

# Building Collaboration Theory Across Education Science and Systems Engineering—The FINDUS Process for Collaboration

Johan Cederbladh<sup>1</sup>  | Simon Sjölund<sup>2</sup>

<sup>1</sup>Portfolio & Architecture, Volvo Construction Equipment, Eskilstuna, Sweden | <sup>2</sup>School of Education, Culture and Communication, Mälardalen University, Västerås, Sweden

**Correspondence:** Johan Cederbladh ([johan.cederbladh@volvo.com](mailto:johan.cederbladh@volvo.com))

**Received:** 19 December 2024 | **Revised:** 27 April 2026 | **Accepted:** 6 May 2026

**Keywords:** collaboration | educational science | systems engineering | systems thinking

## ABSTRACT

Systems Engineering (SE) relies on industry–academia collaboration for much of its research. Such collaborations are frequently described valuable in practice. At the same time, there is a need to align between partners to maximize the value of collaboration through acknowledging and working with nuances between parties to share and develop knowledge. At its essence, collaborative efforts might not achieve complete partner alignment to drive value if not emphasized, which could be averted with foresight and planning efforts. In the educational sciences there is a rich history of collaboration, and many models and theories for multi-stakeholder collaboration have emerged over time. In this work, we investigate the potential carry-over from educational sciences to collaboration between industry and academia in systems engineering, and discuss how an existing model of activity theory could be used to increase *value* in collaborative efforts between different partners. We formulate a model of activity theory applicable for systems engineering and present the Frame, Investigate, Negotiate, Do, Understand, Share (FINDUS) process to help practitioners apply the model pragmatically. The FINDUS process is presented through a set of questions that can be used as a checklist during collaboration.

## 1 | Introduction

Collaboration often occurs in research between heterogeneous stakeholders. In engineering, research collaboration is often discussed through the lens of industry–academia, where there is potential value for either party in successful collaboration [1–3]. For companies there is potential value in scientific knowledge being investigated and evaluated in a company specific context. For researchers there is value in the realistic context provided by companies to evaluate scientific theories and tools. In fact, many funding organizations seek to foster this kind of collaboration through explicit funding calls in the context and intersection of academia and industry [4, 5]. As a result, “good” engineer-

ing research is often expected to be validated, originating, or integrated in some form of industrial setting [6]. Therefore it is of great interest for academic researchers to achieve successful collaboration with industrial practitioners, and the same is often true for the industrial practitioners as there are potential new insights and knowledge transfer [7].

In the Systems Engineering (SE) domain collaboration between industry and academia is an important research pillar [8]. Notably, many of the leading SE actors such as the International Council on Systems Engineering (INCOSE) actively promote industry–academia collaboration, for example through the yearly INCOSE International Symposiums and International

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Systems Engineering* published by Wiley Periodicals LLC

Workshops.<sup>1</sup> In fact, in their vision for SE 2035 INCOSE argue that increased emphasis on collaboration is a key enabler for future SE [9]. Particularly, the vision (p.41) argues largely that SE needs to progress from a place of acquisition to one of collaboration, introducing a need for increased emphasis of these topics in the SE landscape and additional training for practitioners to adopt these principles. Collaboration is often expressed as requiring balancing and alignment between industry and academia goals, attributed to underlying differences between actors, expressed for example through language and norms [10]. So, while collaboration is increasingly seen as an essential aspect for SE, it is nonetheless an effort to start and perform efficient collaboration [3].

Similarly, in the field of education, collaboration between researchers and practitioners is promoted in many Western countries to bridge the gap between research and practice [11, 12]. In Sweden, for example, educational law states that education should rest on a scientific basis [13]. This has led to a deeper focus on how to create successful collaborations and various frameworks [14, 15] and theories [16, 17] have emerged to support researchers and practitioners. Collaboration between different stakeholders naturally creates friction. Finding a good “compromise” between partners with differences in the underlying domain, goal(s), and scope rarely leads to an optimal solution for all partners and requires effort in finding an acceptable level of *value* for the affected partners [18]. Notably, there are several models for how to recognize frictions between collaborative partners, and how these points of friction could be used to learn more together, turning an original *problem* into part of the *solution*.

In this article we are interested in understanding how researchers and practitioners in SE might collaborate effectively and move toward a context as expressed by the INCOSE SE 2035 vision. One relevant perspective in this context is through *cost* and *value*. Practically, collaboration infers a cost which should be lower than the eventual value it provides. Specifically, the notion of collaboration can often be somewhat ad hoc or without a commonly understood collaborative framework between different partners. The *roles* of partners in collaboration is therefore not always explicit nor easily understood [3], reducing overall opportunities for value generation and efficient project performance.

In this article we ask; How would a model of collaboration look when merging insights from educational science within the context of SE? We explore this question through a set of fundamental principles and terminology from educational science research and observe these through an existing theory on activity systems from Engeström [16, 19]. Then, we discuss how this model can be used as a foundation to reason and apply a *systems thinking* [20] process for collaboration between researchers and practitioners in SE. We provide a conceptual model on collaboration based on a common understanding between SE and educational sciences. We supplemented this model with a pragmatic application process to assist users in a systems thinking application of collaboration between industry and academia.

We summarize our contributions in this article as follows:

Collaboration. We provide a discussion about collaboration from the perspective of SE and educational sciences, and

formalize a set of concepts. Particularly, we connect the concepts of collaboration to the notion of *value*.

Process. To support application of the collaborative concepts, we propose a generic process for the definition and performance of collaboration. The process emphasizes how value-creation is promoted.

The rest of the article is structured as follows: We provide background and related work content in Section 2. We discuss collaboration more broadly in Section 3. Section 4 frames collaboration in SE and provides a definition and example of a conceptual collaborative model. Section 5 discusses our vision for the transferal of the explored conceptual model to SE. The article is discussed in Section 6 and concluded in Section 7.

## 2 | Background and Related Work

SE is an engineering discipline that distinguishes itself from other engineering disciplines in a few aspects. While engineering is often argued to be about “creating solutions” SE is instead positioned as “making decisions” [21, 22]. Likewise, SE is per definition a multidisciplinary field, required in the engineering of *systems*. A system is defined by INCOSE as: “A *system* is an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not” [21]. To support engineering of systems, SE combines both “hard” aspects of traditional engineering disciplines in addition to “soft” aspects of social sciences [22]. Notably, essential to SE is the notion of *systems thinking*, a means of over-viewing and reasoning about complex systems. Systems thinking can be defined as: “*Systems thinking* is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects. These skills work together as a *system*” [20]. This definition of systems thinking lends itself well to the application of less tangible systems as collaboration, in addition to technical systems, and therefore deemed appropriate for this article.

In SE there is an increasing presence of collaborative research in industrial settings with academic institutions [10, 21]. Partially this is due to the emergence and adoption of cutting edge technologies in industrial engineering contexts [1, 3], for example observed with the explosive rise of artificial intelligence in recent years [23]. Often engineering research is as a result performed through some collaboration with industry, either directly or indirectly, resulting in an overall need to collaborate between academic partners and industrial partners [3]. In many cases, these collaborations are performed in the form of project-based co-development [1]. A common method of this type of collaboration in Sweden is through the use of industrial PhD students [2]. This way, a common interactive point is created from the industrial and academic perspective, and research is framed from the onset as *collaborative* through the research definition itself, observed to have several benefits [24]. Another form of collaboration is through the industry as a laboratory research method [25, 26].

In spite of the increasing focus on collaboration, engaging in fruitful collaboration between industry and academia is known

to require joint effort from *all* the involved parties to achieve [3, 10]. Commonly reported alignment points relate to the differences in scope, resources, backgrounds, and communication. While specific aspects of collaboration are interesting to observe and work toward in their own right, we take a step back and observe collaboration through a lens of abstraction. Concretely, due to the underlying differences between parties in industry and academia there will be *frictions* in any collaborative attempt [27]. Frictions can arise due to any number of reasons, but generally relate to the difference in context between collaborative partners such as deliverables, time-scale, and communities. Nonetheless, without these differences collaboration is inherently *flawed*, as the collaboration expects different partners to jointly come together. As such, eliminating these differences is in many way counter-productive, as diversity is often observed to be a strength in collaboration [28, 29]. Nevertheless, without acknowledging these differences and accounting for them, the likelihood of successful outcomes in collaboration decrease [10].

