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COMMENTARY

Learning Health Systems

Socio-technical infrastructure for a learning health system

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1 | INTRODUCTION

This commentary is in many ways a follow-on to, and elaboration of, the commentary published in the July issue of this journal.[1] The previous commentary introduced three characteristics that contribute to the uniqueness of learning health systems (LHSs) as an approach to health improvement. The three characteristics introduced there were: "(1) a multi-stakeholder learning community that is focused on the (targeted) problem and collaboratively executes the entire cycle; (2) embracing, at the outset, the uncertainty of how to improve against the problem by undertaking a rigorous discovery process before any implementation takes place; and (3) supporting multiple co-occurring cycles with a socio-technical infrastructure to create a learning system."

This commentary focuses on the very important third characteristic, infrastructure. It examines the role of infrastructure in the overall architecture of an LHS and describes LHS infrastructure in terms of 10 interconnected socio-technical services accompanied by a brief description of each. Like the previous commentary, this one seeks to bring an increased level of focus to discussions of LHSs and move an emerging field, what is coming to be called "Learning Health System Science",[2] toward a sharper conception of its core principles.

2 | ARCHITECTURE OF A LEARNING HEALTH SYSTEM

A learning health system (LHS) requires three interacting and tightly linked elements:

1. *Improvement cycles directed at critical health problems*: LHSs improve individual and population health through cycles that assemble and analyze data to create knowledge, combine that knowledge with relevant evidence already existing in the world, apply the combined knowledge to generate targeted evidence-based interventions, implement the interventions, and collect fresh data based on those interventions to drive further improvement. As shown in Figure 1 below, improvement cycles are initiated and directed by multi-stakeholder communities[3] that co-discover the new evidence and co-design the interventions.
2. *Socio-technical infrastructure providing key services supporting co-occurring improvement cycles*: Infrastructure is what makes the system a system. LHS infrastructure—consisting of people, technology, processes, and policies—provides services supporting all co-occurring improvement cycles. These services, as described below, can support improvement cycles addressing any health problem because all cycles operate in fundamentally the same way: taking performance to data (P2D), data to knowledge (D2K), and knowledge to performance (K2P). The sharing of services across cycles enables the system to have economy of scale that is essential to sustainability. The relationship between multiple co-occurring improvement cycles and an infrastructure that supports all of them is illustrated in Figure 2 below.
3. *Governance of the system*: LHS governance enables the system to evolve creatively while providing guardrails to maintain coherence, focus, and accountability. The governance must strike a balance of top-down control and bottom-up innovation. It must promote communication so that the improvement cycles can share

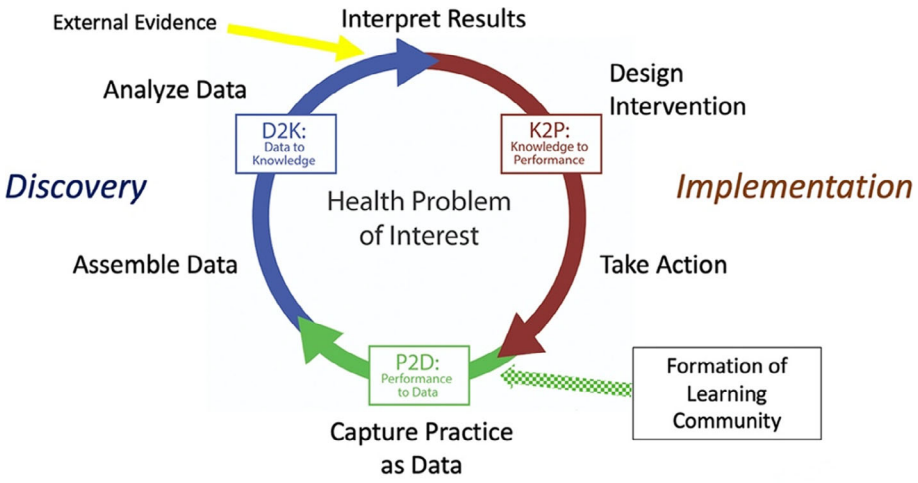

FIGURE 1 The improvement cycle "marrying" discovery with implementation.

