How can networks help encourage the development and professionalisation of innovative early STEM Education in a changing world?

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Abstract: The world is becoming more complex and requires, among other skills, STEM[1] knowledge and literacy of its learners, community members, and societies alike. Thus, an extensive advocacy for quality early STEM Education is needed. This paper outlines how impact networks (formed to address complex social or environmental issues) can promote the development and professionalisation of early STEM Education. It aims to support field-developing institutions to increase the impact of their work for a better and easily accessible education worldwide. After reviewing the intended impact of early STEM Education in the present context, the paper presents various network types and then assesses the network approaches of educational organisations and their network partners in multiple countries. It reflects on the various functions and success factors of networks in relation to the authors' six organisations' networks in their respective countries and analyses the networks according to opportunities and challenges. The paper argues for the relevance of network collaborations and for the potential of networks as agents of change, exemplifying their impact on improving STEM Education in a changing world.

Keywords: STEM Education, impact network, co-creation, collaboration, IDoS

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Overview

This paper outlines the outcome of the International Dialogue on STEM Education (IDoS) among six members known as "IDoS peers" worldwide in 2022. IDoS peers are leading organisations who focus on early STEM Education and engage as developers in the field by promoting and professionalising high-quality STEM Education in their respective countries or impact regions in the world (see Table 1).

[1] The abbreviation "STEM" stands for science, technology, (information) engineering/computer science, and mathematics. We define STEM Education as an education combining science, technology, (information) engineering, and math concepts and methods in an integrated way that transforms the discipline of science.

Initiated by the Stiftung Kinder forschen and Siemens Stiftung, the IDoS peer organisations meet regularly in virtual or on-site meetings and discuss topics of strategic importance for their work in fostering STEM Education.

The purpose of this paper is to outline how impact networks (formed to address complex social or environmental issues) can promote the development and professionalisation of innovative early STEM Education in a changing world (a world focused on, e.g., sustainable development, digitalisation, and changing work environments). It aims to support institutions engaging as field-developers in education to increase the impact of their work for a better and more easily accessible education.

After reviewing the need for STEM Education initiatives in the present context and examining the targeted impact for which early STEM Education organisations and their partners in several countries engage, the paper presents a set of network types and how they work (Part I). The paper then reflects on the various functions and success factors of networks in relation to examples from the IDoS peers' networks in their respective countries and analyses these networks according to opportunities and challenges (Part II). The paper argues for the relevance of network collaborations and for the potential of impact networks to emerge as the agents of change, exemplifying their impact on improving early STEM Education in a changing world (Part III).

This paper reflects the current state of thinking and discussion on the topic, as shared by the involved international experts. As the dialogue with experts from science and practice continues, future adjustments are possible.

Table 1. List of the IDoS peer organisations

Name of peer organisation	Type of organisation	Year established	Headquarter (Country)	Region of main impact/activity	Type of main funding
Stiftung Kinder forschen	Non-profit foundation	2006	Berlin, Germany	Germany	Publicly and privately funded
Siemens Stiftung	Non-profit foundation	2008	Munich, Germany	Germany, Latin America, Africa	Endowment Capital
Smithsonian Science Education Center	Non-profit (with quasi-governmental status in the U.S.)	1985	Washington, DC (USA)	Global	Gifts and grants (public and private)
Luma Centre Finland	Non-profit University network	2013	Helsinki, Finland	Finland	Publicly funded
Fondation La Main à la Pate	Non-profit foundation	2011	Paris, France	France	Publicly and privately funded
Office for Climate Education	Non-profit foundation	2018	Paris, France	France, Latin America, South-East Asia, Africa	Publicly and privately funded

Part I: Networks for impact: Why and how networks help promote change in early STEM Education

Over the past years, STEM Education has gained importance in many countries around the world, as shown by the increasing volume of publications in this domain (Li, Wang, Xiao & Froyd, 2020). Governmental and non-governmental organisations, as well as private industry who rely on building a strong workforce, are increasingly recognising the need for quality education in science, technology, engineering/computer science, and mathematics (STEM) from an early age (Freeman, Marginson & Tyler, 2019; Li et al. 2020). The authors of this paper share this view.

At a time of international crises such as, for instance, the climate crisis, the COVID-19 pandemic, the looming economic recession, and increasing shortage of skilled workers, the need to equip students to deal with these challenges becomes more and more pressing (Gibson, Short & O'Donnell, 2023). Quality STEM Education is the key to help children from an early age to acquire the skills needed in this changing environment.

"STEM Education for Sustainable Development", a term coined by some of the authors in a previous paper, aims at fostering knowledge and competencies for reasonable action in the world, both locally and globally. In 2019, they therein argued for an integrated approach to STEM Education for Sustainable Development ("STEM4SD Education"):

> "STEM Education for Sustainable Development encourages children and youth to draw on their STEM competence and the process of science as a key basis for reasonable action in our world. Knowledge, skills, and understanding of science, technology, engineering, and mathematical phenomena are vital to helping students understand global problems and support actions in society that address these challenges in a meaningful and knowledge-based way" (Pahnke, O'Donnell & Bascopé, 2019[2]).

However, delivering quality STEM Education faces many challenges. Financial resources and the widespread offer of continuing professional development programmes are limited. Single actors operating on their own run the risk of lacking the necessary size, human and financial resources, scale, and time for producing impact. To address these challenges and to promote quality early STEM Education against the backdrop of a changing world, collaboration between leading organisations who focus on early STEM Education and have the capacity to create lasting synergies among their peers is key.

The IDoS peer network was formed in 2020 with the goal to build a global peer dialogue of leading educational players in the field of STEM Education that further promotes high-quality early STEM Education and increases global awareness for this high-potential education sector. Before its formation, two highly successful international IDoS conferences took place in Berlin in 2017 and 2019. Here, over 100 experts from around the world exchanged know-how and best-practice ideas and discussed challenges of early STEM Education. The conference generated a strong demand for a recurring exchange platform. As a result, the two initiators of IDoS, the Stiftung Kinder forschen (Little Scientists Foundation) and Siemens

[2] The "STEM4SD Education" paper was written in connection to the IDoS 2019 conference and analyses critically how an integrated and transdisciplinary focus on inquiry-based STEM Education could serve to enhance sustainable development and build capacity for future generations. As such, the international paper promotes the idea of a transdisciplinary framework of education, acknowledging the complex context of global challenges and the need for integrating values, ethics, and world views towards the development of sustainable mindsets and using science to do social good. The paper was endorsed by the various experts participating in the IDoS 2019 conference, among others. It is an example of a combined output of authors from different networks working closely together towards a common purpose.

Stiftung, decided to establish an international peer dialogue between leading organisations (the "IDoS peers") whose primary focus of work is on early STEM Education for Sustainable Development, with the flexibility to expand the topics into other areas, such as early STEM Education in the digital age.

The IDoS peers share the conviction that global developments as outlined above and the demands for a quality education arising thereof can best be tackled by working together internationally. They are seeking a systematic and regular exchange, combining the global knowledge on STEM Education and its local practice, from which the organisations involved can benefit in a sustainable way. By engaging with leading institutions across the globe, the parties can enhance the efficiency and effectiveness of their work, implementing it in a context-specific, knowledge-based, and practice-oriented manner.

The organisations contributing to the present paper draw from years of experience of working in the field of STEM Education. They all face the growing complexity of STEM Education. Not only do STEM disciplines become more intertwined as sustainable development goals evolve, but the environments in which they are being taught is changing as well, as they come to include digital tools like Open Educational Resources (OER), blended- or hybrid learning, and on-line learning (i.e. STEM Education in a progressively digitalised world). Organisations that specialise in teachers' training and in the provision of pedagogical resources need to be able to adapt to these new environments. That is why the contributing organisations have invested extensively in building and maintaining effective network collaborations with global and local partners and formed IDoS - a network of networks operating in the domain of early STEM Education.

