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Training the next generation of learning health system scientists

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Abstract

Introduction: The learning health system (LHS) aligns science, informatics, incentives, stakeholders, and culture for continuous improvement and innovation. The Agency for Healthcare Research and Quality and the Patient-Centered Outcomes Research Institute designed a K12 initiative to grow the number of LHS scientists. We describe approaches developed by 11 funded centers of excellence (COEs) to promote partnerships between scholars and health system leaders and to provide mentored research training.

Methods: Since 2018, the COEs have enlisted faculty, secured institutional resources, partnered with health systems, developed and implemented curricula, recruited scholars, and provided mentored training. Program directors for each COE provided descriptive data on program context, scholar characteristics, stakeholder engagement, scholar experiences with health system partnerships, roles following program completion, and key training challenges.

Results: To date, the 11 COEs have partnered with health systems to train 110 scholars. Nine (82%) programs partner with a Veterans Affairs health system and 9 (82%) partner with safety net providers. Clinically trained scholars (n = 87; 79%) include 70 physicians and 17 scholars in other clinical disciplines. Non-clinicians (n = 29; 26%) represent diverse fields, dominated by population health sciences. Stakeholder engagement helps scholars understand health system and patient/family needs and priorities, enabling opportunities to conduct embedded research, improve outcomes, and grow skills in translating research methods and findings into practice.

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Challenges include supporting scholars through roadblocks that threaten to derail projects during their limited program time, ranging from delays in access to data to COVID-19-related impediments and shifts in organizational priorities.

Conclusions: Four years into this novel training program, there is evidence of scholars' accomplishments, both in traditional academic terms and in terms of moving along career trajectories that hold the potential to lead and accelerate transformational health system change. Future LHS training efforts should focus on sustainability, including organizational support for scholar activities.

KEYWORDS

embedded research, health system partnership, learning health systems workforce, patient-centered outcomes research, training

1 | INTRODUCTION

The potential of learning organizations to address the most pressing business, economic, and social problems has generated growing interest over the past three decades.[1] Within the healthcare sector, the National Academy of Medicine defines the learning health system (LHS) as one in which science, informatics, incentives, and culture are aligned for continuous improvement and innovation, with best practices seamlessly embedded in the delivery process and new knowledge captured as an integral by-product of the delivery experience.[2,3] The Agency for Healthcare Research and Quality (AHRQ) and the Patient-Centered Outcomes Research Institute (PCORI) have seen the development of the LHS as a key strategy to help healthcare organizations make transformational changes to improve healthcare quality and value, and have invested in efforts to promote the development, synthesis, and rapid movement of new evidence into practice.[4] A brief but representative list of publications[5-19] from our institutions is included in the references. This selection contributes, if fractionally, to a rapidly growing body of impactful literature on the LHS.

The LHS strategy requires a workforce capable of generating new knowledge that is responsive to stakeholder needs, accelerating the systematic adoption of evidence and insights to improve health and healthcare, and promoting data-driven decision-making in health systems. AHRQ defines the LHS scientist as "an individual who is embedded within a health system and collaborates with its stakeholders to produce novel insights and evidence that can be rapidly implemented to improve the outcomes of individuals and populations and health system performance."[20] Recognizing the need to train such scientists, AHRQ commissioned the development of a set of core competencies[21] to guide the design, implementation, and evaluation of training programs for LHS scientists and these have been recently amended[20] (Appendix A, Table A1). These competencies integrate health services research skills that foster development of new, generalizable knowledge with domains from improvement and data sciences that support stakeholder engagement, change management, and innovation. With these competencies as the foundation, AHRQ and PCORI designed a Learning Health System Scientist Training institutional mentored K12

career development initiative to grow the LHS researcher and practitioner workforce. In September 2018, AHRQ and PCORI awarded $40 million in grants over 5 years to 11 institutions around the country with proven expertise in conducting LHS research to develop and implement a mentored training program for early career scientists conducting patient-centered outcomes research or improvement science within healthcare organizations (Appendix B, Table B1). These centers of excellence (COEs) aim to produce the next generation of LHS scientists who have the skill sets to design, conduct, apply, implement, disseminate, and scale patient-centered outcomes research to improve quality of care and patient outcomes in diverse health systems.

2 | QUESTION OF INTEREST

The combined experience of these 11 COEs affords an opportunity to reflect on learnings 4 years into the training program—two of which occurred during a devastating pandemic—in the hopes of informing the rapidly moving field of LHS science. This report focuses on the question: What can we learn from the approaches developed by 11 COEs to promote partnerships between scholars and health system leaders while delivering mentored research training experience?

3 | METHODS

3.1 | Development of LHS COE

Since 2018, the LHS COEs have enlisted senior faculty, secured institutional resources, partnered with health systems, developed, and implemented curricula, recruited early career faculty (ie, instructor or assistant professor equivalent), and provided mentored training. In addition to training individual scholars, the COEs have developed a series of activities aimed at promoting meaningful partnerships between embedded scientists and health system leaders—partnerships that are essential to driving system change. Indeed, some of this program's trainees have

formal roles as health system leaders in areas such as informatics, quality, and clinical operations. As such, they are well-positioned to use research methods and findings to inform decision-making. The COEs also invested in activities to increase organizational awareness of and engagement in the central precepts of LHS methods. The emphasis on health system partnership distinguishes this initiative from other embedded research training programs.