At the same time in the field of education, several state reforms in the Western world encourage research to inform educational practice [11, 12]. However, a persistent gap exists between research and practice in education [30]. Collaborative approaches between researchers and practitioners, emphasising engagement rather than distance, are promising for bridging this gap [30, 31]. Collaboration is argued to produce more timely and relevant research and practical innovations that enhance student learning opportunities [32]. While promising, collaborative partnerships in education are not without challenges. Participants often face resource and contextual constraints that can lead to conflicts [33]. Researchers, for instance, struggle to balance academic goals with producing actionable outcomes [34]. Educational practice partners, meanwhile, contend with issues such as leadership turnover, prioritization, heavy workloads, and funding limitations [35, 36]. Common obstacles include turnover, misaligned timelines and incentives, and the need to involve those with authority in decision-making roles [37]. Scholars suggest that many of these challenges arise from cultural differences that must be addressed in partnerships [38]. Ultimately, the longevity and success of collaboration depend on the people and organizations involved, though research indicates that organizational characteristics and environment are more fundamental for effective collaboration than individual attributes [39]. Collaboration in education research often focus on teacher practicum and education development efforts [40]. There are exceptions, as historically, education research has involved teachers in action and design research [41]. These efforts are described as practice-near or practice-based research, open to varying contextual interpretations [42]. Practice-near research includes five anticipatory narratives: ensuring a school based on scientific knowledge and proven experience, curing educational research of little relevance, increasing teaching efficiency, making teacher education research-based, and enhancing the attractiveness of the teaching profession.

A review of practice-near research in Nordic countries reveals a highly diverse field in terms of theories, methodologies, and practitioner involvement [43]. Practitioner involvement falls into three categories: teachers conducting lessons planned by researchers, teachers planning teaching with researchers, and teachers planning and analysing with researchers. This variation

means that practitioners are not always meaningfully engaged in research. Moreover, maintaining scientific rigor while collaborating with diverse groups is challenging [44]. Effective practice-based research requires researcher competence and poses epistemological challenges. Key conditions for meaningful teacher engagement include time and support from headmasters, early involvement in problem identification and research planning, equal collaboration, and shared research aims [45]. Additionally, ethical considerations, such as anonymity, must be thoroughly addressed when recognising teachers' contributions.

### 3 | On Collaboration

While we have mentioned that there are benefits for industry-academia collaboration more broadly, some benefits are more often reported than others. For example, Assbring and Nuur [2] discovered the following reasons in Swedish industry; knowledge, competence, improved products and processes, and legitimacy. For smaller companies this leans toward direct impact in products and processes, while larger companies instead lean toward competence and knowledge. Salazar and Cabrera-Ríos [46] investigated collaboration between industry and academia in Latin America. They identify that liaisons between industry and academia are necessary to establish a point of value-return acceptable for industry. Nyemba et al. [8] perform several studies in Sub-Saharan Africa in the SE context. They argue that collaboration between industry and academia is crucial for the sustained development in the region, and draw parallels between collaboration and systems thinking. Honoré-Livermore et al. [47] investigate the academic competence in both project management and SE. They reason that these skills are essential in efficient collaboration and integration of academic research in industrial settings, and identify a mixed and lacking maturity in this regard. Also relevant is the large body of knowledge on industry-academia collaboration in the Software Engineering (SwE) field. Garousi et al. [10] performed a systematic review on the challenges of industry-academia collaboration in SwE. They discuss many challenges, but the more prominent regard differences in objectives, scope, and matching industrial and academic relevance.

It is clear that in the application of SE and surrounding engineering research there is an identified need for industry-academia collaboration, while at the same time it is acknowledged that current practices are lacking [3, 10]. Nonetheless, finding a balance in collaboration to promote academic principles of freedom and transparency in relation to industrial principles of competitiveness is a fundamental challenge in engineering research [48]. Some authors draw parallels between collaboration and systems thinking, as a collaborative effort can be viewed as a collaborative system. To support the application of systems thinking when designing and performing collaboration, we aim to transfer knowledge from educational science. While SE and educational sciences are quite different fields, the foundations of *collaboration* are strictly speaking not domain-specific. We provide a conceptual view of the fields common understanding (based on Section 2) in collaboration in Figure 1.

We briefly define the different figure elements as follows:

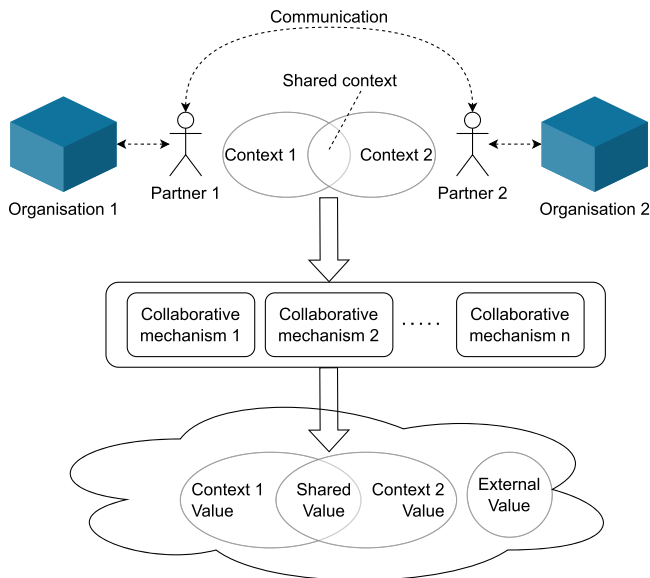


FIGURE 1 | A conceptual view of collaboration.

**Partner.** A partner is the individual researcher or practitioner involved in collaboration. This might be more than one individual, but is a sub-group of the overall organization and its context. At least two partners are required for collaboration, but there is no strict upper bounds. Partners perform *communication* through various channels, as meetings, workshops, emails, and so forth.

**Organization.** The organization contains the partner, and sets the boundary for the tools, processes, aims, responsibilities, tasks, and so forth. for the corresponding partner(s). Some partners belong to more than one organization (e.g., an industrial PhD student to both a company and university).

**Context.** The context is the combination of objective, scope, constraint, and resources from a given partner. Between any number of individual partners there is a potential overlap of these contexts where collaboration can be performed.

**Collaborative mechanism.** The collaborative mechanism is the practical implementation of collaboration in terms of methods, processes, and so forth. This can be the scientific method that is used to gather data, implementation at the company, workshops, and so forth. The mechanism should produce new knowledge through joint work in the shared context.

**Value.** As collaboration happens, value is produced through the collaborative mechanisms. The factual value will differ for the specific partner(s) and organization(s), and might or might not be shared. Examples could include scientific publications or process improvements at the organization, and external value could be resulting effects on society through scientific or commercial advances.

In collaborative efforts between schools and universities in education, a central element involves negotiating how to weave together and balance school development and research, where on one hand, school development should occur with the support of research, and on the other, research should be created that is relevant to educational practice. For collaboration to be

valuable, both similarities (shared context) and differences (parts of context 1 and context 2 that are not shared) are needed. Similarities, bringing partners together, often constitute a common interest to collaborate around. Additionally, complementary expertise/knowledge (difference) is required so each partner has something to contribute to the other. So, one could say that both a shared and a separate context are required. The shared context often sets the direction for the partnership, while the separate context contains much of the learning and development that the collaboration entails. The separate context also contains the potential for friction and conflicts, which also contain learning potential if navigated successfully. The shared context often comes to the forefront at the beginning when the direction for collaboration is being negotiated, often in terms of the aims of research and development. It is then, when the school and university set up a plan for this work together that differences in terms of, for example, different timelines/work pace, prior knowledge, communication strategies, and incentives can create “boundaries” [27] to be navigated.

There are several mechanisms or practices that can facilitate the navigation of these boundaries. In education, the main process for collaboration can be divided into three different types of partnerships based on their main collaborative mechanisms [49]. Firstly, some partnerships employ collaborative inquiry in order to gain more knowledge on a problem of practice. Secondly, others rather collaboratively design solutions to a problem of practice. Lastly, some partnerships employ dissemination mechanisms to utilize each other’s different expertise and experience. The roles one finds oneself in based on these can be described in terms of how tasks, responsibility and authority are distributed. It is also worth noting that mechanisms of learning underpin these surface-level collaborative mechanisms. So even though we define and establish a collaborative mechanism it is not clear that any development will occur unless we can leverage learning mechanisms underlying collaborative work. These learning mechanisms can be divided into the following four categories [50]:

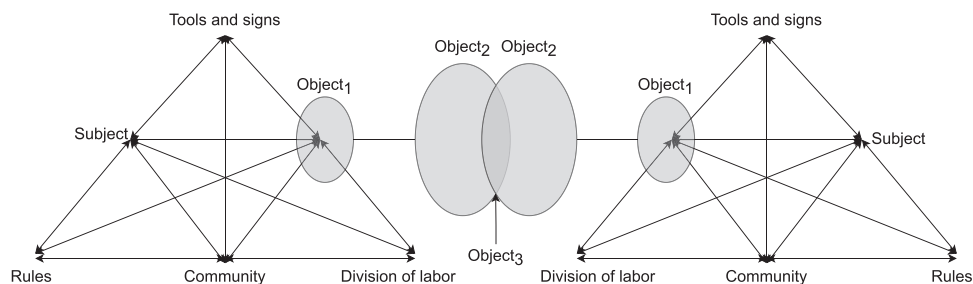
**Identification.** Boundary crossing leads to redefining intersecting practices and how they can coexist. This involves efforts to distinguish “us vs. them” and legitimising the differences and coexistence of practices.