Through the present paper, the IDoS peers aim to share networking experience with other organisations that are working in the field of STEM Education and to reflect collectively on the:

- strategic role of networks;
- potential impact that networks have on local and global initiatives and on the professional development in the changing field of STEM Education (and on the necessity to assess this impact); and,
- success factors and the obstacles that can be encountered in building and maintaining networks.

By doing so, the IDoS peers believe they can inspire and encourage other networking initiatives in the field of early STEM Education (including, for example, STEM Education for Sustainable Development and STEM Education in a world marked by increasing digitalisation).

I.1 What impact do the peer organisations and their partners strive to achieve in the field of early STEM Education?

The IDoS peers share a common goal: to strengthen children's and youth's knowledge and understanding for the future, fostering their skills and competencies necessary to live and innovate in a world with pressing global issues, challenges, and opportunities. Through their respective initiatives, the peers support quality education that encourages the development of skills such as *communication, creativity, critical thinking, and collaboration* (Fadel, Bialik & Trilling, 2017).

Quality early STEM Education encourages children to ask questions and supports them in acquiring knowledge and methods for tackling those questions, and for developing inquiry-based learning. Quality early STEM Education not only benefits children's literacy in the domains of science, technology, engineering/ computer science, and mathematics but also has the potential of preparing them to navigate in a complex and ever-changing world. STEM Education for Sustainable Development promotes what the Smithsonian Science Education Center refers to as sustainability mindsets (Gibson, 2021) – i.e. open mindedness and reflection; equity and justice; local and global connection; and empowerment and agency. Early STEM Education for Sustainable Development promotes children's skills and attitudes necessary to engage with global issues on a long-term basis, empowers the next generation of decision makers capable of taking informed action about the complex socio-scientific issues facing human society, helps children become change agents in their local community, and develops the spirit of action-taking that is necessary to overcome the complex socio-scientific issues facing our planet (O'Donnell, 2018). Children can develop scientific and digital competences as well as sustainability mindsets from an early age. Nurturing these digital literacy skills and sustainability mindsets can enable individuals to contribute to making a better society through their future actions. Therefore, STEM Education is widely recognised as a crucial element in enhancing a country's science capital and driving economic growth.

Early education is proven to achieve the greatest economic output and therefore the highest impact (OECD, 2020). Children with an interest in STEM subjects are

more likely to enter jobs where these skills are required, thus benefiting the market, and balancing out shortages of STEM skills that have been troubling countries for years.

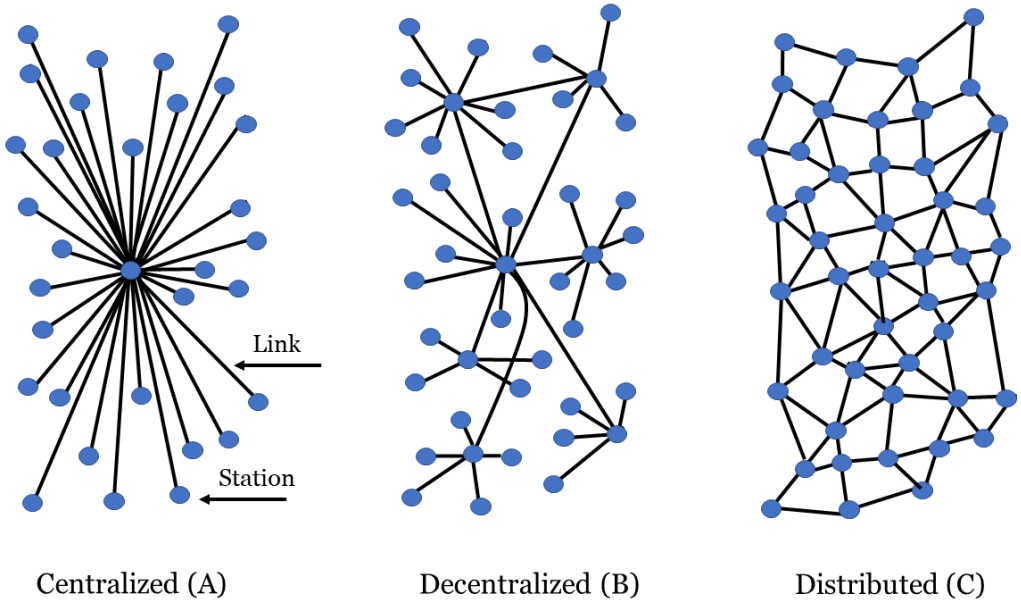
To ensure children are receiving quality education, the IDoS peers and their respective national and international networks focus on providing teachers and early childhood educators and caretakers with the training needed to steer children and youth in their daily exploration and understanding of the world. Their initiatives offer continuing professional development programmes including on-site trainings and online courses, professional events and symposia – and learning material designed to equip teachers and educators with skills and tools to create engaging learning environments for students in a changing world.

I.2 What is the potential of networks to encourage the envisaged impact?

To achieve their objectives, the IDoS peers initiated widespread impact networks that support them in their missions. **Impact networks** are webs of relationships connected to address, for example, social, educational, or environmental issues (Ehrlichman, 2021; Vandor, Leitner, Millner & Hansen, 2019). Such networks bring actors together for learning and coordinated actions based on a shared purpose. But what is a network in the first place?

In a generic sense a network is a "set of connections that link (discrete) elements" (Levine, 2015). The roots of the term are believed to derive from the language of metallurgy and textiles and "imply interwoven strands moving in multiple directions rather than directed toward a single end" (Slaughter, 2017). All networks have a form and a structure and can be defined by their degree and density of connections as well as by their centrality (see Figure 1), which means they can be described in terms of who is connected to whom, how well they are linked to each other, and how critical and central specific nodes in a network are compared to others.

Figure 1. (A) centralised, (B) decentralised, and (C) distributed structures (adapted from Baran, 1964, p. 1)



Social networks link individuals or organisations and are prone to facilitate collective action. In fact, inter-organisational networks, like the networks of IDoS peers, are often deliberate means to do so. They differ from markets and hierarchies (Powell, 1990) as a more distributed structure that promises to be more resilient, more able to create change and to respond to change (Ehrlichman, 2021).

How networks come into existence and how they function varies. Ehrlichman proposes three defining **functions** (actions or operations) and thus types of networks: Learning Networks, Action Networks and Movement Networks (Ehrlichman, 2021). Slaughter takes a different angle and differentiates networks based on their main **purpose** (reason for which the network exists), namely: Resilience Networks, Task Networks and Scale Networks (Slaughter, 2017). By combining the two perspectives, it is possible to categorise networks according to five core functions and purposes: improving dynamic social resilience, upscaling solutions, performing action/tasks or creating products together, inducing movement, and learning (see Table 2).

Table 2. Network types based on Slaughter (2017) and Ehrlichman (2021).

Function	Resilience Networks	Scale Networks	Action Networks (Task Networks)	Movement Networks	Learning Networks
Purpose	Focused on improving dynamic social resilience; building strength, stability, and capacity	Focused on bringing promising solutions to scale (upscaling solutions)	Focused on performing tasks and coordinated action, and creating products together	Focused on aligning networks around common aims; inducing movement	Focused on connecting and learning of members

The six IDoS organisations contributing to this paper (see Table 1) can all be perfectly linked to these network types, without necessarily fitting in one category exclusively, often overlapping and fulfilling specifics of other types. Nonetheless, an allocation to one of the five types will be made in the following, thereby introducing the organisations and their focus of work.

I.3 What are examples of different network types from each IDoS peer?

