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POSITION PAPER

A Case for a Systems Approach to EdTech

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Abbreviations

ACE	Adolescent Community of Engagement
CAL	Computer-assisted learning
Covid-19	Coronavirus 2 (SARS-CoV-2)
GST	General Systems Theory
ICT	Information and Communication Technologies
ICT4E	ICT for Education framework
ISTE	International Society for Technology in Education
NGO	Non-governmental organisation
OIP	Organisation Improvement Plan
PISA	Programme for International Student Assessment
SABER-ICT	Systems Approach for Better Education Results — Information and Communication Technologies
SES	Socio-economic status
SNA	Social Network Analysis
STEM	Science, technology, engineering, and mathematics
TPACK	Technological, Pedagogical, and Content Knowledge
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Terminology

Systems research is a complex area with a unique terminology. Some terms are subjective and used differently by different authors. To help guide the reader, we set out how we define certain key terms here.

EdTech EdTech Hub describes Educational Technology (EdTech) as "technologies — including hardware, software, and digital, television and radio content — that are either designed for or appropriated for educational purposes" and encompass the "use of information and communication technologies (ICT) at any point within the education system — in ministries, schools, communities, and homes, including between individuals and for self-learning" (↑Hennessy et al., 2020).

System A system consists of elements and interconnections "that [are] coherently[1] organised in a way that achieves something" (↑Meadows, 2008)(p. 11). There may be a set of networked or hierarchical subsystems within the system.

Education system A system of elements and interconnections organised towards a common purpose of achieving learning.

EdTech system An education system supported by the use of educational technology.

Systems inquiry or systems approaches Systems inquiry or systems approaches support the understanding of and inquiry into the complexity of interacting variables in a system, and make it possible to identify functions and components, and predict, observe and measure the effect of change or variations in components and functions in tandem rather than in isolation (↑Banathy, 1968).

Systems research Systems research provides methodologies that enable researchers to observe interactions and patterns in systems that were not necessarily visible before (↑Stowe, 1973) (↑Williams & Hummelbrunner, 2020).

Framework A general outline that describes the interrelationships of the various subjects in the field; it shows how the parts fit together (↑Jones, 1983).

[1] Often systems may not be coherent in their stated and actual goals, and within a system, sub-systems may not be aligned with the larger goals of the system. Having said that, education systems are usually coherent around learning as a goal.

Figure 1. *Dialogue highlighting the origins and long history and origins of systems thinking.*

"The year was 1954. At the Center for Behavioral Sciences, at Stanford University, four Center Fellows — Bertalanffy (biology), Boulding (economics), Gerard (psychology), and Rappoport (mathematics) — had a discussion in a meeting room. Another Center Fellow walked in and asked: 'What's going on here?' Ken answered: 'We are angered about the state of the human condition' and asked: 'What can we — what can science — do about improving the human condition?'. 'Oh!' their visitor said: 'This is not my field….' At that meeting the four scientists felt that in the statement of their visitor they heard the statement of the fragmented disciplines that have little concern for doing anything practical about the fate of humanity. So, they asked themselves, 'What would happen if science would be redefined by crossing disciplinary boundaries and forge a general theory that would bring us together in the service of humanity.' Later they went to Berkeley, to the annual meeting of the American Association for the Advancement of Science, and during that meeting established the Society for the Advancement of General Systems Theory."(↑Banathy & Jenlink, 2003).

1. Overview

More than half the children in low- and middle-income countries cannot read a simple text by age ten (↑World Bank, 2020). Technology has the potential to improve learning outcomes, not only by directly impacting students and teachers, but also by improving the efficiency of education systems. However, efforts to design and use technology to strengthen education are often confounded by complex causal pathways to outcomes, contextual variation in implementation and evaluation, and challenges with scale and sustainability. Traditional approaches to understanding and researching Educational technology (EdTech) appear inadequate as they break down the problems into simplistic components, failing to include the dynamic and interactive nature of the system. Understanding where and how to use EdTech and maximise its impact therefore requires a view of education systems that is more than a sum of inputs and outcomes.

Systems inquiry is a promising approach to EdTech as it challenges well established, linear research approaches and compels us to examine indirect causes and unintended consequences. Systems approaches can be applied to EdTech implementation, EdTech management, EdTech design, and EdTech research as well as analysis of the political economy of EdTech. In this position paper we focus on the application of systems approaches to EdTech research. We:

1. Outline the complexity of EdTech and discuss systems approaches for EdTech;
2. Discuss the application of systems approaches to EdTech research with the examples of macro- as well as micro-level questions; and
3. Describe the first EdTech knowledge graph based on the analysis of existing EdTech frameworks.

We conclude that systems approaches enable EdTech research to embrace the complexity of a host of interacting variables, add a repertoire of mathematical tools such as game theory, linear programming, and matrix theory to traditional analytical methods, and allow for the observation of interactions and patterns that were not necessarily visible using other methods (↑Stowe, 1973).

2. The complexities of EdTech

EdTech Hub defines EdTech as "technologies — including hardware, software, and digital, television and radio content — that are either designed for or appropriated for educational purposes" and encompass the "use of information and communication technologies (ICT) at any point within the education system – in ministries, schools, communities, and homes — including between individuals and for self-learning" (↑Hennessy et al., 2020).[2]

In times of unprecedented societal change, increasing attention has been paid to the role technology can play in improving learning outcomes, particularly in low- and middle-income countries where quality education remains out of reach for many. The importance of EdTech has been especially highlighted by the Covid-19 pandemic (↑Nicolai et al., 2021).

However, large expenditures on EdTech have not always yielded comparable or consistent results in terms of learning outcomes, as access, uptake, and scalability as well as cost-effectiveness of interventions tend to vary across contexts. Embedding technology in education systems and practices is a complex process, and, "while most agree that EdTech can be helpful under some circumstances, researchers and educators are far from a consensus on what types of EdTech are most worth investing in, and in which contexts" (↑Escueta et al., 2017) (p. 3). EdTech programmes are deeply contextual, with implementation of a given intervention playing out differently in different contexts, and even over different iterations in a single context (↑Niederhauser et al., 2018). EdTech interventions and research do not take place in isolation, but necessarily have to navigate the politics and political economy factors of the education systems they sit within (↑Pellini et al., 2021). Successful implementation of EdTech initiatives therefore needs to consider curricular, pedagogical, technological, individual, and organisational factors (↑Howard & Thompson, 2016). It requires the bringing together of people, procedures, ideas, devices, and organisations for the purpose of analysing problems, and involves devising, implementing, evaluating, and managing solutions (↑B. Johnson et al., 1977).

In this section we review the literature around the heterogeneity of the impact of EdTech to underscore the contextual variations, complex causal pathways to impact, and challenges with scale and sustainability.

[2] The EdTech Hub also includes non-digital radio and television as part of this definition of EdTech.

2.1. Contextual variation

Context has a significant impact on learning gains from EdTech interventions. The differential impact of Computer-assisted Learning (CAL) programmes outlined in this section highlights the context dependency of outcomes and illustrates this challenge.

> **"There is no single "ed-tech" initiative that will achieve the same results everywhere — simply because school systems differ in learners and educators, as well as in the availability and quality of materials and technologies."**
>
> **– ↑Ganimian et al., 2020 (p. 62)**

A literature review conducted by Bettinger et al. (2020) showed "substantial heterogeneity in findings on the effectiveness of CAL ranging from null effects to extremely large positive effects" across location and context (↑Bettinger et al., 2020) (p. 2). In India, for example, one CAL program demonstrated improved student maths scores[3] (↑Banerjee et al., 2007) while another CAL programme presented mixed results, and impacted different students differentially (↑Linden, 2008). In yet another technology-aided personalised learning programme in India, learning gains were much higher for academically weaker students (↑Muralidharan et al., 2016), while in Ecuador computer-aided instruction led to positive impact on maths test scores and a negative impact on language test scores for primary schools students (↑Carrillo et al., 2011). A CAL programme in China showed no significant impact on Chinese language standardised test scores while maths scores for students from poorer families improved (↑Lai et al., 2013).

Kaye and Ehren (2021) outline a number of factors that impact the implementation of computer-aided learning initiatives in detail. These include:

- The operating environment
- Stakeholder engagement

[3] Teachers' social attitudes and community prejudices were the main factors influencing students' motivation and hence learning outcomes (↑Banerjee et al., 2007)

- Infrastructure
- Technological trust
- Tool design
- Content curation / creation
- Student engagement
- Integration
- Teacher capacity
- Student capacity
- Data collection and use (↑Kaye & Ehren, 2021).