**Coordination.** Diverse practices find ways to cooperate efficiently, even without full consensus. This involves establishing communication links, organising activities smoothly, and creating reliable routines.

**Reflection.** Mutual understanding and openness to others’ perspectives lead to a better grasp of each practice’s unique viewpoints. This is marked by efforts to both make and take different perspectives.

**Transformation.** Changes occur either within existing practices or through the creation of new hybrid practices. This involves recognising shared problems, merging perspectives, and developing new ideas, plans, tools, or procedures.

Learning mechanisms and the value they create happen at three levels [51], Organizational, interpersonal and intrapersonal.



**FIGURE 2** | A conceptual model of interacting activity systems as described by activity theory [16, 19].

While there might be nuances in the collaborative instances roughly adhering to the conceptual framework in Figure 1, much of what is observed in educational sciences hold true for SE as well. Additionally, considering the emphasis on collaboration from research funding organizations, for example seen in many European Commission calls for funding,<sup>2</sup> there are potential benefits from investigating already existing collaborative theories and models from surrounding scientific fields. Educational sciences notably frame these differences as *opportunities to learn*, highly relevant for contemporary SE science as well. In SE it is often reported that the differences between academia and industry is significant [10], yet with correct framing and acknowledgement this can become a strength in collaborative efforts. Therefore we argue an inclusion of existing collaborative models from educational sciences could be a useful tool, given the rich history and high demands on collaborative efforts with diverse partnerships.

#### 4 | A Model for Activity Theory

In this section we investigate how the Engeström activity system theoretical model could be a useful tool for SE collaboration [16, 19], and discuss the potential transfer and integration into SE research practice. Notably, we believe activity systems to be a suitable foundational theory for collaboration in SE as it is a relatively generic including aspects of both the individual partner (or actor), and the underlying organization. Engeström's [16] activity theory addresses the challenges of cultural diversity and dialogue between different traditions and perspectives. Activity systems are made up of several parts [19]. The depiction in Figure 2 represents the interaction of two activity systems that are used to capture the complex, socially mediated nature of human action. At the heart of the model is the subject, the individual or group whose perspective frames the activity. Acting upon an object, which represents the shared goal or problem space that gives the activity its purpose. This interaction is mediated by mediating artifacts, which consist of tools and signs that enable the subject to work on and transform the object. The upper part of the triangle illustrates this mediated action, while the lower part represents the social organization that shapes and constrains the activity. Rules refer to explicit and implicit norms, conventions, and regulations that govern how the activity is carried out. The division of labor describes how roles, responsibilities, power, and authority are distributed within the community, both horizontally in terms of tasks and vertically in terms of decision-making. The activity results in an outcome, the transformed object, which may be a material product, a

changed practice, or a new understanding. This triangular model emphasizes that human activity is a historically and culturally embedded system in which tools, social relations, rules, and shared purposes are deeply interconnected.

The circle around the object in Figure 2 indicates both the focal role and inherent ambiguity of the object of activity. The object invites interpretation, personal sense-making, and societal transformation. Influenced by ideas on dialogicality, the third generation of activity theory includes new conceptual tools to understand multiple perspectives and networks of interacting activity systems [16]. Notions of activity networks and boundary crossing, such as the “third space” concept in classroom discourse, have emerged. The basic model of activity theory has been expanded to include at least two interacting activity systems, reflecting the dynamic nature of objects as they evolve from raw material to collectively meaningful constructs. In Figure 2, the object transitions from an initial state of unreflected, situationally given “raw material” (object 1; for example, a specific student entering a classroom) to a collectively meaningful object constructed by the activity system (object 2; for instance, the student understood as a representative of a particular educational need or learning category, thereby becoming an instance of the general object of education/learning). It then moves to a potentially shared or jointly constructed object (object 3; such as a collaboratively developed understanding of the student's unique circumstances and personalized learning plan). The object of activity is a moving target, not easily reduced to conscious short-term goals. In the next section we reflect on how this framework could be applied to support collaborative research in SE.

#### 5 | Applying Activity Theory to SE

Taking our conceptual view of collaboration defined in Figure 1, we merge this view with the activity systems as defined by Engeström [16, 19]. With these contributions we propose the following generic model in Figure 3 as a basis for understanding, discussing, and exploring collaborative efforts.

The figure illustrates unpacking an organization in terms of community, rules and division of labor. In doing this we can explore the constraints and support that organizations constitute in collaborative efforts. Additionally, we can helpfully conceive of the individual collaborative partner as a subject that through mediating tools and signs interact with an object. Although activity theory in this sense primarily focuses on the activity itself, this article further explores, in Figure 3, the collaborative

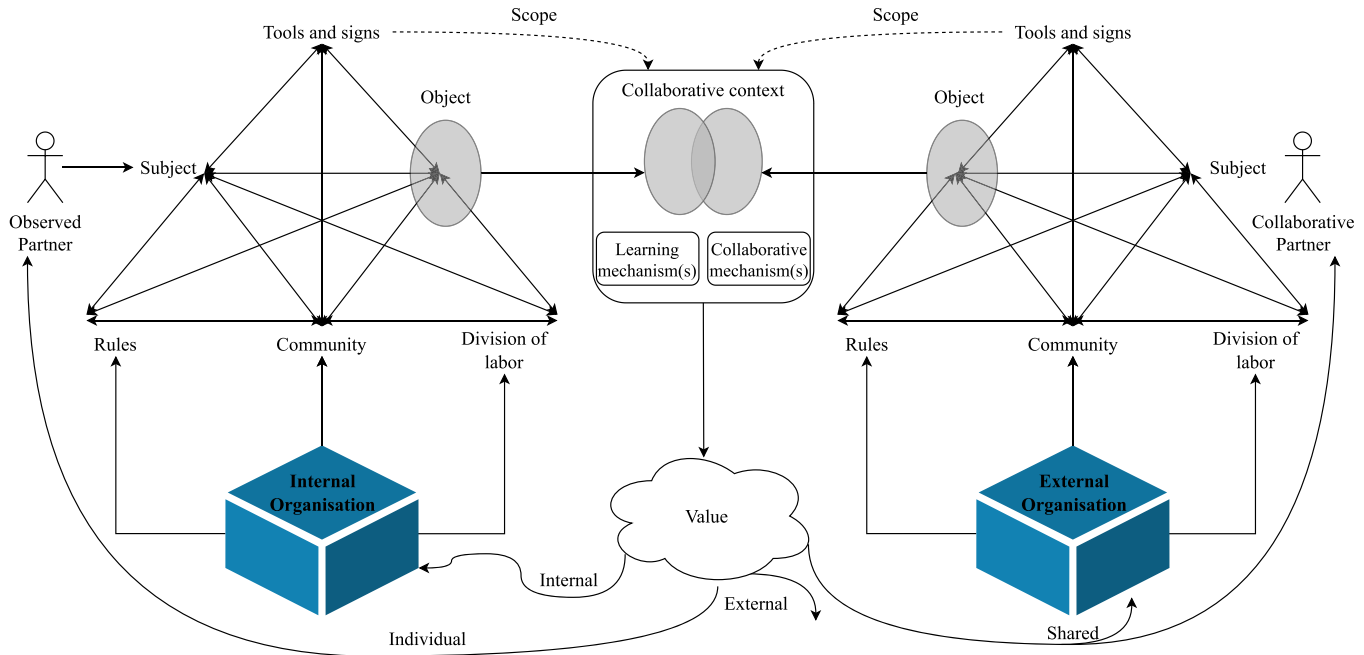


FIGURE 3 | Understanding partners and organizations as part of an activity system.

mechanisms and the value they aim to create. While this is a key issue to explore, we argue that it is not sufficient to completely capture what is required to create value. In this, educational science theory can contribute by highlighting the underlying learning mechanisms [50] to provide another layer on the mechanisms that can lead to value in collaborative efforts. In the end, this model frames a *way of thinking*, much in line with what is considered as *systems thinking* in SE [20].

To make sense of activity theory in terms of SE and further clarify Figure 3, we consider the fictive collaboration of *Alice*, a practitioner in a large company that designs self-driving machines, and *Bob*, a PhD student researching AI for object detection. For the rest of the article we will recurrently describe a collaboration between them to anchor the theory practically. First, we revisit the terminology defined for collaboration in Section 3 and Figure 1;

**Partner.** We divide the partner in two categories; the observed partner and the collaborative partner. In the context of the activity system, the partner is considered as the subject from where the collaborative perspective originates, influenced by the underlying organization and community. Different partners interact through collaborative mechanisms, which are influenced by the tools and signs in the respective community (e.g., software tools or modeling languages) in addition to learning mechanisms.