Siemens Stiftung and its STEM*plus* Territories – "Resilience Networks"

Resilience Networks aim at building strength, stability, and capacity in their communities and improving social dynamic resilience (see Table 2).

As a non-profit, internationally operative foundation, Siemens Stiftung promotes sustainable social development, which requires access to basic services, high-quality STEM Education, and the understanding of culture in all its facets. To this effect, Siemens Stiftung's project supports people in taking the initiative to responsibly address current challenges. Since 2017, Siemens Stiftung initiated a network of STEM*plus* Territories in Latin America, where in addition to the STEM subjects an additional "*plus*" was added, which refers to the open initiatives on relevant topics around supplementary areas like arts, humanities, languages, media, and sustainability. The communities have the flexibility to add additional subjects based on their regional contexts (see Reiss & Filtzinger, 2023).

The purpose of the STEM*plus* Territories is to foster and develop local educational networks that promote a learning environment for STEM Education, where schools, teachers, students, and actors from the civil society, government, and

the economy collaboratively develop tools to address community problems and take on the future challenges of their own specific contexts. The territorial and collective nature of the network model generates a sense of responsibility and commitment to the community. All STEM*plus* Territories are interconnected, generating a network of internationally connected local initiatives.

Thus, the STEM*plus* Territories are an example of Resilience Networks (see also Chabay, 2022).

Stiftung Kinder forschen (Little Scientists Foundation) and its network partner system – "Scale Networks"

"Scale Networks" are focused on bringing promising solutions to scale (see Table 1).

The non-profit Stiftung Kinder forschen is Germany's largest early childhood education initiative in the domain of STEM Education. With a complementary focus on Education for Sustainable Development (ESD), the aim of the programme is to strengthen children for the future, provide them with important skills, and enable them to act in a sustainable way. Together with its local network partners, the foundation provides a nationwide continuing professional development programme that supports pedagogical staff at early childhood education and care centres, after-school centres, and primary schools in facilitating the exploration, inquiry, and learning of children between the ages of three and ten.

The foundation's nationwide network helps disseminating the foundation's continuing professional development programme (its on-site workshops, digital courses, and educational events) throughout Germany, thus securing the participation of the foundation's target group (pedagogical staff at early childhood education and care centres, after-school centres, and primary schools) in as many regions in Germany as possible. The initiative prides itself in this system of multipliers (over 200 network partners and over 500 pedagogical trainers and process companions) that scale the programme to regional and local networks and pedagogical institutions.

Thus, Stiftung Kinder forschen and its network partner system in Germany is an example for a Scale Network. LUMA Centre and *La main à la pâte* Foundation (LAMAP) are also examples of Scale Networks in Finland and France, respectively.

LUMA Centre Finland and its university network – "Scale Networks"

LUMA Centre Finland is a science education network of Finnish universities. LUMA's aim is to inspire and motivate children and youth into mathematics, science, and technology (STEM). To achieve their goal, they develop new methods and activities of science and technology education based on research. Furthermore, they support the life-long learning of teachers working on all levels of education from the early childhood to universities and strengthen the development of research-based teaching.

The mission of LUMA Centre Finland is to reach a high-level know-how in science and technology among pupils, students, and teachers to ensure qualified and skilful professionals for labour markets and for personal, knowledge-based civic life actions. The LUMA Centre Finland network involves 11 research universities housing 13 regional LUMA centres. Each node is a connection point to develop research-based STEM activities and actions to be shared with other centres via on-site, off-site, and online actions. Moreover, all development programmes involve teachers and educators from schools and academic institutions. This allows to discuss, communicate, and distribute new ideas, materials, practices, and support in a fast and united manner. Thus, LUMA Centre Finland is a practical and effective example of Scale Networks where educational support and developments are distributed to a whole national educational system locally and personally.

La main à la pâte Foundation (LAMAP) and its Houses for Science – "Scale Networks"

The *La main à la pâte* Foundation (LAMAP) brings together teaching and scientific communities to improve the quality of science education in primary and middle schools. It offers teachers a wide range of classroom and training resources to promote lively and inclusive science education, to tackle societal issues, and develop scientific and critical thinking for all.

To achieve its missions, *La main à la pâte* relies on three different national networks that have been created at different times during its 25-years-long history. Each network covers different roles: providing professional development, guidance, and support to teachers, proposing classroom activities and resources, connecting educational actors among them and with scientists. All the networks have the specificity of operating locally. This supports teachers at the level of the territory, identifies and answers specific needs, as well as connects them and their pupils with

the local community of STEM institutions like universities, research laboratories, and museums.

Among these networks, the Houses for Science (Maisons pour la Science, MPLS) deserve a particular attention. MPLS represents a large-scale multi-stakeholder national network, specifically aimed at the professional development of in-service teachers in science, technology, and engineering. Each House is hosted by a university. The creation of the MPLS network aimed at structuring teachers' training locally (at the regional level), and at freeing resources for developing at-distance, on-line training. In this way, LAMAP has diversified its global offer, to answer to local priorities and to be more scalable in terms of deployment. Also, since each House has its premises within the university campus, the Houses have facilitated the interaction between the local STEM professional community and the educational community.

Office for Climate Education (OCE) and its ALEC Network – "Scale and Action Networks"

"Action Networks" or "Task Networks" focus on performing tasks and coordinated action and creating products (see Table 2).

The Office for Climate Education (OCE) promotes climate change education at primary and secondary school levels worldwide with a view to furthering the 2030 Sustainable Development Agenda, and in particular Sustainable Development Goals 4 (Quality Education) and 13 (Climate Action) (United Nations General Assembly, 2015).

The OCE's network ALEC (America Latina para la Educacioón Climatica / Latin America for climate education) was launched in 2019 to support the implementation of a regional climate change education project in Latin America. This multi-stakeholder network is composed of a wide range of local actors in Mexico, Colombia and Chile, including national academies of science, local governments and NGOs.

The network is organised and maintained to serve two joined objectives. Firstly, ensuring that the project's output is the actual result of the combined expertise of all network members. Indeed, together the network actors need to adapt OCE's pedagogical resources to their local context as well as deliver professional development workshop series to teacher trainers, teachers, and policy makers in their regions. Secondly, guaranteeing the regional aspect of the project by creating a

setting in which Mexican, Colombian and other Latin American partners can work together and learn from each other.

This two-pronged approach allows the network to focus on coordinating and performing actions at their local level while, at the same time, providing a structure to identify and scale-up the successful ones at a regional scale.

Smithsonian Science Education (SSEC) / LASER network – "Movement Networks"

"Movement Networks" are focused on aligning networks around common aims to induce movement (see Table 2).

The Smithsonian Science Education Center (SSEC) is an organisation of the Smithsonian Institution dedicated to transforming "K-12" education through science, in collaboration with communities across the globe. "K-12" is defined here as primary and secondary education from kindergarten up to the twelfth grade for students ages 5 through 18.

The SSEC has three goals: innovation (to promote authentic inquiry-based STEM teaching and learning through hands-on and digital experiences); inclusion (to ensure diversity, equity, accessibility, and inclusion in STEM Education); and sustainability (to advance STEM Education for Sustainable Development). Using a transdisciplinary approach, they want students to discover, understand, and act on the world's most pressing challenges and opportunities; but, to also explore and engage with STEM-related topics more deeply to develop not only scientific literacy, but sustainability mindsets to prepare for a world of transformation and change (O'Donnell & Day, 2022).