Given that similar EdTech programmes can have such heterogeneous outcomes, understanding the context of the student, the teacher, the system, and the causal pathways is therefore crucial (↑Valentine, 2002; ↑Phillips, 2016).

2.2. Complex causal pathways

Social and structural factors impact access as well as usage of digital technology. In a review of experimental and quasi-experimental studies, Escueta et al. (2017) conclude that while technology access programmes can have a positive impact on increased access to technology, access itself has mixed effects on learning outcomes[4] (↑Escueta et al., 2017). In Peru, for example, providing laptops to students showed improvement in computer proficiency but a decrease in academic effort and no impact on academic achievement or cognitive skills (↑Beuermann et al., 2015). In Colombia, the provision of computers similarly had little effect on students' test scores, with results consistent across grade levels, subjects, and gender.

While access to technology is a necessary condition for successful EdTech interventions, it is by no means a sufficient condition for improving learning outcomes. Cultural diversity and societal inequalities significantly impact how digital devices are used and the resulting outcomes (↑Lu, 2001). Even with increased access, if computers weren't incorporated into the educational process (despite teacher training) (↑Barrera-Osorio & Linden, 2009) or learning was not monitored (and children spend more time playing games instead of learning) (↑Leuven et al., 2007; ↑Malamud & Pop-Eleches, 2011), impact was not observed. An analysis of school computer use by subject area showed that

[4] Interestingly, even access programs only increased the proximal outcome (the having of the computer) by 55 percentage points pointing to the inefficiency of access programs (↑Escueta et al., 2017).

students with low socio-economic status (SES) use computers more for maths and English learning whereas high-SES students are the main users of technology for science courses (↑Becker, 2000; ↑Warschauer et al., 2004). Home computer access raises the academic achievement of high-SES students more than it does for low-SES students (↑Attewell & Battle, 1999; ↑Warschauer et al., 2004). Further, there are differences in how girls and boys use technology. While girls are more likely than boys to use computers for schoolwork (although these differences are not large), boys spend more time playing video games on computers than girls, and girls use computers more for social networking, email, and other communication activities (↑Fairlie, 2016). Thus, simply increasing access to computing devices may not necessarily improve learning outcomes, and the causal pathways to change need to be understood better.

2.3. Scale and sustainability

Sustainability[5,6] and scalability are important for successfully integrating ICT in education (↑Albion et al., 2015; ↑Voogt et al., 2015)[7] and are dependent on a number of factors that include[8] (but are not limited to) the following:

- Government support for infrastructure
- Public and private investment in EdTech
- Evaluation and communication of EdTech effectiveness
- Innovation in EdTech business models
- Strong focus on capacity building and teacher development (↑Omidyar Network, 2019) (p. 22), (↑Hoyles et al., 2013)

The factors impacting scale and sustainability not only operate at a system-wide level, but also interact with each other in various ways in different

[5] Coburn (2003) proposed a multidimensional view of scalability of innovation that outlined depth, sustainability, spread, and shift in ownership (↑Coburn, 2003). 'Depth' refers to an understanding of the essential characteristics of the innovation. According to Coburn, this often requires teachers to change their pedagogical practices and their beliefs about what constitutes "good education." 'Sustainability' involves the maintenance of change over time, while 'spread' addresses the diffusion of an innovation to different contexts. 'Shift of ownership' relates to the need for the innovation to be owned by all involved stakeholders, and that different stakeholders will assume primary responsibility for the initiative over time. Clarke and Dede (2009) extended Coburn's framework to include evolution (↑Clarke & Dede, 2009). 'Evolution' refers to the way stakeholders use, adapt and implement the innovation in their local contexts, i.e. the innovation develops because of the interaction between the users and the designers of the innovation.

[6] Niederhauser et al. (2018) define sustainability as ongoing change, and scalability as the dissemination of this change across different contexts (↑Niederhauser et al., 2018).

[7] The Omidyar Network Report (2019) asserts that often, the "term 'scale-up' is oversimplified to mean an increase in size or quantity, usually through an expanded number of users when, in reality, effective scale-up might require considerable redesign of EdTech products, services, and models of implementation to better meet the needs of diverse users" (↑Omidyar Network, 2019) (p. 21).

[8] In addition to these factors, scaling up from field experiments faces further obstacles such as market equilibrium effects, spillovers, political economy, site-selection biases, and piloting biases (↑Banerjee, 2017).

contexts. In Indonesia, for example, EdTech was scaled through business-to-consumer mobile phone-based apps for extracurricular use and the factors that enabled this expansion included investment in EdTech, widespread access to technological infrastructure (such as mobile phones and social media), and a policy-friendly EdTech environment. In the US, on the other hand, direct marketing by major US hardware manufacturers and software companies accelerated the growth of one-to-one laptop programmes and content adoption (↑Omidyar Network, 2019). Further, a number of factors impact the implementation, scaleup and sustainability of EdTech interventions such as such as market equilibrium effects, spillovers, political economy, site-selection biases, and piloting biases (↑Banerjee, 2017). Traditional methods of investigating education and education systems based on "linear algorithms that simplify and break down systems into isolated, component parts" cannot suffice to understand and research a field as complex as EdTech. The premise of these linear approaches is that "inputs into the system will result in predictable outcomes. While appropriately predictive of some static, closed systems, these models fail to adequately predict the behavior of, or capture the essence and emergent properties of complex systems" (↑Johnson, 2008)(p. 5–6). We therefore propose systems inquiry as an approach to EdTech.

3. Systems inquiry and EdTech research

> **"Previous research has resulted in a long, almost exhaustive, list of factors that may affect the uses of technology in schools. However, these factors are often examined in isolation from each other or from the system in which they interact. Rarely are they studied together under a framework to sort out their relative importance and to identify the relationships among them."**
>
> **-↑Zhao & Frank, 2003 (p. 809)**

3.1. Systems and systems inquiry[9]

A system is a "complex of interacting elements such that the system cannot achieve its purpose without the element, and the element by itself cannot replicate the system's functions" (↑Betts, 1992). One of the most significant attributes of a system is its ability to change and adapt (↑Meadows, 2008). An element is a necessary but not self-sufficient component of a system and the behaviour of the whole cannot be summed up from the isolated elements.[10] In other words, a system consists of elements and interconnections "that [are] coherently organised in a way that achieves something" (↑Meadows, 2008)(p. 11).

As outlined in Table 1, systems inquiry challenges well established, linear approaches that favour neat narratives of theories of change and certainty of outcomes, and compels one to examine indirect causes and unintended consequences and to consider interrelationships to view the system as a whole. Its purpose is to understand complex phenomena and organisations in a manner that does not just examine specific parts or elements but also

[9] The genesis of the field of systems science is credited to von Bertalanffy in his seminal work on General Systems Theory (↑Bertalanffy, 1969). Systems inquiry is vast and has evolved and branched out into many different streams of systems thinking over the years, with numerous theories to understand systems and methods to analyse them (↑OECD, 2017; ↑Banathy & Jenlink, 2003).

[10] Churchman uses the fable about several blind men, each touching a different part of an elephant and drawing conclusions about the specific parts without understanding the whole animal, in order to illustrate his concept of systems (↑Churchman, 1968).

interrelationships, with a view towards understanding the whole picture (↑Arnold & Wade, 2015; ↑Chen, 1975).

Table 1. *Outline of differences between conventional thinking and systems thinking approaches (↑Stroh, 2015).*

Conventional Thinking	Systems Thinking
The connection between problems and their causes is obvious and easy to trace.	The relationship between problems and their causes is indirect and not obvious.
Others, either within or outside our organisation, are to blame for our problems and must be the ones to change.	We unwittingly create our own problems and have significant control or influence in solving them through changing our behaviour.
A policy designed to achieve short-term success will also assure long-term success.	Most quick fixes have unintended consequences: they make no difference or make matters worse in the long run.
In order to optimise the whole, we must optimise the parts.	In order to optimise the whole we must improve *relationships* among the parts.
Many independent initiatives should be aggressively tackled simultaneously.	Only a few key coordinated changes sustained over time will produce large systems change.

Systems theories provide frameworks for analysing systems. To date, systems inquiry (or a systems approach) has been applied to numerous fields such as physics, engineering, and management.

3.2. Possible systems theories for EdTech research

Of the wide range of systems theories, those most commonly applied to education are General Systems Theory (GST), Ecological Systems Theory, and Complexity Theory / Complex Adaptive Systems Theory / Dynamic Systems Theory.[11] In this section we briefly describe these systems theories.