**Organization.** The organization represent the aspects of rules, community, and division of labor in the respective activity system containing a partner. These pillars supports the partner in grounding the collaboration in the internal community (e.g., a specific engineering domain), by adhering to the rules (e.g., regulations in the domain) and division of labor.

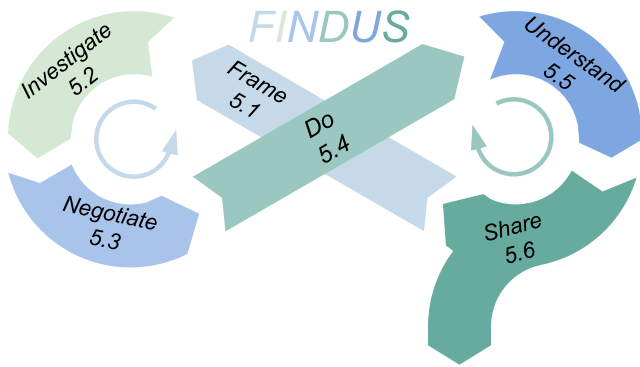
**Context.** For each partner the context is the result of the object of collaboration, scoped by the internal organization

and partner. The contexts are directly affected by the rules in addition to the community which restricts the context. Likewise, the individual partner and corresponding tools and signs will also influence this context, perhaps through limiting the context to specific technical solutions. The collaborative context is the union of both partner contexts.

**Collaborative mechanism.** The collaborative mechanism is the vehicle for collaborative efforts. This includes funding, contracts, agreements, scientific methods, and so forth. These are directly scoped by the tools and signs from each partner, in addition to the specific contexts themselves (e.g., a research problem). Furthermore, the underlying learning mechanisms (e.g., co-development) provide restrictions in the performance of collaboration.

**Value.** The main output of collaboration we observe is value. We distinguish four specific categories of value. *Individual* value which benefits the observed partner, which could include a scientific publication or personal knowledge. *Internal* value, which corresponds to the organization itself, perhaps referring to a process improvement or new research opportunities. *Shared* value, which is given to all involved parties of collaboration, for example joint scientific recognition. *External* value, corresponding to society at large, which might include things as new inventions. It is worth noting, that unsuccessful collaboration could not only lead to unproductive ventures, but also a *loss* of value, in the sense that the cost is higher compared to value produced, or even *destruction* of existing value [18, 52]. Not only is the loss of value a direct negative, but might have long lasting negative impacts due to soured relations or reputations.

The activity system is shown from Alice's perspective, positioned on the left: the subject and observed partner (Alice) works on the object of improving on-machine object detection under hard constraints such as available camera hardware, embedded system



**FIGURE 4** | The FINDUS approach considering two separate loops in developing and operating collaboration. We map the stages to the corresponding sub-sections that explains the process step.

computational limits, safety certification, delivery deadlines, and company guidelines. Her tools and signs include producing datasets, prototypes, the company’s software toolchain, and internal guidelines; her rules encompass contractual obligations, sector regulations, and IP/publication restrictions; her community spans the product team, managers, safety officers, and customers; and the division of labor assigns Alice responsibility for framing the need, securing data access, and coordinating integration with engineering teams. On the right of the activity system is the collaborative partner, i.e. Bob: the subject (Bob) pursues the object of developing and validating a novel object-detection algorithm and producing publishable research for his dissertation. His tools and signs include academic literature, and computing resources; his rules involve ethics review, supervisory guidance, and conference/journal norms and timelines; his community includes supervisors, lab mates, and peer reviewers; and the division of labor centers on Bob designing experiments, analysing results, and writing. The two systems interact around a partially shared object, testing and refining Bob’s algorithm on Alice’s real-world constraints. Their interactions will be expanded in the coming Section with a fictive example of a collaborative process between Alice and Bob.

We believe this conceptual framing is very useful to anchor collaborative aspects. Nonetheless, to make the application and use of activity theory more explicit in the SE context we also reason that an application process is required. A parallel can be drawn with Model-Based Systems Engineering (MBSE) [53], where modeling as a concept requires a method for meaningful implementation [54]. While we do not equate this article as part of MBSE, the need for a structured method to apply our conceptual model is nonetheless required. To support the practical application, we propose the FINDUS process as visualized in Figure 4. The process is meant to be used as a form of “gated-process”, in a sense that transition from one state/stage to another requires a fulfilment of certain criteria. This process has been created by mapping concepts from evolutionary approaches, like DevOps [55], toward the collaborative concepts discussed in this article. As discussed by INCOSE [21] the use of evolutionary approaches are suitable when requirements or context is not fully understood, which is often the case for collaboration between different partners. We express this process as a reference for others, acknowledging that adaption or tailoring might be necessary for successful integration into a collaborative context. Nonetheless,

the separation of two separate processes and their interweaving remains central to our collaborative framework.

## Application Guidelines

Our aim with the FINDUS process is to enable a pragmatic means of conceptualizing collaboration with a simple process. Particularly the process should assist in developing a collaboration understood by each partners. Often it is assumed goals should be *common* or *shared* [52], but it might just as well be *complementary* or *aligned* [56]. To support this we provide a set of guiding questions for each of the steps, requiring specific tailoring to the collaboration and partners at hand. Specifically, the guiding questions are explicit but not specific for a given domain or process. We discuss each of the different stages in separation for the rest of the section through the perspective of *Alice* and *Bob* and their fictive interactions during collaboration.

### 5.1 | Frame

*Alice works at a division at the company making self-driving machines. In her role at the company she has identified that there is a problem with object detection, and would like to collaborate with academic researchers to solve this issue. Bob works at a local University and has been spending several months developing a new novel algorithm for object detection, and is looking to test his new algorithm on an industrial problem. Both identify a need for collaboration.*

Before any collaboration can occur it is necessary to first understand the internal need for collaboration. As a partner or organization, it might be easy to identify direct problems and immediately look toward a solution, in this case Alice might believe the AI solution Bob offers could address her problems. However, 6 months into starting their collaboration they might realise that Bob’s algorithm does not in fact fit Alice’s case, as they have different requirements on tools, or perhaps there is not enough computing power available on Alice’s machine to support the algorithm. The notion that a lack of internal and external communication contributes to collaborative failures is well known [57]. To avoid jumping to conclusions in collaboration, there is a need to first identify the internal restrictions and *frame* collaborative needs. It is a common trap to jump to the solution instead of clearly identifying the problem, part of what SE aims to address this trap through rigorous and iterative application [21]. At the same time, learning critical thinking in decision-making is a well known challenge [58, 59]. Similarly, neither Alice nor Bob might have the agency to manage their time, and might require support from other stakeholders to approve collaboration. These stakeholders might in turn have different expectations of collaboration, naturally incurring a need to discuss wider reaching internal needs for collaboration. Therefore a pragmatic support in the internal framing is helpful to reason about collaboration. Perhaps Alice did not need an AI-algorithm, perhaps a different camera would solve the problem at hand, eliminating the need for collaboration and probably saving resources. A poorly framed collaboration could lead to not only wasted resources but value destruction in the context. Indeed, from the SE perspective the *framing* proposed is much in line with

correctly identifying *stakeholder needs*, in addition to defining requirements [21]. However, when it regards collaboration the act of seeing the big picture is required by more than “just” a systems engineer, and the following checklist can support this:

- 1.1 What are the concrete needs you have as a stakeholder?
- 1.2 Have you identified other internal stakeholders?
- 1.3 Are there strict requirements on the eventual integration of solutions with problems?
- 1.4 What resources are you willing to allocate?
- 1.5 Are the possibilities to solve the problem without collaboration exhausted?
- 1.6 Have sufficient pre-studies been made to understand the scope?
- 1.7 How can the collaboration success be measured?