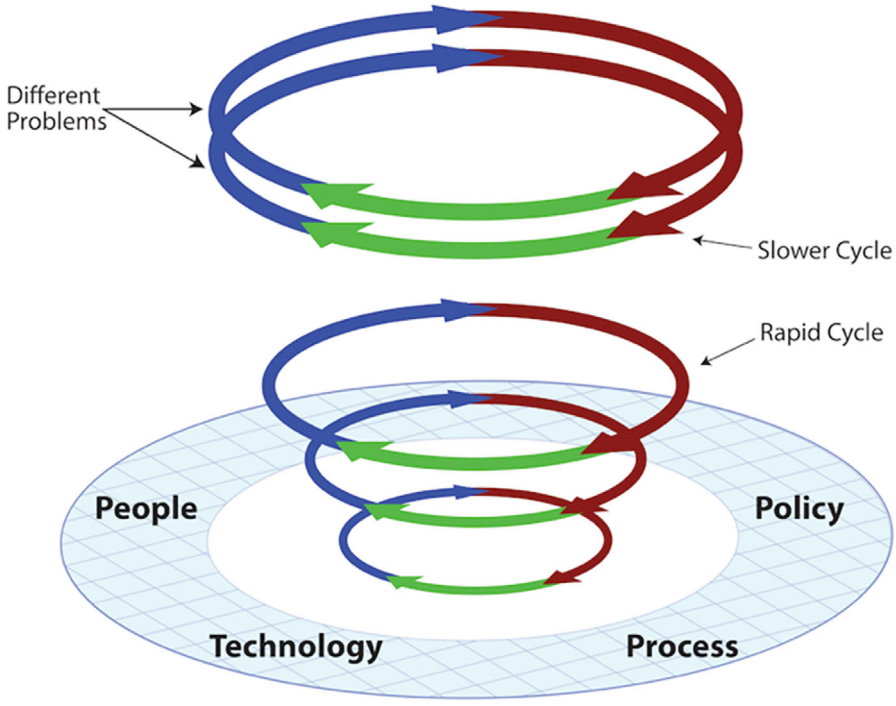

FIGURE 2 A socio-technical infrastructure platform supporting multiple co-occurring improvement cycles.

experiences and learn from each other, to promote a culture of learning and improvement.[4] While governance of LHSs is very important, a more detailed discussion of governance is out of scope for this commentary.

3 | THE SCOPE AND MEANING OF SOCIO-TECHNICAL INFRASTRUCTURE

Critically, LHS infrastructure must extend beyond digital technology in order to support improvement of individual and population health. The infrastructure must be socio-technical in the sense that it incorporates the roles that a wide range of people must play at different levels of social organization: as individuals, as teams, as members of organizations, and as citizens of civil society.[5] Technology, alone, only establishes a potential for health improvement through an LHS.

In broad terms, the services provided by socio-technical infrastructure include:

1. People, members of a trained workforce, who do the actual work.
2. Technologies that support the people in carrying out the work of improvement: transforming performance into data, data into knowledge, and applying that knowledge to performance.