3.2 | Data collection

Program directors (PDs) for each COE provided descriptive data in the following areas: program context and setting, scholar characteristics, stakeholder engagement, health system partnerships, and scholar roles following program completion. Exemplar scholar vignettes from the COEs were solicited to describe strategies for and experiences with health system partnerships. Scholars' reflections on their experience in the training program were gathered through email and virtual meetings with scholars. PDs identified key challenges related to LHS research training; common themes across programs were identified. All the authors of the current report are either COE PDs or AHRQ staff involved in directing the K12 program.

4 | RESULTS

The 11 COEs will have recruited and trained a total of 125 scholars by the end of the program's funding period. This includes 46 scholars who have completed the program, 64 who are currently enrolled and 15 positions to be filled (Table 1). Ninety-five of these positions are supported by the AHRQ-PCORI-funded K12 training grants; five programs are funding an additional 30 scholar positions using institutional and other grant funding. All programs offer 2-year training positions, and nine programs offered some options for 3-year positions. Approximately one fifth of scholars will receive 3 years of training.

4.1 | COE context

The 11 COEs collaborate with 59 different health systems nationwide. The number of health systems that the training programs partner with ranges from 1 to 12, with a mode of 4. Notably, the lower end of the range is represented by a large academic health system that comprises 15 hospitals and over 180 outpatient units across three counties in the New York metropolitan area. All 11 programs partner with academic medical centers.

Nine (82%) programs also partner with a VA health system. Nine (82%) programs partner with safety net providers (defined as federally qualified health centers, public health departments, and/or other organizations serving low-income and marginalized populations). Most COEs partner with integrated health systems, including accountable care organizations. Three COEs partner with regions of Kaiser Permanente in California Washington State and Oregon. A few COEs also partner with

TABLE 1 Characteristics of learning health system (LHS) K12 centers of excellence (COEs)

Total trainee positions across all 11 COEs		125
Funding source for positions	Funded by K12	95
	Funded with supplemental funding[a]	30
Trainee status	Completed	46
	Currently enrolled	64
	Positions to be filled	15
Trainee positions per COE	Range	8-30
	Median	10
	Mode	8
Health systems engaged in LHS training across all 11 COEs, total		59
Health systems per COE	Range	1–12
	Mode	4
Type of health system engaged, n (% of COEs)	Academic medical center	11 (100%)
	VA health system	9 (82%)
	Safety net provider[b]	9 (82%)
Geographic location of 11 COEs (US census region)	West	4
	Midwest	3
	Northeast	2
	South	1
	National (all four regions)	1

[a]Five COEs funded a total of 30 scholar positions using institutional and other grant funding. Numbers of positions funded/total positions: 2/12 (LITI/Indiana), 5/13 (MN-LHS), 21/30 (PEDSnet Scholars), and 1/10 (both NW-PACT and ACCELERAT/Northwestern).
[b]Safety net provider is defined as federally qualified health centers, public health departments, and/or other organizations serving low-income and marginalized populations.

community-based primary care groups (n = 2) and private community hospitals (n = 2). One COE (LHSS/Vanderbilt) partners with a historically Black academic health science center, Meharry Medical College. Several COEs have partnerships with schools, prisons, and community agencies. While all the COEs are based in learning healthcare systems, the programs reach beyond to the broader health ecosystem, addressing population health through their various partnerships.

The one national program (PEDSnet Scholars) has a presence in all four US census regions: West, Midwest, Northeast, and South. The remaining 10 programs span all four regions, with seven of 11 concentrated in the West and Midwest

