assignments in each STEM category. If a teacher taught multiple STEM subjects, they were categorized into the subject with the most assigned time.
b. An educational specialist degree (e.g., Ed.S.) is a terminal professional degree for individuals who have already completed a master's degree in education.

TABLE 7. Characteristics of STEM Teachers in the Base Cohort – Continuous Variables

VARIABLE	MEAN	SD	*N*
Annual salary (before deductions, 2011-2012 academic year)	52,405	16,658	2,166
Hours of professional development (2011-2012 academic year)[a]	40	26	1,718

a. Only ACT 48 professional development courses were included.

TABLE 8. Proportion of STEM teachers in the base cohort by Category and Sex ($N = 2{,}170$)

STEM CATEGORY	FEMALE	%	MALE	%
Elementary All Subjects	1,237	86	205	14
Middle/Secondary Science	130	54	112	46
Middle/Secondary Math	186	61	121	39
Computer and Information Technologies	39	40	58	60
Other Career and Technical Education	23	28	59	72
Total	**1,615**	**74**	**555**	**26**

Method

Calculating survival times

In order to conduct the survival analysis, a survival time was calculated for each teacher in the base cohort. The survival time was defined as the number of days a teacher taught full-time in the school where they were first hired and was calculated by counting the number of days between the date on which the teacher started to teach full-time in one school (i.e., start date) and the date on which they ceased to teach full-time in that school (i.e., end date).

Start date. The date a teacher was hired by a K-12 public school in Pennsylvania was considered to be the date on which the teacher started to teach full-time in one school (i.e., start date). The way in which the base cohort was defined meant that the start date for all teachers in the base cohort fell during academic year 2011-2012 (i.e., between July 1, 2011 and June 30, 2012).

End date. Identifying the date on which a teacher ceased to teach full-time in the school where they were first hired (i.e., end date) was more complicated and conditional on one of several situations, each explained below.

Teacher's contract was terminated. If a teacher's contract with the district was terminated, the date on which this occurred (based on information in the PIMS Staff dataset) was recorded as the end date.

Teacher's PTA for teaching assignments fell below 100. If a teacher's contract had not been terminated, and if the PTA for a teacher's teaching assignment in the school where they were first hired fell below 100, the date on which this occurred (based on information in the PIMS Assignment dataset) was recorded as the end date.

Teacher's record disappeared from the dataset. If a teacher's records disappeared from the dataset, but no termination date was documented, it was assumed that they remained a full-time teacher until June 30 of the previous academic year (the date on which the datasets were updated), and this date was considered to be the end date.[4]

Survival time. The number of days between a teacher's start date and the end date – the number of days the teacher taught full-time in the school where they were first hired – was taken as the teacher's survival time. On June 30, 2018 (i.e., the date on which the datasets were last updated), if a teacher was still teaching full-time at the school where they were first hired, the teacher's survival time was indicated as being right-censored, that is, the exact value is unknown, but it is greater than the recorded value.

Cox Proportional Hazards Models

Survival analysis investigates factors associated with a higher or lower risk of an event happening (Allison, 2010). Cox proportional hazards models were used to identify factors associated with the risk of a teacher ceasing to teach full-time in the school where they were first hired (i.e., the "event"). These models take into account the survival times that are right-censored, and they also assume that all groups defined by covariates have the same underlying hazard function and that the hazard functions are proportional to one other. The Efron method was used to deal with tied events (i.e., when more than one event happened at the same time).

In the final Cox proportional hazards model, 11 variables were included: six teacher-level variables (sex, race/ethnicity, years of work experience, highest degree earned, annual salary, and cumulative hours of

4 For example, if a teacher's records did not appear in the dataset for the 2015-2016 academic year, the end date was considered to be June 30, 2015.

professional development) and five school-level variables (urbanicity, school size, Title 1 eligibility, school type, and percent of minority students).

Results

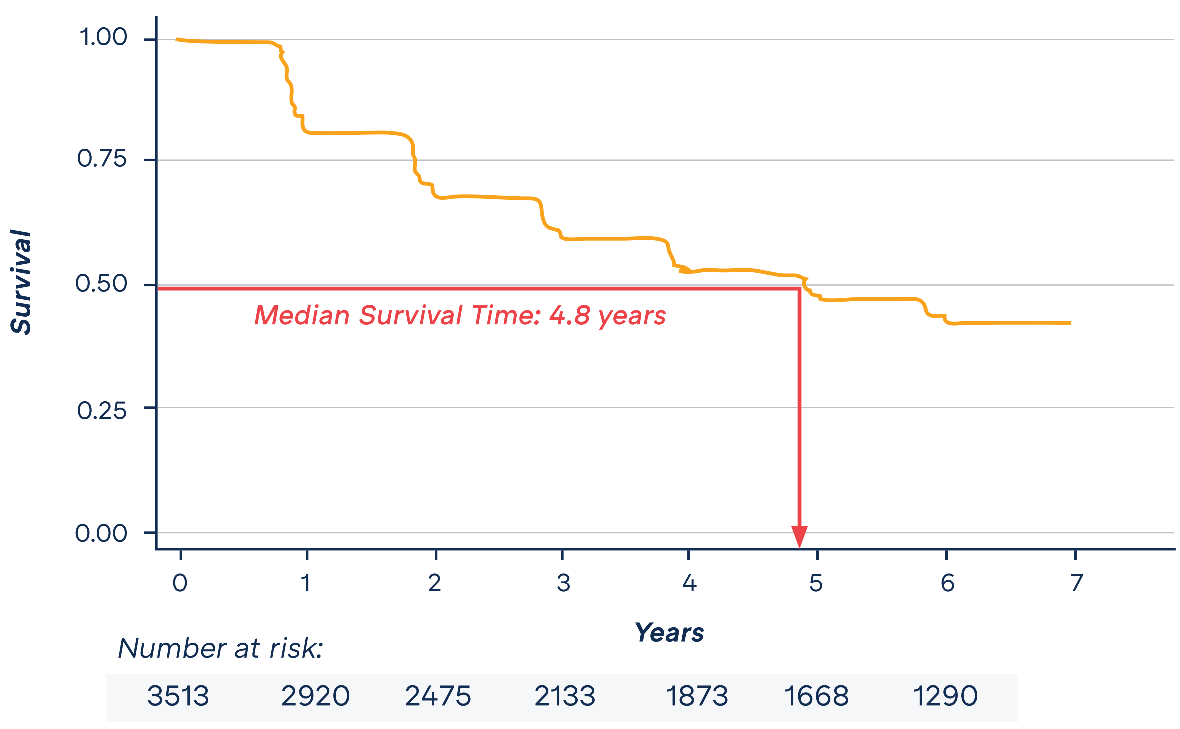
Survival Times

Figure 1 presents the survival curve of the entire base cohort. The zero on the x-axis represents the day on which a teacher was hired, and each interval of one on the axis represents one year since the teacher was hired. For each time point on the x-axis, the value on the y-axis indicates the percentage of teachers that were still teaching full-time at the school where they were first hired (out of the 3,947 teachers included in the base cohort). On the bottom of the figure, the "number at risk" is the number used to estimate the survival probability and may not be equal to the number of remaining teachers. It is interesting to note that most of the attrition occurred at the end of each academic year, but since the start date and end date can be different across teachers, attrition is staggered across several months.

Middle/Secondary Math teachers left the full-time teaching position into which they were first hired more rapidly than other STEM teacher types. Fifty percent of this group reported survival times less than 3.86 years after the date of hire.

The median survival time for the entire base cohort (including STEM and non-STEM teachers) was 4.8 years, which means that half of teachers in the base cohort had survival times longer than 4.8 years, while the other half had survival times shorter than 4.8 years. It also means that 4.8 years after the date of employment, only half of teachers in the base cohort were still teaching full-time in the school where they were first hired. By the end of the seven years included in the study, only 41% of the teachers in the base cohort were still teaching full-time in the school where they were first hired.

FIGURE 1. Survival curve of the entire base cohort. *N* = 3,513



Figures 2 to 11 present the survival curves of the base cohort disaggregated by different variables. Each subgroup starts at one on the y-axis (representing 100% of the subgroup), and at each time point on the x-axis, the value on the y-axis indicates the percentage of teachers in the group that were still teaching full-time at the school where they were first hired. If the subgroup is large, the attrition of one teacher will not cause a large drop in the survival curve, depicted as a smooth drop in the curve (as in Figure 1). However, if the subgroup is small, the attrition of one teacher may cause a sharp drop in the curve (as can be seen for the Doctoral/Specialist group in Figure 9).