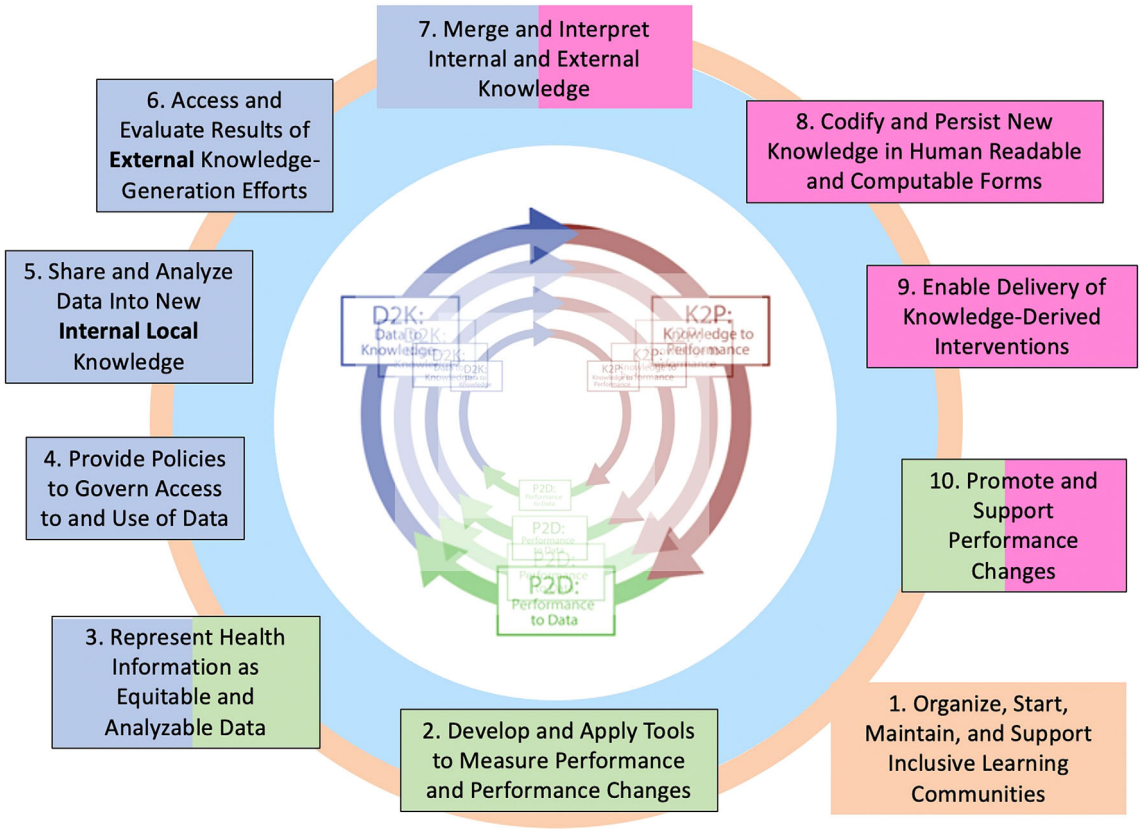

FIGURE 3 Infrastructural services aligning with and supporting each stage of the improvement cycle.

3. Policies that shape how the work is performed.
4. Processes that establish routines enabling the work to be carried out efficiently.

4 | SHARED INFRASTRUCTURAL SERVICES FOR LEARNING HEALTH SYSTEMS

LHS infrastructure can be best described in terms of 10 services, 9 of which align with the stage of the improvement cycle that each primarily supports, and one that is active throughout the cycle. This is illustrated in Figure 3 below, which depicts how Figure 2 appears if one "looks down" through the vertical axis of Figure 2. Brief descriptions of each service follow.

1. Services supporting development and function of learning communities: Learning communities are multi-stakeholder, collaborative groups that work coherently in pursuit of a shared health improvement goal. Engagement of all relevant stakeholders will help ensure that equity is built into all stages of the improvement cycle. These groups will not become cohesive and productive unless effectively facilitated. Socio-technical infrastructure supporting these groups include "manuals" for facilitators to assist them through the stages of group formation and facilitation, as well as well-developed interpersonal processes (such as Deliberative Dialogues) to help groups function as teams, share learning resources, develop shared understanding, prioritize potential actions, and reach decisions. Importantly, this service remains active throughout the entire cycle, as illustrated by the continuous orange band on the infrastructure ring in Figure 3.
2. Services to develop and apply tools that measure performance and performance outcomes: The "performance to data" stage of the improvement cycle requires the development of tools, process, and/or instruments to capture meaningful, unbiased, and usable data. This could include processes for developing a cohort, creation of a dataset, development of survey instrument, or qualitative interview guides. Where validated measurement instruments for these purposes exist, they constitute important infrastructural technology; where they do not exist, individuals with experience in developing measurement tools provide essential support to learning communities. This includes expertise to help learning communities understand the limitations of performance measures and outcomes, as well as the value of other types of data, including qualitative data, to assess or understand performance outcomes.
3. Services to provide health information as analyzable data: Internal health system data that are routinely collected and stored in repositories are a key infrastructural service component to support improvement cycles. These services enable learning communities to minimize what are often manual processes to collect data required for the "data to knowledge" phase of the improvement cycle. Repositories exist at varying levels of scale, from national

(such as PCORNet[6]) to regional or organizational. At any of these levels of scale, repositories require policies that standardize the data, database technology to maintain and access it, and an informatics workforce trained to provide these shared services—as well as assistance to help learning communities know what data are available and how they could be used to guide discovery.