All the COEs focus on training faculty in patient-centered outcomes research, improvement and implementation science, and engagement science. They all share an emphasis on practical impact: addressing real-world problems, rapid translation of research findings, impacting the quintuple aim[22]—population health, patient experience, cost, care team experience, and health equity. Formal connection between scholars and health system leaders is a key component of the programs. Many of the COEs focus explicitly on historically marginalized populations—including persons of color, immigrants,
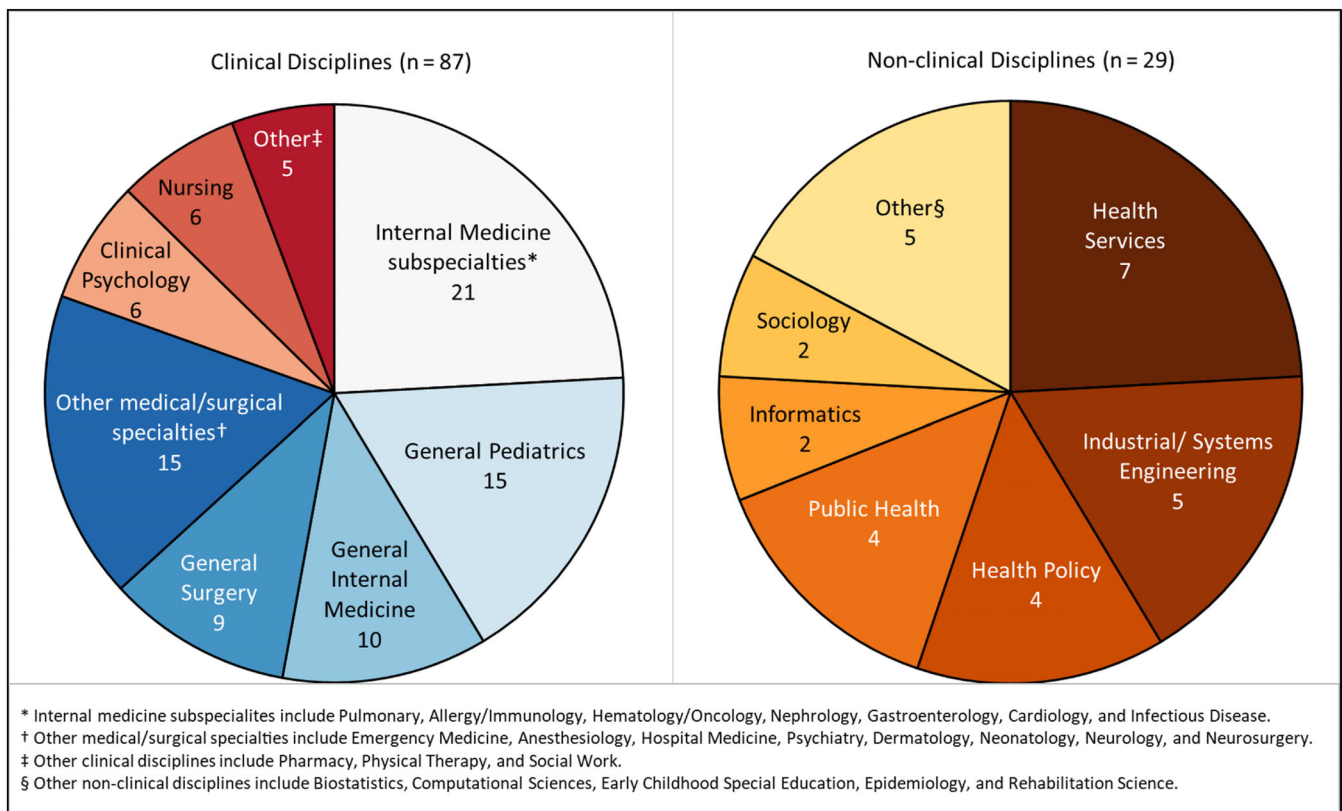
FIGURE 1 Learning health system (LHS) scholar discipline and specialty (n = 110). Note that the two pie charts are not mutually exclusive.

refugees, and low-income populations; most scholars across the 11 COEs conduct their research in these populations. One program (PEDSnet Scholars) focuses on children. One COE (NW-PACT) aims to develop a network that includes health systems, academic institutions, health policy agencies, and community-based organizations.

To accomplish their training objectives, the COEs conduct seminars, work-in-progress sessions, and grand rounds in partnership with other training programs and departments in their respective institutions. Faculty with diverse expertise from different partner departments and organizations lead interactive learning sessions. Work-in-progress sessions foster a sense of community among trainees and enable peer mentoring. Some COEs have fully integrated the K12 with other research training programs in related fields, including informatics, health services research, and quality improvement. Eight of the COEs are based at institutions that are also Clinical and Translational Science Award recipients. Two COEs (PEDSnet Scholars and LHSS/Vanderbilt) are partnered with PCORnet.[23] Each COE used its own rubric and approach to evaluate their scholars, who come to the program with varied skill sets and backgrounds. COEs typically ask scholars to self-assess at program entry and periodically after that, using rubrics based on the LHS competencies. Mentors play a role in prioritizing areas for further training and development. One COE (MN-LHS) has developed a competency appraisal inventory and is piloting it with current scholars.[13]

AHRQ hosts monthly LHS K12 videoconferences at which PDs, AHRQ, and PCORI staff discuss emerging issues. The lack of focus on health equity in the original seven LHS research competencies[21] led this group to jointly draft a new competency domain[20] centering health and healthcare equity and justice (Appendix A, Table A1). Program administrators at several of the COEs convene periodically to share best practices. Program-wide annual meetings bring together all the scholars and PDs to network and share learnings. AHRQ is conducting an evaluation to determine how the K12 program has met its goals of delivering value to scholars and health systems in which they are embedded.

Some COEs also leveraged their resources to the benefit of scholars at other sites. For example, NW-PACT hosts a national LHS leader seminar every other month which all scholars and PDs are encouraged to attend. The LHSS/Vanderbilt COE held an Implementation Science and Learning Health Symposium in May 2021 which was open to LHS scholars from all COEs. NW-PACT conceived of and operationalized the AcademyHealth "LHS Challenge Awards" in 2022. Two COEs (CATALyST/Washington and NW-PACT) conducted a joint two-part symposium in January and March 2022.

4.2 | Scholars

Among the 110 current or graduated scholars, 67 are physicians (MDs)—two of these being MD/PhD and one JD/MD—and three are osteopathic physicians (DOs). In addition, 44 (40%) scholars hold PhDs, and one scholar each holds doctoral degrees in public health

(DrPH), clinical psychology (PsyD), and physical therapy (DPT) . Two scholars hold RN degrees. Ninety (82%) scholars also have a master's degree; 32 scholars have an MS, 29 have an MPH, and the remainder have degrees in 12 other fields such as health services, health policy, clinical investigation, public policy, social work, bioethics, and biomedical informatics.