## 5.2 | Investigate

*Alice has framed her problem, and has written a problem description. Alice has confirmed with the company how much resources can be allocated, and has written a call for collaboration in a forum of researchers the company is part of. Bob reads the call, and wants to collaborate with Alice as the description matches with his work.*

With a framing of the internal context it is possible to reason about the collaborative opportunities with external partners. Ideally, potential collaborative partners would have their own framing, but that cannot be expected nor is it necessarily required. Instead, what is vital is that there is enough framing present to reason about suitability of collaborative candidates. As an example, it is quite common that collaborative projects between industry and academia spend significant project time in defining collaborative efforts *after* a project has already been funded [3]. In the case of Alice, there is a *problem* defined where one or more *solutions* are required. Even if Bob hasn't strictly defined the offered solution, *enough* of it can be inferred through communication. Therefore a necessary aspect of the investigation is the joint communication between partners to realise any potential barriers for collaboration. For example, Alice might mention that the company has a policy that inhibits scientific dissemination, which might make collaboration challenging for Bob who needs to publish papers to progress the PhD studies. Another example could be that the tools used by each partner are incompatible, perhaps the company Alice works at have invested in a tool that does not support the language that Bob's algorithm is written for. Additionally, collaboration is often performed in teams, and between teams [1]. While it might have been individuals that initiated the identification for collaboration, it rarely happens on a one-to-one basis, introducing a team dynamic perspective. Some differences between parties are also to be expected, nonetheless these differences must be brought to the surface to ensure that there is not *too large* a difference for collaboration *before* collaboration starts. Likewise, it is often good practice to jointly formulate the problem to be solved in collaboration [1, 6]. Therefore, some level of flexibility in the collaborative investigation might be required. It could be useful to use System Dynamics (SD) [60] as means to define and overview the influencing factors

among stakeholders, particularly the different reinforcing and balancing elements in the collaborative system/context. Some guiding questions in this process are the following:

- 2.1 What constraints or rules from the organization might influence collaboration?
- 2.2 What resources are you willing to allocate?
- 2.3 How much adaptation of the collaborative framing can be done?
- 2.4 Does the collaboration require additional partners to achieve coverage of the problem(s) defined using the offered solution(s)?
- 2.5 What type of value is useful for each partner, and how should this be realised?
- 2.6 Can the needs from each stakeholder be satisfied?
- 2.7 What teams are expected to collaborate?

## 5.3 | Negotiate

*Alice and Bob agree that collaboration would be beneficial. They involve their respective organizations and start collaborating using a standard agreement for collaborative research between Alice's division and Bob's academic group. Bob requires data from Alice to implement his algorithm.*

Identifying potential collaborative partners is a necessary step for collaboration. However, “simply starting to collaborate” is rarely appropriate as there might be concerns from either organization, in addition to the need to formulate a suitable collaborative mechanism. For Alice, the organization might consider to allocate 10% of time during the work week to be suitable. While for Bob, the University might expect a 100% focus due to the research being the primary concern for Bob. The alignment of resources and working processes is a predominant success factor for collaboration in industry [1, 57]. Similarly, there might be sensitive data involved necessitating formal contracts that requires integration of the organizations both Alice and Bob belong to. The negotiation is also a means of providing some insurance for the collaboration, in a sense that all parties agree on a scope of resources to provide. *Trust* is another aspect that is often essential for successful collaboration [6]. Part of the negotiation is the decision and definition of the collaborative mechanisms, which could refer to the type of project. In education science, for instance, a recent literature review [49] of research-practice partnerships (RPPs) identified three overarching collaborative mechanisms. Some partnerships focus on *inquiry*, working together to deepen their understanding of an issue. Others engage in *design*, jointly developing solutions to tackle a problem. Additionally, some partnerships use *dissemination*, leveraging their diverse expertise and experience to share insights and outcomes. This phase might also include a multitude of partners, for example considering larger collaborative research projects, where negotiations need to be had on multiple levels. It is also at this stage that a final cancellation can be made before the collaboration is launched, enabling an exit before significant resources are invested. While not desirable, Alice and Bob could save a lot of effort by realising collaboration is not

feasible before it starts, also enabling both parties to re-start the framing and investigation for collaboration quicker. In academic and industrial collaborations a common tension might be the academic freedom contra company competitiveness [61]. Bob might want to publish their findings transparently and open, while Alice and the company might want to keep findings internal to provide a competitive edge. Such concerns are vital to bring to the surface before starting to collaborate, and the following questions can assist in negotiating collaboration;

- 3.1 What is the timeline for the project? Is this feasible for all collaborative partners?
- 3.2 What should be done with the research results? Who owns what?
- 3.3 What agreements need to be in place from a legal perspective?
- 3.4 Are there concerns of the research requiring additional investigations? E.g., ethical concerns.
- 3.5 Under what conditions should the project terminate early? How is this measured?
- 3.6 What are shared and individual responsibilities in the collaboration?
- 3.7 What milestones or check-offs should the project have? Who is responsible? How often should they be made?
- 3.8 How will data be managed?

## 5.4 | Do

*Alice and Bob have started to work together. Alice gives Bob some data and problem description to work on. Bob works in the University lab and presents his findings at a quarterly check-off, where Alice realises Bob has solved a problem that does not exist.*

Eventually, collaboration should be *done*. Ideally, the act of performing collaboration should follow the what has been negotiated to the extent possible. While the collaborative mechanisms involved, along with partners and responsibilities, should be commonly understood, there are bound to be deviations from the expected plan. This is part of the reason why there is a need to continuously perform a framing, investigation, and negotiation as in agile practices & DevOps [55, 62]. Some contingency plans are part of negotiation, but there is still a need for the involved parties in collaboration to ask themselves a set of continuous questions about the collaboration. As each partner has their own context which partially does *not* overlap with one another, there is always some uncertainty between each of the partners. Likewise, unforeseen events might happen, like in the case of Alice realising Bob has worked on “the wrong thing”. Therefore, there is a need to perform a continuous evaluation, possibly impacting the execution of collaboration. It can also be the case that with new knowledge gained during collaboration impacts the desired outcomes, for example by realising that Bobs algorithm could solve more than one problem. We consider the following questions:

- 4.1 Are we working toward the same goal? If not, do we need to change something?

- 4.2 Are we on time? If not, how do we address this?
- 4.3 Are the collaborative partners still appropriate? If not, do we need to change the structure or participants?
- 4.4 Are we following the collaborative mechanism? If not, how do we adapt to still generate value?
- 4.5 Are we content with the current goals? If not, how do we re-scope?
- 4.6 Are there systems in place to support interruptions in collaboration? If not, what is required to support collaborative partners?
- 4.7 Are there unacceptable dependencies between partners in the collaboration? If so, how can these be addressed?

## 5.5 | Understand

*Bob has performed many experiments with the help of Alice. Through meticulous analysis, Bob has formally proved several advances toward accepted benchmarks in the research field, following well-known statistical methods. Bob shares his findings with Alice, who has no scientific background.*

Through the act of *doing*, new insights are gained for each of the partners. Nonetheless, these insights are often attached to specific partners and their tools and signs. An essential part of the collaboration is the extraction of this knowledge and formulation in commonly held understandings to increase the aggregated *value*. In the case of Bob, Alice might have been in need of a document without technical details since corresponding stakeholders at the organization are not aligned with the language in complex scientific publications. Likewise, this process is innately related to the creation of value and how it can be increased. Sometimes, science is discussed through the lens of *impact* [63], acknowledging that valuable science should expand beyond specific scientific communities. The transferral of knowledge gained from each partner to the larger collective collaboration is a means of promoting value generation. The learning mechanisms are a facilitator for this understanding and is something that should be continuously monitored and updated. As a baseline partners can draw on the learning mechanisms (described in Section 3) (a) *identification*, that redefines intersecting practices, legitimizing differences and coexistence, (b) *coordination*, that ensures efficient cooperation through communication, organization, and routines, (c) *reflection*, that fosters mutual understanding by sharing and adopting perspectives and (d) *transformation*, that creates change by merging perspectives and developing new, shared practices. To further enable this process, the following checklist can be used;

- 5.1 Is data captured and documented in a meaningful way?
- 5.2 Are collaborative results communicated in appropriate language to each stakeholder?
- 5.3 Are there stakeholders not originally considered that have emerged during collaboration?
- 5.4 Are there appropriate mechanisms to learn? If not, how can they be constructed?

## 5.6 | Share

*Alice and Bob have gained many insights during their collaboration. Bob would like to submit a research article laying out the research in a transparent manner, describing the original practice and potential improvements using their new algorithm. Alice is worried that this research article could be seen as reflecting negatively on the company and advises Bob not include company specifics.*

To maximize the generated value it needs to be shared. For many partners, the very act of sharing might be one of the main value offerings, as is the case for researchers with scientific articles. Likewise, companies gain little from insights “locked” to specific personnel as opposed to the wider organization. Nonetheless, the mechanism for sharing value is not straightforward and often might clash between collaborative parties [3, 61]. The company Alice works for might prioritize the protection of their image or IP over sharing the experiences gained during the collaboration. Likewise, Bob might not have an interest in sharing insights apart from the academic dissemination expected in research. It might also be that sharing and dissemination cannot be fully planned for until certain progress has been made in collaboration. Initially, Alice might have thought the value was only relevant for a specific problem, but later realized other parts of the company might find value in the collaboration as well. Nonetheless, the scope of sharing is largely negotiated in the “negotiate” stage of FINDUS. The act of sharing is also a precursor for future collaboration, either with the same parties or with new ones. Therefore, sharing of collaborative insights and results is important also for future collaboration, and not only for the current collaboration and generated value. It might also have been that the scope of the project has shifted from the start, and through the act of sharing it becomes more transparent for all stakeholders what actually was the main output. Through sharing, the wider community can also partake in the insights gained, which might provide value on a wider scale. A result of this is that the act of sharing might need to be performed multiple times for different intended audiences. The following checklist can assist in this activity.