4. Services to enable and govern access to and use of data: Whether considered to be highly regulated research or less highly regulated "quality improvement" projects, the data to knowledge phase of the improvement cycle requires policies to ensure that the ethics and rights of individuals are preserved and respected. The work of learning communities can be supported by infrastructure in the form of shareable policies (such as data sharing and data use agreements) and templates that can be customized and repurposed. When learning communities span organizations, mechanisms such as SmartIRB[7] comprise important infrastructural services. This also includes services and expertise to manage distinctions between work considered to be research and that considered to be quality improvement.
5. Services to share and analyze data: Tools for analysis of quantitative and qualitative data (e.g., statistical packages and qualitative coding software), as well as data visualization and querying tools, are well-established components of infrastructure supporting learning communities. It is often the case that the data-to-knowledge component of the cycle requires data from different organizational homes. In such cases, processes, policies, and technologies that merge these data are essential infrastructural services. Distributed analysis, allowing rigorous statistical procedures to be carried out across a federated network,[8] is an important emerging method. The results of these sharing and analysis processes generate what may be called internal knowledge that reflects the experience of the entities represented by the learning community.
6. Services to access and evaluate external knowledge: Any health problem important enough to generate passion within a learning community is likely to have been studied elsewhere. The knowledge generated by these external studies can be an important contributor to the work of a learning community. Having access to resources and tools to support the learning community in finding these external sources in journal articles, books, and the "grey literature" is important to contextualize and synthesize the local findings.[9] In addition, having resources and tools to assist learning communities in evaluating the quality of these external sources is important to determine which constitute the best and most relevant evidence.
7. Services to merge and interpret internal and external knowledge: As the learning cycle reaches the key transition from data to knowledge (D2K) to knowledge to performance (K2P), the community must combine what it has learned from its own analyses with what has been discovered from the external sources. These processes are predominantly deliberative in nature and require many of the same resources that are provided through Service 1.
8. Services to codify and persist new knowledge in human and computer-readable forms: The merger of internal and external knowledge readies the community to design and implement improvement strategies. These may be *de novo* strategies that are created by the community, but may instead be strategies that are uncovered from the external evidence, and then adapted to the local context.[10] In order to implement change, it is vital that this knowledge be formally represented, and in order for it to be implementable at scale, it is important whenever possible, to represent the knowledge in computable forms.[11] New knowledge can be transformed into code and pseudo-code that can aid exchange between different technical systems and can be stored for analysis by computers. Socio-technical infrastructure to support this process takes the form of policies that include standards for representing knowledge, technologies for managing knowledge, and people who oversee related processes.
9. Services to enable delivery of knowledge-directed interventions: Learning health systems can leverage omnipresent digital information and communication technology to deliver "precision" messages to providers, patients, and other stakeholders as part of the knowledge to performance phase of the improvement cycle. This, however, requires infrastructure that includes, for example, the technology that can create and deliver the messages, as well as policies and processes to determine what messages get delivered to whom, and when.
10. Services to promote and support performance changes: The field of dissemination and implementation science has identified methods and theories/models/frameworks for planning and implementing tailored strategies directed at translating evidence into practice, with an emphasis on sustainability and scale-up. These infrastructural components include mechanisms to communicate evidence (e.g., icon arrayportraying risk) and monitor change (e.g., audit and feedback reports), to engage often-underserved target populations, and to introduce change in planned increments and adapt strategies as needed to support change. These services emphasize process and behavior change within complex organizational systems and require a workforce trained in implementation methods.

5 | CONCLUSIONS

Viewing its infrastructure in terms of socio-technical services could be beneficial in several ways beyond working toward a consensus view of LHS structure and function. Most notably, such a modular approach could lead to sharing of interoperable infrastructure components and the possibility that sharing of such components might promote the more rapid adoption of LHS methods. Moreover, compatibility of LHS architectures could enable smaller scale LHSs to compose into a single system that functions at larger scale. Logical next steps to mature LHS infrastructure would include building consensus around the constituent services and developing specifications for each one.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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