Through SSEC's Leadership and Assistance for Science Education Reform (LASER) model, the SSEC provides the infrastructure for transforming K-12 STEM Education through 5 pillars of reform: research-based, inquiry-driven curriculum; professional development; materials support; administrative and community support; and aligned assessment. The purpose of LASER is to bring together networks of schools, school districts, state education agencies, ministries of education, and education organisations around the globe to engage together in systemic reform around a common aim. Based on research and best practices, LASER provides education networks an opportunity to address a given problem of practice (e.g., how to promote inquiry-based science education or STEM Education for Sustainable Development; how to ensure diversity, equity, accessibility, and

inclusion in STEM Education; how to prepare students for a world of innovation and digital transformation). Each regional network or "LASER hub" prepares its own strategic plan for reforming STEM Education in their respective region around a given aim (e.g., scaling up IBSE; diversifying the STEM teaching workforce; ensuring zero barriers in STEM for students with disabilities) with the support of SSEC during implementation. SSEC studies the collective impact through research grants in collaboration with university partners and international organisations (O'Donnell, D'Amico, Zoblotsky & Alberg, 2017).

The IDoS peer network: A network of networks – "Learning Networks"

All networks presented above are exemplarily at contributing to the common goal of enhancing STEM Education for children, youth, and communities by professionalising pedagogic staff and collaborating with multipliers in the field, connecting important actors, and coordinating the distribution of their education programmes. The organisations cannot execute these tasks alone, it is their networks that facilitate collective action, that creates sustainable impact.

The IDoS peer network—a "network of networks"— makes use of the impact achieved by its member organisations and their respective networks. Due to the network's focus on connecting its members and having them learn from one another and share their lessons learned, the IDoS dialogue network can be specified as "Learning Network", based on the definition of network types by Slaughter (2017) and Ehrlichman (2021) (see Table 2).

By aligning the knowledge, expertise, and reach of STEM initiatives from different countries, the topic of STEM Education gains greater international visibility (whether its focus is on STEM Education for Sustainable Development, STEM Education in a progressively digitalised world or other challenges where STEM Education can be part of a solution). Moreover, a combined exchange helps identify topics that are meaningful and pressing in the field at hand and share experiences and strategies to enhance impact of the respective initiatives. Thus, local activities can profit from global exchange and learning. This paper is an example of an area - How can networks promote innovative early STEM Education in a changing world? - that was identified as important for STEM Education initiatives around the world.

Part II: Thriving Networks: Success factors for impact network collaboration

Impact networks address social problems that compel collaboration. A network of collaborators is often considered promising due to the complexity of social problems that early STEM Education faces and needs to address. When actors of early STEM Education collaborate in networks, they have an exceptional potential to generate new knowledge and to bring about ideational and structural change (Kolleck, 2012, p. 152; Kolleck, Bormann, de Haan, Kulin & Schwippert, 2016). However, networks can take up many different pathways in producing this impact. Looking at the set of networks represented by IDoS peers, we see networks that have become fully educational ecosystems, influencing and implementing national educational policies, uplifting capacities of teachers and educators significantly, building connections and fostering collaboration between formerly improbable allies, or strengthening local ties and sector wide involvement in advancing early STEM Education despite challenging conditions. In doing so, the role each network fulfils i.e., how the network promotes value, varies. Network members can support each other in doing their own work better, they can coordinate their efforts with those of other members or they can fully act together as a single agent of change.

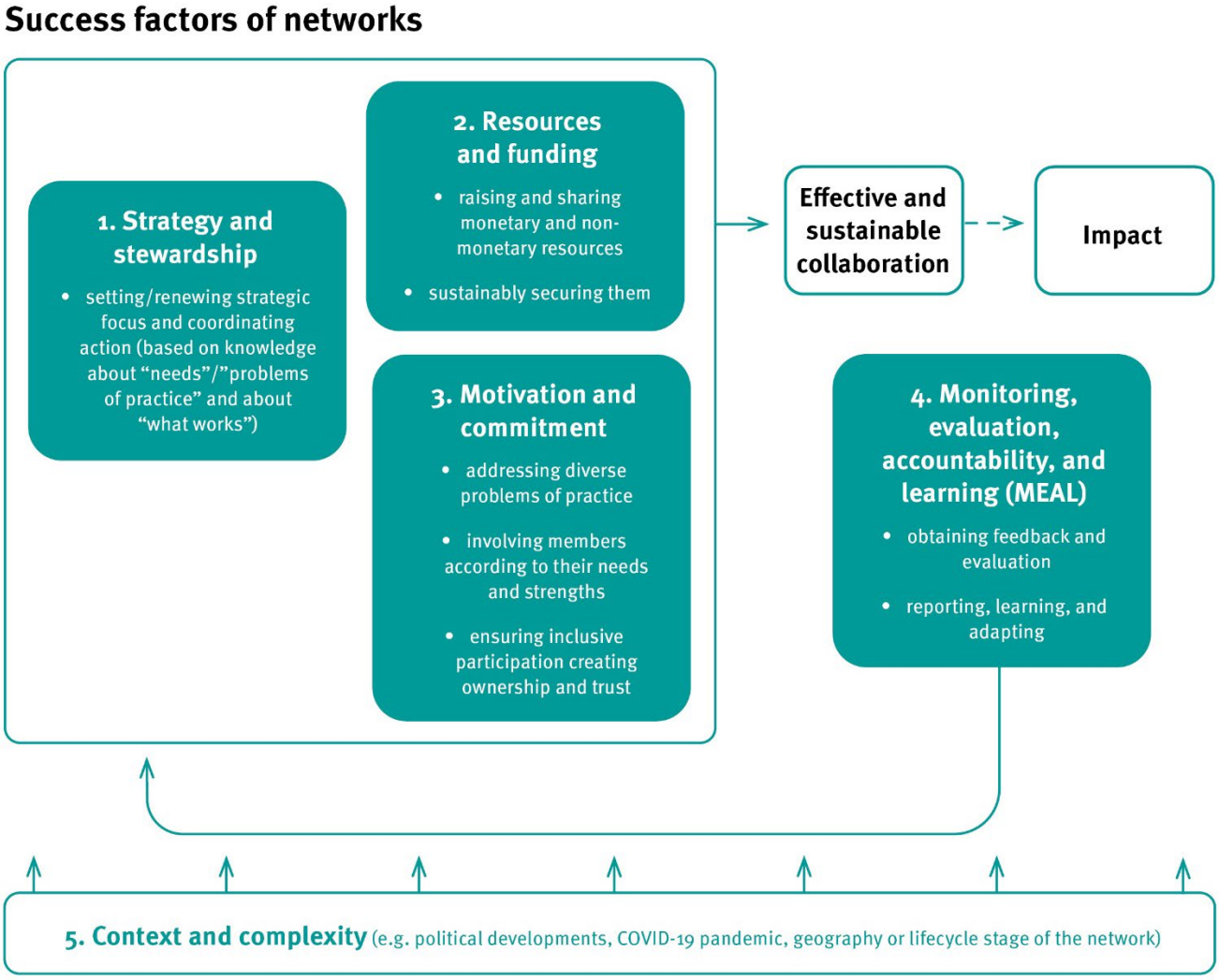
Notwithstanding their enormous potential for impact, networks are neither the answer to all problems nor are they an easy structure to develop that leads to success. As a groundwork for this paper, each IDoS peer has contributed a case study of one of its most long-standing networks (see Part I for short profiles) and each case study draws attention to both opportunities as well as challenges along the networks path. Research from management and social science also emphasises that there are fundamental and at best balanceable dilemmas associated with network collaboration (Shumate & Cooper, 2022).

To support other organisations in handling these challenges, this paper now sets out to share reflections and practical findings derived from the IDoS peers' cases. It hereby aims to encourage more actors of early STEM Education to pursue networks and collaborate to create an impact that exceeds the sum of their individual parts.