Many of the clinicians are practicing in their health systems. The disciplines and specialties of the 87 scholars with clinical training are shown in Figure 1. These include 15 general pediatricians, 10 general internists, 9 general surgeons, and 36 physicians across another 15 specialties. Other clinical disciplines represented include clinical psychology (n = 6), nursing (n = 6), pharmacy (n = 2), social work (n = 2), and physical therapy (n = 1). Eleven non-clinical disciplines were represented (29 scholars), the most common being health services (n = 7), and industrial and systems engineering (n = 5), health policy (n = 4), and public health (n = 4). There were two scholars each in informatics and sociology, and one scholar each for biostatistics, computational sciences, early childhood special education, epidemiology, and rehabilitation science.

The LHS scholars conduct research that emerges from and is directly applicable to real-world settings and that focuses on improving patient or system outcomes. They draw on diverse methods to address their research questions (Box 1), ranging from using predictive analytics to inform clinical decision support and population surveillance to engaging patients, communities, and delivery systems in co-design of interventions such as developmental screening or promoting educational readiness. Many of the scholars work closely with and receive training and support from informatics and data science groups at their institutions. This includes collaborations for extraction or access to electronic health data, data standardization and validation, data linkage, data analyses, predictive modeling, clinical decision

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BOX 1   Methods and traditions commonly used by learning health system scholars

- Behavioral economics
- Community-engaged research
- Data science and health informatics
- Engagement science
- Human-centered design
- Implementation science
- Improvement science
- Mixed methods, qualitative analysis
- Pragmatic trials
- Predictive modeling
- Transportation analysis

BOX 2   Scholar Vignette A

Discipline:	Biostatistics
Motivation:	Health equity, ensuring that clinical advances reduce, rather than exacerbate, existing disparities
Learning health system (LHS) setting:	Integrated health system
Health system partners:	Operational leaders in various units, informatics leaders
Project title:	Statistical methods to improve clinical risk prediction
Scholar focus during LHS training:	Developing methods to reduce racial and ethnic disparities in suicide risk prediction, identifying ways in which suicide prediction models provided less benefit to some racial and ethnic groups.
	Statistical methods for developing and deploying electronic health record (EHR)-based clinical prediction models in a variety of clinical areas that are accurate, actionable, and ethical. Collaborating with several different operational teams to improve care delivery using rigorous methods, including randomized trials of EHR interventions. Helped operational partners to "go the last mile" in seeing statistical tools correctly implemented into care delivery.
	Growing knowledge of data provenance needed to accurately use clinical data.
Scholar opportunities:	Bi-directional partnerships with senior leaders in clinical operations and IT afforded the scholar access to data and opportunities to conduct their own research, as well as developing their skills in translating research methods and findings into practice.
	Scholar became scientific lead for the advanced analytics core for internally funded LHS program.
	Obtained R01 funding from NIH for methods work related to reducing disparities in suicide prediction.
Impact on health system:	Randomized trials within the EHR led to adoption of interventions.
	Advised on implementation of the epic modeling license to support predictive modeling.

BOX 3   Scholar Vignette B

Discipline:	Internal medicine physician, master's in health services research
Motivation:	Address disparities in digital health access and quality of care for racial/ethnic minority and limited English proficiency (LEP) populations.
Learning health system (LHS) setting:	County health system
Health system partners:	Primary care leaders, public health department leaders, medical director of digital patient engagement
Project title:	Engaging Patients with Diabetes Mellitus into a Bilingual Patient Portal in the Los Angeles County Safety Net
Scholar focus during LHS training:	Training in health systems operations and health record informatics, health systems improvement theory, and user-centered technology design for LEP populations. Surveys and focus groups to understand awareness about the patient portal and how safety net patients relate to this technology. Developing strategies to increase health technology engagement among diverse low-income patients in one of the largest municipal health safety net systems in the nation.
Scholar opportunities:	Bidirectional partnerships with operational health department leaders afforded the scholar access to data and set the stage for future opportunities to test pilot projects on a larger scale. Scholar was appointed as the academic research partner for the local department of health services Virtual Care Workgroup, alongside primary care clinic directors, patients and community advocates, interpreter services, social work, and chronic disease health educators. This group that shapes policy and determines the evidence-based interventions that drive the delivery of telemedicine. Obtained K23 funding from NIH to build on the above work.
Impact on health system:	Informed decision-making in safety net clinics, including critical changes in digital services workflow.

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support, patient-facing health informatics tools, and other activities. Common areas of focus for scholar projects include some of the major issues currently influencing health and healthcare, such as telehealth, social determinants of health, patient-reported outcomes, management of prescribed opioids, and the diagnosis and treatment of opioid use disorder, and addressing health disparities (related to race, ethnicity as well as rural populations, children, and elders). Exemplar project titles can be found in Appendix C, Table C1. Many of the projects reflect the scholars' interest in the practical application of their research findings and alignment between their scientific aims and health system operational priorities. Examples include the evaluation of the business case for addressing social determinants and the co-design with clinical leaders of an adolescent integrated mental health intervention in preparation for a system-wide implementation.

