



# Expansive Pathways in Co-Creative Problem Solving: Emergence of Transformative Agency by Double Stimulation in Complex Learning Environments in Higher Education

Guillaume Isaac

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# THÈSE DE DOCTORAT

## Trajectoires expansives en résolution de problème co-créative

Émergence de l'agentivité transformatrice par double stimulation en  
activité complexe d'apprentissage en enseignement supérieur

**Guillaume ISAAC**

Laboratoire d'Innovation et Numérique pour l'Éducation (LINE)

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d'Université Côte d'Azur

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INNOVATION CENTRE  
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## **Expansive Pathways in Co-Creative Problem Solving**

Emergence of Transformative Agency by Double Stimulation in Complex Learning

Environments in Higher Education

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## **Abstract**

In both higher education and the workforce, the ability to solve problems creatively is becoming increasingly important (Hakkarainen, 2013; Yang et al., 2022). Scholars have been approaching this phenomenon from a variety of perspectives to study and understand complex dynamics at play when solving complex, ill-defined, open-ended problems (Frensch & Funke, 2014; Funke et al., 2018). This dissertation examines a specific problem type that, from the viewpoint of higher education, calls for problem solvers to work collaboratively and creatively to address issues from the real world (Halpern & Dunn, 2021; Nowell et al., 2020; Sarathy, 2018). This research is based on a naturalistic inquiry approach (Lincoln & Guba, 1985; Yamagata-Lynch, 2010) and Cultural Historical Activity Theory (Engeström, 2015; Engeström et al., 1999; Sannino et al., 2009) through a conceptual framework based on Transformational Agency by Double Stimulation (Sannino, 2015b, 2016, 2022; Sannino & Laitinen, 2015). This research aims to understand how participants in complex learning environments across higher education and private sector (Yamazumi, 2013, 2020) negotiated a common purpose, an activity we identified as problem definition or problem finding (Reiter-Palmon, 2017; Sannino, 2023). The findings from this PhD study provide insight in the pathways used in heterogenous and temporary groups (Engeström, 2008; Kerosuo, 2017, 2018) across the classroom and the real world. These pathways show how resistances and expansion may emerge and evolve over time. We identify five problem-solving units, and presents the collective pathways used by the collective participants to overcome competing options and difficulties (Barma et al., 2015, 2023) in a phase dedicated to the iteration and creation of an object (Engeström, 1996). This PhD study further identifies clusters of discursive manifestations of contradictions (Engeström & Sannino, 2011), and expansive learning actions (Haapasaari et al., 2016) to characterize the emergence and

evolution of transformative agency by double stimulation over time. It specifies the role of *knots* as essential to the problem-solving process.

*Keywords:* problem solving, creativity, co-creativity, transformative agency, double stimulation

## Résumé

Dans l'enseignement supérieur comme dans le monde du travail, la capacité à résoudre des problèmes de manière créative devient de plus en plus importante (Hakkarainen, 2013 ; Yang et al., 2022). Les chercheurs ont abordé ce phénomène sous différents angles afin d'étudier et de comprendre les dynamiques complexes en jeu lors de la résolution de problèmes complexes, mal définis et ouverts (Frensch & Funke, 2014 ; Funke et al., 2018). Cette thèse examine un type de problème spécifique qui, du point de vue de l'enseignement supérieur, appelle les résolveurs de problèmes à travailler en collaboration et de manière créative pour résoudre des problèmes du monde réel (Halpern & Dunn, 2021 ; Nowell et al., 2020 ; Sarathy, 2018). Cette recherche est basée sur une approche d'enquête naturaliste (Lincoln & Guba, 1985 ; Yamagata-Lynch, 2010) et la Théorie Historico-Culturelle de l'Activité (Engeström, 2015; Engeström et al., 1999; Sannino et al., 2009) à travers un cadre conceptuel basé sur l'Agentivité Transformative par Double Stimulation (Sannino, 2015, 2016, 2022 ; Sannino & Laitinen, 2015), cette recherche vise à comprendre comment les participants à des environnements d'apprentissage complexes impliqués dans une activité d'apprentissage hybride entre l'enseignement supérieur et le secteur privé (Yamazumi, 2013, 2020) ont négocié un objectif commun, une activité que nous avons identifiée comme la définition ou la recherche de problèmes (Reiter-Palmon, 2017 ; Sannino, 2023). Les résultats de cette étude donnent un aperçu de l'émergence de trajectoires expansives dans les groupes hétérogènes et temporaires. Ces trajectoires montrent comment les résistances et l'expansion émergent et évoluent au fil du temps. L'étude identifie cinq chaînes de résolution de problèmes (Lund & Vestøl, 2020), et présente les trajectoires collectives utilisées par les participants pour résoudre des conflits de motifs (Barma et al., 2015, 2023) dans une phase consacrée à l'itération et à la création d'un objet (Engeström, 1996). L'étude identifie en outre des

groupes de manifestations discursives de contradictions (Engeström & Sannino, 2011) et d'actions d'apprentissage expansives (Haapasaari et al., 2016) pour caractériser l'émergence et l'évolution de l'agentivité transformatrice par double stimulation au fil du temps. Il précise le rôle du travail en nœuds comme essentiel au processus de résolution de problèmes.

