

Essay

You'll Never STEM Alone: Analyzing the Social Fabric of Resilient Learning Trajectories via the E³ Framework

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Abstract

Maintaining a stable STEM learning trajectory over an extended duration is a rare achievement. This conceptual paper uses the E³ Framework as an analytical lens to propose that stability is not a default state but a functional achievement of the entire system comprising Resources (E1), Regulation (E2), and Time (E3). We focus specifically on the “social fabric” through which these ecological domains may become functionally interconnected. We then use the online mentoring program CyberMentor as an illustrative case to show how the five functions postulated in the E³ Framework (social robustness, social regulatory realignment, social reproductive renewal of resources, social informational persistence, and social environmental fit) may contribute to trajectory stability. Our conceptual analysis suggests that a strong social fabric may contribute to the stability of STEM learning trajectories by helping ensure that no student has to “STEM alone.”

Keywords: STEM; E³ Framework; social fabric; learning trajectories; resilience; mentoring; CyberMentor

1. Introduction

STEM learning trajectories depend on the social space in which they unfold. A person born in the 11th, 16th, or 21st centuries would have very different STEM experiences and would understand science in fundamentally different ways (Roth & Tobin, 2007). Even within the 21st century, socioeconomic status (Betancur et al., 2018; Peters & Engerrand, 2016), gender and gendered expectations (Makarova et al., 2016; Schmader, 2023), ethnicity (Collins, 2018; McGee, 2021), migration background (Boyd & Tian, 2018; Min & Jang, 2015), urban versus rural location (Clark, 2013; Saw & Agger, 2021), and many other socially shaped characteristics determine the resources, role models, and recognition a learner receives (Ziegler & Stoeger, 2023). But even without others' direct presence, the social aspect remains paramount and permeates all our STEM experiences. The expectations we internalize from significant others (e.g., parents, teachers, peers, etc.) remain with us throughout our lives (Carlone & Johnson, 2007; Pfeuffer et al., 2025). Self-concept, stereotype threat/boost, and implicit beliefs about belonging continue to exert their influence even in isolation (Spencer et al., 1999). This highlights a core observation about identity formation: We do not become a STEM person by thinking like one; we become a STEM person when others recognize us as one (Carlone & Johnson, 2007). The same applies to our environment and the media (Steinke, 2017). Books, films, podcasts, other digital formats,



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museums, and libraries shape our STEM identity. And the technology surrounding us is—ultimately—social STEM intelligence made tangible.

Despite STEM's ubiquity in our lives, we see a systematic erosion: STEM trajectories rarely remain stable over the long term (Maltese & Tai, 2011; Sadler et al., 2012; Wang & Degol, 2017). It is not just that individual engagement fades; the supporting impulses from the ecological environment also dry up or become irrelevant (Fouad & Santana, 2017; Lent et al., 1994; Tai et al., 2006). This process seldom manifests as a sudden loss of knowledge or interest, but rather as a discontinuation of a path forward. We learn mathematics but do not major in math; we acquire biological knowledge but never pursue a PhD in the life sciences; we build complex structures with technical toys but do not become engineers; and we use computers with high proficiency without ever considering a degree in computer science.

Existing approaches already explain why these paths erode and important aspects of STEM persistence. For example, STEM identity research emphasizes competence, performance, and recognition, while research on belonging highlights the importance of perceived membership in STEM communities (Carlone & Johnson, 2007; Hansen et al., 2024). Social cognitive career theory focuses on self-efficacy, outcome expectations, goals, and contextual supports and barriers (Lent et al., 1994). Mentoring, social-capital, and ecological approaches, in turn, highlight supportive relationships, networks, resources, and connections across learning settings (Barron, 2006; Bronfenbrenner, 1994, 2000; Rhodes, 2005). Reviews and theoretical syntheses further indicate that STEM participation and persistence are shaped by influences operating across individual, relational, educational, and broader sociocultural levels (Schmader, 2023; Wang & Degol, 2017). Building on this multifactorial understanding, the present article addresses a complementary question: how the coordination of resources, regulatory processes, and temporal structures may support the persistence and recovery of a STEM trajectory across disruptions and transitions. The E³ Framework was selected because it is specifically designed to analyze this coordination across resources (E1), regulation (E2), and time (E3), conceptualizing stability as a functional achievement of the developmental system (Ziegler & Stoeger, 2026).

This article focuses on the 'social fabric'—the social web through which these ecological domains may become interconnected in ways that support a resilient STEM trajectory—one that persists even when external guidance tapers off, or plateaus are reached. We first outline the E³ Framework, then develop a conceptual account of how social processes permeate each ecology and function specified in the framework, and finally use the online STEM mentoring program CyberMentor (Stoeger et al., 2021) as an illustrative case through which the proposed concepts are mapped onto the structures of a real-world program.

2. The Social Fabric Across the E³ Ecologies

Before analyzing the social fabric of resilient STEM trajectories, we briefly outline the three ecological domains of the E³ Framework: resources, regulation, and time (Ziegler & Stoeger, 2026). Our aim is not to argue that the social dimension is more influential than other dimensions, but to conceptually examine how social processes may permeate all three ecologies and may contribute to their stabilizing functions. We develop the concept of social fabric as a conceptual extension of the E³ Framework to capture how social relationships, shared expectations, and patterns of interaction may help coordinate resources, regulatory processes, and temporal structures in ways that support trajectory stability. This focus does not imply that endogenous resources or regulatory processes are wholly socially constituted: intrinsic motivation, cognitive autonomy, and self-initiated regulation may operate even when immediate social support is weak or absent.