Because of the diverse contexts, roles, and functions of networks in early STEM Education, there is, of course, no best practice that is appropriate for any network or any problem. Yet, despite the heterogeneity of networks built by the IDoS peers a few findings stand out as common. Figure 2 visualises them as elements and key practices that are critical for the success of a collaborative network in education.

They include: the strategy and stewardship of the network (1), its resources and funding (2), the motivation and commitment of network members (3). Additionally, the application of effective practices of monitoring, evaluation, accountability, and learning (MEAL) (4) are important factors to ensure and maintain the relevance of network activities and thereby the network's impact. Similarly, the context and complexity of the field in which networks operate also determine how successful they are (5).

Figure 2. Success factors and success criteria of networks in STEM Education for early learning



II.1 Strategy and stewardship

Successful networks have a clear mission that has been adopted by all network members, and a strategy which is consistent with the mission. Underlying their strategy, impact networks ideally have a Theory of Change (Rogers, 2014) which is

based on a root cause analysis of the problem that the network is trying to solve and explains exactly how the network's activities will contribute to solve the problem and whose needs they will attend to. In early STEM Education, popular contributions of networks are creating new products or services together or scaling up already proven solutions, but networks can also advance the quality of their members' work, advocate for policy change or to join forces with other networks for system change (Shumate and Cooper, 2022, pp. 88-90). Moreover, the activities of impact networks can claim outcomes on four different levels (Shumate and Cooper, 2022, p. 50):

- outcomes on individuals who participate in network activity (I),
- outcomes experienced by organisations who are part of the network (II),
- outcomes on level of the network partnership itself (III), and
- outcomes on impact level, i.e., on clients, on a field, community, geographic region etc. (IV).

A good strategy defines expected results on all these levels. This does not imply that goals cannot or should not change over time. On the contrary, strategy and goals must remain adaptive to constantly thrive for impact. Having clarity about envisaged outcomes, about how they interconnect and what is necessary to achieve them, enables and fuels collaborative networks to take goal-directed action.

Once set on track, networks need consistent stewardship. A group must have the mandate to act as a decision-making body that (re-)builds strategic focus and coordinates action towards it. Since networks must constantly prove their relevance by promoting value, stewarding entities need to combine a) addressing member needs, b) steering towards solving recognised "problems of practice" in the field and c) building linkages by integrating new knowledge. As we know, activity in collaborative networks is voluntary and driven by a diversity of interests and backgrounds. Therefore, network stewardship best follows principles such as equity and trust and takes an enabling rather than controlling approach.

The importance of some such aspects is visible in the case of the Smithsonian LASER network, which has a Theory of Change (see https://ssec.si.edu/laser-model) which aligns movements of networks in STEM Education around a common theme (or "problem of practice"): starting with an initially narrow focus on promoting inquiry-based science education (IBSE) and a fairly defined approach in doing so, it became clear over time that interest in and potential for the model existed for other common themes in STEM Education as well. Instead of exercising more control and restricting application of the model, this tension was used to adjust leadership

accordingly and start to both open up and decentralise, broadening the scope to universal design to reduce barriers in STEM Education for students with disabilities, to diversifying the STEM teaching workforce, and enabling higher adaptation and impact altogether, with each network in the movement creating its own logic model or strategic plan for how it would tackle the problem of practice locally (Lee, 2022).

Lessons learned especially from Siemens Stiftung's STEM*plus* Territories point to another important element in establishing stewardship that combines these needs: to ensure both ownership "on the ground" and relevance to the local communities. This network was deliberately designed to "let go", i.e., to focus on decentralising and with this seek to permanently iterate and adapt where most value can be created. For this, local networks were always initiated and scoped together with key partners in the identified community, i.e., less specific requirements to qualify for collaboration, and success indicators were not imposed but jointly created. As a result, the number of STEM*plus* Territories grew significantly from four to more than 40 in just three years. Form and focus on the local networks vary between focused communities and wider stakeholder networks; and a high level of leadership and engagement can be seen in the respective networks.

As, for instance, Hearn (2011) further outlines this often requires for the stewarding entities to take on the role of a facilitator more so than a manager aiming to ensure that "the priorities of individual members and homogenous communities add up to or contribute towards the network's priorities." Particularly foundations working transnationally and internationally cannot assume a natural or granted role as they may face cultural and organisational barriers that need to be overcome to step in and be accepted in this role. As an example, OCE reflects on the beginnings of their network as a phase where cultural distances occasionally led to such tensions around roles, something that was then overcome by placing certain coordinative functions closer to the communities that were intended to be involved. Over the course of less than a year this then led to a change of culture and communication that was largely report-driven to a more mutual and collaborative approach that laid the foundation for the eventual success of the network.

While networks thrive on collaboration and empowerment, what is often underestimated especially when considering field-developing and ecosystem-forming initiatives is the competitiveness between actors particularly in the same sector. As outlined in the Brokering Better Partnerships Handbook (Partnership Brokers Association, 2019), it is thus essential "to explore and build on the added

value of collaboration and understand the right of all partners to gain from their engagement in the partnership as starting point to build commitment to the shared goals."

This can only be underlined by looking at the structures of LUMA in Finland or Stiftung Kinder forschen in Germany, where roles for key network nodes and partners have been defined and are also genuinely considered as critical for the success of the overall network.

The example of *La main à la pâte* also shows how establishing a network (and governance) ultimately may lead to restructuring the entire organisation to become more distributed and connected. After the creation (and multiplication) of the Houses for Science, *La main à la pâte* has redefined its perimeter of action, focusing more on the production of resources for on-line teachers' training associated with classroom activities (and less on the proposal of in-presence training sessions gathering teachers from all over the country). This is because the Houses for Science have taken the role of proposing teachers' training in presence and in close contact with the reality of teachers, in their own territory. Moreover, following a period characterised by the creation of separate programmes, interdependencies and synergies became visible between the Houses, the foundation, and the other networks the foundation coordinates. Resources and on-line teachers' training tutorials are more often co-created and shared to be re-used in in-presence training sessions. Also, the Houses for Science have strengthened their relationship with the other networks that the foundation coordinates and act themselves as local coordinators of projects that take place in these other networks. As a result of division of roles and labour, there is a growing trend towards greater integration, which is facilitated by the foundation's sustained dialogue with and between the networks.

II.2 Resources and funding

Networks are highly resource intensive (Hearn, 2011). The visible operational coordination and the mostly invisible curation of connections and relations require investment of time and money that is largely underestimated and for many networks insufficiently available. Consequently, network-leading organisations may quickly find themselves over-mandated and under-resourced, setting in motion a critical downward spiral. This can unfortunately often still be seen in grassroot and

innovative bottom-up initiatives that are certainly also needed in transforming STEM Education and remains a challenge for networks.

The IDoS peers arguably are a specific and privileged sample of network-building organisations as they are mostly well established and adequately funded for their work. However, reaching nation-wide or international scale and influence has also required (and still requires) each of them to build strategic partnerships, create proof and evidence for a model to work, and attract other resources, such as political will and influence.

When *La main à la pâte* started its Houses for Science network in 2014, its focus was to bring one university together with the local directorate (or rectorate) of national education services which implements in the academy the educational policy defined at the national level. Funding was mainly ensured by a national call for projects, supplemented by in-kind contributions from the Universities in the form of staff. After the phase of establishment of the first half-dozen Houses for Science, and despite the end of the initial funding, the network has widened and more than tripled in size, to cover most of the regions, henceforth of the country, eventually becoming France's largest non-governmental teachers' training organisation in the domain of science education. This is because more universities and rectorates had been inspired by the first Houses and aimed at bringing the same model in their region. Besides the in-kind contributions assured by the universities, the network now relies on local sponsors and on a limited national funding assured by *La main à la pâte*, via national sponsors.