Even if there is a large difference in the survival curves of different subgroups, it does not imply that the disaggregating variable caused a difference in the survival times (i.e., association does not imply causation). In some cases, such as a school's eligibility for Title 1 status or school type, the differences in the survival times between the subgroups became insignificant when controlling for other variables in the Cox proportional hazards models.

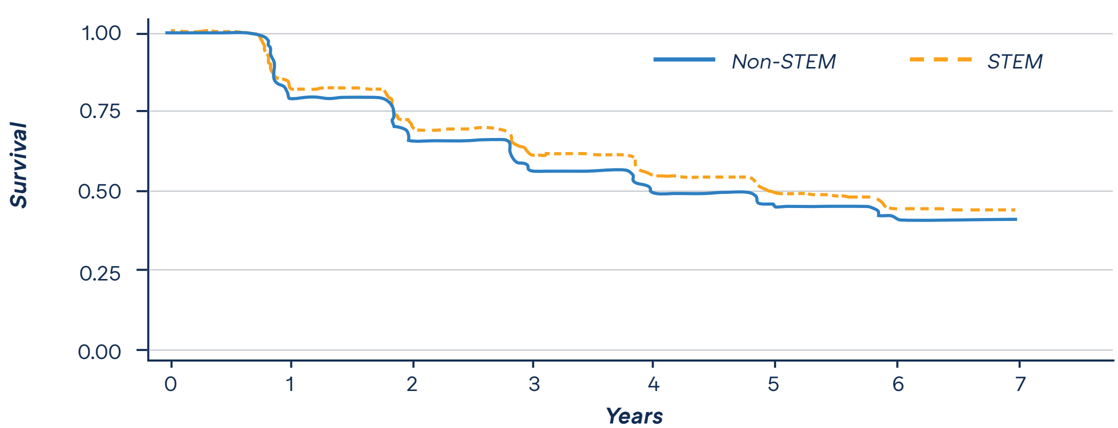
Survival Times (STEM Teachers)

Figures 2 presents the survival curves of STEM teachers (as one group) compared to non-STEM teachers in the base cohort. As mentioned, STEM teachers in the base cohort were classified based on their teaching assignment in academic year 2011-2012 in a subject within Elementary All Subjects, Middle/Secondary Science, Middle/Secondary Math, Computer and Information Technologies, and Other Career and Technical Education. In Figure 2, the survival curve for non-STEM teachers appears under the survival curve for STEM teachers, indicating that across the seven years of the study, non-STEM teachers were less likely than STEM teachers to keep full-time status in the school where they were first hired.

Figure 3 shows survival curves for each category of STEM teacher (based on their teaching assignment), represented by dashed lines, as well as non-STEM teachers, represented by a solid line. Only Middle/Secondary Math teachers report a survival curve below that of non-STEM teachers, indicating that this subgroup is at greater risk of leaving full-time status at the school where they were first hired than non-STEM teachers or teachers of other STEM subjects. However, the difference fades out in the later years.

Table 9 presents the median survival time for each category of STEM teachers. Teachers of Other Career and Technical Education subjects are least likely to leave full-time teaching status at the school where they were first hired. Fifty percent of this group remained in full-time teaching longer than 5.76 years, the group's median survival time. By contrast, Middle/Secondary Math teachers left the full-time teaching position into which they were first hired more rapidly than other STEM teacher types. Fifty percent of this group reported survival times less than 3.86 years after the date of hire.

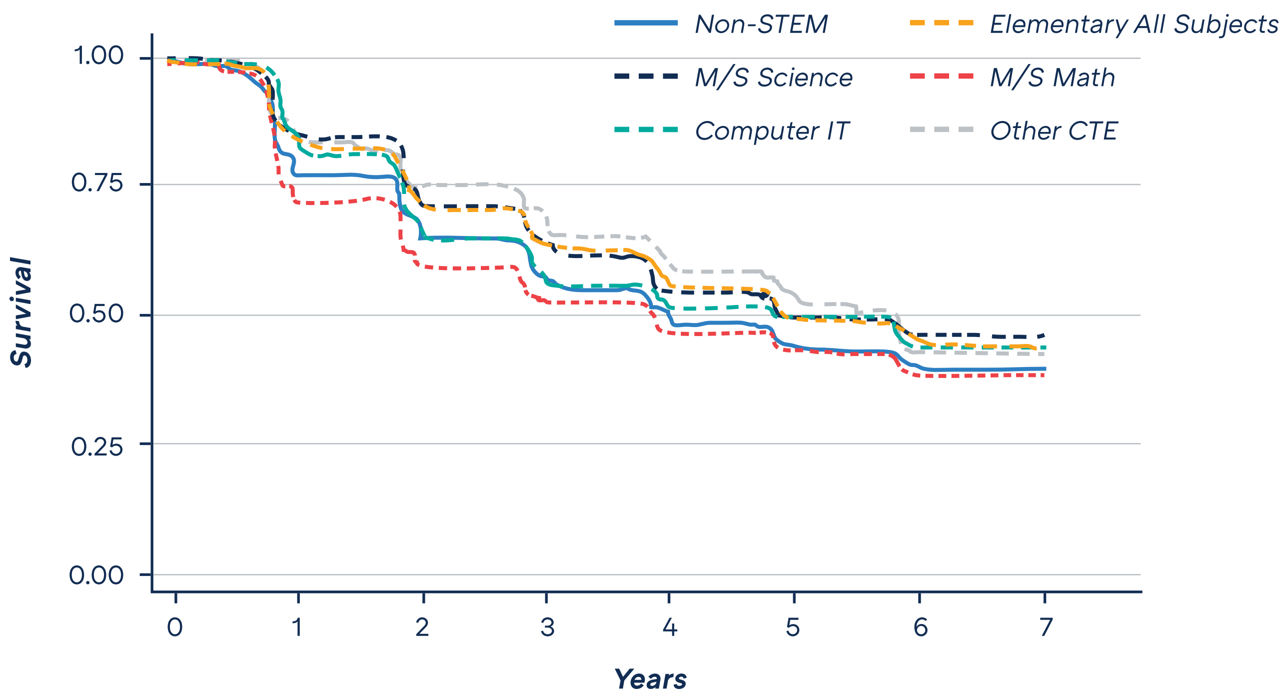
FIGURE 2. Survival curves disaggregated by STEM teacher status. *N* = 3,513



Number at risk:

Non-STEM	1295	1055	884	752	655	577	442
STEM	2218	1865	1591	1381	1218	1091	848

FIGURE 3. Survival curves disaggregated by STEM teaching assignment category. ***N*** **= 3,513**



Number at risk:

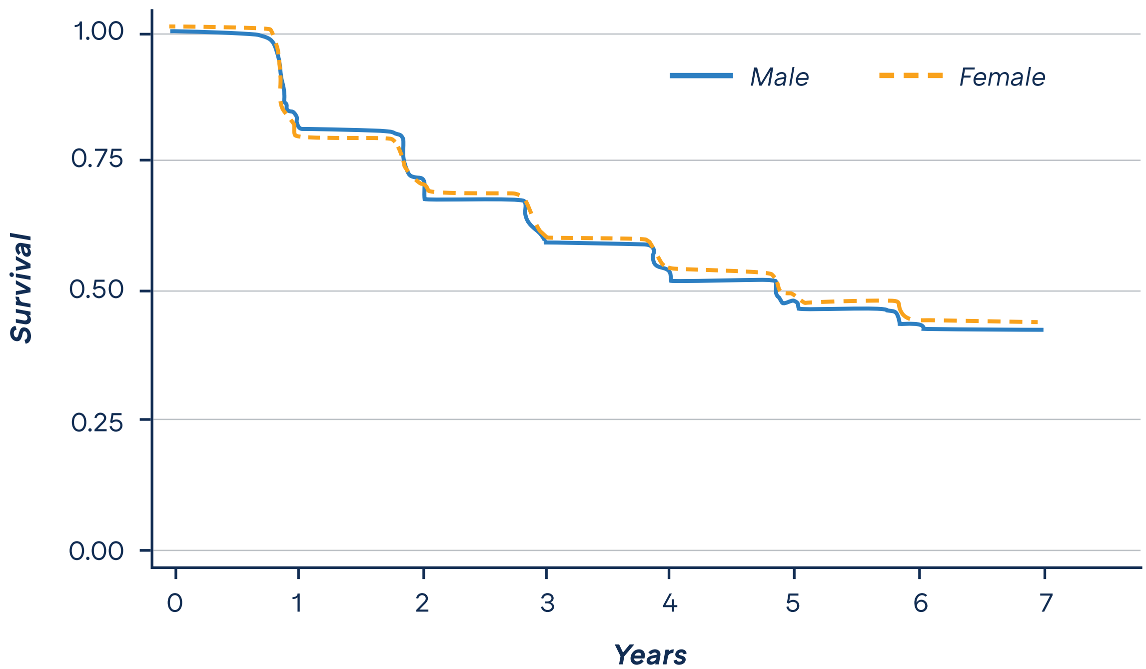
Non-STEM	1343	1091	914	771	673	593	455
EAS	1442	1237	1061	928	820	732	562
MS/Science	242	209	180	155	133	120	97
M/S Math	307	230	189	165	147	131	102
Computer IT	97	84	69	57	52	48	39
Other CTE	82	69	62	57	48	44	35