2.1. The Resource Ecology

In the E³ Framework, resources are defined as anything with the potential to foster STEM competency development at any level. To understand how they work, we first categorize resources by their location: Exogenous resources, also referred to as educational capital, are provided by the environment; endogenous resources, also referred to as learning capital, are internal to the learner (Harder et al., 2025; Ziegler et al., 2017). We also distinguish different types of roles that resources play in the learning process. We distinguish between five types of educational capital (economic, cultural, social, infrastructural, and didactic) and five types of learning capital (organismic, telic, attentional, actional, and episodic). Tables 1 and 2 give an overview of the different types of educational and learning capital. Two of the capitals (economic educational capital, such as financial wealth, and organismic learning capital, such as physical health) are proto-capitals as they are not directly related to STEM learning but need to be transformed into other types of educational or learning capital in order to make learning possible. All other categories are functional capitals, because they constitute the actual tools and skills used to reach the goal of expertise.

Importantly, however, these resources are not inherently active. A STEM textbook that is not read, for example, remains an unused resource (Harder, 2025). Resources may be activated either through learners' own activity or with support from the social environment. Although only one form of capital is explicitly labeled "social," all capitals are socially saturated. The social world may influence how resources are created and used. For example, exogenous resources—such as laboratories—are built by society, and the social environment may influence who is allowed to use them. Even endogenous resources, such as a person's "talent," may be supported by social conditions (e.g., access to healthcare), or become visible as talents through social recognition. The social fabric may influence not only which resources are available, but also who receives recognition and encouragement to use them to build a STEM identity. Tables 1 and 2 illustrate how social processes define the value and accessibility of these resources.

Table 1. Definition, Prototypical Examples, and Illustrative Social Influence of Exogenous Resources (Educational Capital): Selected Examples within the E³ Framework.

Type	Definition (E ³)	Prototypical Example	Illustrative Social Influence
Economic	Financial resources and wealth applicable to education	Funding for a STEM summer camp	Not just "money," but also illiquid assets (e.g., a social safety net) that allow for long-term "risky" investments in a STEM career
Cultural	Value systems, traditions, and societal norms	A family or community tradition of valuing scientific inquiry	A "social inheritance" that defines which STEM goals are considered desirable, prestigious, or even "thinkable"
Social	Access to social networks and supportive individuals	A mentor or a peer group in a STEM club	As a primary resource of activation, social bonds can transform otherwise unused resources into functional developmental impulses
Infrastructural	Material objects and environments facilitating learning	A high-end school laboratory or a 3D printer	Its utility is defined by social access rights, communal "permission" to experiment, and technical standards
Didactic	Organized knowledge and methods of instruction	A well-designed STEM curriculum or a textbook	Instruction is a social transaction; its effectiveness depends on the shared language and didactic "contracts" between involved parties

Table 2. Definition, Prototypical Examples, and Illustrative Social Influence of Endogenous Resources (Learning Capital): Selected Examples within the E³ Framework.

Type	Definition (E ³)	Prototypical Example	Illustrative Social Influence
Organismic	Physiological and constitutional resources of the learner	Physical health and cognitive processing speed	Sustained by social structures (e.g., nutrition, healthcare) and perceived through social labels (e.g., “talent”)
Telic	Goal orientations and long-term intentions	Being determined to become a chemical engineer	Goals are social constructs; they may be aligned with—or developed in opposition to—social expectations and roles
Attentional	Capacity to focus and manage mental energy	The ability to concentrate on a complex coding task	Attention can be socially directed; we focus on what our “social fabric” signals as relevant or rewarding
Actional	Repertoire of skills and procedural knowledge	The ability to conduct a titration or write a script	Skills are often co-constructed and validated through social feedback loops (e.g., Master–Apprentice dynamics)
Episodic	Experience-based knowledge and personal history	Remembering the excitement of a first successful experiment	Memories may be socially framed; we remember and value experiences that are “narrated” as significant by our environment

2.2. Temporal Ecology: The Organization of Momentum

A STEM trajectory is, by definition, a process that unfolds over time. Its stability arises from the system’s capacity to maintain a consistent developmental direction despite changing endogenous and exogenous resources over time. The temporal ecology focuses on this persistence or lack thereof. It addresses how the social fabric structures time—from the rhythm of a single afternoon to the transitions between life stages—in ways that help prevent a trajectory from stalling or being outpaced by more coherent alternative ecologies. This temporal organization is especially critical for out-of-school learning. In these contexts, time is a precarious resource that must be actively carved out and protected by the social fabric to prevent STEM activities from being crowded out by more dominant school or leisure routines. Table 3 provides examples of a temporal ecology at different temporal layers. These examples illustrate how time in STEM learning can be socially structured and shaped in ways that enable or disrupt the flow of learning.

Table 3. Examples of How the Social Environment Structures Time in STEM Trajectories.