General Systems Theory

GST, credited to Ludwig von Bertalanffy's seminal work on systems inquiry, is a science investigating general laws for arbitrarily complex arrangements of elements — or 'systems'. GST formulates and derives principles that are valid for systems in general (↑Bertalanffy, 1969). Bertalanffy explicitly drew attention to the possibility of using GST as a basis for education. His thesis was that GST provides basic interdisciplinary principles that could structure an integrated

[11] The Cynefin Framework, informed by complexity science has gained significant popularity for decision making as well (↑Snowden, 1999).

curriculum and help move away from the compartmentalised study of physics, biology, and chemistry. Under Bertalanffy's analysis, the introduction of system concepts holds out the prospect of meaningful reform at the level of classroom curriculum (↑Chen & Stroup, 1993; ↑Bertalanffy, 1969). In education, GST has been applied to conflict management for students (↑Oyebade, 2001) as well as science and technology education (↑Chen & Stroup, 1993).

Ecological Systems Theory

Developed by psychologist Urie Bronfenbrenner, Ecological Systems Theory explains how human development is influenced by different types of environments. Bronfenbrenner's (1977, 1979) work on the theory described the child's ecosystem in terms of a set of nested levels of the environment (↑Bronfenbrenner, 1977; ↑Bronfenbrenner, 1979; ↑Bronfenbrenner, 1986; ↑Bronfenbrenner, 1992; ↑Bronfenbrenner, 1994). In 2006, Bronfenbrenner revised his original theory, adapting the name to bioecological systems theory, emphasising the active role of the individual in the developmental process (↑Ettekal & Mahoney, 2017). Ecological Systems Theory has been applied to early childhood education (↑Elliott & Davis, 2020; ↑Paat, 2013; ↑Msangi, 2012; ↑Leonard, 2011).

Complexity Theory / Complex Adaptive Systems / Dynamic Systems

While GST asserts that organisations have stable patterns of relationships within structured boundaries where feedback corrects disequilibrium and the structure of the system is preserved (↑Gibbs et al., 2019), Complexity Theory or Complex Adaptive Systems Theory moves away from this model. Complexity Theory views organisations as having less predictable outcomes and being more chaotic (↑Cilliers & Spurrett, 1999; ↑Gibbs et al., 2019). According to Mason (2008), "complexity theory[12] offers some useful insights into the nature of continuity and change, and is thus of considerable interest in both the philosophical and practical understanding of educational and institutional change" (↑Mason, 2008) (p.2). Educational initiatives tend to be complex (↑Duit et al., 2010; ↑Davis & Sumara, 2008), and complexity approaches have been used in education for accelerating science, technology, engineering, and mathematics (STEM) capacity (↑Stephens & Richey, 2011), and for

[12] Complexity theory (↑Cilliers & Spurrett, 1999; ↑Byrne, 1998) is sometimes referred to as dynamic systems theory (↑Fogel et al., 1997) and education has also been viewed as a dynamic system (↑Nicolescu, 2017; ↑Van Geert & Steenbeek, 2015; ↑Haggis, 2008). Dynamic systems approaches have been used to examine topics such as second language acquisition (↑De Bot et al., 2007).

understanding educational leadership ↑Gibbs et al., 2019), problem based learning (↑Mennin, 2007), and learning environments (↑Weichhart, 2013).

Current thinking favours Complexity Theory for education as it accounts for emergence (emergence occurs when an entity is observed to have properties its parts do not have on their own) and the dynamic nature of education systems. We assert that systems theories applicable to education would also be applicable to EdTech and EdTech research. However, further work is needed to understand the nature of EdTech systems in order to apply the appropriate theories for researching them.

4. Systems approaches and EdTech

Systems approaches may be applied to EdTech for various purposes. These include the design of EdTech interventions, and the evaluation, management, implementation (including political economy analyses), and research of EdTech programmes. However, for the purposes of this paper, we limit the scope of the application of systems approaches to EdTech research.

4.1. Systems approaches and education research

Systems approaches have been differentiated from education research, although there are synergies between the two. In citing Goldberg, Banathy (1967) states, "the systems approach makes available to education a logical and psychological scheme for 'analyzing, coordinating, and controlling the complex of interrelated factors which contribute to the output — the educated people.'" (↑Banathy, 1967) (p. 283). Systems approaches are "neither identical nor synonymous" to educational research, differing in the kind of information that is collected, analysed and used (↑Stowe, 1973) (p. 169). Educational research is an inquiry-oriented activity that traditionally employs objective, empirical, and controlled methodology that produces replicable findings with a high level of confidence[13] and generates theories that are generalisable. In contrast, the systems approach is a collection of procedures involving the analysis of a system and a re-alignment of its components directed towards optimisation of specific 'real-world' outcomes and involving the addition of feedback loops and possibly a temporal dimension.

Despite these distinctions, education research and systems approaches have commonalities. Both are problem-solving methodologies based on objective and empirical approaches. Both have predictive capabilities and hence can be applied to real world problems. Both need to be selective about the aspects of reality they address, and finally, both have predictive power often supported by mathematical reasoning / modelling (↑Stowe, 1973). In summary:

1. Systems approaches allow for the structuring of many variables into meaningful patterns (↑Stowe, 1973).
2. Systems methodologies enable researchers to observe interactions and patterns that were not necessarily visible before (↑Stowe, 1973).
3. Systems approaches add a repertoire of mathematical tools to traditional research methods (↑Stowe, 1973).

[13] The paradigm that was subject to major debates subsequently (↑Gage, 1989).

4.2. Old issues, new perspectives

The idea of approaching research from a systems perspective has been contrasted with a traditional scientific approach in that the scientific approach presumes that entities are best understood through isolating them from their environments in order to reduce extraneous influences and biases, and that the properties of these entities could be understood by reducing them to their most essential components (↑Metcalf et al., 2014).

Researching complex issues in EdTech such as data in education and technology for girls' education using traditional linear approaches poses limitations, as traditional research approaches seek definitive answers to complicated questions. Instead, the systems approach "encourages a wider view that is not driving at a single solution but rather at an integrative approach that would incorporate already existing knowledge and structures with those emerging and with those present in other, interrelated disciplines" (↑Snyder, 2013) (p. 9). However, in order to incorporate systems approaches into EdTech research, the questions need to be redefined, methods need to be redesigned and analytical strategies need to be updated.

We take the examples of the macro-level issue of data and technology in education and the micro-level issue of girls' education and EdTech to demonstrate how systems approaches can contribute new perspectives and methods to research in these areas. On the one hand, education systems often lack systematic data that can aid decision-making (↑World Bank, 2017), and while technology has the potential to address the this gap (↑Crouch, 2019), it also poses the challenge of data acquisition, management and user safety (↑Unwin et al., 2020). On the other hand, the challenge of using technology for girls' education, while directly impacting stakeholders at the micro-level, extends well beyond the education sector to underlying social, cultural, economic, and political factors that often discriminate against girls (↑Martínez, 2018; ↑Vodafone Foundation, 2018). Both of these are complex issues operating at different and multiple levels of the system, and can be researched holistically using systems approaches.

Figure 2. *Sample issues in EdTech that can be addressed using systems approaches.*

Issues with data in education

The lack of quality data, low usability of existing data, and safe data management are macro- or sector-level problems caused by a host of underlying — and often interacting — factors. Insufficient staffing and funding of data collection and monitoring initiatives within government ministries (↑Crouch, 2019) leads to scarcity of quality data. Lack of capacity for data analysis, inscrutable data presentation, deliberate neglect (↑World Bank, 2017), and an absence of open technology standards hinders interoperability of datasets (↑Pathways for Prosperity Commission, 2019), leading to data underutilisation. Further, while on the one hand there is little demand for data from stakeholders such as parents and the community (↑Verhulst & Young, 2017), on the other hand there are questions around the adequacy of measures for the protection of this data (↑Polonetsky & Jerome, 2014) and barriers to data safety, including a scarcity of legal frameworks around both data privacy and storage and global standards for the collection, use, and management of data (↑Global Partnership for Sustainable Development Data, 2019; ↑UNICEF, 2020).