TABLE 9. Median survival times by STEM category

STEM CATEGORY	NUMBER OF TEACHERS	MEDIAN SURVIVAL TIME IN YEARS
Elementary All Subjects	1,442	5.00
Middle/Secondary Science	242	4.86

STEM CATEGORY	NUMBER OF TEACHERS	MEDIAN SURVIVAL TIME IN YEARS
Middle/Secondary Math	307	3.86
Computer and Information Technologies	97	4.87
Other Career and Technical Education	82	5.76
Non-STEM	1,343	4.00
Total	**3,513**	**4.86**

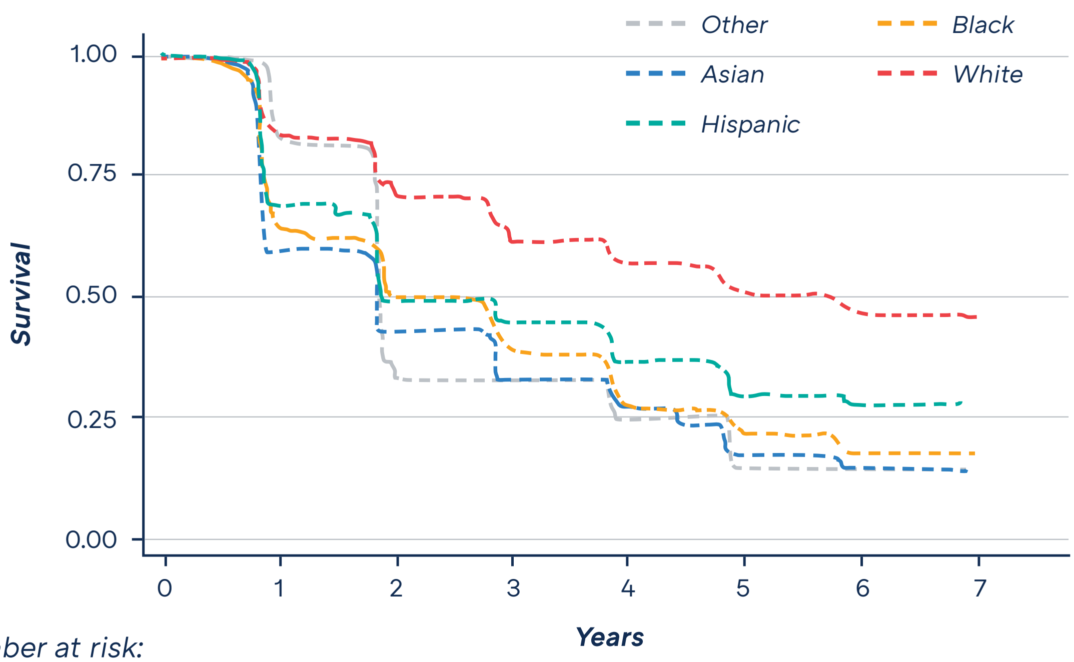
FIGURE 4. Survival curves disaggregated by teacher sex. *N* = 3,513



Number at risk:

Female	2527	2106	1781	1534	1339	1185	927
Male	986	814	694	599	534	483	363

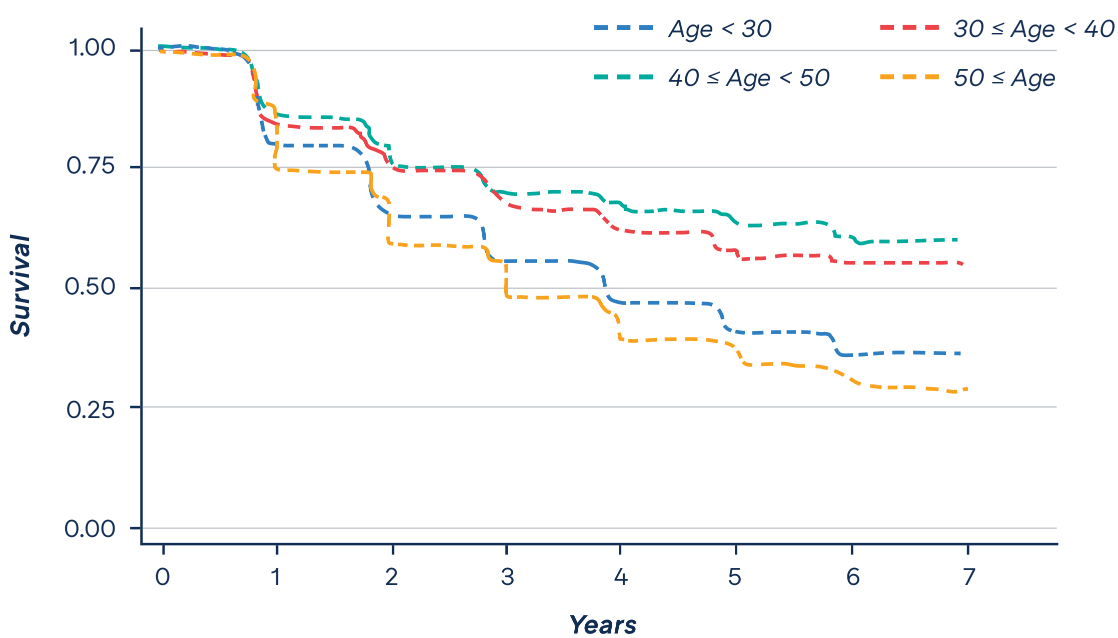
FIGURE 5. Survival curves disaggregated teacher race/ethnicity. *N* = 3,513



Number at risk:

Other	29	20	9	8	11	6	5
Black	229	151	120	91	62	49	33
Hispanic	58	41	28	26	21	17	14
Asian	48	28	20	15	12	7	6
White	3149	2680	2298	1993	1767	1589	1232

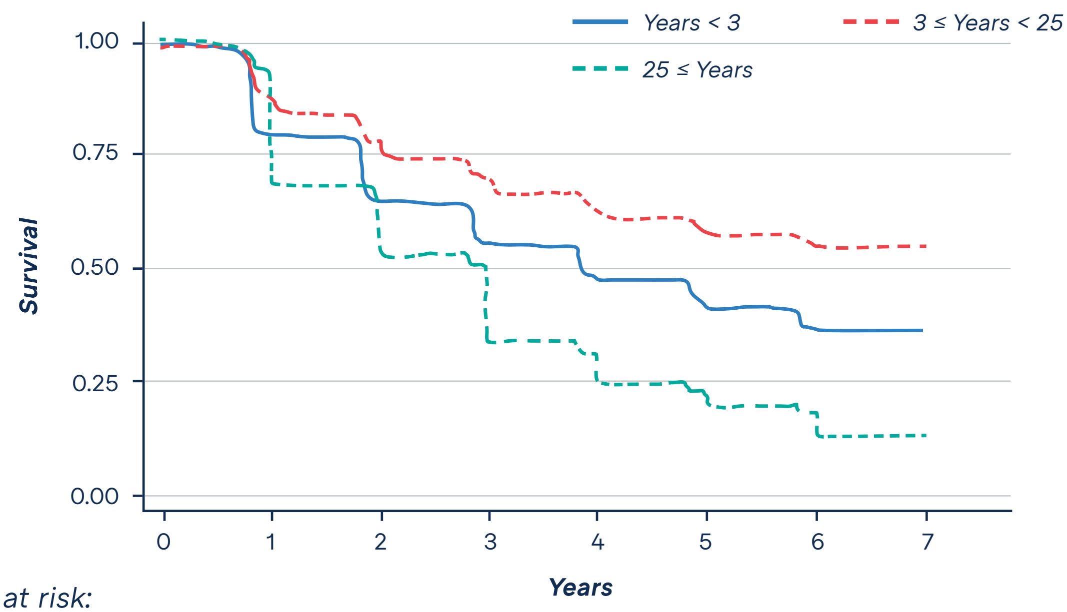
FIGURE 6. Survival curves disaggregated by teachers' age (when hired). *N* = 3,513