Temporal Layer	What Happens (Structure)	Social Influence (the “Others”)
Micro time	Short 45 min lessons vs. long, focused work	The school bell decides when interest must stop. Deep focus is a “social permission” that rigid schedules rarely give
Macro time	Moving fast through new topics vs. time for review	Most programs only push forward. There is no “social space” or time to go back and fix gaps if the path becomes unstable
Developmental stages	Switching from one school or educational stage to the next	Transitions are walls. A learner’s past successes often vanish unless social bridges, for example, a “digital backpack,” are built to systematically collect and synthesize learning progress
Learning stages	Getting stuck on a level, even when there is more potential	Striving towards the highest achievement levels is a social task. It needs an environment that rewards effort, even when visible progress slows down
Learning Logics	Rigid test dates vs. the personal pace of daily life	STEM rhythms are often too stiff. Other activities, like sports, win because they fit better into the time spent with friends.

2.3. Regulatory Ecology: Steering the STEM Trajectory

The regulatory ecology encompasses the processes that actively guide, correct, or divert a STEM trajectory. This perspective highlights that learners' decisions and regulatory processes can be socially embedded. We act in response to others' suggestions, take social expectations into account, or simply carry out what figures such as parents or teachers prescribe.

In out-of-school contexts, steering often happens through the daily social forces a learner faces and the degree to which STEM activities align with the learner's evolving social identity. The "social fabric" can just as actively destabilize a trajectory by drawing attention and resources toward other, competing environments, such as sports or peer cultures, or by reinforcing expectations and patterns of inclusion and exclusion that constrain learners' choices. The stability or erosion of the trajectory is therefore the result of constant social steering, in which STEM goals often must be defended against the "pull" of alternative lifestyles. Table 4 provides an overview of these social steering dimensions.

Table 4. Examples of How the Social Environment Steers STEM Trajectories.

Area of Steering	How It Works	Social Influence (the "Others")
Setting goals	Deciding what is important and where to go	Reacting to suggestions, expectations, or direct commandments from parents and teachers
Monitoring	Checking the current status and learning progress	Using feedback, praise, or criticism from the environment
Execution	Doing daily tasks and following routines	Following schedules, school rules, or family routines
Correction	Changing the path when stuck or when conditions change	Using tips or new ideas offered by others such as mentors
Distraction	Losing focus or leaving the STEM field	Being pulled away by friends, unrelated hobbies (e.g., sports), or leisure activities (e.g., social media)

The analysis of the three ecologies demonstrated the social embeddedness of each individual ecological domain. However, to understand how a learning system develops resilience against erosion, we must examine how these domains interact functionally. The following section describes five stabilizing functions specified in the E³ Framework through which the social fabric may help maintain or restore the stability of a STEM trajectory, even under adverse conditions or in the absence of external guidance.

3. The Social Fabric: Five Stabilizing Functions

The preceding conceptual analysis highlighted the social embeddedness of the three ecologies. However, we did not clarify how they support the stability of STEM learning trajectories or what role social factors play in this process. The following five functions were conceptually developed in the original formulation of the E³ Framework (Ziegler & Stoeger, 2026) to capture distinct systemic processes that may contribute to maintaining or restoring trajectory stability: resistance to disruption, correction after deviation, renewal of depleted supports, continuity across change, and alignment with the broader environment. Accordingly, the functions are distinguishable by the primary challenge to trajectory stability that they address: robustness concerns buffering disruptions without losing developmental direction; regulatory realignment concerns detecting and correcting deviations from that direction; reproductive renewal concerns replacing or regenerating resources and supports that have become depleted or ineffective; informational persistence concerns preserving relevant knowledge, experience, and identity across changes in

settings or actors; and environmental fit concerns reducing incompatibilities between the trajectory and the learner's broader ecology. Together, they are proposed to address five complementary challenges—disruption, deviation, depletion, discontinuity, and contextual misfit—although their distinctiveness and collective adequacy remain to be examined empirically. The present article extends this theoretical formulation by examining the specifically social manifestations of each function. For an integrative visual overview of the three ecologies, the five stabilizing functions, and their relationship to trajectory stability, see Figure 1 in Ziegler and Stoeger (2026).

3.1. Social Robustness

Social robustness refers to a STEM learning trajectory's capacity to maintain stability through the social fabric's resistance and redundancy.

- Resources (E1): Robustness comes from both the strength and the number of resources. Strength means, for example, having a very high level of personal drive that is not easily broken. Redundancy means having backup options, such as multiple mentors or alternative ways to access tools. If one resource is weakened, is temporarily missing, or fails, the others are strong enough to carry the load.
- Regulation (E2): This is about how social rules protect the path. A family or a classroom in which mistakes are treated constructively and as opportunities allows the learner to fail without feeling the pressure to quit. When many people—such as peers, parents, and teachers—support the same goal, their shared expectations make it much harder to alter the trajectory.
- Time (E3): Robustness requires “protected time.” This means, for example, having fixed project cycles or weekly routines that are hard to change.
- Social fabric logic: Robustness is the total strength of the social configuration. Conceptually, such robustness should make the STEM path less vulnerable to competing activities.