Issues in girls education and EdTech

Technology could either help bridge the gender divide or possibly widen the gap (↑Webb et al. 2020), and lead to further marginalisation of already already disadvantaged girls (↑McCowan & Unterhalter 2015; ↑Szabo & Edwards, 2020). For example, while in some contexts, the use and ownership of technology is perceived to be a 'masculine' luxury (↑Zelezny-Green, 2011), and in other contexts, girls are discouraged from using cyber cafés as they are deemed 'unsuitable' (↑Leslie Steeves & Kwami, 2017), targeted technology-driven interventions can support outcomes for girls (↑Akmal, 2020; ↑Jenkins & Winthrop, 2020; ↑Allier-Gagneur & Coflan 2020); however, for technology to have any impact, a concerted set of factors need to be tackled together, and, according to ↑Crompton et al. (2021), digital access, digital freedom, digital literacy, digital design, and digital pedagogies are all essential for improving girls' outcomes via technology.

A systems approach to EdTech research would require the redesign of research questions and research methods as well as the adoption of newer analytical methods. We briefly explore the redesign in this section using data and girls' education as examples.

4.2.1. Redefine research questions

> **In studying a complex system such as education, "the researcher needs to understand the non-linear relationships between the elements of a system and how these change across time and space. The research questions need to address not just the 'what' of education systems, but also the 'how' and 'when' in order to shed light on the factors that enable or constrain quality, equitable learning outcomes."**
>
> **– ↑Magrath et al., (2019) (p. 14)**

Adapting from Snyder (2013), if we are to tackle the example of data, the research question: *What governance structures do we need to create to improve data use in education?* would become: *How can we enhance and utilise the structures, resources, and processes already present to improve the equity and effectiveness of education?* under a systems lens. Or the question: *How can data be used to improve student outcomes?* would be transformed to: *What are we learning from current data and how could it tell us more?* (↑Snyder, 2013)

Similarly, for girls' education the research question: *What are the structural enablers and barriers impacting girls' access to and utilisation of EdTech?* becomes: *How might we utilise the structures, resources, and processes existing in a girl's socio-cultural and economic context to improve access to education?*

4.2.2. Redesign research methods

There are a vast number of systems research methods that can be applied to understanding the issues in EdTech, including data and girls education (↑Williams & Hummelbrunner, 2020).

- **Causal Loop Diagrams** can be used to understand nonlinear interrelationships between various components of the system and what impacts what.
- **System Dynamics** could be used to understand feedback loops and time lags — this technique is particularly useful for data-related questions.

- **Social Network Analysis** could be used to map the nature of relationships between various actors which might prove to be valuable in leveraging the most influential stakeholders.

- **Outcome Mapping** could be used to explore how certain interventions contribute to specific outcomes and impact in a complex setting (↑Williams & Hummelbrunner, 2020).

- **EdTech Hub's 6P framework** (Box 2) (↑Haßler et al., 2021; ↑Simpson et al., Forthcoming) outlines a comprehensive set of factors, processes, and entities within EdTech that need to be considered to examine the system.[14]

Figure 3. *The 6Ps framework, EdTech Hub.*

EdTech Hub uses the 6P framework to develop and audit a set of 'sandboxes' supported by the Hub that are a testing ground for designing, implementing, and evaluating scale-up strategies of EdTech interventions in low- and middle-income countries.

The '6Ps' are a helpful framework to identify components to include in the system. These include:

- **People.** All those involved in education. This includes children and young people (including learners, the out-of-school, and those who are marginalised within the national education system), their parents, their educators, innovators, researchers, and those working towards improved provision of education on a global level.
- **Practices.** The practice(s) of those people, including teaching and learning behaviours, pedagogy, and research methodology and design.
- **Places of learning (formal, non-formal, and informal).** This includes learning contexts for children, educators, researchers, and policymakers such as educational authorities, non-governmental organisations (NGOs), and international donors.
- **Provision of human and material resources.** Provision of human and material resources including educator allocations, supply chains, and infrastructures such as connectivity and power.
- **Products and resources.** Products and resources to aid teaching and learning: textbooks, educational materials, equipment, and technology devices.
- **Policies.** Official agreements, including sector plans, legislation, national and sub-national regulations, and global frameworks and conventions (↑Haßler et al., 2021).

4.2.3. Consider additional analytical methods

In contemporary education settings there is significant complexity of interacting variables. Systems frameworks such as the Cynefin framework can be used to identify the nature of problems that are being solved within the

[14] Research using systems approaches also treads the fine line between developing tools for data collection that are highly contextualised as well as dynamic, and meeting these criteria while demonstrating validity and reliability (↑Magrath et al., 2019). Technology can support the development and administration of innovative tools that can afford flexibility of context as well as specificity (↑Ford et al., 2019).

system (↑Kurtz & Snowden, 1999) and apply appropriate systems methods to the research questions. The systems approach makes it possible to identify functions and components of systems, describe their interaction, and predict, observe and measure variations in components and functions (↑Banathy, 1968) (p.84). It also expands the toolkit of a researcher to include game theory, linear programming, and matrix theory methods (↑Stowe, 1973).

5. Understanding the EdTech system

In applying systems inquiry to any problem, we need to ask: *How are we to know that we are dealing with the whole and not just a part of it? What constitutes a whole? And, since every system is a subsystem of a larger system, how far can the system boundary be drawn without rendering the idea of a system meaningless? And what are the actual entities and attributes of the system?* (↑Chen, 1975)

Understanding what type of system one is working with is crucial for the selection of the approach and methods that are appropriate to the inquiry of that system. But foremost, we need to know what the components / parts of a system are. In this section we attempt to outline the bounds of the EdTech system based on the analysis of existing EdTech frameworks, and discuss entities, interrelationships, and possible theories for analysis.

5.1. Limitations of current EdTech frameworks

In reviewing the literature, we identified 17 EdTech frameworks (listed in Annex 2) developed for policy and research as well as implementation purposes, and that display a range of operationality. For this study, frameworks positioning EdTech at different levels (macro, meso, micro, and multi-levels) were selected and the frameworks' functionality was used as a core inclusion criteria. To be included in this study an EdTech framework was required to be aligned with at least one of the following three functionalities:

1. Using EdTech as part of multi-stakeholder interventions to improve educational outcomes;
2. Using EdTech to improve educational stakeholders' coordination; and
3. Using EdTech to enhance the functionality of education systems (↑Jones, 1983).

Jones (1983) defines a framework as a "general, macro-level model that describes the interrelationships of the various subjects in the field; it shows how the parts fit together and refutes the notion that the field is nothing but a collection of loosely related topics" (↑Jones, 1983) (p. 560). Cherner and Mitchell (2020) argued that this definition was suitable to define an EdTech framework and added that EdTech frameworks could be used at different operational levels. For example, they could adopt a macro-level perspective that situates EdTech as part of an education system or a micro-level perspective that places EdTech as an instructional tool to improve learning outcomes. These frameworks fulfil the crucial role of bridging theory and practice within the EdTech ecosystem (↑Cherner & Mitchell, 2020).

While EdTech frameworks are crucial for understanding and implementing EdTech, they face certain criticisms. Whereas some of the frameworks have a narrow focus (for example, EdTech frameworks aimed at educational institutions, heads of education institutions, and teachers focus specifically on the adoption and integration of EdTech within the school) (↑CoAction Learning Lab, 2019; ↑Chisholm, 2020), others aimed at scale and sustainability fail to account for implementation constraints (↑Clarke & Dede, 2009). Still other EdTech frameworks fail to account for the context and complexity of technology integration and have been criticised for being rigid in their design, and linear in approach (↑Hamilton et al., 2016). Further, while some may provide a macro picture of institutions and actors across the EdTech ecosystem, others focus more on a micro-level view of EdTech use by teachers and learners. As a result, it has been a challenge to construct a comprehensive view of the EdTech system and observe several moving parts and actors simultaneously, and identify the prominent levers for change.

Despite these limitations, existing EdTech frameworks provide a valuable resource to start building a deeper understanding of the EdTech system. In the next section, we describe the development of a knowledge graph representing a **theoretical network of EdTech stakeholders** using EdTech frameworks, and explore some of the characteristics of interactions in this system.

Figure 4. *Summary of EdTech frameworks by operational level.*

In this box, we use the five levels of the Ecological Systems model developed by Bronfenbrenner (1994) and modified by Johnson (2008)[15] to classify the EdTech frameworks by the level of operation within the EdTech sector.

Macro-level EdTech frameworks (policymakers)

- The **SABER-ICT Framework** is primarily intended for policymakers and governments to aid their process of designing and assessing key policies linked to the use of ICT in K-12 education (↑Trucano, 2016).
- The **UNESCO Framework** provides policymakers with policy objectives to reform teacher capacity and professional development. It has been used to develop nationwide EdTech policies in Guyana, Bahrain and Russia. It can also be leveraged by teachers and teacher training experts (↑UNESCO, 2011).
- The **Asian Development Bank Framework** for policymakers provides guidance on establishing the coordination between policy direction and teacher capacity building along with a focus on infrastructure development, student learning outcomes, and private public partnerships (↑Asian Development Bank, 2017).