*Mots-clés* : résolution de problèmes, créativité, co-créativité, agentivité transformatrice, double stimulation

## Publications

### <sup>1</sup> [ACL\_01]

Isaac, G., Romero, M., & Barma, S. (2022). Understanding co-creativity in real-world problem solving in project-based learning in higher education. *Revue internationale du CRIRES : innover dans la tradition de Vygotsky*, 6(3), 86-99.

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### [ACL\_02]

Isaac, G., Barma, S., & Romero, M. (2022). Cultural historical activity theory, double stimulation, and conflicts of motives in education science : Where have we been? (2012-2021). *Revue internationale du CRIRES : innover dans la tradition de Vygotsky*, 5(2), 86-94.

<https://doi.org/10.51657/ric.v5i2.51287>

### <sup>2</sup>[ACTI\_01]

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<sup>1</sup> Peer-reviewed international or national journals

<sup>2</sup> Proceedings of international conferences



**[ACTI\_02]**

Isaac, G. Romero, M. & Barma, S. (2022, November). Conflicts of motives and contradictions in co-creative real-world problem-solving activities in higher education. *Finnish Educational Research Association Conference, Cultural Historical Special Interest Group: Fostering development and transformation in and beyond the academia with cultural-historical activity theory.*

**[ACTI\_03]**

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## List of terms

*Artificial Photosynthesis Technology*

APT, 97

carbon dioxide

CO<sub>2</sub>, 97

Cultural-Historical Activity Theory

CHAT, 27

Developmental Work Research

DWR, 2

Digital Systems for Humans

DS4H, 96

Discursive Manifestations of Contradictions

DMC, 3

Expansive Learning Actions

ELA, 3

Istituto Italiano di Tecnologia

IIT, 407

Large Group Meetings

LGM, 103

Small Group Meetings

SGM, 103

Stimulated Recall Interviews

SRI, 412

Sustainable Development Goals

SDG, 8

Transformative Agency by Double Stimulation

TADS, 2

Università di Bologna

UniBo, 96

Université Côte d’Azur

UCA, 96

## 1 Chapter 1: Statement of the Problem

This PhD study finds its origin in the need for contemporary society to solve problems of increasing complexity (Funke, 2021). In a context of multiple challenges running over multiple dimensions of individual and collective activity (Sternberg et al., 2022) regarding both environmental (Bhaskar, 2002) and human dimensions (Pahl-Wostl et al., 2023), this research investigates the relation of societal issues to higher education (J. Foster & Yaoyuneyong, 2016; Halpern & Dunn, 2021; Hill et al., 2010) and questions the potential of the latter for transformation and expansion across academia and the real world (Engeström, 2020b). While topics of societal prevalence and their adoption as instructional strategies are still lacking formalization (Nowell et al., 2020), understanding how hybrid collectives composed of academic and professional members may model a new object of activity (Yamazumi, 2021) may contribute knowledge to the collective creative solving process of consequential problems (Funke, 2021). This research explores one aspect of collective creative problem solving: the formation of collective will (Sannino, 2015b) to expansively resolve conflicting motives (Barma et al., 2023) over a micro-cycle of expansive cycle (Engeström, 1996) dedicated to problem finding (Sannino, 2023). Problem finding in complex open-ended problems may require a complex process of identification of relevant information and discrepancies within a problem space (Mumford et al., 1996; Yang et al., 2022) while managing persistence over long stretches of time (Grohman et al., 2017; Nijstad et al., 2010). Indeed, problem finding may be the most important phase of problem solving; however, it remains understudied (Mumford & England, 2022).