4.3 | Stakeholder engagement and partnerships with health system leaders

Engagement of stakeholders in all aspects of the research is one of the eight LHS core competencies.[20] Relevant stakeholders may include patients, families, clinicians, health plan administrators, clinical leaders, and/or community partners. All 11 COEs require their scholars to engage stakeholders, with the goal of making their research more patient-centered, relevant, feasible, and, ultimately, leading to community health improvement. All scholars engage at least one stakeholder group in co-designing and/or conducting their research. Stakeholder engagement occurs at all stages of scholars' research, from project development and study design to implementation, data collection, data analysis, and dissemination, in accordance with the PCORI engagement rubric.[24]

A key stakeholder group is health system leadership; indeed, partnership between scientists and health system leaders is a hallmark of LHS research. Our LHS scholars are embedded in a variety of healthcare settings (eg, hospital units, clinical IT, and quality/safety departments and county departments of public health), affording them the opportunity not only to conduct their research in the health system, but also to develop meaningful and mutually beneficial relationships.

Two scholars' experiences (Boxes 2 and 3) are provided as examples of the ways in which bidirectional partnerships between scholars and health system leaders support health system transformation. They include a biostatistician embedded in an integrated health system, focused on methods to detect and reduce racial and ethnic bias in prediction models (CATALyST/Washington); and an internal medicine physician, embedded in a county health system, addressing barriers in access to online portal for patients with limited English proficiency (SPIRIT/UCLA). All 11 COEs focus on enabling relationships between scholars and health system leaders, including executives, operational

BOX 4   Development of partnerships with health system leaders—Illustrative scholar quotes

"The LHS-K12 allowed me to meet with and engage the LHS leaders at Indiana University and Regenstrief… I was able to participate in the Regenstrief Indiana Learning Health System Initiative team meetings which helped inform me of current projects and goals."—LITI/Indiana scholar

"My embedded research experience was a key factor in securing a new leadership role as Research Director within the UCSF Age-Friendly Health System."—LEAP/UCSF scholar

"Regular meetings with senior UCSF Health leaders were essential to understanding health system priorities, legitimizing my presence in the clinical delivery system and facilitating my embedded research."—LEAP/UCSF scholar

"The CATALyST Program gave me opportunities to develop partnerships with senior leaders and business owners in care delivery. I provided statistical, modeling and data expertise to inform operational decision-making. In return, I got access to data and opportunities to conduct research, as well as developing skills in translating research methods and findings into practice."—CATALyST/Washington scholar

"Being embedded in a health system greatly expanded my career horizons. The structured exploration of implementation science, systems theory, and research methodology prepared me to pose new questions with an attentive focus on condensing the translational path and improving outcomes locally. As I begin my new role as Vice President for Equity in Research, I am appreciative of the opportunities the K12 program created for me to engage with system leaders and participate in discussions relating the organization and conduct of research at our center."—MN-LHS Scholar

TABLE 2   Scholar status following completion of learning health system (LHS) K12 program (n = 46)

		n (%)
Types of roles Numbers do not add to 46 because some scholars had multiple roles	Researcher	30 (65)
	Health system leader	17 (37)
	Educator	4 (9)
	Other leadership role	3 (6)
Scholars with research funding upon completion of training		42 (92)
Funding source n = 65 grants	NIH[a]	24
	Health system funding	10
	AHRQ	8
	Private foundation	8
	VA	4
	PCORI	3
	Industry	3
	Other[b]	5
Funding type (for NIH and AHRQ grants)	Individual K[c]	11
	R01	6
	Other R awards[d]	4
	VA Career Development Award	4
	U24	1

[a]NIH grants include NIA grants, NHLBI, NIMH, NCI, NIDCD, NIGMS, NIAID, and COBRE.
[b]Other funding sources include HRSA, CDC, and FDA.
[c]K awards include five scholars with K23 awards, three scholars with K08 awards, and two with K01 awards.
[d]Other R awards include two R21s, one R33, and one R34.

leaders, and frontline managers. This includes both relationship-building as well as gaining an understanding of how to thrive as researchers in the clinical setting. COEs enlist health system stakeholders to advise on scholar research projects, and help ensure that the research is feasible, practical, and meets the needs of stakeholders. Some COEs require scholars to identify a health system leader as an operational mentor or sponsor as part of their application process to gain entry into the training program, while other COEs pair scholars with operational leaders during the course of the training experience. Some of the COEs relied on a single committee that engaged with multiple scholars, while at other COEs, scholars conducted stakeholder studios or convened committees with specific relevance and expertise to their individual projects.

Scholars voice appreciation for the value of these partnerships both to their research and their career development; see representative quotes in Box 4. Scholars describe these partnerships as helping them gain an understanding of health system needs and priorities,

enabling access to data and opportunities to conduct research, growing their skills in translating research methods and findings into practice. Many scholars have been active participants in health system decision-making, and some have been afforded opportunities to take on new leadership roles in their health systems. During the pandemic, LHS scholars actively participated in local health system responses and COVID-related research projects, emphasizing the multiple roles for LHS scholars.