Likewise, Stiftung Kinder forschen gained significant growth in their reach through its partnership with the German Federal Ministry of Education and Research. Now they are working with well over 500 trainers and 200 partners to reach schools and kindergartens across the country with their continuing professional development programme. This case also highlights another key component regarding resources and funding: the opportunity to receive funds for network-work by members and/or partners of that network. The resources contributed by the network partners amount to six million euros per year and can be read as a tangible success of joint collaboration in the Stiftung Kinder forschen initiative.

Similarly, the LUMA Centre Finland is co-funded by the government and the research universities involved on an equal basis. This enabled the network to become very effective in developing and sharing actions, materials, and educational

support throughout the whole country. Moreover, creating a common strategy and shared decision-making responsibilities created trust and cooperation that benefitted all centres – small and big – in the same way by sharing resources, knowledge, and activities. In the last decade, its early successes in one university led to eventually anchoring it as part of Finland's educational strategy with presence on every national university campus.

The Smithsonian Science Education Center networking activities are fully funded by gifts and grants. These funds support programming and are shared with network members through both monetary (e.g., honorarium for mentors; travel support) and non-monetary (e.g., free professional development; free attendance at convenings; free STEM curriculum) resources. While it is challenging to scale a movement network like LASER through term-limited gifts and grants, LASER's demonstrated success through rigorous evaluations have led to sustainably securing funding.

OCE reflects on the shift that was possible in their network's engagement as they switched from voluntary to a compensated role in the network. At the same time, neither of the IDoS peers – in their network practice – acts as a traditional funder, and still maintains a highly operational approach and presence "on the ground" and inside their networks.

II.3 Motivation and commitment

Networks are dependent on connections and the exchange of value such as competency, knowledge, or resources (Plastrik, Taylor & Cleveland, 2014). A critical component is that of "network weaving" on personal level and that of moving a network from "scattered fragments" over "hub and spoke" and "multi-hub" to potentially "core and periphery" structures, indicating that connected actors and type of connections evolve as networks mature and pursue more impact (Holley, 2012). To develop connections within a network, it is essential to align both personal and institutional intents and agendas with the network's goals. This alignment is necessary to avoid inherent conflicts that could undermine the required "weaving". It is also critical to maintain this alignment and commitment over time.

All networks in this sample of IDoS peers have directly or indirectly built a relatively large community of members as well as multipliers; yet they still had to overcome key challenges related to the commitment and motivation of their networks in their developments. Looking back at the first steps taken by OCE, their process was initially considered not inclusive enough and feedback from invited co-

creators noted that the network objectives, values, and ideas were too centrally defined by OCE themselves. This was only overcome by granting more autonomy and finding a balance of addressing collective and individual to both shape the network and motivate each participating partner. While the starting phase is particularly "sensitive" to such tensions, it remains one of the most challenging tasks to create and maintain such trustworthy atmosphere for collaboration and co-creation, as the Smithsonian Science Education Center's LASER network's creators note and reflect on their experience.

Additionally, learned cultural norms or contextual factors play an important role, e.g., all networks operate in an educational system that is defined especially by distinct disciplines of teaching and assumed roles of educators, teachers, authorities (see also the reflections shared in point II.5). However, a flatter, more collaborative approach of networks is needed to break through the purely professional and to appeal to the personal level of its participants. Only then can the desired form of engagement be reached, as also LUMA reflects on their journey of seeking to build collaborations where previously silo mindsets prevailed. When first starting the initiative, LUMA was confronted with strong resistance to working together – or even connecting – with departments of other disciplines or at other universities. After close to two years of intense advocating and concrete offers to experience this new form of working together, LUMA could finally see a significant difference in the way information was more freely shared and active voices brought into the conversation.

This lesson is not to be underestimated: Networks are personal and consist of people representing the network member organisations. Any development or change will thus require ensuring inclusive participation at all stages as well as to create a feeling of ownership and trust as the core components of a member's network experience. The new IDoS peer network particularly builds on this factor: While the intention is to connect leading educational field developers which includes a formal declaration of accession by each organisation, the approach is also very personal and focuses on building connections, fostering learning and developing trusting-relations for and between the relevant people inside the participating organisations. Feeling invited as individual in addition to participating as an employee is a key experience and remains a core promise of this learning network.

Looking at the risks stemming from this, Plastrik et al. (2014) identifies domination, exclusion, and lack of succession as the most common challenges for

networks. Particularly as a funder and founder of a network it is essential to navigate the risks of cutting off, silencing, or failing to develop supportive conditions for more voices, broader engagement, as well as inclusive decision-making in the network. Engaging in a network will ask everyone for a level of trust and letting go of individual control for the better functioning of the network as a whole. Here, matters of strategy and stewardship (as outlined in point II.1) and consideration of motivation and commitment strongly interrelate.

This can be seen at the most recent of the sampled networks, Siemens Stiftung's STEM*plus* Territories, where the design directive for local communities was very limited and it was actively requested to bring in own needs and expectations with regards to topics in focus and stakeholders to invite. Besides setting the agenda, giving recognition is another strategy that can be pursued to increase and maintain high level of motivation.

Almost all networks considered for this paper co-create key components of their offerings with other network members (and credit these as such), be it learning materials or network meeting formats. For example, before addressing any new problem of practice, the Smithsonian Science Education Center forms Advisory Committees who include diverse members representing a variety of needs, strengths, geographies, and expertise related to the problem of practice being addressed (see: https://ssec.si.edu/advisory-committees), which ensures inclusive participation of the network members to create ownership and trust. For their engagement and seeking new opportunities, network members receive positive reactions, thus feeling even more motivated in return.

A strong indicator for the level of commitment can be found when measuring the willingness of network members to give and receive support to or from another member as Vandor, Leitner & Millner (2020) have shown in a recent network evaluation. Comparing the hours of peer support provided with the resources invested in coordinating the network, the former often outweighs the latter by a significant factor, e.g., seven-fold more time invested as peer-resource than staffed as dedicated coordination capacity.

II.4 Measurement, evaluation, accountability, and learning (MEAL)

It is an unfortunate yet regular observation that many network organisers are still insufficiently prepared to articulate and support the achieved impact with evidence that goes beyond anecdotes (Plastrik et al., 2014) This is relevant for both staying in

the known of the results (i.e. the actor-level and outcome-level perspectives), the processes by which they are achieved as well as the health, sustainability, and development of the network and its members altogether.

As relatively mature sample of network organisations and with even stronger scientific ties and standards, IDoS peers do have contributions to make, however. In summary, the following indicators and findings proved to be most helpful in tracking the success and development of a network over time, and with this have served as guidance for the network stewards and facilitated adequate reporting to its sponsors:

- "A medium scale RCT-study has helped focusing on potential limits of professional development actions, especially in relationship with transfer and application to the classroom. A national funding of the National Research Agency has made it possible to set up an evaluation system under ecological conditions (160 teachers trained in the project) by means of a randomised controlled experiment (of a total duration of four years, two of which occupied by the training), coupled with a fine qualitative observation approach. Four Houses for science have been implied in the study, at the very moment of the installation of the Houses for science network. In addition to the Houses for science, the RCT study has mobilised three different research laboratories in France, specialising respectively in econometry, cognitive science and didactics. The RCT has not produced clear indications for the improvement of the training actions, nor has it reduced the necessity of other forms of evaluation, such as the continuous assessment of progress and of achievement of objectives (project evaluation), or quality assurance. Presently, *La main à la pâte* is developing new tools and strategies for the evaluation of effects and impact on its beneficiaries. The aim of the new tools is to gather clear indications for improvement, in relatively short time. In addition to which, evidence monitoring has been strengthened to build (and share within the network) a strong evidence base for the production of resources and of training actions." (La main à la pâte)