In the first chapter, we introduce the problems posed by real-world, grand societal challenges and their relevance to higher education; in particular, we are interested in the way higher education participates in their resolution. The nature of problems is further defined, and

the social and scientific prevalence of developing so-called 21<sup>st</sup> century competences to respond to those challenges is discussed. We follow Admiraal and contributors (2019) who defined so-called 21<sup>st</sup> century competences as cognitive, affective, motor and regulative skills that may enable individuals and groups to deal with complex situations, such as co-creative problem solving involving competences such as creativity, collaboration, critical thinking and problem solving (Romero, 2017). Having described the characteristics of complex problem-solving when they involve different domains and fields, we then question the main avenues and challenges their introduction poses to higher education. The chapter proceeds to establish the prevalence of critical thinking, collaboration, creativity, problem solving as priorities in education such as the transformations required by climate change. Having asserted an agentic and transformative perspective, the chapter proceeds to link creativity, problem solving, critical thinking, and learning under a sociocultural perspective.

The second chapter presents the conceptual framework of the PhD study based on Developmental Work Research, and it introduces the coverage in the literature of the concepts used; it presents the inquiry framework leading to the research objectives and the research questions; systemic contradictions are asserted as major elements driving the dialectical process of expansion and transformation, and double stimulation is shown to be both a central epistemological principle and a method of collective regulation of volition. The inquiry framework rests on a thorough review of the literature on the uses of the model of Transformative Agency by Double Stimulation (TADS) (Engeström & Sannino, 2020; Sannino, 2015a, 2022) used to study the emergence of volitional action (Engeström et al., 2014) through the resolution of conflicting motives.

The third chapter is dedicated to the methodology of the research and presents the framework of analysis. We characterize the analysis, the data collected, and the sample of the study. The chapter also presents the prevalence of an  $S1 \leftrightarrow S2$  unit of analysis according to the necessity identified in the literature to reflect the totality of the phenomenon observed. Discursive Manifestations of Contradictions (DMC), Expansive Learning Actions (ELA), are subsequently delineated in chapter four which attempts to describe the emergence and evolution over time of TADS; we subsequently describe the TADS model.

The fifth chapter in this thesis discusses the relevance, the strength and the reach of the results and the theme of this PhD study. We further stress the primary contradictions of creativity, higher education, and sustainable development. The prevalence and relevance of relying on a dialectical framework to analyze and visualize the problem-solving process is further highlighted. Finally, chapter six concludes by introducing the scientific and practical contributions of the research, while highlighting the thoughts of the authors.

## **1.1 Context: Grand Societal Challenges and Higher Education**

In this section we seek to describe different types of problems identified in the literature; we integrate the various definitions and describe them as *runaway objects*. We then proceed to identify the types of problems that may be introduced and dealt with in higher education with the potential to benefit both learning and society at large. Among the main issues encountered in the literature, we introduce environmental issues as recurring and potentially fruitful avenues for higher education. We conclude this section by stating the challenges posed to higher education instruction by such runaway objects.

### 1.1.1 From Simple to Real-World Problems

*All life is problem solving* (Popper, 1999). Both in professional and personal contexts, humans solve problems daily (van Merriënboer, 2013). For Duncker and Lees (1945), problem solving refers to the actions required from an organism to reach a goal that it does not yet know how to reach, i.e., to breach an execution gap (Norman, 1986). According to Probst and contributors (1989), problems may be characterized according to the degree of their complexity and the clarity of their goals: *simple problems* comprise elements with limited interaction potential which are stable over time. *Complicated problems* are also composed of limited elements which interact in limited ways, and they may be solved through *routine problem solving*. *Complex problems*, on the other hand, may not be solved through routine thinking. They require solutions that do not yet exist, and these solutions depend on novel connections between the elements composing the problem, i.e., on a recombination based on prior knowledge of the participants, as neither of its initial and target states are known ahead of time.

Getzels (1979) defines problems according to the clarity and complexity of their goals and further suggests a typology of (a) *presented problem situations*, where a formulation and a solution already exists, and (b) *discovered problem situation* whereby the problem is not already formulated, nor pre-existing solutions are known. Finally, (c) *created problem situations* are situations whereby the formulation and subsequent solving process need to be actively pursued. Problems *in the real world* comprise a *given state* and multiple potential *goal states*, separated by constraints that prevent the organism from reaching the goal in a predetermined way. To reach the goal of a complex problem, problem solvers need to process information based on states of knowledge, operators and constraints which involves decision-making processes. For Mackinnon and Wearing (1980) complex problem solving *in the real world* involves the efficient interaction

between a solver and situational constraints related to the task at hand which mobilizes cognitive, emotional, personal and social abilities (Funke et al., 2018). Complex problem solving involves non-routine problem solving (Frensch & Funke, 2014) implied by the decision-making process in dealing with *real-world problems*. Critical challenges such as crises of our planet appear in a fragmented way in the literature and are covered in higher education. In this research, we are interested in addressing problems that are complex created problems admitting multiple solutions and complex decision-making processes (ECE, 2011; European Commission, 2012, 2017; OECD, 2014, 2018; Rieckmann, 2017). To better understand what the decision-making processes involved first requires understanding real-world problems. In the following section, we introduce wicked problems, real-world problems, grand societal challenges, consequential challenges, and runaway objects as instances of this phenomenon.