For their part, health system leaders also benefit from these partnerships. Examples include projects led by LHS scholars who:

- Led a human-centered design project to improve patient education materials for liver transplant candidates. The goal was development of a tool to help patients feel confident and prepared to navigate the organ offer process. The positive response from patients and clinicians helped health system leaders appreciate the value of the project, support it and make it sustainable. (MN-LHS)
- Designed an evidence-based implementation approach for an integrated adolescent mental health intervention that the health system is using for system-wide implementation. (CATALyST/Washington)
- Developed an artificial intelligence algorithm to identify possible cases of COVID-19 based on chest X-rays. The project resulted in

EHR-embedded diagnostic tools that clinicians could use as an adjunct to clinical decision support of COVID-19 diagnosis. (MN-LHS)

Beyond the work of any one scholar, such partnerships can also benefit the health system by building up its LHS capacity. The COEs invite the organization's clinical and informatics leaders to seminars and scholar work-in-progress sessions and include health system leaders on scholar mentoring teams. Such activities aim to promote organizational learning, helping systems to become more intentional, rapid, and nimble at assessing data; incorporating LHS approaches; and ultimately, reducing time to adoption of evidence-based practices and advancing innovative approaches to value-based care.

4.4 | Training outcomes to date

Among the 46 scholars who have completed training as of April 2022, 92% have received research grant funding, including 11 individual K awards, 6 R01s, 4 other R-type awards, and 4 VA career development awards (Table 2). Funding agencies include traditional public research funders like NIH (n = 24), AHRQ (n = 8), VA (n = 4), and PCORI (n = 3), as well as private foundations (n = 8), and industry (n = 3). Of note, 10 scholars report receiving health system funding for their ongoing research. At last count (July 2021), scholars at the 11 COEs had contributed nearly 400 publications to the peer-reviewed literature on LHS since the program's inception.

While the majority (65%) of graduated scholars are in primarily research roles, 37% have assumed a health system leadership position upon completion of the LHS training program. These include medical director roles—both operational (eg, general surgery) and programmatic (quality and safety)—as well as executive positions, like chief medical officer and chief medical information officer. Two examples of novel roles that reflect the value that these health systems place on the LHS model include implementation science lead for digital patient experience and research director for age friendly health system (LEAP/UCSF). Thus, the LHS K12 scholars are straddling traditional funding paths and health system leadership opportunities.

4.5 | Challenges Encountered

Across the centers, developing and executing LHS training presents different challenges at each phase in the training cycle. Recruitment for some single-institution COEs is challenged by limited depth and diversity of applicants; this is less of a concern for those centers that recruit nationally and those that do not require accepted scholars to relocate. Some COEs face competition for qualified and interested applicants from other career development programs, especially those programs with longer durations of support. The LHS K12 program attracts and trains a large portion of clinician scientists, particularly physician scientists. This is an important achievement given concerns about vanishing numbers of physician scientists. However, some COEs find it difficult to recruit physicians in highly compensated specialties given the large gap between the non-clinical time required for the LHS program and these clinicians' typical salaries. There is also a need for better coordination with academic departments as COEs bringing on new scholars navigate the tight timeline between the K12 admissions process and the academic appointment/hiring process.

During the scholars' time in the program, PDs must respond to three major issues. First, they need to serve as advocates and institutional community-builders for the scholars, overcoming the challenges of meeting virtually, facilitating networking with other early-career scholars in aligned areas, and serving as liaisons between scholars and health system leaders. In connecting scholars with leaders, PDs sometimes need to coach health system leaders in understanding the value added by the LHS scholars and their unique skill sets. Second, PDs must develop programming that meets the scholars' needs, including helping them understand and access institutional resources such as grant writing support and pilot funding. In most cases, the pandemic has required the COEs to adapt to providing programming and guidance virtually. Third, PDs have had to support the scholars through roadblocks that have threatened to derail their research projects during their limited time in the program, including: institutional review board delays; delays in access to clinical and operational data, especially in cases where health system partners may not have a clear appreciation of the value of the scholars' projects to the health system; lack of standard definitions for electronic health record data elements; a need to pivot to alternative modes of data collection during COVID-19-related restrictions on research (eg, conducting virtual as opposed to in person focus groups); and shifts in organizational priorities with the resultant need to alter research objectives or risk loss of engagement, sponsorship, and resources.

PDs face two major challenges as they support scholars as they transition to their post-K12 phase. First, they must help scholars bridge the worlds of operations-oriented work and extramurally funded research. LHS scholars have few role models who embarked on LHS research careers at an early stage. PDs and mentors therefore face challenges in helping scholars define pathways forward that do not carry undue professional risk with regard to career trajectory and subsequent promotion. In particular, the deliverables of LHS research may not align with current promotion metrics at many institutions and thus may not be fully recognized through standard review criteria. Second, in evaluating the effectiveness of their programs, PDs have had to identify relevant metrics that capture the multifaceted nature of LHS science. While COEs collect traditional metrics such as publications and grant funding, other important concepts such as stakeholder engagement, institutional readiness for change, or impact on practice (eg, total cost of care, patient outcomes/experience, health equity) are more difficult to characterize.

In keeping with the concept of a learning organization, COEs have largely been able to adapt to the challenges they encounter, marshaling local resources to financially support the scholars, building community, and effectively integrating the scholars into the work of the health system.