- "We collected evidence on LASER's efficacy through a large-scale randomised control-trial (RCT) study of 60,000 students in 124 schools across three state-level networks with 9000 students followed longitudinally over three years and assessed the impact of LASER on student achievement and teachers' professional learning (What Works Clearinghouse, 2021). During this time, we

believed that by helping the school, school district, state education agency, or network of education organisations set up their own LASER network, we would measure success if the five pillars of LASER (curriculum, professional development, community support, materials, and assessments) were sustainable over time. A follow-up study measured that sustainability. When applying LASER to new diverse problems of practice, we collected information on each 'activity system' involved in building the network and reported on common challenges and successes." (Smithsonian LASER network)

- "There are annual peer review sessions between regional centres to discuss activities, as well as the challenges and successes of activities. Also, each centre goes through review session with the central administration office of the whole national network. An external review has been initiated after each large-scale national project to build further actions on previous learning and outcomes." (LUMA Centre Finland)

- "Scientific research, monitoring, and evaluation are key elements of our work." (Stiftung Kinder forschen) All activities of the Little Scientists Foundation are continuously evaluated and accompanied by research. The foundation sees itself as a learning organisation and promotes the exchange of knowledge between research and practice. In addition to carrying out continuous internal monitoring, with a focus on quality assurance and quality development, the foundation works with a Scientific Advisory Board and renowned external partners who conduct accompanying research aimed at ensuring scientifically sound practices. Quality monitoring and evaluation include needs assessment and the regular and systematic collection of feedback on the professional development workshops and the pedagogic practices of the foundation. Aspects monitored and data analyses include the extent to which the offerings and resources are suitable for achieving the intended effects. The foundation's continuing professional development programme is planned and evaluated according to an impact logic model defining inputs, outputs, and outcomes; for various sub-programmes specifically detailed logic models exist. The findings are used for the continuous impact orientation and quality development of the various formats.

  As evaluations show, the participating educators perceive the programme as highly motivating and easily accessible. They express a high level of

satisfaction with the usability of the programme. They also feel well prepared to implement the STEM topics addressed in their daily work with children. The participants feel they improved their STEM knowledge and enhanced their subject-specific pedagogical-didactical competencies in STEM Education. They also perceive high self-efficacy in inquiry-based activities with children and their experience (motivation, professional competencies, and behaviour in pedagogical practice) increases successively (see Scientific Series and the Monitoring Reports of the foundation (Stiftung Kinder forschen, 2022).

In the experience of the Stiftung Kinder forschen it is necessary to monitor the development of network partnerships (and thus the entire network) continuously and systematically, establishing an iterative process that allows partners and the foundation to check the status of the partnership regularly and to identify necessary adaptations and modifications.

Nevertheless, the practice of MEAL (Monitoring, Evaluation, Accountability, Learning) also caused challenges and lessons learned in the networks of this sample. In some cases, initial frameworks – especially randomised control trials – proved too complex at first and could only provide relevant information at a later and more mature stage of the network. In other cases, measurement efforts were underestimated with respect to the time needed by both members and coordinators, leading to lower engagement levels than expected and required to achieve meaningful results. It often took longer than anticipated and required some repetition to find the right rhythm and regularity for evaluation, the results of which would be used to develop a system for learning and accountability.

Improving on the practice of MEAL remains a key priority for IDoS peers and one of the identified areas where mutual learning and exchange of practice can well be facilitated. This latter aspect is relevant given that besides on the level of the individual practices of each network, little to nothing can be found on the evidence of collaboration in the wider field that supports STEM Education. Aligning approaches, opening one's methodologies, and actively engaging in learning from the different results attained will be critical building blocks to advance the efforts around STEM Education in early learning.

II.5 Context and complexity

The bigger and more complex the challenge, the more likely some sort of network structure will be needed (London in Monitor Institute, 2015). According to the Cynefin Framework, networks may offer highest value in situations that are inherently interconnected, prove to be in constant flux and have a certain degree of unpredictability (Snowden & Boone, 2007). On the contrary, if issues are simple and action requires less interaction, networks may not have an edge over other structures and may fail expectations of a speedy, uncontested way of coming to a solution or desired result. In these cases, a more centralised structure may need to be created.

The field of STEM Education in early learning, particularly focused around areas of innovation including sustainable development and digitalisation, is inherently complex as it combines issues ranging from education to technology, matters of inclusivity and demographics, and has clear social, economic, and political aspects to consider. It also requires the collaboration across sectors and functions. It is thus prone to be addressed through networks – and yet this alone does not make it any easier to succeed.

Reflecting on the experiences of the IDoS peers represented in this sample, the following considerations stand out: To reach scale political will, support, and permission (as opposed to political restrictions) is required. Be it in the form of strategic grant funding as provided to Smithsonian's LASER network for the purpose of scaling as well as sharing the key findings; the strategic mandate that Finland's educational ministry gave LUMA to scale their approach across the country; the strategic partnership that the German Federal Ministry of Education and Research has with Stiftung Kinder forschen in order to provide kindergartens and schools nationwide with opportunities; or the political and financial support that *La main à la pâte* and OCE receive from the French Ministry of Education and its directorates, or even from the Universities hosting the *La main à la pâte* Houses for Science, in order to operate networks with national and international scale on science education, education for climate change, and sustainable development. Important for the success of these networks was also that these partnerships with the public sector were institutional (as opposed to political) so that eventual changes in governments or ministries did not affect the agreed mandate.

While political developments are a critical permanent contextual factor, the global pandemic in the last few years provided an example of a sudden "external

shock" that affected networks of all kinds – and also left its mark on the networks of IDoS peers. Educators were suddenly faced with closures of schools and early childcare facilities, meaning they had to switch and adapt to distance learning models. At the same time, distance learning shone a light on social differences and inequality; meaning, for instance, that access to computers or even the internet was not a matter of course in some households where children needed to learn remotely. These social differences became far more wide, visible, and challenging. Thus, innovation and adaptation were required a) on a direct operational level, as much needed in-person formats and interactions were no longer possible and new virtual alternatives needed to be developed, and b) on a more indirect general level, to acknowledge the need to support early learning facilities and educators who were directly impacted by the pandemic and to provide them with resources to keep the system running. The role of networks was crucial in this context to address the need for innovations through forums and exchange within their communities of peers. In hindsight, COVID-19 proved to be challenging and complex, yet lead to networks helping to trigger innovations and paradigm-changes that before had not been considered. As the IDoS peers jointly conclude, the coordinated networks and contextual factors all had a lasting effect back into their own institutions and organisations.

Part III: Opportunities and outcomes: Why the IDoS peers embrace networks as agents of change

As STEM Education is a complex issue, especially in its reference to sustainable development and digitalisation in societies, and because working in networks is of value for complex challenges, STEM Education initiatives should work with a networks approach to promote impact and change. Here, the authors tried to gain insights into how networks can help promote and professionalise STEM Education in a changing world. To enhance the engagement and impact of field-developing institutions involved in the IDoS network, a systemic and co-creative approach for a better and easily accessible education is needed, where experiences and innovations are shared for better local and global actions. This is important to achieve functional and successful networks for impact.