- 6.1 Is there any sensitive information to share? What actions are necessary to ensure ethical and useful sharing?
- 6.2 What mediums should be used for sharing?
- 6.3 How do insights gained impact future collaboration/investigations?
- 6.4 Who should have access to what is shared?
- 6.5 What stakeholders and communities might benefit from the knowledge sharing?
- 6.6 Who should perform the act of sharing, and to what communities using what mediums?

By following these steps in the FINDUS process practitioners are offered a pragmatic means of applying the underlying theories and principles of activity theory. The process is kept generally high-level, and we welcome any extension for the specific implementation.

## 5.7 | Activity Theory and FINDUS

Connecting back to the original discussion on activity theory, we believe FINDUS can act as a guide and support to integrate collaborative concepts in a straightforward manner. The FINDUS process itself a high-level process framework that incorporates activity theory concepts to a more engineering appropriate framing and wording. The model itself is inspired from the DevOps concept [55], where there is a separation from the *development* and *operation* with their own continuous processes, but nonetheless acknowledging the coupling and interaction. In the case of FINDUS, we consider the separation from configuring/enabling collaboration and the performance and analysis of collaboration. Each of these processes are of course running continuously in parallel, but there is also the iterative connection between them. Therefore we take inspiration from the agile & DevOps conceptualization as a means of supporting intuitive representation.

Through the FINDUS process we embed the terminology of activity theory and collaboration directly to a number of processes and items on a check-list. Specifically, we map the role of the different elements and aspects of collaboration into discrete stages and how they manifest and/or relate to the collaborative partners. Aligning the theory and terminology to a gated-process we believe could be a means of offering tangible support in applying and reasoning about activity theory.

A reason for this definition is that activity theory concepts are aligned more with the needs and terminology of educational sciences. Using Alice and Bob to exemplify how these concepts can be translated and discussed in the context of SE, and more generally engineering, is an important part of the FINDUS definition. The process itself considers six stages of collaboration we believe to be generic enough to apply to the wider community. In case the stages or process is not applicable we also encourage tailoring the process where needed.

## 6 | Discussion

The conceptual model we propose is generic in an attempt to not limit its applicability, while still providing meaningful framing of collaboration. Further expansion on the model could perhaps aim to encode the concepts more formally, and is something that could be explored in future work (perhaps through a meta-model or ontology). A more formal application could be means of integration with MBSE, which is seen as a significant pillar of future SE [64, 65]. Integration with MBSE could be done in several ways, but comparing FINDUS with other processes for collaboration such as DevOps for MBSE [66], might provide a starting point for practical integration. These initial concepts could then be used as a means to formulate aspects of collaboration from a theoretical perspective. Similarly, we aim to not overload potential collaborative practitioners through overly complex theoretical foundation. Involvement and participation of a broad range of stakeholders is a necessity for broader collaboration, for example explored in the field of participatory modeling [67, 68]. Therefore, this conceptual model should be applicable for managers and other decision-makers in defining

collaborative efforts between parties, and not only the individual collaborative partners.

This work has been framed from the perspective of including aspects of educational science in engineering, but it could likewise be flipped to consider the inclusion of engineering in educational sciences. One such aspect could be the formulation of *models*, as there is a rich history of formal modeling for both software and systems engineering [53, 69]. These insights could be of some assistance for the existing and future conceptual/formal models proposed in the social science domain. Likewise, the collaborative mechanisms for either field (or others) are an ample avenue to extend and integrate new knowledge across domains. At an even higher level, the fundamental principles and theories of disciplines can have positive impacts on one-another. An anecdotal example is SE, which undoubtedly is an engineering discipline, yet borrows a large part of the definitions and principles of *thinking* from social sciences [21]. In some sense, as systems become more complex in engineering, we require not only new ways of engineering, but also to organize, collaborate, communicate, and think about this complexity, and here there are many learnings from the social sciences. As mentioned earlier in this article, when considered from the product-manufacturing point of view, SE can be seen as a process-centric discipline [22]. A commonly reported success factor in collaboration is through framing collaboration as something existing past a specific project [3, 6]. Of course, collaboration eventually ends, and possibly results in completely new directions as a result of the sharing process. So far in this article we have adopted a relatively positive outlook on collaboration. There are however threats to collaboration between industry and academia that stems from the basic principles of collaboration. A large concern from academics is that of maintaining academic freedom during collaboration [48]. Industry does not have an explicit need for full transparency through academic publishing, and in many cases actively pushes against this transparency [3, 6]. Therefore a robust method for designing and performing collaboration can be a useful tool in highlighting potential barriers *before* starting collaboration, and as a result offer opportunities to successfully navigate past these barriers. Here we believe that FINDUS can be a support for many collaborative contexts. At the same time, collaboration is not a *solution* to all problems. Collaboration between external partners is a costly endeavour as many resources need to be invested, and often has a highly uncertain future in terms of value [70].

The ideas presented in this article have been conceptualized for a generic case of collaboration. Although we discuss industry and academia in terms of SE, we have made a conscious effort to apply the theory in a generic way to not limit the potential use in other domains. Also, we provide a process for how practitioners could apply the collaborative framework in a systematic fashion. We take experiences from our own collaborative experiences and to combat this bias we perform an external validation through a workshop with experts on the topics. Notably, this workshop included experts on collaboration from the “Research on Collaboration (RoC)” group at Mälardalen University, including experts on collaboration from engineering, business management, and innovation management. The workshop consisted on discussing the figures and theories presented in this article in addition to an early draft, and used a short presentation and a joint discussion on

the topics presented during a 90 minute slot. Comments in regard to the draft and main ideas were collected beforehand through an internal peer-review of this document to help structure and condense the workshop. The feedback from the workshop helped to define the conceptual models in addition to framing various concepts part of collaborative research. Particularly, through the workshop it was agreed that the main merging of theories and ideas across the different research fields was a valuable contribution, and it was suggested to expand on the Alice and Bob example.

## 6.1 | Related Work

In this section we place our own model in relation to other established models and approaches for collaboration between industry and academia engineering fields to give the reader a better sense of the conversation we are contributing to. In the engineering field there are several such models that we need to highlight that has made significant contributions to understanding and improving collaboration between industry and academia. For instance Sannö et al. [1] discuss experiences of industrial PhD students in Sweden and collaboration through the Swedish Knowledge Foundation co-production model. While they offer useful insights and attach them to an established model, the model is abstract and difficult to strictly apply, instead used as a conceptual view of collaboration. The industry as a laboratory method is another form of advocating for industry-academia collaboration through explicit methods [25]. Indeed, applying the industry as a laboratory method has seen success in the SE context when teaching broader SE skills [26]. Nevertheless, differences between the academic and industrial settings can cause frictions in the collaboration, for example if a PhD student is doing a lot of the practical work. There also exist larger initiatives to foster close collaboration between industry and academia, like TNO-ESI in the Netherlands,<sup>3</sup> SERC in the US,<sup>4</sup> RISE in Sweden,<sup>5</sup> and so forth. Sadovykh et al. [71] discuss the use of hackathons as part of incubating collaboration between partners in industry-academia projects. In their study hackathons are perceived as highly beneficial to kick-start collaboration and appreciated by both industrial practitioners and academic researchers. However, while hackathons are highly useful they are specific tool in the collaborative process and cannot be used to replace collaboration planning, nor are they suitable as the main collaborative mechanism. Marijan and Gotlieb [72] present the CERTUS model for industry-academia collaboration. The model presents an agile workflow to achieve research knowledge co-creation through continuous dialogue and problem-alignment. This model differs from ours in its foundational core, as we utilize activity theory while they instead rely on agile project management. Additionally, the approach is firmly rooted in SWE and expected in the research of software tools.

While the models and examples above have served the function to place this article in discussion with significant work in the engineering field, we similarly need to place this article in conversation with seminal theories that has contributed to how collaboration is viewed in Education sciences. For instance Communities of practice (CoP) is an established theory used to understand how and why people from different disciplines or organizations collaborate on a common issue or topic

[17, 73]. While CoP contributes with social learning aspects and how shared practices emerge through sustained interaction, it pays less attention to the systemic contradictions and power dynamics that activity theory explicitly addresses. Actor-Network Theory (ANT) [74] offers another perspective on collaboration by treating both human and non-human actors as equally important in networks of relations, adding the active roles of non-human actors to the conversation. The triple helix model has emerged in innovation studies [75], which along with the more recent quadruple helix has been used in several fields to study collaboration between industry, government, academia, and civil society [76]. This model has been seminal in pushing our understanding of how these institutions may interact. Other more local models – such as models for understanding research-practice partnerships in education [14, 15] – have also contributed with a more interdisciplinary discussion on collaborative efforts. However, these models are relatively early in development and do not go into the same nuanced characterization of the system that sets the boundaries and opportunities for collaboration that activity theory does.