5 | DISCUSSION

The 11 COEs funded by the AHRQ/PCORI LHS K12 program have worked together over the past 4 years to develop approaches to training the next generation of LHS scientists, and program leaders across the COEs have been learning from these early experiences. Four years into this novel training program, there is considerable, albeit early, evidence of these scholars' collective accomplishments, both in traditional academic terms (competencies, peer-reviewed publications, independent grant funding) and in terms of moving along career trajectories that hold the potential to lead and accelerate transformational health system change. The LHS K12 program differs in several ways from many other training programs, such as those focused on health services research or clinical effectiveness. A major difference is that scholars are embedded in health systems and are trained in LHS competencies as well as PCOR. The scholars also receive mentoring in the development of stakeholder partnerships to inform their research approaches and enhance the relevance and impact of their findings. Scholar success is defined in terms of both partnership and impact. Indeed, the LHS scholars have benefitted from rich operational leadership opportunities that position them to influence health system decision-making. However, program leaders are still learning how best to support early career scientists in navigating health system operational structures while also learning research methods and working towards scientific independence. Variability across COEs is providing opportunities to learn about the value of different training approaches. In addition, AHRQ is conducting a formal evaluation of the LHS K12 program to assess its impact and to plan future investments. To make real the promise of LHSs, it will be important to learn from the experiences of the COEs in the AHRQ/PCORI LHS K12—along with those of other LHS programs across the country that train doctoral and post-doctoral researchers[25-27] and clinicians.[28]

In one sense, the COVID-19 pandemic represented an ideal use case for LHS principles and approaches. Given the rapidly evolving evidence base regarding the diagnosis and treatment of COVID-19, there was a need for health systems to identify and synthesize evidence very quickly to address the clinical challenges associated with this novel virus. Health systems needed to create COVID-19 patient registries, data marts, analysis tools, and feedback cycles to assess system performance in near "real time." System care maps and guideline processes and technologies had to be created and updated frequently to facilitate the application of new knowledge to the process of healthcare delivery. The role and importance of formally trained implementation scientists, like our scholars, and authentic patient engagement became manifest to institutional leaders. At one COE (MN-LHS), the centrality of the LHS scholars and their value in addressing the challenges of COVID-19 was so clear to health system leaders that it led to their investment in the nascent University of Minnesota (UMN) Center for Learning Health System Sciences, a collaboration between the UMN schools of public health and medicine.

PDs have identified several improvement opportunities that could inform the efforts of other groups seeking to grow the LHS scientist workforce. While the AHRQ/PCORI K12 program has recruited physicians in large numbers, it will be important to make inroads into nursing, pharmacy, social work and other fields, in order to ensure that clinical disciplines are more broadly represented in the LHS workforce. Addressing structural barriers would support recruitment of a more racial and ethnically diverse pool of scholars. For example, remote participation may make this novel training program more appealing to candidates who would find it undesirable to relocate to a new city and undertake training in a field with an uncertain career trajectory. Scholars also need more support as they transition to their next step post-K12. In addition to preparing scholars for the traditional research pathway—obtaining a subsequent K (or an R) award—COEs and their health system partners should explore other means of supporting scholars with committed funding and operational roles at the conclusion of the K12 training period.

Future LHS training efforts in the AHRQ/PCORI K12 program and in other LHS programs should focus on sustainability, including organizational support both for embeddedness of scholars and for their training. This requires that health system leaders understand the value proposition of the LHS vision. Recognizing that LHS scholars are doing work that benefits health systems can incentivize leaders to support LHS training. Researchers and clinical leaders should work together to promote the understanding that quality improvement is the responsibility of every member of the healthcare team, and that all stakeholders in the LHS have a role to play in organizational learning. In addition to supporting the sustainability of LHS training, these cultural shifts would also help bring the LHS vision to life.

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CONFLICT OF INTEREST

With the exception of Francis D. Chesley, Jr., all authors are grantees of the program that is the subject of this paper.

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APPENDIX A

TABLE A1 Learning health system scientist competency domains[a]

Systems science	To understand how health systems operate and how to apply systems theory to research and implementation.
Research questions and standards of scientific evidence	To ask meaningful questions and evaluate the usefulness of scientific evidence and insights
Research methods	To conduct research within the context of complex health systems using appropriate study designs and analytic methods to assess outcomes of interest to health systems stakeholders.
Informatics	To know how to use information systems to conduct LHS research and improve patient and health system outcomes.
Ethics of research and Implementation in health systems	To ensure that research and quality improvement done in healthcare settings adheres to the highest ethical standards.
Improvement and implementation science	To reduce avoidable variation in process and outcomes and ensure the systematic uptake of research findings in a health system.
Engagement, leadership, and research management	To engage stakeholders in all aspects of the research process and effectively lead and manage LHS research teams and projects.
Health and healthcare equity and justice[b]	To know how to assess health equity and apply LHS science methods to advance equity and justice in healthcare delivery systems and health.

[a]Agency for Healthcare Research and Quality.[20]

[b]The equity domain was developed during the third year of the AHRQ/PCORI K12 program, by the COE PDs in collaboration with AHRQ.