The defining functions for an **impact network** (see Ehrlichman, 2021) relate to focused learning (Learning Networks), to perform common actions on issues that

are important globally (Action Networks) and to focus ones aims on a common ground for a common purpose (Movement Networks). Simultaneously, there is a need to improve dynamic social resilience so that collective actions head for sustainable development and better quality of life (Resilience Networks). This also presents the possibility to scale up distribution of knowledge and actions learned, to share good practices, and co-create collaborative actions built on good practices for new situations and social contents (Scale Networks) (Slaughter, 2017; Ehrlichman, 2021). A successful impact network has a clear mission that has been adopted by all network members. For IDoS peers and their respective networks, this is an accessible and quality-oriented STEM Education aimed at creating a better life and society for all citizens. Here, the strategy is to build impact networks that provide knowledge, practices, and shared resources consistent to the mission. Underlying the IDoS peers' impact networks is a Theory of Change which was developed on the basis of a general analysis of global problems and the lack of STEM literacy, a qualification that benefits people across the globe. The network of impact networks described here is a co-creative project on a larger scale to answer the needs of learners, stakeholders, and societies to build up knowledge-based STEM literacy, recognition, and innovation, thus to provide answers for global challenges on local and individual citizen level.

Networks are highly resource intensive. The visible operational coordination and the mostly invisible curation of connections and relations require investment of time and money that is largely underestimated and for many networks insufficiently available. While the networks of the IDoS peers have the privilege of being well-established and funded in most cases, they relied on building strong partnerships, developing sound strategies, and attracting support nonetheless to achieve the scale and impact they have today.

As stated above, networks are dependent on connections and the exchange of value such as competency, knowledge, or resources (Plastrik et al., 2014). While developing the connections within a network, the alignment of intents and agendas with the goal of the network is essential. It is also critical to maintain this alignment and commitment over time to achieve long standing, systemic views and actions striving for the network aims and goals. Trust in the skills and competencies of peers is very important to gain mutual respect and recognition of a peer as a significant actor in the network. In an equal impact network, all parties are important *agents of change* bringing their own valuable contribution to the network.

As demonstrated here, it is important for a network to articulate and support the achieved impact with evidence that goes beyond anecdotes (Plastrik et al., 2014). This is relevant for identifying and knowing targeted outcomes, to know the processes by which they are achieved as well as the sustainability, resilience, and further development of the network, its members, and actions for common goals. Therefore, the development of networks and their functions needs to be assessed thoroughly to make any knowledge-based decisions for changes or further development.

An impact network is built on **L**earning and broad knowledge, experiences, and capabilities of **A**ctions, aligned collaborative **M**ovements to achieve long-standing impact and support the **R**esilience of societies, as well as reasonable and effective opportunities for **S**caling up and mitigation of knowledge and well-being (Slaughter, 2017; Ehrlichman, 2021).

In the IDoS peers' dialogue network, all the peers have been categorised in this paper under a particular topical network (see Table 2). However, in the first steps of collaboration it was already very clear that every peer has indications and engages in activities in all five different network types. These depend on the aims and focuses needed to function in an effective manner and to achieve the set goals, as presented in Table 3 for particular IDoS peers. For IDoS network this provides a strong basis for collaboration and co-creation targeted to support and enhance learner-centred and society-related STEM needs (Aksela, 2019). As stated, members of IDoS are convinced that global developments and the demands for quality education arising thereof can best be tackled in association with others, sharing experiences across borders and learning from each other. The systematic and regular exchange of globally available knowledge and practices on the topic of early STEM Education in a changing world and collective learning is critical to achieving impact on a global scale, through local action - in a true *glocal* manner.

This paper posits that impact networks designed to support early STEM Education – such as those described by the IDoS peers – play an important role in advancing childrens' understanding of and actions towards the complex, rapidly changing conditions of the world. If successful, such networks can create a culture of sustainability (see Chabay, 2022) - meeting the critical needs of the present on both a local and global scale, without compromising the needs of the future.

Table 3. Overview of all example networks and their success factors

Peer organisation	**Network type(s)**	**Main focus of the network**	**Structure** (A) centralised (B) decentralised (C) distributed structures	**Success factors of the network**
Stiftung Kinder forschen **(Little Scientists Foundation)**	**Scale Network**	Disseminating the foundation's continuing professional development programme in the field of STEM Education for Sustainable Development for pedagogical staff at early childhood education and care centres, after-school centres, and primary schools – nationwide (Germany). Thus, supporting the foundation in its mission to strengthen children aged 3 to 10 for the future. Impact orientation, needs analysis and research-based actions for target group-specific offer development and dissemination	A/C	• Strong strategic focus based on established MEAL-practice • The foundations' nationwide network system of locally engaged partners allows a high reach of its educational offers through multiplication • Durable and reliable investment of human and financial resources of the foundation and the (network) partners • Good networking with politics and society ensures the needed political support
Siemens Stiftung	**Resilience Network**	Providing continuing education opportunities for educators and high-quality teaching and learning materials, making a genuine, concrete contribution to high-quality STEM lessons that are accessible to everyone along the entire education chain. International networks that bring together different countries and disciplines, harnessing innovative ideas on a global scale.	B	• Consideration of existing networks and partnerships • Actors with common goals • Impact orientation and concrete activities • Structured coordination and establishment of working groups • Secured resources raised by international, national, and local actors • Continuous outward communication for networking and fundraising • Consideration and identification of/with local context

Smithsonian Science Education Center	**Movement Network**	Transforming K-12 education through science in collaboration with communities across the globe. Network teams attend leadership development institutes to plan the implementation of inquiry-based, hands-on, and digital instructional materials (innovation); promote diversity, equity, accessibility, and inclusion in STEM (inclusion); and support STEM Education for Sustainable Development (sustainability). Network teams receive support for key aspects of implementation such as professional development for teachers, access to curriculum and instructional materials, collaboration with community members, and research and scholarship.	C	• Empowering schools, districts, state education agencies, and ministries of education to: • Identify and share science education problems of practice • Develop and implement action plans to address these problems • Create a shared vision for instructional improvement • Set short- and long-term goals • Form partnerships, build coalitions to scale and sustain transformations in science education
Luma Centre Finland	**Scale Network**	Inspiring and motivating children and youth into STEM subjects through the latest methods and activities of science and technology education. Supporting the life-long learning of teachers working on all levels of education from early childhood to universities.	C	• Enforce common strategy, goals, management, and communications for network activities • Establish collaborative network of research universities for research-based actions. • Adopt local centres to regional priorities and expertise • Nurture cross-centre activities and trust for co-creation, collaboration and shared expertise and materials • Striving for strong national and international web of networks between researchers, teachers, policy makers and stakeholders for learning and practise • Using transparent assessment procedures for effective development and improvement
Fondation La Main à la Pate	**Scale Network**	Bringing together teaching and scientific communities to improve the quality of science education in primary and middle schools in France.	A	• Division of work. Specialisation of La Main à la pâte National Centre in the provision of training for trainers and teachers via on-line platform, specialisation of the networks in the provision of in-presence training, in close connection with local needs and opportunities. • Mutualisation of resources, co-creation of on-line training contents and exploitation of on-line training contents in the framework of local in-presence or hybrid training sessions

Office for Climate Education	**Scale Network and Action Network**	Implementing quality climate change education (with a focus on developing countries) by bridging the gap between science and pedagogy and providing teachers, teachers trainers and policy officers with pedagogical tools, professional development, and support.	A	• Placing coordinative functions closer to the communities that were intended to be involved. • Providing a structure to identify, share, and scale-up successful actions at a regional scale. • Providing compensation for key roles in the network • A thorough and transparent process for resource production (internationally tested, validated by experts).
IDoS peer network	**Learning Network**	Network of cooperating organisations with a similar focus of working internationally, learning from one another, and sharing lessons learned in/with the field of early STEM Education for Sustainable Development	B	• United group of peers selected according to specific criteria as a strong basis for collaboration and co-creation (all are multipliers and field-developers) • Central coordination by "architects" as backbone organisation (setting strategic focus and coordinating actions) • Commitment and ownership from all peers (motivation and capacity to contribute to the network) • Regular working meetings (virtual and in presence)

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