In sum, while several of these could provide relevant insights into the topic of this article, and have been seminal in our current understanding of collaboration, we found that Engeström's [16] activity theory, in a way the others do not, could help make explicit the system that creates the challenges with collaboration discussed in previous sections. Its strength lies in its ability to simultaneously consider individual and collective transformation, historical development, and systemic contradictions while providing analytical tools for understanding how different elements of an activity system interact and evolve.

## 7 | Conclusion

This article discusses the need for collaboration in Systems Engineering (SE). The notion of collaboration is detailed through a generic view, applied in the context of SE. Findings from educational sciences provide support to reason about collaboration through various theories and developed models. By defining a conceptual view of collaboration, we leverage an existing model for activity systems founded in educational sciences and propose a conceptual framework for activity systems in SE. This framework bridges theory from educational science and applies it to collaboration in an engineering context. Through this transferral of knowledge we push for a increased understanding and integration of collaboration across research disciplines and contexts. This framework can be used by researchers and practitioners in collaborative projects to strengthen their understanding of their roles and potential value in collaboration through applying a thinking centred around mutually beneficial collaboration. To practically support the frameworks application, we create the Frame, Investigate, Negotiate, Do, Understand, Share (FINDUS) process and discuss the process steps in detail. FINDUS is supported by several lists of guiding questions to support practitioners in reasoning and thinking about collaboration.

In future work this framework could be further extended to encompass a more fine grained example, perhaps mapping an existing collaborative effort toward the concepts. Collaborative efforts could also include this framework as part of the overall

project activities to define collaborative boundaries. Finally, practitioner feedback on the concepts and process through interview or focus group studies would be highly beneficial and help provide feedback for the future development of the framework.

---

### Acknowledgments

This work was supported by the Research on Collaboration (RoC) research environment, which provided research time and reviews contributing to the completion of this study.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

### Endnotes

<sup>1</sup>Read more about INCOSE events at: <https://www.incose.org/events>

<sup>2</sup>Read more at: [https://research-and-innovation.ec.europa.eu/funding\\_en](https://research-and-innovation.ec.europa.eu/funding_en)

<sup>3</sup><https://esi.nl/about-us/tno>

<sup>4</sup><https://sercuarc.org/about/>

<sup>5</sup><https://www.ri.se/en/about-rise>

### References

1. A. Sannö, A. E. Öberg, E. Flores-Garcia, and M. Jackson, "Increasing the Impact of Industry–Academia Collaboration Through Co-Production," *Technology Innovation Management Review* 9, no. 4 (2019): 37–47.
2. L. Assbring and C. Nuur, "What's in It for Industry? A Case Study on Collaborative Doctoral Education in Sweden," *Industry and Higher Education* 31, no. 3 (2017): 184–194.
3. J. Cederbladh, R. Eramo, V. Muttillio, and P. E. Strandberg, "Experiences and Challenges From Developing Cyber-Physical Systems in Industry-Academia Collaboration," *Software: Practice and Experience* (2024).
4. B. Grimpe, B. C. Stahl, C. Ten Holter, et al., "From Collaborative to Institutional Reflexivity: Calibrating Responsibility in the Funding Process," *Science and Public Policy* 47, no. 5 (2020): 720–732.
5. C. Miller and Y. Ahmad, "Collaboration and Partnership: An Effective Response to Complexity and Fragmentation or Solution Built on Sand?" *International Journal of Sociology and Social Policy* 20, no. 5/6 (2000): 1–38.
6. P. E. Strandberg, *Automated System-Level Software Testing of Industrial Networked Embedded Systems* (Malardalen University, 2021).
7. Y. Arayici and P. Coates, "A System Engineering Perspective to Knowledge Transfer: A Case Study Approach of BIM Adoption," *Virtual Reality-Human Computer Interaction* 2006 (2012): 179–206.
8. W. R. Nyemba, C. Mbohwa, and K. F. Carter, *Bridging the Academia Industry Divide: Innovation and Industrialisation Perspective Using Systems Thinking Research in Sub-Saharan Africa* (Springer, 2021).
9. INCOSE Technical Operations, *Systems Engineering Vision 2035* (International Council on Systems Engineering).
10. V. Garousi, K. Petersen, and B. Ozkan, "Challenges and Best Practices in Industry-Academia Collaborations in Software Engineering: A Systematic Literature Review," *Information and Software Technology* 79 (2016): 106–127.

11. L. Beckett, "Raising Teachers' Voice on Achievement in Urban Schools in England: An Introduction," *Urban Review* 46 (2014): 783–799.
12. E. Farley-Ripple, H. May, A. Karpyn, K. Tilley, and K. McDonough, "Rethinking Connections Between Research and Practice in Education: A Conceptual Framework," *Educational Researcher* 47, no. 4 (2018): 235–245.
13. U. Utbildningsdepartementet, "Skollagen, sfs 2010: 800," *Stockholm: Utbildningsdepartementet* (2010).
14. C. C. Farrell, W. R. Penuel, A. Allen, et al., "Learning at the Boundaries of Research and Practice: A Framework for Understanding Research–Practice Partnerships," *Educational Researcher* 51, no. 3 (2022): 197–208.
15. K. Yamashiro, L. Wentworth, and M. Kim, "Politics at the Boundary: Exploring Politics in Education Research–Practice Partnerships," *Educational Policy* 37, no. 1 (2023): 3–30.
16. Y. Engeström, "Expansive Learning at Work: Toward an Activity Theoretical Reconceptualization," *Journal of Education and Work* 14, no. 1 (2001): 133–156.
17. E. Wenger, *Communities of Practice: Learning, Meaning, and Identity* (Cambridge University Press, 1999).
18. J. E. Austin and M. M. Seitanidi, "Collaborative Value Creation: A Review of Partnering Between Nonprofits and Businesses: Part I. Value Creation Spectrum and Collaboration Stages," *Nonprofit and Voluntary Sector Quarterly* 41, no. 5 (2012): 726–758.
19. Y. Engeström and A. Sannino, "Studies of Expansive Learning: Foundations, Findings and Future Challenges," *Educational Research Review* 5, no. 1 (2010): 1–24.
20. R. D. Arnold and J. P. Wade, "A Definition of Systems Thinking: A Systems Approach," *Procedia Computer Science* 44 (2015): 669–678.
21. D. D. Walden, T. Shortell, G. Roedler, et al., *INCOSE Systems Engineering Handbook*, 5th ed. (Wiley, 2023).
22. R. Haberfellner, P. Nagel, M. Becker, A. Büchel, and H. von Massow, *Systems Engineering* (Springer, 2019).
23. R. S. Peres, X. Jia, J. Lee, K. Sun, A. W. Colombo, and J. Barata, "Industrial Artificial Intelligence in Industry 4.0-Systematic Review, Challenges and Outlook," *IEEE Access* 8 (2020): 220121–220139.
24. A. Sundström, G. Widforss, M. Rosqvist, and A. Hallin, "Industrial PhD Students and Their Projects," *Procedia Computer Science* 100 (2016): 739–746.
25. C. Potts, "Software-Engineering Research Revisited," *IEEE Software* 10, no. 5 (2002): 19–28.
26. G. Muller and W. Heemels, "Five Years of Multi-Disciplinary Academic and Industrial Research: Lessons Learned," in *Proceedings of the 5th Annual Conference on Systems Engineering Research (CSER 2007)*, March 14–16, 2007 (Springer, 2007).
27. S. Sjölund and J. Lindvall, "Examining Boundaries in a Large-Scale Educational Research–Practice Partnership," *Journal of Educational Change* 25, no. 2 (2024): 417–443.
28. R. B. Freeman and W. Huang, "Collaboration: Strength in Diversity," *Nature* 513, no. 7518 (2014): 305–305.
29. C. H. Liao, "How to Improve Research Quality? Examining the Impacts of Collaboration Intensity and Member Diversity in Collaboration Networks," *Scientometrics* 86, no. 3 (2011): 747–761.
30. W. R. Penuel, R. Riedy, M. S. Barber, D. J. Peurach, W. A. LeBouef, and T. Clark, "Principles of Collaborative Education Research With Stakeholders: Toward Requirements for a New Research and Development Infrastructure," *Review of Educational Research* 90, no. 5 (2020): 627–674.
31. V. Tseng, J. Q. Easton, and L. H. Supplee, "Research–Practice Partnerships: Building Two-Way Streets of Engagement," *Social Policy Report* 30, no. 4 (2017): 1–17.
32. C. E. Coburn and W. R. Penuel, "Research–Practice Partnerships in Education: Outcomes, Dynamics, and Open Questions," *Educational Researcher* 45, no. 1 (2016): 48–54.
33. S. F. Akkerman, L. H. Bronkhorst, and I. Zitter, "The Complexity of Educational Design Research," *Quality & Quantity* 47 (2013): 421–439.
34. A. Gamoran, "Advancing Institutional Change to Encourage Faculty Participation in Research–Practice Partnerships," *Educational Policy* 37, no. 1 (2023): 31–55.
35. K. Klein, "It's Complicated: Examining Political Realities and Challenges in the Context of Research–Practice Partnerships From the School District Leader's Perspective," *Educational Policy* 37, no. 1 (2023): 56–76.
36. S. McGeown, E. Oxley, Love to Read Practice Partners, J. Ricketts, and L. Shapiro, "Working at the Intersection of Research and Practice: The Love to Read Project," *International Journal of Educational Research* 117 (2023): 102134.
37. C. C. Farrell, K. L. Davidson, M. Repko-Erwin, et al., "A Descriptive Study of the IES Researcher–Practitioner Partnerships in Education Research Program: Final Report," *National Center for Research in Policy and Practice*, Technical Report no. 3 (2018).
38. J. B. Cousins and M. Simon, "The Nature and Impact of Policy-Induced Partnerships Between Research and Practice Communities," *Educational Evaluation and Policy Analysis* 18, no. 3 (1996): 199–218.
39. C. Mull and K. Adams, "The Identification, Influence, and Impact of Boundary Spanners Within Research-Practice Partnerships," *Exploring the Community Impact of Research-Practice Partnerships in Education* (2017): 271–291, <https://doi.org/10.1108/978-1-68123-830-2>.
40. S. Lillejord and K. Børte, "Partnership in Teacher Education—A Research Mapping," *European Journal of Teacher Education* 39, no. 5 (2016): 550–563.
41. T. S. Proitz and E. Rye, "Actor Roles in Research–Practice Relationships: Equality in Policy–Practice Nexuses," in *From Education Policy to Education Practice: Unpacking the Nexus* (Springer International Publishing, 2023), 287–304.
42. M. Serder and M. Malmström, "Vad talar vi om när vi talar om praktisknära forskning?" *Pedagogisk forskning i Sverige* 25, no. 1 (2020): 106–109.
43. P. Magnusson and M. Malmström, "Practice-Near School Research in Sweden: Tendencies and Teachers' Roles," *Education Inquiry* 14, no. 3 (2023): 367–388.
44. I. Carlgren, "Praxisnära forskning—varför, vad och hur," *Forskning av denna världen II* 7 (2005): 7–17.
45. I. Eriksson, "Lärares medverkan i praktisknära forskning: Förutsättningar och hinder," *Utbildning och Lärande/Education and Learning* 12, no. 1 (2018): 27–40.
46. Á. P. A. Salazar and M. Cabrera-Ríos, "Building Bridges Between Academia and Industry for Industrial and Systems Engineering in Latin America," *Latin American & Caribbean Journal of Engineering Education* 5, no. 1 (2011): 7–11.
47. E. Honoré-Livermore, K. R. Fossum, and E. Veitch, "Academics' Perception of Systems Engineering and Applied Research Projects," *Systems Engineering* 25, no. 1 (2022): 19–34.
48. M. Chankseliani and T. McCowan, "Higher Education and the Sustainable Development Goals," *Higher Education* 81, no. 1 (2021): 1–8.
49. S. Sjölund, J. Lindvall, M. Larsson, and A. Rye, "Mapping Roles in Research-Practice Partnerships—A Systematic Literature Review," *Educational Review* 75, no. 7 (2023): 1490–1518.
50. S. F. Akkerman and A. Bakker, "Boundary Crossing and Boundary Objects," *Review of Educational Research* 81, no. 2 (2011): 132–169.
51. S. Akkerman and T. Bruining, "Multilevel Boundary Crossing in a Professional Development School Partnership," *Journal of the Learning Sciences* 25, no. 2 (2016): 240–284.