APPENDIX B

TABLE B1　Learning health system (LHS) K12 centers of excellence

Prime institution(s)	Program	Partner institutions
Albert Einstein College of Medicine	EXPLORE: Center of Excellence in Promoting LHS Operations and Research	Montefiore Health System
Children's Hospital of Philadelphia	PEDSnet Scholars: A Training Program for Pediatric Learning Health System Scientists	Boston Children's Hospital Children's Hospital Colorado Children's Hospital of Philadelphia Children's National Hospital Cincinnati Children's Hospital Medical Center Lurie Children's Hospital of Chicago Nationwide Children's Hospital Nemours Children's Health Seattle Children's Hospital Stanford Children's Health Texas Children's Hospital
Indiana University School of Medicine	LITI- PCORLHS: Leveraging Infrastructure to Train Investigators in Patient-Centered Outcomes Research in the LHS	Regenstrief Institute for Health Care Indiana University Health Richard L. Roudebush VA Medical Center
Kaiser Permanente Washington Health Research Institute	CATALyST: Consortium for Applied Training to Advance the LHS with Scholars/Trainees	VA Puget Sound Health Care System University of Washington School of Public Health Washington State University
Northwestern University	ACCELERAT: A Chicago Center of Excellence in LHS Research Training	Northwestern Medicine Lurie Children's Hospital Rush University Cook County Health Alliance Chicago University of Illinois College of Medicine NorthShore University Healthsystem Loyola Medicine University of Chicago Edward Hines, Jr. VA Hospital
Oregon Health and Science University and Kaiser Permanente Northwest Center for Health Research	PACT: NW Center of Excellence & K12 in Patient-Centered Learning Health Systems Science	Portland VA Health Care System Legacy Health System OCHIN Central City Concern Oregon Rural Practice Network Oregon Health Authority Oregon State University Portland State University
University of California, Los Angeles	SPIRIT: Stakeholder-Partnered Implementation Research and Innovation Translation Program	Kaiser Permanente Southern California Department of Research and Evaluation Kaiser Permanente Bernard J. Tyson School of Medicine VA Greater Los Angeles Healthcare System Los Angeles County Department of Health Services
University of California, San Francisco	LEAP: Learning Health System Early Career Acceleration Program	Zuckerberg San Francisco General Hospital San Francisco VA Medical Center University of California, Fresno
University of Minnesota	MN-LHS: Minnesota Learning Health System Mentored Career Development Program	Mayo Clinic Hennepin Healthcare M Health Fairview
University of Pennsylvania	T-GAPP: Transforming the Generation and Adoption of PCOR in Practice	Penn Medicine Public Health Management Corporation Philadelphia VA Medical Center
Vanderbilt University Medical Center	LHSS: Learning Health System Scholar Program at Vanderbilt	Monroe Carell Jr. Children's Hospital at Vanderbilt VA Tennessee Valley Healthcare System Meharry Medical Center/Meharry-Vanderbilt Alliance Vanderbilt Health Affiliated Network

APPENDIX C

TABLE C1 Common focus areas of lhs scholars' research, with example project titles

Health disparities	The impact of Geographic Disparities on Parental Experiences, Growth Outcomes and Healthcare Utilization in the Care of Very Low Birthweight Infants (PEDSnet Scholars) Addressing Racial Disparities in Low-Risk Chest Pain and Anxiety (LITI/Indiana) Culturally sensitive resources to support African-American kidney transplant candidates (MN-LHS) Co-designing developmental screening with parents/caregivers from marginalized communities using a community-driven approach (CATALyST/Washington) The Latino School Readiness Gap: Engaging parents, educators and pediatricians in novel primary care solutions (NW-PACT)
Telehealth	Transitioning a Shared Decision Making Dashboard to Telemedicine Clinical Encounters (ACCELERAT/Northwestern) Delivering a Telehealth Language Intervention to Children and their Caregivers in Rural Communities (NW-PACT) Telerehabilitation program to enhance access to quality rehabilitation following hospitalization for persons with dementia (MN-LHS)
Opioid use	Health Systems Approaches to Improving Opioid Management (EXPLORE/Einstein) The Substance Use Intervention Team: Addressing Health Disparities with a Systems-Level Strategy to Identify and Treat Opioid Misuse (ACCELERAT/Northwestern) Tailoring Acute Opioid Prescribing to Patient Reported Outcomes: A Patient-centered Approach to Reducing Opioid Excess and Misuse (T-GAPP/Penn)
Patient-centered outcomes	Utilization of Patient Reported Outcomes to Decrease Readmissions and Complications after Surgery (T-GAPP/Penn) Effect of a Policy Implementation on Patient-Centered Outcomes for Youth with Autism Spectrum Disorder (SPIRIT/UCLA) Simple Rankings vs Quantitative Relative Valuations of Patient/Caregiver-Preferred Perioperative Outcome Metrics (PEDSnet Scholars)
Social determinants of health	Design and implementation of social determinants of health module in electronic health record (LEAP/UCSF) Assessing the Business Case for Social Health Investment in a Large Integrated Delivery System (SPIRIT/UCLA) Developing and implementing trauma-sensitive, patient-centered primary and preventive healthcare practices for women who have experienced sexual assault (MN-LHS)