Number at risk:

Age < 30	1727	1380	1128	956	816	699	557
30 ≤ Age < 40	883	755	682	603	549	506	402
40 ≤ Age < 50	493	431	389	349	330	315	232
50 ≤ Age	410	354	276	225	178	148	99

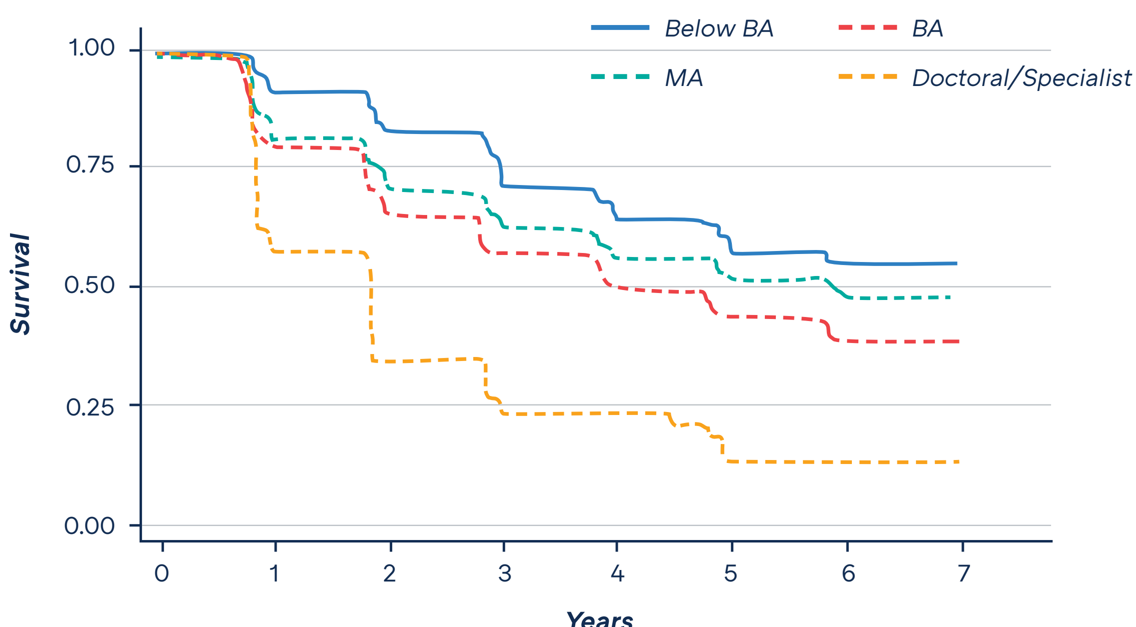
FIGURE 7. Survival curves disaggregated by teachers' years of work experience (when hired). *N* = 3,513



Number at risk:

Years < 3	1965	1565	1287	1089	944	819	619
3 ≤ Years < 25	1396	1202	1065	941	845	771	591
25 ≤ Years	149	138	98	74	45	34	27

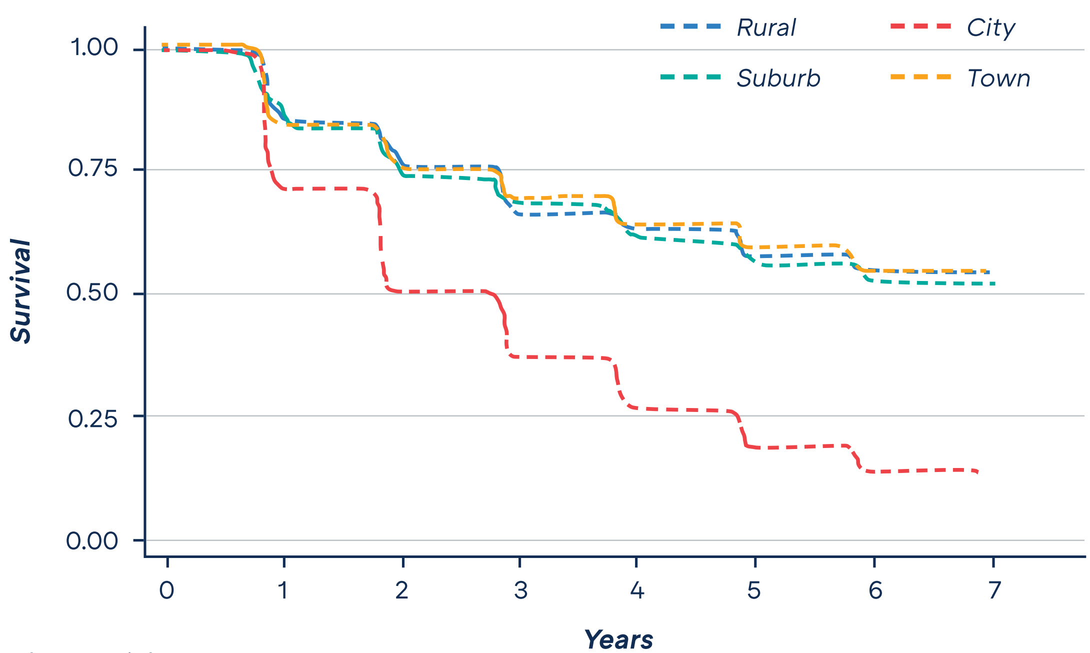
FIGURE 8. Survival curves disaggregated by teachers' highest degree earned (taking into account the changes in teachers' educational attainment over time). *N* = 3,513



Number at risk:

Below BA	72	66	64	56	47	43	39
BA	2025	1496	1164	905	728	592	431
MA	1396	1341	1237	1150	1072	1025	812
Doctoral	20	17	10	10	9	4	5

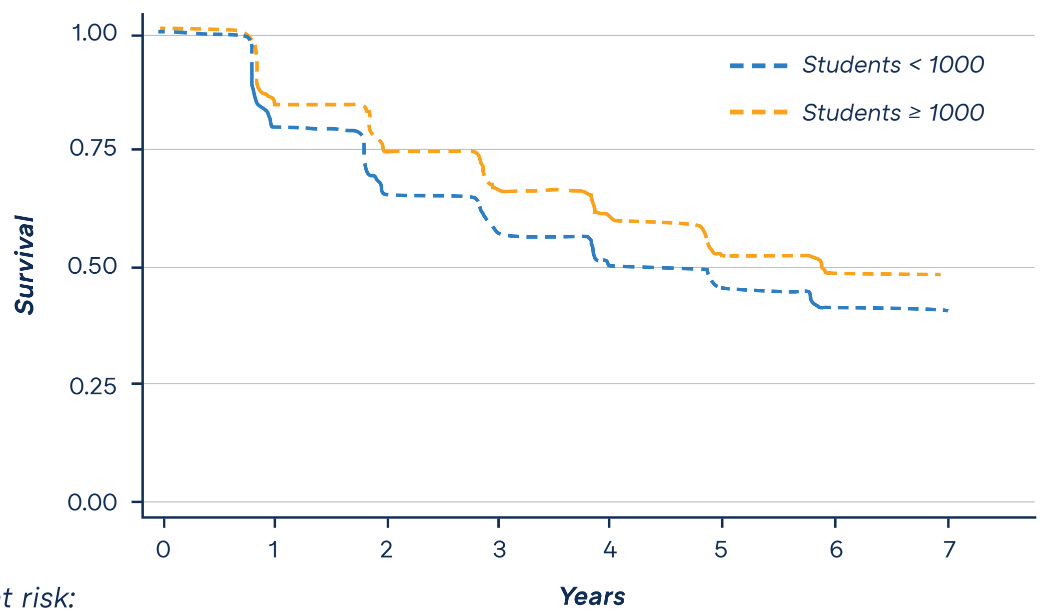
FIGURE 9. Survival curves disaggregated by school's urbanicity (during the 2011-2012 academic year). ***N*** **= 3,512**