3.2. Social Regulatory Realignment

Social regulatory realignment refers to a STEM learning trajectory's capacity to overcome a standstill because the social fabric affords the corrective processes and new opportunities needed to bring the learner back on track.

- Resources (E1): When the old ways of learning fail, the environment may need to provide new didactic “inputs.” This might entail a different explanation from a new mentor or access to more advanced tools that match the learner's growing skills.
- Regulation (E2): Others—mentors or peers, for example—notice when a learner hesitates or makes a mistake. They give feedback or change the task to help the learner move forward again. This social response prevents small problems from becoming big reasons to quit.
- Time (E3): Realignment takes time. Social expectations and support structures need to allow learners to slow down, reconsider their approach, or explore a new direction. Without this social allowance, the pressure to progress rapidly may impede rather than support development.
- Social fabric logic: Realignment is a communicative act. It saves the learner from giving up by offering social resonance and new options.

3.3. Social Reproductive Renewal

Social reproductive renewal refers to a STEM learning trajectory's capacity to sustain its momentum because the social fabric actively replaces exhausted resources and introduces new developmental impulses.

- Resources (E1): Sometimes, trajectories need a renewal of resources or simply fresh inputs. Old materials and even a formerly effective mentoring style often lose their motivational power as a learner develops. The environment may need to offer new challenges or different experts that match the learner's higher level.
- Regulation (E2): Social events such as hackathons, camps, or competitions act as external triggers. They break the boredom of daily routines and provide a jolt that restarts the learner's engagement.
- Time (E3): The social environment structures cycles of return. This means alternating phases of high activity with planned seasonal breaks. These rhythms allow motivation to recover so the learner can return with fresh energy.
- Social fabric logic: Renewal is a shared task. The "others" in the social fabric help keep the support mechanisms from becoming outdated and contribute to replacing them when they do.

3.4. Social Informational Persistence

Social informational persistence refers to a STEM learning trajectory's capacity to maintain the learner's history, knowledge, and STEM identity. The social fabric may support this continuity by preserving and transmitting this information across different life stages or locations.

- Resources (E1): This includes identity-bearing structures such as a sense of belonging to a STEM community. Physical artifacts—a digital backpack or a portfolio, say—help store academic and social information so it is available in new settings.
- Regulation (E2): Continuity depends on social actors who manage transitions. They pass on monitoring data—such as what a learner has already achieved—to new teachers or mentors so the STEM learning journey does not have to start from scratch.
- Time (E3): Social relationships that last through different life stages act as bridges over time gaps. They provide a sense of continuity, helping the learner return to their work after a break.
- Social fabric logic: Persistence happens when the social environment helps keep the meaning of the trajectory alive. Others help the learner stay connected to their history and identity as they move to new places.

3.5. Social Environmental Fit

Social environmental fit refers to the alignment between a STEM learning trajectory and the rest of the learner's life. The social fabric supports this by reducing the friction between STEM activities and other daily routines.

- Resources (E1): Fit exists when STEM resources (e.g., tools, books, or experts) are part of the learner's daily world, such as their home or peer group. The skills they learn must be recognized and valued by the people who matter to them.
- Regulation (E2): The social environment helps when it sends consistent signals across different areas of life. For example, when parents and mentors send the same positive signals, the learner does not feel torn between different worlds.
- Time (E3): This requires temporal synchronization. STEM activities must fit into the rhythms of family life and other social commitments. If STEM constantly clashes with social time, the trajectory becomes fragile.
- Social fabric logic: Fit is the absence of social friction. It ensures that an individual's STEM trajectory is a natural part of that person's lived reality.

The educational value of the five functions depends on the nature of the relationships, expectations, and structures through which they operate. Social regulatory realignment may become restrictive when alignment with others' expectations overrides learner au-

tonomy; social environmental fit may reinforce conformity to existing norms; and social informational persistence may preserve limiting identities or labels. Social coordination is therefore supportive only insofar as it remains responsive to learners' evolving goals and expands rather than narrows their opportunities. This qualification should also be kept in mind in the following illustrative analysis of CyberMentor.

4. CyberMentor: Programmatic Implementation of a Resilient Social Fabric Through Online Mentoring

The preceding discussion helps explain why maintaining a stable STEM trajectory is so difficult. Its stability may depend on the sustained coordination of multiple resources, regulatory processes, and temporal structures. This systemic complexity may also help account for why many STEM interventions yield only small to modest results that often fade quickly (Belland et al., 2017; Chang et al., 2024; Chen et al., 2025; Lu et al., 2025; Siregar et al., 2020). Bicakci et al. (2026) analyzed nearly 6000 intervention effect sizes in STEM and found a median of $g = 0.48$, yet the publication bias-adjusted median was only $g = 0.32$. According to Cohen's (1988) widely used conventions, this represents only a small effect (see also Heller et al., 2026). From the E³ Framework perspective, this sobering finding is consistent with the proposition that isolated STEM interventions often struggle to produce substantial long-term shifts in learning trajectories. One possible limitation is that such interventions may not build a dense social fabric that interlocks resources, regulation, and time.