[15] The model is comprised of four layers of systems which interact in complex ways. A fifth dimension of time was added later (↑Bronfenbrenner, 1994). Johnson (2008) adapted the model for school systems (↑Johnson, 2008) and Gu et al. (2009) use a similar breakdown of the EdTech system based on Bronfenbrenner's classification (↑Gu et al., 2019).

- The **PISA ICT Framework** gives a complete picture on students' access to, and use of, technology as well as their learning outcomes. It also identifies how educational institutions and teachers incorporate technology into the classroom. Through this information, it allows policymakers to explore the influence of system level factors on students and schools use of ICT. It also helps nations and individual educational institutions understand their position in comparison to others (↑OECD, 2020).
- The **Development Framework** aims to help policymakers analyse the context in their country, develop suitable goals, and coordinate policies and programmes which lead to systemic change (↑Kozma, 2005).

Meso-level frameworks (educational institutions and heads of institutions)

- **E-Learning Stakeholders' Responsibility Matrix** is responsible for e-learning and aims to ensure coordination amongst stakeholders. It is designed for higher educational institutions to understand, integrate, and adapt EdTech initiatives. It highlights that each stakeholder plays a key role by outlining their key motivations and concerns (↑Wagner et al., 2008).
- The **Holistic Integration Framework** guides educational institutions and provides them with a system to improve the evaluation of student learning and enhance the education system. It can be adapted to suit the needs of varied contexts (↑Khudair & Abdalla, 2016).
- **ICT for Education** (ICT4E) is a conceptual framework which contributes to the design of activities that lead to sustainable change in pedagogical practices in schools. It focuses on the integration of technology into teaching and learning (↑Rodríguez et al., 2012).
- The **Framework for Stakeholder Inclusion** helps the heads of institutions select inclusive technology and plan for its adoption by taking into account the considerations of students, teachers, and technology leaders (↑CoAction Learning Lab, 2019).
- The **Organisation Improvement Plan** (OIP) is envisioned as an approach for educational leaders to support teachers with the integration of technology into K-12 education. Its designed is based on a systems thinking approach (↑Chisholm, 2020).

Micro-level EdTech frameworks (teachers)

- The TPACK framework elaborates upon the knowledge a teacher requires to successfully incorporate technology into instruction. Its primary intended users are teachers but we hypothesise it could also be leveraged by teacher training experts (↑Mishra, 2019).
- The **T3 framework** promotes the use of EdTech by providing an actionable path for implementing EdTech and assessing the impact of innovative teaching and learning. It can be used by teachers to evaluate the use of EdTech in the classroom (↑Magana, 2020).

Multi-level EdTech frameworks (multi-stakeholder)

- The **International Society for Technology in Education (ISTE) standards** help teachers and education leaders ensure that learning is a learner-driven activity. It targets leaders, teachers, and students and aims to enhance implementation of technology and improve learning outcomes (↑Trust, 2018).
- The **Framework for Evaluation Appropriateness of EdTech** assists multiple stakeholders such as teachers, educational institutions, technology providers,

policymakers, and district / state level administrators. It helps in the planning and implementation of EdTech before and during the adoption of an EdTech initiative (↑Osterweil et al., 2016).

- **Scaling Access and Impact** is an ecosystem model which caters to government stakeholders such as ministries of education, education innovations, and private philanthropic capital providers. It helps them understand their role in supporting access to and use of EdTech (↑Omidyar Network, 2019).
- The **Adolescent Community of Engagement (ACE) Framework** assists with the design and creation of adolescent online learning environments by building on four key constructs: student, teacher, peer, and parent engagement (↑Borup et al., 2014).

5.2. Methodology[16]

In order to develop the knowledge graph representing the EdTech system, we conducted an extensive desk review to shortlist 17 EdTech frameworks from the literature. Google Scholar was used as the primary search engine for this exercise and the review draws upon the research literature and grey literature. A key word combination of the words 'frameworks, teachers, student, policy, government, education, systems, stakeholders, networks, ICT, EdTech, learning, technology, apps, tablets, schools, and "K-12"' identified a range of EdTech frameworks. Stakeholder analysis methods were used to generate a detailed codebook for identifying stakeholders and their interactions, as well as factors such as leadership and accountability that impact the uptake and outcomes of EdTech interventions. The frameworks were then analysed using Dedoose — a qualitative analysis software.

One of the outputs of this analysis was a stakeholder co-occurrence matrix — that is, how many times two stakeholders occur together in a sentence / code. As an example, a code such as "Blau and Hameiri (2012) also found a relationship between online activity levels of teachers and mothers, indicating a possible relationship between teacher engagement and parent engagement" is tagged with parents and teachers in one sentence and hence the two stakeholders co-occur in the matrix. Social Network Analysis (SNA) was applied to this stakeholder co-occurrence matrix as a one-mode network where the nodes are stakeholders and the edges or connections demonstrate whether these stakeholders appear together, directly linked in a statement and plotted as a network graph. While this study has some limitations, to the best of our knowledge this is the first visualisation of an EdTech stakeholder map.

[16] Two main lines of systems research have been recognised. The first, empirical method, developed by von Bertalanffy, takes the world as we find it, examines the various systems in it — the zoological, physiological etc. — and draws up statements about observed patterns. The second method considers the set of all conceivable systems and subsequently reduces the set to a more reasonable size (↑Bertalanffy, 1969)(↑Ashby, 1958).

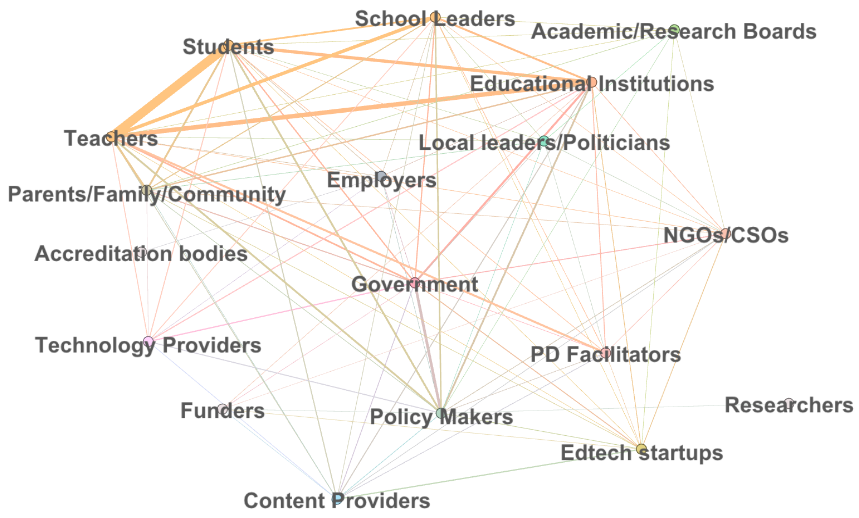
Figure 5. *Matrix showing the frequency of stakeholder co-occurrence within the EdTech frameworks (density of cells shows intensity of interaction).*

	Employers	Government	Educational Institutions	Students	Teachers	Accreditation bodies	Content Providers	NGOs/Civil Society Organisations	EdTech incubators/accelerators/innovators	Heads of Institutions/School Leaders	Edtech startups/Entrepreneurs	Local leaders/Politicians	Academic/Research Boards	Parents/Family/Community	PD Facilitators/Teacher Trainers	Policy Makers	Funding Councils/Investors/Private Banking/Funders	Teachers unions	Religious leaders	Researchers	Trade Unions	Tax Payers	Local Media and police	Technology Providers
Employers																								
Government	1																							
Educational Institutions	1	18																						
Students	2	10	30																					
Teachers	1	14	43	90																				
Accreditation bodies	1	0	0	0	0																			
Content Providers	0	5	7	8	5	0																		
NGOs/Civil Society Organisations	0	6	3	1	2	0	3																	
EdTech incubators/accelerators/innovators	0	0	0	0	0	0	0	0																
Heads of Institutions/School Leaders	1	9	17	15	32	0	3	1	0															
Edtech startups/Entrepreneurs	0	6	4	1	1	0	9	5	0	1														
Local leaders/Politicians	0	1	0	1	1	0	0	1	0	1	0													
Academic/Research Boards	0	0	0	1	1	0	0	1	0	1	1	1												
Parents/Family/Community	0	7	11	16	19	0	2	2	0	7	2	2	2											
PD Facilitators/Teacher Trainers	0	2	6	3	18	0	4	2	0	3	1	1	0	0										
Policy Makers	1	25	15	16	16	0	3	4	0	12	3	1	1	3	3									
Funding Councils/Investors/Private Banking/Funders	0	2	2	0	0	0	2	1	0	0	2	0	0	0	0	1								
Teachers unions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
Religious leaders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
Researchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0					
Trade Unions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
Tax Payers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Local Media and police	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Technology Providers	1	9	8	7	6	0	3	0	0	5	0	0	0	1	0	7	0	0	0	0	0	0	0	

5.3. Mapping the EdTech network: descriptive statistics

A network is described by a set of nodes representing stakeholders / entities and edges representing connections between these nodes as emergent from co-occurrence in the coded frameworks. The pathways emerging from these connections lead to the formation of a structure where stakeholders are directly or indirectly linked in a network (↑Borgatti & Halgin, 2011). Analysis of this network identified th"structures, positions, and dyadic properties (such as the cohesion or connectedness of the structure) that define the overall 'shape' (i.e., distribution) of ties" (↑Borgatti et al., 2009) (p. 894).