Number at risk:

Rural	576	501	449	385	358	333	261
Suburb	1680	1478	1308	1176	1055	967	727
City	899	639	445	325	232	158	112
Town	357	302	273	247	228	210	190

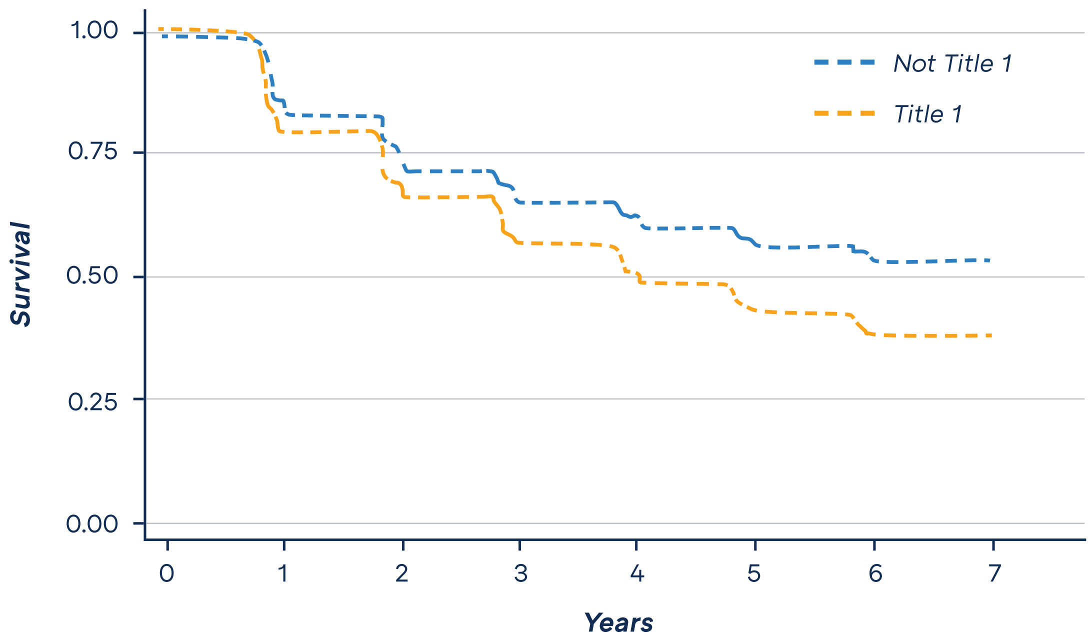
FIGURE 10. Survival curves disaggregated by school size (averaged across the 2011-2012 to 2016-2017 academic years). ***N*** **= 3,512**



Number at risk:

Students < 1000	2548	2087	1739	1479	1294	1160	894
Students ≥ 1000	964	833	736	654	579	508	396

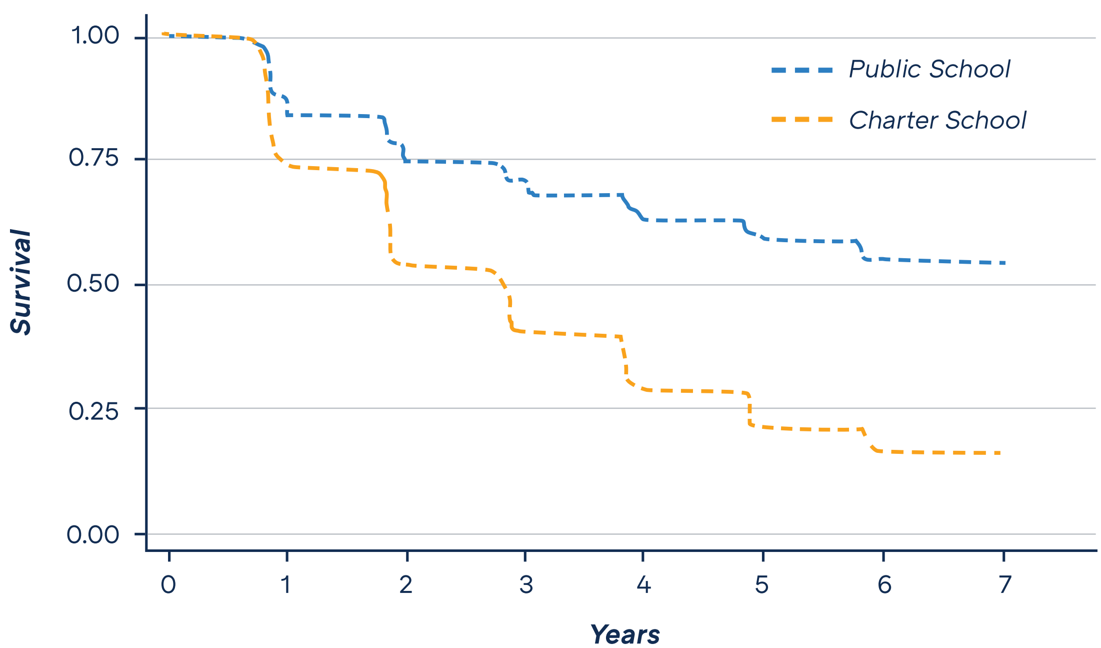
FIGURE 11. Survival curves disaggregated by school's Title 1 eligibility (during the 2011-2012 academic year). *N* = 3,378



Number at risk:

Not Title 1 eligible	1043	893	780	697	642	599	404
Title 1 eligible	2335	1913	1595	1353	1162	1005	830

FIGURE 12. Survival curves disaggregated by school type (during the 2011-2012 academic year). *N* = 3,512



Number at risk:

Public school	2447	2128	1907	1707	1568	1453	1126
Charter school	1065	792	568	426	305	215	164

Cox Proportional Hazards Models

The results of the Cox proportional hazards models are presented in Table 10. Model 1 includes all teachers in the cohort, while Models 2 to 5 disaggregate teachers by subjects taught when they were first hired. Model 2 describes non-STEM teachers only, Model 3 describes STEM teachers only, Model 4 describes departmentalized STEM teachers only (i.e., STEM teachers excluding Elementary All Subjects), and Model 5 describes Elementary All Subjects teachers only. Models were divided to ascertain any distinctive features between STEM and non-STEM teachers and across types of STEM teachers. Elementary All Subjects teachers were excluded from Model 4 in particular because this was the only group of STEM instructors at the elementary level, with significant other subject-area responsibilities; otherwise, all STEM categories represented secondary grades.

In the models, when the hazard ratio for a variable is less than one, it indicates that the variable is associated with a lower risk of a teacher ceasing to teach full-time at the school where they were first hired (i.e., it is a protective factor), controlling for all other variables in the model. Conversely, a hazard ratio greater than one indicates that the variable is associated with a higher risk of a teacher ceasing to teach full-time at the school where they were first hired (i.e., it is a risk factor), controlling for all other variables in the model. It is important to reiterate that an association does not imply causation. Also, it should be kept in mind that only 83% of the teachers in the base cohort (3,273 teachers out of 3,947 teachers) reported data on all 13 variables included in the model, so the results may be biased if data on some variables were not missing at random.

STEM. For the entire base cohort, compared to non-STEM teachers, Elementary All Subjects teachers were less likely to stop teaching full-time at the school where they were first hired, controlling for all other variables in the model. Teaching other STEM subjects slightly lowered the risk of ceasing to teach compared to non-STEM teachers, but the decrease was not statistically significant.

Sex. Among STEM teachers, being male neither increased nor decreased the risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model. For non-STEM teachers, being male was associated with a 20% higher risk of ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Race/ethnicity. For the entire base cohort and for the four teacher subgroups (Non-STEM teachers only; STEM teachers only; departmentalized STEM teachers only [excluding Elementary All Subjects]; and Elementary All Subjects teachers only, described by Models 2-5), being from a non-White racial/ethnic group neither increased nor decreased the risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Age (when hired). Teachers were classified into one of three age categories: teachers who were under 30 (the younger group), teachers who were 30 and over but under 50 (the middle-aged group), and teachers who were 50 and over when they were hired (the older group). In general, membership in the middle-aged teacher group was associated with a lower risk of ceasing to teach full-time at the school where a teacher was first hired, whereas membership in the older age group was associated with a higher risk of ceasing to teach full-time.