To illustrate how a program may move beyond isolated impulses and develop an interconnected social fabric, we now apply the E³ Framework to CyberMentor. CyberMentor was selected purposively as an information-rich illustrative case—not as a typical, critical, or representative case—because its long-term, multicomponent design makes it possible to examine how resource, regulatory, and temporal structures may be coordinated within a single program. The program serves as a real-world example of how an out-of-school environment can translate the ecological components and five stabilizing functions proposed above into concrete program structures and practices. However, this theory-guided analysis concerns their programmatic implementation and does not constitute an empirical test of whether these functions explain CyberMentor's documented outcomes.

4.1. Overview of the Program

CyberMentor is Germany's largest research-based online mentoring program for girls and women in STEM and was founded in 2005 (Stoeger et al., 2013). The program aims to spark and sustain girls' interest in STEM, with the long-term goal of increasing women's participation in STEM education and careers. Each year, up to 800 female students in grades 5–13 in German secondary schools (mentees) participate in the program. They are matched with female STEM professionals or graduate students majoring in STEM (mentors) in one-on-one mentoring relationships, based on shared subject interests.

Participation requires a minimum commitment of one year, with at least 30 min of mentor–mentee interaction per week. Participation is free of charge for mentees, and mentors volunteer their time. Communication and collaboration take place on a members-only online platform that provides tools such as email, text chat, video chat, and discussion forums.

Within this framework, mentors serve as role models, provide insights into their careers and daily work, and support mentees both academically and personally. In addition to one-on-one mentoring, the platform facilitates networking among all mentors and mentees. It also provides training and support for mentors and mentees through videos, online meetings, and program staff-led office hours.

The mentoring year is structured in four phases, each lasting about three months. In the first phase, the mentees get to know their mentors and learn more about STEM fields and professions. Additionally, the mentees explore and discuss day-to-day STEM phenomena with their mentors to demonstrate that STEM is everywhere. In the second phase, mentees work on STEM projects related to their primary area of interest. Depending on the mentees' age and prior knowledge, the projects can focus on several smaller, hands-on activities and experiments or on more extensive, multi-week STEM projects. In the third phase, mentees work on interdisciplinary projects with their mentors and mentoring dyads from other STEM fields. The final phase is dedicated to reflecting on the mentoring year. Mentees consider what they have learned and their favorite experiences, for example, by writing articles for a platform-internal STEM magazine edited by the CyberMentor team and participants. At the end of the mentoring year, participants decide whether to continue for another year.

Research has demonstrated the program's short-term, midterm, and long-term effectiveness (Stoeger et al., 2013, 2016, 2023). Studies have also identified key moderating factors, such as mentees' communication and networking behaviors (Stoeger et al., 2017, 2019, 2021; Uebler et al., 2023). The findings have been systematically used to continuously improve the program.

To enhance effectiveness, CyberMentor has been combined with in-school components since 2018. In this extended format, mentees engage in the online mentoring described above and attend weekly STEM clubs at their schools. These STEM clubs are led by STEM teachers, typically include six to eight mentees, and provide opportunities for hands-on project work in a structured group setting (Kupersmidt et al., 2020). The activities in the school STEM clubs align with the four phases of the online mentoring program, thereby strengthening the integration of in-school and out-of-school learning experiences (Stoeger et al., 2026).

Importantly, although studies provide empirical evidence for CyberMentor's effectiveness and have examined several factors associated with program outcomes, they did not operationalize the E³ ecologies or the five stabilizing functions proposed in the present paper. The analysis that follows therefore represents a retrospective, theory-guided mapping of CyberMentor's program structures and practices rather than an empirical test of the framework or the proposed functions' explanatory role. It was informed by the published program descriptions and evaluations cited above and by the authors' direct knowledge of the program. Features were mapped deductively based on their primary correspondence with the definitions and conceptual boundaries of the three ecologies and five functions presented above. Alternative and overlapping interpretations were considered because individual features could plausibly correspond to more than one ecology or function. Premature match closure and participant dropout were considered as nonconfirming cases demonstrating that the presence of a program structure does not ensure realization of a proposed function (Uebler et al., 2023). No formal coding or independent assessment was conducted; to make the resulting risk of confirmatory interpretation transparent, we distinguish documented characteristics and outcomes from hypothesized E³ correspondences and treat the mapping as illustrative and hypothesis-generating.

4.2. Conceptual Mapping of CyberMentor onto the E³ Framework

From the perspective of the E³ Framework, CyberMentor's program structures and practices can be understood as elements of an interconnected social fabric rather than isolated mechanisms of action. The following conceptual analysis examines how these structures and practices may correspond to the resource ecology (E1), the regulatory ecology (E2), and the temporal ecology (E3) and the five stabilizing functions. In the mapping below,

descriptions of program structures refer to documented characteristics of CyberMentor, whereas statements about how these structures may operate within the E³ Framework represent theoretical interpretations. Only correspondences that are explicitly supported by findings from previous CyberMentor research are treated as empirically grounded.

4.2.1. CyberMentor's Ecological Building Blocks

Resource Ecology: Mapping CyberMentor to the E³ Capital Categories

CyberMentor provides mentees with a range of endogenous and exogenous resources that support their STEM-related learning. In the following, we will map CyberMentor onto the E³ capital categories set out above (see Tables 1 and 2).