Figure 6. *Network graph showing interconnectedness of the stakeholders within the EdTech system.*[17]



Analysis of the code co-occurrence matrix emerging from the EdTech framework literature identified a total of 18 prominent stakeholders / entities[18] (nodes) and 93 unique interactions or relationships (edges) in the EdTech undirected knowledge graph (Figure 6). The network measures are described in further detail in this section.

5.3.1. Network density and diameter

The ease with which information flows in a network is indicated by its network diameter (maximum distance between two nodes) and distance (the shortest path between nodes). Network diameter closer to 1 indicates an easier communication path between stakeholders (↑Faul, 2016). The EdTech stakeholder network has a diameter of 3 and average distance of 1.45 (Table 2). This means that a stakeholder needs to pass through a maximum of 3, and on average, 1.45 other nodes to communicate with another stakeholder. An average distance of 1.45 indicates that the interactions between stakeholders are not highly dispersed and they are able to communicate with each other with relative ease.

[17] The edges (connections) are scaled based on the strength of the connection (calculated from frequency of co-occurrence).

[18] There were a total of 27 stakeholder codes at the start of the study. From these, no data emerged for six stakeholders (Trade Unions, Tax Payers, Local Media & Police, Religious Leaders, EdTech Incubators / Accelerators, and Teacher Unions). The codes for 'Ministries (Education / Finance / Planning)' were collapsed with the code for 'Government' owing to high overlap and lack of clear distinction between them. Similarly, 'Funding Councils / Private Banking' were merged with 'Philanthropists / Investors' to form the code 'Funding Sources' due to the same reason. The entities or nodes within the network are multilevel — i.e. some entities are individuals and some institutions. However, each entity that can take action within the EdTech space has been mapped as a node or stakeholder.

Table 2. *Overall network metrics.*

Network Metrics	Number
Nodes (Stakeholder)	18
Edges (Number of interactions)	93
Graph Density	0.60
Maximum Distance (Diameter)	3
Average Distance	1.45
EdTech Frameworks Analysed	17

The interconnectedness of a network is also identified by the density of its ties / interactions (↑Knoke, 2011). Any two stakeholders (nodes) in a network can be connected through a third stakeholder even if they do not share a direct link. Density is a measure of the possible number of edges (interactions) in a network as opposed to only the actual number of edges (↑Matthes et al., 2017). Networks with high interconnectedness are better at transmitting information (↑Burt, 2005).

The EdTech stakeholder network has a network density of 0.60[19] (Table 2), indicating a moderately high degree of interconnectedness among stakeholders, even though not all stakeholders are directly linked. The high interconnectedness of the EdTech network is demonstrated by a number of observable direct interactions as outlined in the framework papers as follows:

- In educational institutions implementing EdTech initiatives, heads of institutions engage directly with teachers and directly and indirectly with students in order to create shared visions and plans (↑Chisholm, 2020, ↑Omidyar Network, 2019).
- Direct interaction also occurs between teachers and students who collaborate to create, implement, and monitor projects through digital technologies (↑Asian Development Bank, ↑Borup et al., 2014 ↑UNESCO, 2011).
- Teacher–student interaction encourages teachers to interact with fellow teachers as well as external experts for continued learning (↑UNESCO, 2011); further, it also triggers interaction among teachers and parents in order to assess student behaviour, well-being, and performance, and to engage parents in increased e-learning support (↑Borup et al., 2014).

[19] The value of network density ranges from 0-1. A value closer to 1 indicates greater density (↑Matthes et al., 2017, ↑Prell et al., 2009)

- Online educational institutions engage with accreditation bodies to ensure their degrees are accredited as required, which in turn increases their credibility with employers (↑Wagner et al., 2008).
- Direct interactions are also fostered between educational institutions and their heads, technology providers, and content providers, who in turn seek financial inputs and feedback from governments and educational institutions (↑Wagner et al., 2008, ↑Omidyar Network, 2019).
- Educational institutions and their heads also engage directly with teacher training experts, who support the effective implementation of EdTech initiatives (↑Chisholm, 2020 , ↑Rodríguez et al., 2012, ↑Trucano, 2016 ↑CoAction Learning Lab, 2019).

5.3.2. Centrality

The concept of centrality relates to the structural importance or prominence of a node in the network (↑Borgatti et al., 2009). Centrality measures help identify the key stakeholders (nodes) in a network and the degree to which a stakeholder is connected to others (↑Matthes et al., 2017). Centrality is indicative of a stakeholder's power within the network. The more central a node, the more likely it is to exert power within a network (↑Borgatti et al., 2009).

Degree centrality[20]

Degree centrality measures the importance of a node based on the number of connections it holds. A node with a higher degree is considered more central, making degree an effective measure of the influence / importance of a node in a network (↑Matthes et al., 2017).

Based on degree centrality scores, the policymaker node (with a degree measure of 16) demonstrates the highest number of connections / relationships as indicated by co-occurrence in the frameworks, followed by the government, heads of institutions, teachers, and students (at the same level with a degree measure of 14) (Annex Table 5). It is unsurprising that policymakers emerge as the stakeholders with the highest number of connections in the EdTech network as they invariably play a central role in the EdTech system. These interactions are summarised from the frameworks as follows:

[20] Closeness centrality measures the average distance between nodes. A more central node will have a lesser distance to all other nodes. This helps recognise the individuals who are likely to be the fastest at spreading information and thus are important influencers of the network (↑McKnight, 2014) (↑McKnight, 2014). In the case of the EdTech network, the order of closeness centrality of some of the key nodes coincides with their ranking of degree centrality. Policymakers and governments have the highest scores followed by heads of institutions, teachers, and students. Closeness centrality scores indicate that these stakeholders could exert influence over the network via controlling the flow of information within the network. In comparison, accreditation bodies have the lowest closeness centrality scores followed by researchers, indicating potentially low overall influence in the network.

- Investment in technology is increasingly being viewed as a mode of improving education and economic development by nations (↑Kozma, 2005), and policymakers have significant roles in framing policies and implementation strategies to meet the needs of EdTech; they work "to meet the expectations, needs and desires of their stakeholders" (↑Khudair & Abdalla, 2016) (p. 85), and face the challenging task of managing the expectations of government, non-government, and private entities (↑Kozma, 2005).

- Governments have emerged as the node with the second highest number of connections; they control funding and budget allocations, as well as capacity building and the EdTech innovation and development ecosystems (↑Asian Development Bank, 2017; ↑UNESCO, 2011; ↑Kozma, 2005; ↑Trucano, 2016) and, unsurprisingly, demonstrate high degree centrality.[21]

Teachers and students also display high degree centrality in addition to sharing the strongest direct connection with each other in the network. Heads of educational institutions also occupy a position which allows them to spread information rapidly.

- Heads of institutions play an important role in the implementation and sustainability of EdTech (↑Asian Development Bank, 2017) and high degree centrality is indicative of their position in the network that allows them to interact with other stakeholders, and communicate visions and plans (↑Chisholm, 2020; ↑UNESCO, 2011; ↑Omidyar Network, 2019; ↑Asian Development Bank, 2017; ↑Hew & Brush, 2007).

[21] In this network, the code 'government' includes 'ministries' and clearly is a node that is connected to a number of other stakeholders within the EdTech system.