For the entire base cohort, being in the middle-aged group was associated with a 31% lower risk, and being in the older group was associated with a 55% higher risk, of ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

For non-STEM teachers, being in the middle-aged group was associated with a 35% lower risk of ceasing to teach full-time at the school where they were first hired, whereas being in the older group neither increased nor decreased the risk, controlling for all other variables in the model.

For all STEM teachers, being the middle-aged group was associated with a 30% lower risk of ceasing to teach full-time at the school where they were first hired, whereas being in the older group was associated with a 67% higher risk.

For departmentalized STEM teachers (excluding Elementary All Subjects teachers), being in the middle-aged group neither increased nor decreased the risk of ceasing to teach full-time. Being in the older group was associated with a 123% higher risk of ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

For Elementary All Subjects teachers, being in the middle aged group was associated with a 35% decrease, while being in the older group was associated with a 53% increase, in the risk of ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Years of work experience (when hired). For the entire base cohort, and for the subgroups of all non-STEM teachers, all STEM teachers, and all Elementary All Subjects teachers, each additional year of work experience was associated with approximately a 4% higher risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model.

For departmentalized STEM teachers (excluding Elementary All Subjects), each additional year of work experience neither increased nor decreased the risk of a ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Highest degree earned (when the event occurred). For the entire base cohort, teachers possessing a Doctoral/Specialist degree in addition to a Bachelor's degree, compared to possessing only a Bachelor's, was associated with a 95 % higher risk of ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

For non-STEM teachers, having a Master's degree or a Doctoral/Specialist degree was associated with a 23% higher risk and a 130% higher risk, respectively, of ceasing to teach full-time at the school where they were first hired.

For all STEM teachers; for departmentalized STEM teachers (excluding Elementary All Subjects); and for Elementary All Subjects teachers only, the highest degree earned did not result in any statistically significant differences in the risk of leaving a full-time role at the school of initial hire, controlling for all other variables in the model.

Annual salary (when the event occurred). For the entire base cohort and all four teacher subgroups, a $6,000 increase in annual salary (which translates to an approximately $500 increase in monthly salary) was associated with a lower risk of ceasing to teach full-time at the school where a teacher was first hired. The decrease in risk ranged from 11% to 18%. Notably, a $6,000 salary bump decreased the risk more for non-STEM teachers (18%) than for STEM teachers (13%).

Cumulative hours of professional development (when the event occurred, including only ACT 48 professional development courses). For the entire base cohort and the four different STEM teacher groups, a 10-hour increase in cumulative hours of professional development was uniformly associated with 3% lower risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model.

Greater cumulative hours of professional development was a protective factor for all groups of teachers under study, and it is interesting to note that the magnitude of the "protection" was stable across the groups.

Urbanicity (during the 2011-2012 academic year). The National Center for Education Statistics classifies all schools in the U.S. as one of four, mutually exclusive geographic descriptors: rural, town, suburb, and city. For the entire base cohort, teaching in a city school, compared to teaching in a rural school, was associated with a 45% higher risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model. Teaching in a suburban school, compared to teaching in a rural school, was associated with a 21% higher risk. There was no difference in risk between teaching in a town and in a rural area, controlling for all other variables in the model.

> The influence of school locale on ceasing to teach full-time at the school of initial hire was strongest for the non-STEM teacher group, and risk generally increased with urbanicity. For non-STEM teachers, compared to teaching in a rural area, teaching in a town was associated with a 69% higher risk of attrition; teaching in a Suburb was associated with a 77% higher risk; and teaching in a city was associated with a 109% higher risk, controlling for all other variables in the model.
>
> For all STEM teachers as a group, school locale neither increased nor decreased the risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model.
>
> For the departmentalized STEM teachers only (excluding Elementary All Subjects), locale was associated with risk. Teaching in a town, compared to teaching in a rural area, was associated with a 56% lower risk of ceasing to teach full-time at the school where a teacher was first hired, and teaching in a suburb, compared with teaching in a rural area, was associated with a 53% lower risk.
>
> For the Elementary All Subjects teachers only, teaching in a suburb, compared to teaching in a rural area, was associated with a 32% higher risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model. Teaching in a town or in a city neither increased nor decreased the risk.

School size (averaged across the 2011-2012 academic year to the 2016-2017 academic year). The size of a teachers' school of initial hire was defined as a binary: larger schools enrolled 1,000 or more students, and smaller schools enrolled less than 1,000 students. For the entire base cohort, working in a larger school compared to a smaller school was associated with a 34% lower risk of ceasing to teach full-time at the school, controlling for all other variables in the model.

> For STEM and non-STEM teachers, working in a larger school compared to a smaller school was associated with 30% and 31% lower risk, respectively, of ceasing to teach full-time at the school, controlling for all other variables in the model.
>
> For departmentalized STEM teachers (excluding Elementary All Subjects), teaching in a larger school compared to a smaller school neither decreased nor increased the risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the models.
>
> For Elementary All Subjects teachers, teaching in a larger school compared to teaching in a smaller school was associated with a 51% lower risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Title 1 eligibility (during the 2011-2012 academic year). For the entire base cohort and all four teacher subgroups, teaching in a school eligible for Title I status, compared to teaching in a school non-Title I school, neither increased nor decreased the risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

School type (during the 2011-2012 academic year). Teaching in a public charter school, compared to teaching in a traditional public school, was only a risk factor for Elementary All Subjects teachers. Charter school status was associated with a 57% increase in the risk of ceasing to teach full-time in a school where a teacher was first hired. For other teacher subgroups, difference in school type neither increased nor decreased the risk of a teacher ceasing to teach full-time at the school where they were first hired, controlling for all other variables in the model.

Percent of minority race/ethnicity students (averaged across the 2011-2012 academic year to the 2016-2017 academic year). For the entire base cohort and all four teacher subgroups, a one percentage point increase in the proportion of minority race/ethnicity students in a school was associated with approximately 1% higher risk of ceasing to teach full-time at the school where a teacher was first hired, controlling for all other variables in the model.

TABLE 10. Cox Proportional Hazards Models (Hazard Ratios)

VARIABLE	MODEL 1: ALL TEACHERS (*N* = 2,934)	MODEL 2: NON-STEM (*N* = 1,078)	MODEL 3: STEM (*N* = 1,856)	MODEL 4: STEM EXCEPT EAS (*N* = 538)	MODEL 5: EAS (*N* = 1,277)
Individual-level variables					
STEM Category *(Reference: Non-STEM)*					
Elementary All Subjects	0.750***				
Middle/Secondary Science	0.863				
Middle/Secondary Math	0.944				
Computer and Information Technologies	0.309				
Other Career and Technical Education	0.940				
Sex *(Reference: Female)*					
Male	0.913	0.807*	1.136	0.965	1.153
Race/ethnicity *(Reference: White)*					
Black	1.021	1.251	0.932	0.999	0.857
Hispanic[a]	0.728	0.885	0.588	3.650	0.541
Asian[a]	1.134	1.040	1.222	1.536	0.779
Other[a]	1.198	0.644	1.205		1.230
Age group when hired *(Reference: < Age 30)*[b]					
30 ≤ Age < 50	0.689***	0.653***	0.699***	0.883	0.650***
Age ≥ 50	1.552***	1.317	1.674***	2.232**	1.529*
Years of work experience[b]	1.043***	1.051***	1.038***	1.017	1.039***
Highest degree earned *(Reference: Bachelor's)*[c]					
Below Bachelor's[a]	0.279	0.270	0.281	0.185	0.000
Master's	1.072	1.230*	1.002	0.988	1.053
Doctoral / Specialist[a d]	1.955**	2.301**	1.471	1.692	1.533
Annual salary[e]	0.853***	0.820***	0.872***	0.863***	0.886***
Cumulative hours of professional development[f]	0.972***	0.973***	0.972***	0.966***	0.972***
School-level variables					
Urbanicity *(Reference: Rural)*[g]					
Town	1.184	1.685**	0.989	0.441**	1.346
Suburb	1.211*	1.772***	1.020	0.466***	1.318*
City	1.446**	2.092***	1.272	0.727	1.404
School size *(Reference: Under 1,000 students)*[h]					
1,000 or more students	0.664***	0.697***	0.693***	0.794	0.492**