Rittel and Webber (1973) described *wicked problems* as a peculiar type of problem under ten criteria. (a) They may not be encapsulated by a definite formulation: their formulation is part of the problem itself. (b) They have no stopping rules and there is no end to the causal chain linking interacting parts of the problem. (c) Tentative solutions are inherently ambiguous as correctness may be determined by different parties involved in the solving process; (d) there is no ultimate test to a solution to a wicked problem as repercussions of a given solution may extend over a variety of fields and domains, which are impossible to control for or assess. (e) Implemented solutions necessarily leave traces and are therefore consequential. (f) There are no enumerable sets of solutions. (g) Wicked problems are unique and are therefore hardly generalizable from. (h) Every wicked problem is a consequence of another problem and therefore appears in an interlocked network of issues. (i) Wicked problems may be described in a variety of ways. (j) Wicked problem solvers have no right to be wrong due to the consequential nature of



the issues dealt with. Wicked problems may further engender wicked messes (Mitroff, 2020) whereby a web of interconnected problems may arise, as in the prime example of COVID-19 where political issues generated geopolitical issues, while sanitary and political spheres were generating social problems tightly connected to educational issues.

On the other hand, Sarathy (2018) describes real-world problems as a peculiar type of complex problem which is (a) *dynamic* and *discontinuous*, i.e., evolving over time in a nonlinear fashion. (b) They are composed of *subproblems*, which may be *overlapping*. (c) They are *ill-defined* “even when they are well defined” (p. 2), and they are (d) *open-ended*. The strategies required to address these problems are (e) *uncertain* as they are not known ahead of time. Furthermore, they require (f) continuous interactions between the solver and the environment. Finally, the solvers are expected to (g) iterate through *multiple impasses* and *discoveries*. The author sums up the process as *messy* and involving an interplay between *problem solving* and *creativity*.

Nowell and collaborators (2020) suggest *grand societal challenges* require coordinated, collaborative efforts between participants. The authors define grand challenges as (a) affecting large populations and (b) *complex*, i.e., involving various disciplines, fields, or domains. They occur over (c) long time spans and they display (d) *wickedness* i.e., they are composed of large-scale design problems that may admit several solutions; in this respect, (e) they may not admit simple solutions and (f) take long time spans to be solved, sometimes extending to future generations. The authors further describe grand challenges as (g) potentially solvable. *Grand societal challenges* may for instance include environmental issues, human health, global hunger, poverty, climate change, ageing societies, resource depletion or gender inequality. The World Economic Forum suggest the following challenges as further examples from a post-pandemic

world: extreme weather, pandemics, climate action failure, environmental damage, digital gaps, cyber failures, and crisis in lifestyles (McLennan, 2021). From another perspective, Funke (2021) describes consequential problems as *grand societal challenges* involving a large number of people on different scales e.g., climate change, distributive justice, world peace, world nutrition, pollution, or access to education (p. 13). The author characterizes consequential problems as (a) lacking clear goals, (b) admitting more than one solution, (c) requiring information for its solving to be actively searched for, and as (d) *dynamic* occurrences.

*Real-world problems* involve the participation of collaborating groups over different aspects of a problem and may be described as social processes involving humans and their environments. Addressing real-world issues is a process focused on the material world, and engages the responsibility of the participants, therefore mobilizing their ethical and moral sense. Furthermore, they require to reconcile a variety of potentially contradictory perspectives. Finally, *real-world problems* are embedded in a network of incidental activities and may occur over long stretches of time in dynamic processes implying both interruptions and insights. From a CHAT perspective, these open-ended, ill-defined problems may be described as *runaway objects* (Engeström, 2015). Engeström's definition encapsulates previous characteristics identified above in the following manner:

...objects so massively distributed in time and space as to transcend localization, such as climate change or pandemics. Runaway objects have the potential to escalate and expand up to a global scale of influence. They are objects that are poorly controlled and have far-reaching, unexpected effects. Such objects are often monsters: They seem to have a life of their own that threatens our security and safety in many ways. Runaway objects are contested objects that generate opposition and controversy. They can also be powerfully

emancipatory objects that open up radically new possibilities of development and well-being. There are typically numerous activity systems focused on or affiliated with a runaway object. But the object is pervasive and its boundaries are hard to draw (p. xxxvi).