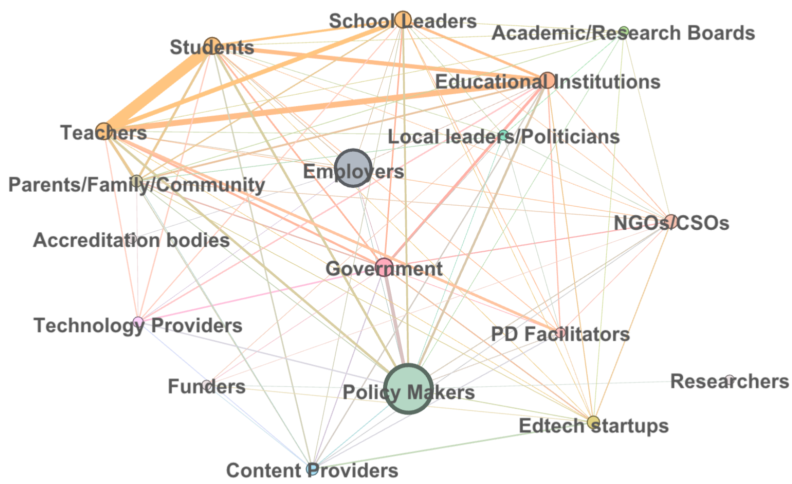
Betweenness centrality

Betweenness centrality measures the extent to which a node falls on the shortest path between pairs of nodes. It is “often interpreted in terms of the potential power that a stakeholder might wield due to the ability to slow down flows or to distort what is passed along in such a way as to serve the actor’s interests” (↑Borgatti et al., 2009) (p. 894). A high betweenness indicates the potential power of a stakeholder and the potential brokerage role they can play to influence a system.

Again, the policymaker node displays the highest betweenness centrality in addition to high degree centrality discussed previously, indicating their potential power to influence the network. Interestingly, employers (stakeholders involved in the school-to-work transition) emerged as the stakeholders with the second highest betweenness centrality (Figure 7). Stakeholders that display a high betweenness centrality score claim ties into the core of the network (↑Faul, 2016). Since a high betweenness score is indicative of influence over a system, it can be hypothesised that both policymakers and employers might conceptually play significant roles in the EdTech system.

- The ‘employer’ node represents those organisations which will hire learners in the future (↑Wagner et al., 2008).
- While employers’ demands for skilled workers are often met by a mismatched skillset (↑Duncan-Howell, 2012), student choices are strongly influenced by employer requirements.
- Employers’ demands have implications for education and content providers as well as curriculum developers.
- Employers could potentially also create demand that can impact government policies and investment in EdTech (↑Kozma, 2005).

Figure 7: *Network graph showing betweenness centrality for stakeholders within the EdTech system.*



In comparison with policymakers and employers, researchers and accreditation bodies have the lowest betweenness centrality scores (that is, the least influence in the EdTech network based on our analysis of existing frameworks). This is similar to the degree centrality measure for both of these stakeholders, which indicates that they are on the periphery of the EdTech network (Annex 3, Table 5). Owing to a lack of connections with other stakeholders it appears that they would find it tougher to influence decision-making in the network. From the perspective of an EdTech research organisation this is a significant finding, worthy of testing 'on the ground' and suggesting the need to further explore issues around EdTech evidence uptake (↑Pellini et al., 2021).

The researcher node has the lowest betweenness centrality, although research was noted as an instrumental step in creating evidence-based policies and supporting the scale-up of EdTech for learning and teaching (↑Asian Development Bank, 2017). It would be critical to examine their influence in an EdTech network in a real-world setting.

We also note that the high betweenness centrality of the employers could be attributed to their connection with accreditation bodies. It is possible that close collaboration between accreditation bodies and employers could serve to influence the overall demands within the EdTech system.

5.3.3. Study limitations

The development of this network was driven by a need to demonstrate the value of a systems approach. The employer node, for example, was not visible as a potentially key leverage point in the EdTech network using traditional qualitative data analysis. This knowledge graph can also form the basis of testing EdTech networks in country contexts. However, there are limitations to this study that are outlined below:

1. This EdTech network has been developed as an undirected graph and high betweenness centrality may not be sufficient to prove influence without understanding reciprocity (indicated by bidirectionality of a relationship (↑Jana et al., 2013). Also, given this network graph has been developed from co-occurrences of stakeholders in theoretical EdTech frameworks, the results need to be interpreted carefully and validated empirically. The reciprocal interaction of other stakeholders with employers and policymakers would determine the actual influence of these stakeholders in the network, and further research into the directionality of interactions is required. Measuring the in-degree and out-degree of centrality would allow us to interpret the results with more depth and precision.

2. The data has been coded in a manner that could be examined as a two-way two-mode dataset (entity / stakeholder and characteristic or framework), or a two-way one-mode dataset (stakeholder co-occurrence). The current analysis has been conducted with the data as a one-mode dataset and does not account for the interconnectedness of some of the entities via the framework from which the codes have been derived. Further analysis of the data will entail analysis as a two-mode network as well as analysis of the interaction type / processes within the defined EdTech network.

6. Conclusion and further work

In this position paper we draw upon the EdTech literature to highlight the complexity of the EdTech system and make the case for a systems approach to EdTech research. As a first step towards research, we also introduce a theoretical EdTech knowledge graph to visualise the EdTech stakeholder network.

While the idea of a systems approach is not novel to EdTech, it is also not widely adopted or used to date.[22] In the educational context, while systems approaches have been applied frequently for purposes such as education planning and management (↑Kraft & Latta, 1972), educational testing (↑Frederiksen & Collins, 1989), conflict management for students (↑Oyebade, 2001), and science and technology education (↑Chen & Stroup, 1993), they have rarely been applied to EdTech, and where applied, the 'systems' aspect has been cursory at best.[23] Some of the examples of applying systems thinking to EdTech include leveraging technology for school improvement (where the researchers used interviews to map eight factors operating in tandem that are involved in the effective implementation of technology in schools (↑Levin & Schrum, 2013), or designing for complex ICT-based learning (where researchers combined design thinking with systems thinking) (↑Markauskaite & Goodyear, 2009).

The applications of systems thinking to EdTech are many, and include design, implementation, evaluation, management, scale-up, sustainability, and research. The approaches are also extremely valuable for the political economy analyses of the operating environment in which EdTech is situated. In this paper we explore the application of systems approaches specifically to EdTech research and show that the approach compels us to redefine research questions and rethink research methodologies and analytical techniques for both macro-level problems, such as the use of data in education, and micro-level problems, such as girls' education and EdTech. Systems approaches also allow researchers to consider fundamental questions like: *Is EdTech concerned with advancing efficiency and effectiveness? Is EdTech value-neutral or laden with socio-cultural meaning? And to whom are educational technologists responsible* (↑Luppicini, 2005)*?*

Since a systems approach takes away the convenience of traditional log frames where inputs are directly correlated with outcomes, and compels one

[22] Ecological models have been proposed to understand scaling up in EdTech (↑Lee, 2017).

[23] The capacity for systems inquiry is limited to specialised groups within the educational research community (↑Banathy & Jenlink, 2003).

to hold ambiguity in the long term, it poses challenges for shifting mindsets from conventional thinking approaches. Newer skill sets such as dynamic thinking, loop thinking, and forest thinking (Table 3 in Annex 1) are required in order to think in systems terms (↑Richmond, 2000). We need to further explore the incentives for researchers or policymakers to take on more complicated approaches to problem solving.

However, similar to how systems approaches in ecology have provided powerful insights that have allowed for the visualisation of determinants appearing seemingly distant from the end stakeholder using linear approaches (↑Williams et al., 2002), systems approaches in EdTech can provide insights not known using traditional research methods. For example, employers emerge as potentially influential stakeholders in the theoretical network but are not prominent determinants in the EdTech system otherwise. Thus, our analysis of EdTech frameworks using one of the many systems methods — Social Network Analysis — highlights the value of this approach.

Further development and validation of the EdTech network could provide insights on stakeholder roles, interactions, and leverage points that could lead to significant improvements in learning outcomes. A robust EdTech knowledge graph could prove to be a valuable tool for understanding and researching EdTech. The EdTech knowledge graph developed in this paper is limited in that it does not account for the directionality of interactions and has been developed from a limited set of EdTech frameworks with different purposes. Further research is required to establish the internal and external validity of this network. Comparative analyses to validate the EdTech network empirically in different county contexts combined with in-depth systematic analysis of EdTech stakeholder interactions could be possible directions for further research.

Unless we know what a system is and how it works, we cannot improve or research it. This position paper serves as a foundation for understanding the EdTech system, by unifying existing EdTech frameworks in a single knowledge graph of stakeholders and highlighting the significance of such an approach.