VARIABLE	MODEL 1: ALL TEACHERS (*N* = 2,934)	MODEL 2: NON-STEM (*N* = 1,078)	MODEL 3: STEM (*N* = 1,856)	MODEL 4: STEM EXCEPT EAS (*N* = 538)	MODEL 5: EAS (*N* = 1,277)
Title 1 eligibility *(Reference: Not eligible)*[g]					
Eligible	1.009	1.025	0.974	1.245	0.952
School type *(Reference: Traditional public school)*[g]					
Public charter school	1.063	0.878	1.179	0.727	1.569*
% of minority race/ethnicity students[h]	1.009***	1.011***	1.008***	1.011**	1.007***

Note: Teachers' STEM category (based on teaching assignment when hired) used to divide them into age groups for Models 2 to 5.

a. These groups have a small sample size (<60).

b. Years of work experience when hired.

c. Highest educational degree when the event occurred.

d. An educational specialist degree (e.g., Ed.S.) is a terminal professional degree for individuals who have already completed a master's degree in education.

e. Salary (before deductions) when the event occurred, in units of $6,000 annually (or $500 monthly).

f. Cumulative hours of professional development when the event occurred, in units of 10 hours. Only ACT 48 professional development courses were included in the analysis.

g. During the 2011-2012 academic year.

h. Calculated by averaging information from the 2011-2012 academic year to the 2016-2017 academic year.

*$p < .05$.

**$p < .01$.

***$p < .001$

Summary and Discussion

This study aimed to calculate the median length of time a newly hired teacher in Pennsylvania taught full-time in the school where they were first hired, with a focus on teachers of STEM subjects. The relationship between teacher attrition and teacher- and school-level characteristics was examined. Administrative records on all teachers in Pennsylvania were used to identify a base cohort of teachers who were newly hired in a K-12 public school, including charter schools, in the 2011-2012 academic year and taught full-time with only one teaching assignment in one school. Each member of the base cohort was observed from this origin time until a specific event occurred, defined as a teacher ceasing to teach full-time at the school where they were first hired. Teachers in the base cohort were classified as teaching one of five broad categories of STEM content, or as a non-STEM teacher, for the purposes of comparing attrition rates in critical subjects. These categories were researcher-defined, based on the STEM teacher retention literature and the data collected by the state of Pennsylvania. The event of ceasing to teach in the school in which a teacher was first hired included teachers who left the teaching profession altogether; teachers who moved to another state, district, or school; and teachers who continued to work at their original school of employment, but with a reduced teaching load. This specific definition of an event informed the results of the analysis. In other words, a different definition of an event may have led to different results, such as less dramatic rates of attrition.

After 4.8 years, approximately **50% of the teachers in the base cohort no longer taught full-time** at the school where they were first hired.

The analysis found that the entire base cohort of teachers reported a median survival time of 4.8 years. That is, after 4.8 years, approximately 50% of the teachers in the base cohort no longer taught full-time at the school where they were first hired. STEM teachers were a large proportion of this cohort (62%) when a "STEM teaching assignment" was broadly defined as Elementary All Subjects teachers (for teaching general math and science in elementary grades); Middle/Secondary Science; Middle/Secondary Math; Computer and Information Technology; and Other Career and Technical Education, which included many job-specific technology teachers (see Table 1). Teachers in the STEM categories reported median survival times between 3.86 years (Middle/Secondary Math teachers) and 5.76 years (Other CTE teachers). Compared to non-STEM teachers' median survival time of 4.00 years, all types of STEM teachers stayed in their roles slightly longer, on average, with the exception of Middle/Secondary Math. This is not necessarily consistent with national research, which suggests that teachers of departmentalized math and science subjects in secondary grades report greater attrition than teachers of non-STEM subjects. The discrepancy may be because this study compared all teachers of all subjects in Pennsylvania to one another and took a broad view of what it means to teach science, technology, engineering, and math. The literature of STEM teacher retention has typically compared a smaller population of STEM teachers (e.g., science and math teachers only) to a smaller, discrete population of other departmentalized teachers (e.g., English, history/social studies, and/or special education teachers) (see Carver-Thomas & Darling-Hammond, 2017; R. Ingersoll & Perda, 2009, 2010; Murnane & Olsen, 1990).

Teachers in the STEM categories reported median survival times between **3.86 years** (Middle/Secondary Math teachers) and **5.76 years** (Other CTE teachers).

This study explored the relationship of several factors to STEM and non-STEM teacher attrition: teachers' sex, race/ethnicity, years of work experience (when hired), highest degree earned, annual salary, and cumulative hours of professional development, as well as schools' urbanicity, size, Title I eligibility, charter school status, and student demographics. Teachers were also divided into four subgroups for analysis:

all STEM teachers; departmentalized STEM teachers only (i.e., STEM teachers excluding Elementary All Subjects teachers); Elementary All Subjects teachers only; and all non-STEM teachers. Cox proportional hazard models were used to generate a hazard ratio for each factor, indicating whether it was a protective factor or a risk factor for attrition among the entire base cohort and each subgroup.

The models indicated that some teacher- and school-level characteristics, such as annual salary, hours of professional development, and school demographics, reported relatively stable hazard ratios for all the subgroups. Increases in salary and more cumulative hours of professional development were both protective factors against attrition for all groups, STEM or otherwise. This is consistent with research on teacher retention that suggests job satisfaction, mentorship, and professional development are important retention strategies, particularly in STEM fields (e.g., Goodpaster et al., 2012; Hasselquist & Graves, 2020; Hutchison, 2012; R. M. Ingersoll & May, 2012). Other factors influenced some subgroups substantially more than others. For example, among the departmentalized STEM teachers (teachers of math, science, computer and information technology, and other CTE, excluding elementary all-subjects teachers), teaching in a town or suburb was associated with a lower risk of ceasing to teach full-time in the school where they were first hired, relative to schools in a rural or city setting. This too reiterates a national finding that science and math teacher churn is greater in rural and urban schools (R. Ingersoll & Perda, 2010). By contrast, among non-STEM teachers, teaching in a town, suburb, or city, compared to teaching in a rural area, was associated with a higher risk of ceasing to teach full-time.

Increases in salary and more cumulative hours of professional development were both **protective factors against attrition** for all groups, STEM or otherwise.

For non-STEM teachers, risk factors for attrition (i.e., factors that were associated with a higher risk of ceasing to teach full-time in the school of initial hire, controlling for all other variables in the model) included being male, having a higher education degree at the Master's level or higher, having more years of work experience (when hired), and teaching in a more urbanized community. Protective factors (i.e., factors that were associated with a lower risk of ceasing to teach full-time in the school of initial hire, controlling for all other variables in the model) included being middle-aged (between 30 and 50 years old when hired) and larger school size.

For all STEM teachers (elementary all subjects, middle/secondary science, middle/secondary math, computer and information technology, and other CTE), risk factors for attrition included being of older age (greater than fifty years old when hired), and having more years of work experience (when hired). Protective factors included being middle-aged and teaching in a larger school. Being of older age was also a risk factor for the attrition of departmentalized STEM teachers only (excluding Elementary All Subjects).
For Elementary All Subjects teachers only, risk factors for attrition included being of older age, having more years of work experience (when hired), and charter school status. Protective factors included being middle-aged and teaching in a larger school.

Among the departmentalized STEM teachers, teaching in a town or suburb was associated with a **lower risk of ceasing to teach full-time in the school where they were first hired**, relative to schools in a rural or city setting.

Limitations

As with any model-based research, the results of the Cox proportional hazards models may not accurately reflect the true association between the variables and teacher attrition if other relevant variables were not included in the model, or if the sample size for some groups included in the model were too small. Also, the results may have been influenced by the particular characteristics of teachers that were newly hired in K-12 public schools in Pennsylvania during the 2011-2012 academic year. In other words, these results may not be generalizable to other populations of teachers. Therefore, the results should be interpreted in light of these limitations.