52. U. S. Bititci, V. Martinez, P. Albores, and J. Parung, "Creating and Managing Value in Collaborative Networks," *International Journal of Physical Distribution & Logistics Management* 34, no. 3/4 (2004): 251–268.
53. A. M. Madni and M. Sievers, "Model-Based Systems Engineering: Motivation, Current Status, and Research Opportunities," *Systems Engineering* 21, no. 3 (2018): 172–190.
54. P. De Saqui-Sannes, R. A. Vingerhoeds, C. Garion, and X. Thirioux, "A Taxonomy of MBSE Approaches by Languages, Tools and Methods," *IEEE Access* 10 (2022): 120936–120950.
55. C. Ebert, G. Gallardo, J. Hernantes, and N. Serrano, "DevOps," *IEEE Software* 33, no. 3 (2016): 94–100.
56. C. M. Branson, "Achieving Organisational Change Through Values Alignment," *Journal of Educational Administration* 46, no. 3 (2008): 376–395.
57. R. Cross and I. Carboni, "When Collaboration Fails and How to Fix It," *MIT Sloan Management Review* 62, no. 2 (2021): 24–34.
58. G. Muller and G. M. Bonnema, "Teaching Systems Engineering to Undergraduates; Experiences and Considerations," in *INCOSE International Symposium*, vol. 23, no. 1 (Wiley Online Library, 2013), 98–111.
59. G. Muller, L. van Veen, and J. van den Aker, "Systems Engineering Education: From Learning Program to Business Value," *Systems* 11, no. 10 (2023): 510.
60. J. W. Forrester, "System Dynamics, Systems Thinking, and Soft OR," *System Dynamics Review* 10, no. 2-3 (1994): 245–256.
61. A. Cox, "Collaboration and Resistance: Academic Freedom and Non-Tenured Labor," in *Forum: Issues About Part-Time and Contingent Faculty*, vol. 22, no. 1 (NCTE, 2018), A4–A13.
62. P. Abrahamsson, O. Salo, J. Ronkainen, and J. Warsta, "Agile Software Development Methods: Review and Analysis," *arXiv preprint arXiv:1709.08439* (2017).
63. D. Wang, C. Song, and A.-L. Barabási, "Quantifying Long-Term Scientific Impact," *Science* 342, no. 6154 (2013): 127–132.
64. K. X. Campo, T. Teper, C. E. Eaton, A. M. Shipman, G. Bhatia, and B. Mesmer, "Model-Based Systems Engineering: Evaluating Perceived Value, Metrics, and Evidence Through Literature," *Systems Engineering* 26, no. 1 (2023): 104–129.
65. K. Henderson and A. Salado, "Value and Benefits of Model-Based Systems Engineering (MBSE): Evidence From the Literature," *Systems Engineering* 24, no. 1 (2021): 51–66.
66. T. Mathieson, T. Mazzuchi, and S. Sarkani, "The Systems Engineering DevOps Lemniscate and Model-Based System Operations," *IEEE Systems Journal* 15, no. 3 (2020): 3980–3991.
67. A. Voinov, K. Jenni, S. Gray, et al., "Tools and Methods in Participatory Modelling: Selecting the Right Tool for the Job," *Environmental Modelling & Software* 109 (2018): 232–255.
68. L. Basco-Carrera, A. Warren, E. van Beek, A. Jonoski, and A. Giardino, "Collaborative Modelling or Participatory Modelling? A Framework for Water Resources Management," *Environmental Modelling & Software* 91 (2017): 95–110.
69. D. C. Schmidt, "Model-Driven Engineering," *IEEE Computer, Computer Society* 39, no. 2 (2006): 25–31.
70. S. M. Wagner, A. Eggert, and E. Lindemann, "Creating and Appropriating Value in Collaborative Relationships," *Journal of Business Research* 63, no. 8 (2010): 840–848.
71. A. Sadovykh, D. Truscan, P. Pierini, et al., "On the Use of Hackathons to Enhance Collaboration in Large Collaborative Projects: -A Preliminary Case Study of the MegaM@RT2 EU Project," in *Proceedings of 2019 Design, Automation & Test in Europe Conference & Exhibition (DATE)* (IEEE, 2019), 498–503.
72. D. Marijan and A. Gotlieb, "Industry-Academia Research Collaboration in Software Engineering: The Certus Model," *Information and Software Technology* 132 (2021): 106473.
73. J. Lave and E. Wenger, *Situated Learning: Legitimate Peripheral Participation* (Cambridge University Press, 1991).
74. B. Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (Oxford University Press, 2007).
75. L. Leydesdorff and H. Etzkowitz, "The Triple Helix as a Model for innovation studies," *Science and Public Policy* 25, no. 3 (1998): 195–203.
76. N. Hasche, L. Höglund, and G. Linton, "Quadruple Helix as a Network of Relationships: Creating Value Within a Swedish Regional Innovation System," *Journal of Small Business & Entrepreneurship* 32, no. 6 (2020): 523–544.