Exogenous Resources (Educational Capital)

- Economic educational capital: Participation is free of charge for mentees, thereby creating a socially financed support structure (a safety net of sorts for the mentees' STEM trajectories) that makes long-term STEM support participation available regardless of the families' financial circumstances.
- Cultural educational capital: Mentors serve as role models, conveying their enthusiasm for STEM and providing insights into their careers, thereby potentially presenting STEM goals as desirable and attainable within the girls' social environment.
- Social educational capital: Within the E³ Framework, the one-on-one mentoring relationships can be understood as a social activator through which the platform's tools and learning opportunities become developmentally meaningful. The program's network of 1600 mentees and mentors who interact via a members-only platform creates an important social support system.
- Infrastructural educational capital: The program and its members-only online platform provide materials and tools (email, chat, forums, wikis, online learning materials) for STEM communication and learning.
- Didactic educational capital: The four-phase structure and support through program-staff-led office hours constitute a "didactic contract" that guides the exchange of knowledge between mentor and mentee.

Endogenous Resources (Learning Capital)

- Organismic learning capital: CyberMentor's temporal flexibility may reduce scheduling-related strains, while its supportive female STEM community may foster psychological well-being. Together, these features may help support participants' mental and physical energy needed for sustained engagement.
- Telic learning capital: From the E³ Framework perspective, the one-year commitment and the connection with mentors who convey enthusiasm for STEM may be interpreted as structures that potentially support mentees' telic capital.
- Attentional learning capital: The requirement of at least 30 min of interaction per week provides a regular occasion for STEM engagement and may therefore be interpreted as a structure that draws learners' attention toward STEM.
- Actional learning capital: Mentees work on projects and attend STEM clubs at school, where their skills are co-constructed and validated through social feedback loops with mentors, teachers, and peers.
- Episodic learning capital: Writing articles for the platform's internal STEM magazine allows mentees to narrate their experiences, turning them into socially framed and significant personal memories.

Temporal Ecology: The Organization of Momentum in CyberMentor

CyberMentor organizes engagement across the multiple temporal layers described above (see Table 3). In the following, we interpret how these temporal program structures may contribute to sustaining STEM engagement over time.

Micro time: The minimum weekly 30 min interaction creates a recurring opportunity for STEM to become a regular part of mentees' everyday lives and may provide social permission for deep STEM focus, independent of rigidly timed instructional periods in school.

Macro time: The four-phase structure over a full year, with long-term projects, provides designated opportunities for review and reflection that may reduce time pressure to more tightly paced instructional settings (such as school curricula).

Developmental stages: By allowing mentees to participate for multiple years and by supporting girls in grades 5–13, CyberMentor provides a potential social bridge across transitions. Although this proposed bridging mechanism has not been examined directly, multiyear participation has been linked to later real-life choices of STEM university majors and careers (see [Stoeger et al., 2023](#)).

Learning stages: Mentors and staff-led office hours provide opportunities for guidance when visible progress slows and may therefore help mentees respond to learning plateaus.

Learning logics: The online platform and integrated STEM clubs offer temporal flexibility and may facilitate alignment with learners' personal pace and social life.

Regulatory Ecology: Steering the Trajectory in CyberMentor

CyberMentor supports mentees' STEM-related development by providing a regulatory ecology. In the following, we describe how the program's regulatory ecology may support mentees' STEM learning and sustain STEM engagement by socially steering their goals, progress, routines, responses to difficulties, and protection from competing demands.

Setting goals: The matching process in CyberMentor is based on shared subject interest, which may facilitate alignment between a mentee's goals and the expectations communicated by a professional role model.

Monitoring: Regular communication and office hours provide opportunities for mentors and program staff to monitor progress and offer feedback and support that may contribute to mentees' motivation and learning.

Execution: The four-phase structure and the one-year commitment act as a social script that helps learners follow through on regular tasks and routines.

Correction: When a mentee is stuck, mentors offer guidance, new ideas, and academic support to help her change course and overcome difficulties.

Managing competing demands: The members-only platform and the integrated school STEM clubs create a strong social environment that may help mentees sustain their engagement alongside competing activities.

4.2.2. The Stabilizing Functions of the CyberMentor Fabric

The preceding analysis mapped CyberMentor's structures and practices onto the three ecological building blocks. The following analysis illustrates how specific CyberMentor structures and practices may instantiate the five stabilizing functions within the program's social fabric. The conceptual mapping should not be interpreted as evidence that the functions account for CyberMentor's documented outcomes.

Social robustness (strength and backup): CyberMentor provides potential sources of relational redundancy. While every girl has a personal mentor, she is also part of a network of 800 other girls and 800 female STEM experts. If one connection is weak, the wider network may offer alternative sources of support.

Social regulatory realignment (getting help when stuck): The program's mentoring relationships and four-phase structure provide potential opportunities for regulatory realignment when mentees reach a plateau. Mentors can offer academic and personal support when mentees face difficulties, while the four-phase structure provides clear goals that may help mentees identify possible next steps. Whether the structures actually produce regulatory realignment has not yet been examined directly.

Social reproductive renewal (new developmental impulses): The program introduces changing topics, project formats, and participant roles across the four phases. These recurring changes can be interpreted as opportunities to renew resources, interests, and developmental impulses throughout the mentoring year.