The research focuses on exploring the survival characteristics of newly hired teachers in Pennsylvania over time, disaggregated by teachers with STEM and non-STEM teaching assignments. Note that the main outcome ("event") is whether a teacher with a full-time STEM assignment at their time of hire ceases to teach full-time in the school in which they were hired, rather than reassignment to a different subject. Teachers' status as a STEM instructor was a fixed value, based on their full-time teaching assignment in academic year 2011-2012 (when hired).

More fundamentally, an important limitation of this study is the potential for errors in the administrative records reported by individual schools. While conducting the study, the research team encountered several errors and inconsistencies in the dataset. For example, there were many teachers in the PIMS Staff dataset (which has information on teachers' contract) that were not included in the PIMS Assignment dataset (which has information on each assignment of the teacher). Also, for some teachers, the end date of the teacher's contract (in the PIMS Staff dataset) preceded the completion date of an assignment (in the PIMS Assignment dataset). For some teachers, there was no information on the end date of their contract in one year, but they disappeared from the dataset in the following year. In addition, although the PIMS manual advised schools to report the years of work experience as one for newly recruited teachers, it was reported as zero for some of these teachers. Also, while PDE advised schools to report salary as zero for teachers whose contract was terminated, this rule was not applied to some teachers. Lastly, for some teachers, information on the start date of the contract, start date of an assignment, and the teacher's birthday was not consistent across datasets from different years. Since it was not possible for PDE or the research team to correct these errors and inconsistencies, the research team made a priori rules on how to deal with each type of issue. This means that the results of the study may not accurately represent the true association between teacher attrition and the variables included in the models. One recommendation to increase the accuracy of future research findings is for PDE to provide stronger guidance to schools on how to accurately report data and to conduct quality checks at the state level to identify and address data entry errors or discrepancies. Accurate data will translate to more meaningful, consistent research and analysis of pressing issues such as teacher attrition.

For all STEM teachers, risk factors for attrition included being of older age (greater than fifty years old when hired) and having more years of work experience (when hired).

Conclusion

This study contributes to the literature examining instability in the STEM teacher workforce in Pennsylvania by describing and analyzing factors associated with the attrition of newly hired K-12 teachers in the state's public schools. By considering the protective factors and risk factors associated with teachers' attrition, PDE can provide better support to teachers, schools, and districts to strategically increase the retention of K-12 STEM teachers.

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ANNEX:

Characteristics of In-Field and Out-of-Field STEM Teachers in the 2017-2018 Academic Year

This analysis initially sought to answer a second research question:

2. What is the average length of time a teacher certified to teach a science, technology, engineering, or math subject is employed in the same school or district?

A restriction in the data obtained from the Teacher Information Management System (TIMS) prevented this study from disaggregating the retention of STEM teachers by in-field and out-of-field assignments. The TIMS dataset included certification information for teachers based on the 2017-2018 academic year (i.e., between July 1, 2017 and June 30, 2018). Only 3% of the teachers (N = 66) in the baseline cohort from school year 2011-2012 reported certifications in the 2017-2018 dataset. Therefore, the study was unable to analyze the survival times of in-field and out-of-field teachers in the baseline cohort. In lieu of that analysis, the following is a brief descriptive study of the characteristics of teachers who were certified to teach a STEM subject in school year 2017-2018.

We use the same definition of STEM teachers here as in the main analysis: teachers who are assigned to teach a STEM subject and teach full-time in one school (PTA is at least 100) (N = 3,513). Within this group, in-field teachers are those who have certifications in a STEM subject. Teachers who are assigned to teach a STEM subject but hold a only non-STEM certification(s) are identified as out-of-field. Teachers who teach multiple STEM subjects are only considered out-of-field when they do not hold certifications for any of the subjects. The majority of STEM teachers in Pennsylvania in the 2017-2018 academic year were in-field teachers (N = 3,210), while 9% of teachers were out-of-field (N = 303).

The demographic and professional information for the in-field and out-of-field STEM teachers is provided in Table 1 and Table 2. Both in-field and out-of-field STEM teachers in the 2017-2018 academic years deviate slightly from the composition of the baseline cohort of STEM teachers in the 2011-2012 school year studied in the main analysis. Compared to the base cohort STEM teachers (see Table 5), STEM teachers in Pennsylvania in later years are generally younger than the base cohort and more likely to hold a Bachelor's degree than a Master's or Doctoral degree.

STEM subjects taught by in-field teachers are different than those taught by out-of-field teachers. In particular, approximately 11% of out-of-field teachers reported a teaching assignment related to computer and information technology, compared to 3% of in-field teachers. Additionally, 1.3% of out-of-field teachers teach other career and technical education (CTE) courses, almost four times the proportion of in-field CTE teachers (0.3%). Elementary all-subjects and departmentalized science and math courses are more frequently taught by teachers with a corresponding certification, while computer and information technology courses or CTE courses are more frequently assigned to a teacher with an out-of-field endorsement. With respect to demographic characteristics, out-of-field teachers are more likely to be male, Black, and close to retirement age than in-field teachers. Furthermore, the out-of-field teachers' average salaries are both higher and more variable than in-field teachers' salaries ($M_{\text{out-of-field}}$ = 52,444 , $SD_{\text{out-of-field}}$ = 12,227, $M_{\text{in-field}}$ = 51,006, $SD_{\text{in-field}}$ = 10,893), likely because out-of-field STEM teachers tend to be older and more experienced.

TABLE 1. Characteristics of In-Field STEM Teachers in Academic Year 2018-2019

VARIABLE	%	FREQUENCY
STEM Category[a]		
Elementary All Subjects	73.4	2357
Middle/Secondary Science	9.4	303
Middle/Secondary Math	13.8	443
Computer and Information Technologies	3.0	97
Other Career and Technical Education	0.3	10
Sex		
Male	18.4	592
Female	81.6	2618
Race/ethnicity		
White	86.6	2780
Black	8.9	287
Hispanic	2.1	66
Asian	1.3	42
Other (Native Hawaiian or Pacific Islanders, American Indian, and Multi-Racial)	1.1	35
Age (when hired)		
Age < 30	67.2	2157
30 ≤ Age < 50	30.1	967
Age ≥ 50	2.7	86
Years of work experience (when hired)		
Experience < 3	45.5	1459
3 ≤ Experience < 25	54.3	1743
25 ≤ Experience	0.3	8
Highest degree earned (at the end of the 2017-2018 academic year)		
Below Bachelor's degree	0.0	1
Bachelor's degree	73.5	2359
Master's degree	26.3	844
Doctoral / Specialist degree[b]	0.2	6

a. Teachers were classified in a STEM category based on their teaching assignment when hired. Refer to Table 1 in the main analysis for teaching assignments in each STEM category. If a teacher taught multiple STEM subjects, they were categorized into the subject with the most assigned time.

b. An educational specialist degree (e.g., Ed.S.) is a terminal professional degree for individuals who have already completed a master's degree in education.

TABLE 2. Characteristics of Out-of-Field STEM Teachers in Academic Year 2018-2019

VARIABLE	%	FREQUENCY
STEM Category[a]		
Elementary All Subjects	76.6	232
Middle/Secondary Science	4.0	12
Middle/Secondary Math	7.6	23
Computer and Information Technologies	10.6	32
Other Career and Technical Education	1.3	4
Sex		
Male	26.1	79
Female	73.9	224
Race/ethnicity		
White	80.5	244
Black	14.5	44
Hispanic	3.3	10
Asian	1.0	3
Other (Native Hawaiian or Pacific Islanders, American Indian, and Multi-Racial)	0.7	2
Age (when hired)		
Age < 30	61.4	186
30 ≤ Age < 50	32.0	97
Age ≥ 50	6.6	20
Years of work experience (when hired)		
Experience < 3	44.9	136
3 ≤ Experience < 25	52.1	158
25 ≤ Experience	3.0	9
Highest degree earned (at the end of the 2017-2018 academic year)		
Below Bachelor's degree	0.0	0
Bachelor's degree	77.6	235
Master's degree	22.4	68
Doctoral / Specialist degree[b]	0.0	0

a. Each sub STEM category was classified based on the nature of teacher's teaching assignment. If teacher teaches multiple STEM subjects, teachers are categorized into the subject with the most assigned time.

b. An educational specialist degree (e.g., Ed.S.) is a terminal professional degree for individuals who have already completed a master's degree in education.

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