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Annex 1: Systems and linear thinking approaches

Table 3. *Differences between systems thinking and linear thinking approaches (adapted from ⇡Richmond (2000)).*

Linear approach	Systems approach
Static thinking	Dynamic thinking
Focusing on particular events	Framing a problem in terms of a pattern of behaviour over time
Systems-as-effect thinking	Systems-as-cause thinking
Viewing behaviour generated by a system as driven by external forces	Placing responsibility for a behaviour on internal actors who manage the policies and 'plumbing' of the system
Tree-by-tree thinking	Forest thinking
Believing that really knowing something means focusing on the details	Believing that to know something requires understanding the context of relationships
Factors thinking	Operational thinking
Listing factors that influence or correlate with some result	Concentrating on causality and understanding how a behaviour is generated
Straight-line thinking	Loop thinking
Viewing causality as running in one direction, ignoring (either deliberately or not) the interdependence and interaction between and among the causes	Viewing causality as an ongoing process not a one-time event, with effect feeding back to influence the causes and the causes affecting each other

Annex 2: EdTech frameworks

Table 4. *List of EdTech frameworks.*

Framework	Provision	References
Framework for Evaluating Appropriateness of Educational Technology use in Global Development Programs	List of questions to help various stakeholders plan and implement EdTech interventions	(↑Osterweil et al., 2016)
Conceptual framework for effective integration of ICT	Process graph to support the establishment of synergies across various stakeholders in implementing ICT in education	(↑Asian Development Bank, 2017)
EdTech Ecosystem Model based on four Categories of Scaling Equitable EdTech	Presentation of principles to transition from a product-oriented approach to a systems-oriented approach in EdTech	(↑Omidyar Network, 2019)
PISA ICT Framework	Graph with processes and contextual factors to assess the integration of ICT in teaching and learning contexts	(↑OECD, 2020)
T3 Framework for Innovation in Education	Process graph to evaluate the impact of implementing EdTech into classrooms	(↑J. "Sonny" Magana III, 2020)
Framework for Stakeholder Inclusion in the Technology Planning Process	Process aiming at promoting inclusive EdTech selection and adoption processes by involving diverse stakeholders	(↑CoAction Learning Lab, 2019)
UNESCO ICT Competency framework for teachers	Table with information to support teachers in using ICT effectively and to enable students to develop various skills (e.g. problem solving)	(↑UNESCO, 2011)
Technological, Pedagogical, and Content Knowledge (TPACK)	Visual chart describing the kinds of knowledge required by teachers for successful integration of technology in teaching	(↑Mishra, 2019)
SABER-ICT Framework	Framework presented as a rubric to help policymakers with decisions on ICT in pursuit	(↑Trucano, 2016)

	of core developmental objectives in the education sector	
Development framework	Table with information aiming at helping policymakers analyse their EdTech national contexts	(↑Kozma, 2005)
E-Learning Stakeholders' Responsibility Matrix	Table with supportive information to help with coordination among EdTech stakeholders	(↑Wagner et al., 2008)
The Integrated Holistic Framework	Process graph to determine, measure, and assess the continuous and cumulative core skills and knowledge acquired using technology at the different levels of education	(↑Khudair & Abdalla, 2016)
International Society for Technology in Education (ISTE) Standards	List of standards intended to help educators and education leaders better understand how to use EdTech	(↑Trust, 2017)
Deconstructing EdTech Frameworks	Analysis of nine EdTech Frameworks based on their creators, features, and usefulness.	(↑Cherner & Mitchell, 2020)
Enhancing the EdTech Ecosystem in a British Columbia School District	An Organisation Improvement Plan (OIP) to support K-12 teachers in using EdTech effectively in the classroom	(↑Chisholm, 2020)
Adolescent Community of Engagement (ACE Framework)	A framework which is a guide to research and design in adolescent online learning environments	(↑Borup et al., 2014)
ICT for Education (ICT4E programme)	A conceptual framework for the sustainable adoption of technology-enhanced learning environments in school	(↑Rodríguez et al., 2012)

Annex 3: EdTech network measures

Table 5. *Network measures of closeness, betweenness, and degree centrality.*

Stakeholder	Closeness centrality	Betweenness centrality	Degree
Employers	0.65	16	8
Government	0.85	5.08	14
Educational Institutions	0.81	3.81	13
Students	0.85	4.25	14
Teachers	0.85	4.25	14
Heads of Institutions / School Leaders	0.85	4.25	14
Accreditation Bodies	0.40	0.00	1
Policy Makers	0.94	22.66	16
Technology Providers	0.68	0.57	9
Content Providers	0.74	1.58	12
NGOs / Civil Society Organisations	0.77	2.51	13
EdTech Startups / Entrepreneurs	0.74	1.82	12
Local Leaders / Politicians	0.65	0.37	9
Parents / Community	0.74	1.39	12
PD Facilitators / Teacher Trainers	0.68	0.36	10
Funding Councils / Investors / Philanthropists	0.59	0.00	6
Academic / Research Boards	0.63	0.11	8
Researchers	0.50	0.00	1

Annex 4: Characteristics of the education system

Characteristics of systems vary greatly based on the type of system being studied, and understanding the characteristics of the EdTech system allows for the identification of appropriate theoretical approaches to understanding its functions. Education systems have been described as purposeful / intentional, soft, open, hierarchical, complex, and adaptive. These characteristics could be extrapolated to the EdTech system. Given the fact that technology-driven systems are understood using hard systems approaches, the question of whether there are hard (technology) systems within a soft (education) system will need to be examined further. We elaborate the characteristics of the education system in this section with a view that these characteristics might be extrapolated to EdTech systems as well.

Purposeful

Education systems are purposeful or intentional systems in that entities within these systems select, organise, and carry out activities in order to attain specific purposes (↑Banathy, 1988) — of promoting student learning (↑Banathy, 1991; ↑Banathy & Jenlink, 2003; ↑Frick, 2020).

Soft

From the 1970s on, it has been widely accepted that the nature of issues in human and social systems is 'soft' in contrast with problems associated with fields such as systems engineering and other quantitative areas of inquiry, which are 'hard'. Soft systems approaches are applied to "messy" [24] problems, which in most cases are attributed to human activity (↑Laszlo & Krippner, 1998; ↑Jackson, 1982). Education and education systems are usually studied using soft systems approaches (↑Banathy & Jenlink, 2003; ↑Karim, 2010).

[24] Ackoff (1981) suggests that a set of interdependent problems constitutes a system of problems, which he calls a "mess" (↑Ackoff, 1981).

Open

A system that is able to import and export energy is called an open system[25], and one that cannot import energy is called a closed system. In this regard, school systems are regarded as moderately open systems as they are constantly interacting with their environment (↑Betts, 1992).

Hierarchical

A system's hierarchy refers to the number of levels within the system. Each successively higher level of the hierarchy encompasses all of the processes at each lower level and is increasingly complex as the number of elements increases(↑Boulding, 1956). Education systems are considered to be hierarchical systems[26] (↑Betts, 1992) and the relations between the various subordinated systems and the super-systems need to be considered in order to understand the properties and behaviour of the individual elements within the system (↑Bertalanffy, 1950; ↑Bertalanffy, 1969).

Complex

Finally, education systems are classified as complex systems (↑Snyder, 2013; ↑Duit et al., 2010; ↑Abdul-Hamid et al., 2017; ↑Betts, 1992; ↑Mason, 2008) (as opposed to simple systems[27]). Organic systems are very complex with many variables, which require a great deal of feedback. The larger and more complex the system, the more energy, in the form of feedback, is required to maintain a dynamic balance among elements and this feedback also allows the system to adapt in real time (↑Betts, 1992).

[25] Katz and Kahn have defined the attributes of an open system (↑Katz & Kahn, 1969) as described by Betts (1992):

- Energy is transformed, and something new is produced.
- A product is exported into the environment.
- The pattern of energy exchange is cyclical; the product that is exported into the environment is the source of energy for repetition of the cycle of activities.
- The system aims to "maximise its ratio of imported to expended energy."
- The system exhibits differentiation, a tendency toward increased complexity through specialisation.

[26] Whether these systems are networked or nested is a notion that has been challenged, with arguments stating that 'nested' may not be the precise way to conceptualise the interrelatedness of the various systems (↑Bronfenbrenner, 1977; ↑Ettekal & Mahoney, 2017).

[27] In simple systems, a formula can be followed and repeated with relatively little expertise and be expected to produce roughly uniform results (↑Snyder, 2013).