Social informational persistence (continuity across time): CyberMentor allows girls to participate for multiple years and accompanies participants across Grades 5–13. This continuity may help preserve STEM-related experiences, relationships, and knowledge across school stages. The platform also stores shared interactions and products that participants can revisit over time.

Social-environmental fit (making STEM a natural part of life): The program's online format and temporal flexibility may reduce friction with the girls' daily lives by facilitating integration into their schedules. From an E³ Framework perspective, these characteristics can be interpreted as potentially supporting the embedding of STEM-related activities in mentees' everyday learning ecologies, both at school—for example, through the accompanying school STEM clubs—and at home.

5. Discussion: Toward a Resilient Architecture for STEM Learning Trajectories

5.1. *Why Most Paths Fade Away*

Maintaining a stable learning trajectory over an extended duration is a rare achievement. Throughout our lives, we all have many different experiences. As children, we paint, sing, play sports, or solve math problems, but most of these activities do not turn into continuous, organized pursuits. We do not all become artists, musicians, or professional athletes.

The E³ Framework offers a perspective that helps to understand why relatively few STEM trajectories remain stable. It conceptualizes stability not as a default state but as a functional achievement of the entire system. According to the framework, the effective coordination of resources (E1), regulation (E2), and time (E3) may support persistence and resilience of a learning trajectory. Conversely, insufficient coordination among these ecological domains may increase a trajectory's vulnerability to disruption and erosion. The framework offers a conceptual heuristic for considering how to strengthen the resilience of learning trajectories. As proposed in this paper, building a dense and interlocking social fabric can play a key role in this process.

This perspective complements established explanations of STEM persistence rather than replacing them. Identity, belonging, self-efficacy, social support, and contextual barriers can be understood within the E³ Framework as components of broader resource and regulatory ecologies whose effects also depend on the temporal continuity and coordination of these ecologies. The framework's specific contribution is to conceptualize how the coordination of these components over time may help preserve or restore the direction of a STEM trajectory.

5.2. *Explaining the “Modest Effects” Gap*

This systemic perspective may also help explain why many STEM programs show only modest effects and fade after a short period. As previously discussed, research shows

that the median effect size for thousands of STEM interventions is only $g = 0.32$ (Bicakci et al., 2026; Heller et al., 2026). From the E^3 point of view, one possible explanation for these small effects is that interventions provide only a single resource (e.g., a one-day event or new learning materials). While these impulses are helpful, they are often isolated. They may lack ongoing regulation or sufficient time to support a trajectory over the long term. To achieve more significant and lasting outcomes, it might be necessary to shift our focus from these “single-shot” efforts toward building a more integrated system.

5.3. Beyond Individual Grit: Resilience as a System Property

Much of the current STEM research focuses on individual traits such as grit (Duckworth et al., 2007) or mindset (Dweck, 2006). These concepts suggest that success depends mainly on a learner’s internal persistence and talent. However, our conceptual analysis suggests that personal interest and individual engagement, while important, may not be sufficient on their own to secure stability. From the E^3 perspective, even a highly persistent student may be unable to sustain a learning trajectory when the social fabric provides insufficient resources (E1), activation through social regulation (E2), and protected time (E3). Therefore, resilience may not be adequately understood solely as a student’s character trait. From the E^3 Framework perspective, it can instead be conceptualized as a functional achievement of the entire social fabric.

5.4. Designing STEM Learning Trajectories

The illustrative analysis of CyberMentor offers a conceptual perspective for designing effective long-term STEM learning trajectories. In addition to supporting individual learners and creating STEM-friendly environments, educators and program designers may benefit from considering the longer-term trajectories that programs are intended to support. The five proposed functions provide a heuristic for examining whether a program includes structures that may contribute to robustness, realignment, renewal, informational persistence, and environmental fit. The present analysis does not establish that all five functions are necessary or sufficient for program effectiveness. Rather, it proposes that the coordinated provision of resources (E1), regulation (E2), and temporal continuity (E3) may increase the likelihood that STEM engagement can be sustained over time.

5.5. Potential Policy Implications: Supporting Long-Term Social Fabrics

Our conceptual analysis offers several provisional design principles that governments and organizations might consider when developing and evaluating STEM education initiatives. Given the conceptual nature of the analysis and its reliance on a single illustrative case, these principles should be understood as starting points for future research and evaluation rather than as established criteria for funding decisions.

Moving Beyond Events and Short-Term Measures: STEM policy initiatives often take the form of short-term measures, such as one-day science festivals or the provision of new learning technologies. Although such measures can provide valuable resources, from the perspective developed here, sustained STEM participation is unlikely to depend on short-term measures but on the functional achievement of a whole system. Sustained long-term funding may be particularly important, not merely because long-term STEM talent-development trajectories take time to emerge, but also because resilient trajectories may only develop when sufficiently stable resource, regulatory, and temporal ecologies are maintained over extended periods of time. These propositions should be examined in future empirical evaluations.

Interlocking E1, E2, and E3: One possible design principle is that funding and design decisions consider whether and how programs connect resources, regulation, and time, rather than addressing these domains in isolation. For example, the potential educational

value of a new laboratory (E1) remains limited if students do not have the time (E3) to use it or the regulation (E2) from a mentor to guide them. Programs could therefore be invited to articulate how the three ecologies (resource ecology, regulatory ecology, and temporal ecology) are expected to work together, and these expectations could subsequently be examined empirically.

Investing in social support structures: Currently, social support is often seen as a nice-to-have add-on. However, our conceptual analysis suggests that resources may remain underused when they are not socially activated. This reasoning suggests that policymakers might consider dedicated funding for the social fabric—including mentors, peer groups, and community networks—rather than treating it as an optional program component.

Supporting transitions: Leaks in the STEM pipeline often occur when students move from one program to the next or from one educational stage to the next. A further design hypothesis is that continuity-supporting measures that preserve students' history and STEM identity may be particularly valuable during transitions between programs and educational stages. Without social informational persistence, even the best students can lose their way when they enter a new environment.

Equality as a system task: Social fabric is not equally distributed; factors such as socioeconomic status and gender still determine who gets the support they need (Ziegler & Stoeger, 2023). From the perspective proposed here, policy initiatives should examine whether access to mentors and networks can compensate for unequal access to supportive social structures in underserved communities.

Implementing functional health checks: The five stabilizing functions could serve as a framework for future program evaluation. Such evaluations might assess not only content and resources, but also whether programs provide relational redundancy, opportunities for regulatory realignment, recurrent developmental impulses, continuity across transitions, and alignment with participants' broader learning ecologies. Before the functions are used as evaluative standards, however, their measurement, distinctiveness, and predictive validity need to be established empirically.

5.6. Limitations

This illustration of the E³ Framework has some limitations. First, we looked at only one example: the online mentoring program CyberMentor. This is a program specifically for girls and women in Germany. We do not yet know whether the social fabric works the same way for boys or differs across cultural contexts. Second, CyberMentor is an online program. A purely face-to-face program might use these functions differently. These contextual differences concern the concrete structures and practices through which the functions may be realized, but not necessarily the relevance of the functions themselves. The five functions are formulated in the E³ Framework at the level of general functional challenges involved in maintaining or restoring trajectory stability rather than in terms of CyberMentor-specific features. Other long-term STEM mentoring and educational programs are likely to face analogous challenges: withstanding disruptions, enabling corrective adjustments, renewing resources and developmental impulses, preserving continuity across transitions, and maintaining fit with learners' broader environments. Accordingly, we expect the functions to be relevant as analytical categories across mentoring and STEM education contexts, even though their concrete manifestations are likely to vary. Comparative research is needed to examine this expectation across different program formats, target groups, institutional settings, and cultural contexts. Finally, although CyberMentor's effectiveness has been demonstrated across short-term, midterm, and long-term outcomes (Stoeger et al., 2013, 2016, 2021, 2023), previous evaluations have not yet directly assessed the E³ ecologies or the five stabilizing functions proposed in the present paper. The correspondence between

specific program features and the proposed functions and how they may help stabilize STEM learning trajectories was established analytically by the authors rather than derived from participant data or formal coding procedures. The authors' involvement in the development and evaluation of CyberMentor provided detailed knowledge of the program but may also have favored a confirmatory interpretation of its structures. Moreover, not all mentoring relationships are sustained; premature match closure and participant dropout also occur (Uebler et al., 2023). These cases underscore that the presence of particular program structures does not ensure that the proposed stabilizing functions are realized in practice, especially when the relationships through which they operate are weak or discontinued. Accordingly, the case analysis should be understood as illustrative and hypothesis-generating rather than as evidence that the proposed functions operate in practice. Future studies should develop measures of the functions and examine their associations with longitudinal outcomes.

5.7. Generalizability

Although the present analysis focuses on STEM, the core principles of the E³ Framework and the concept of social fabric may also provide a useful analytical perspective in other domains. The five proposed stabilizing functions (social robustness, social regulatory realignment, social reproductive renewal, social informational persistence, and social environmental fit) capture functional challenges that may arise as complex expertise develops over time. Individuals pursuing expertise in music, professional sports, or the arts may likewise encounter discontinuities or threats to the stability of their learning trajectories. We therefore propose that the coordination of resources (E1), regulation (E2), and time (E3) through a social fabric may support persistence across different domains. Future research should test whether the five proposed social functions can be reliably distinguished and whether they predict stable learning trajectories within and across domains.

6. Conclusions: You'll Never STEM Alone

In this conceptual paper, we used the E³ Framework to examine how the stability of a STEM learning trajectory may depend not only on individual-level and environmental factors but also on the coordination of resources, regulatory processes, and temporal structures. This perspective builds on and complements established explanations of persistence and resilient STEM learning trajectories. We focus specifically on how the social fabric may contribute to the realization of the five stabilizing functions specified in the E³ Framework by helping coordinate resources (E1), regulation (E2), and time (E3) in ways that maintain and restore trajectory stability. CyberMentor served as an illustrative case to show how program structures and practices may instantiate these functions. This theory-guided mapping is hypothesis-generating and should not be interpreted as empirical evidence that the functions account for CyberMentor's documented outcomes. Nevertheless, the framework provides a basis for future research into whether and how the social fabric may support stable STEM learning trajectories across contexts and help establish conditions in which students do not have to "STEM alone."

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