In the next sections, we introduce the runaway object of global warming as a prevalent issue of our time closely connected to education in general (section 1.1.2). In section 1.1.3, we try to identify the prevalence of such *real-world problems* and runaway objects for higher education.

### ***1.1.2 The Runaway Object of Climate Change***

*Sustainable development* has been defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987, p. 1). The Paris agreement and the Sustainable Goals Development (United Nations Department For Economic And Social Affairs, 2017) call for six major fields of transformation to reach sustainability: (a) education, gender and inequality; (b) health, well-being and demography; (c) decarbonization of energy production and sustainable industry; (d) sustainable production of food and sustainable preservation of land, water and oceans; (e) sustainable management of cities and communities; and (f) digital means of managing sustainable development. Sachs and contributors (2019) further recognize the prevalence of climate action, sustainable cities and education as the most popular fields of transformation. Shulla (2020) further asserts the central role of education and its interconnection to the 17 goals.

SDGs may provide ground and potential for modern societal challenges and problems to be addressed from an educational perspective (Calvera-Isabal et al., 2023) and represent fruitful avenues for education (Avelar et al., 2019) through the following key competences: (a) systems thinking, (b) anticipatory competency, (c) normative competencies, (d) strategy competencies,

(e) collaboration competency, (f) critical thinking, (g) self-awareness and (h) integrated problem solving. However, no clear lines of guidance have been identified to engage in such global development (Agbedahin & Lotz-Sisitka, 2019), a problem which also permeates educational contexts (Hadjichambis et al., 2020, p. 2); classroom activities based on real-world problem submit higher education to high pressures caused by complexity, change and ambiguity (Kelly, 2023) and to bridge the gaps between environmental and economic spheres through active learning in the real world (Orr, 1994). However, for Boyer (1990), both society and higher education may benefit from continuous interaction, and the author (1990, 1996) warned about the potential disconnect between academics and wider communities, pleading for the application of new knowledge to solve real-world problems. Beyond the simple need to strengthen and develop a dynamic relation between academia and society, recent global challenges such as global warming have stressed the need and the opportunity to bridge the gap between the classroom and the real world. In this respect, action competence, service learning and civic engagement may represent fruitful avenues to actively engage in local issues (Monroe et al., 2023) and although community engagement in higher education has reached the unlikely status of global phenomenon (Mbah, 2016), it remains a rare occurrence (Olcoñ et al., 2023). *Academic service learning*, for instance, offers to integrate community service and pedagogical practice; it is a fast developing practice of volunteering and service engagement perspective to promote social justice (Tiippana et al., 2022). However, academic service learning may or may not involve the solving of open-ended, ill-defined problems, despite its potential to foster agency in participants (Monroe et al., 2023) and gain the ability to exert control through intentional pursuit of meaningful goals in social systems (Bandura, 2001). From this perspective, focusing on *agents* rather than *structure*, and therefore assuming an agentic perspective to promote

sustainability in citizenship implies higher education should promote the acquisition of relevant knowledge, skills, and competencies (Granados-Sánchez, 2023) both from the perspective of individual and a collective agency i.e., as socially coordinated efforts in social environments; it therefore promotes the ability to exert some control both over personal and institutional dimensions (Bandura, 2001).

### ***1.1.3 Runaway Objects in Higher Education***

From an educational perspective, developing agency in the age of the Anthropocene requires to link academic disciplines in ways that promote competences relating the individual to larger scale systems stressing potential fateful consequences (Monroe et al., 2023). However, the challenges of sustainability imply paradigm shifts and systemic redesign, which in turn require pedagogical methods to produce the necessary conditions for co-learning and collective agencies to emerge: education should not solely be a method to promote sustainable development, but it should also be part of the development itself (Lotz-Sisitka et al., 2015). Furthermore, according to Agbedahin and Lotz-Sisitka (2019), sustainable development itself should include intentional development and capacity building, i.e., opportunities for humans to develop agential capacity to effect socio-ecological change.

Tentative benefits brought by the integration of grand societal challenges as instructional strategies in higher education have not been established (Nowell et al., 2020). Ferraro (2015) called for more research on effective learning strategies to carry out work involving runaway objects and education, developing solutions and evaluating their impact. Addressing grand challenges may require the active pursuit of multiple perspectives and collaboration and may represent a fruitful avenue for higher education students to engage in creative problem solving in extended and distributed teams of collaborators (Nowell et al., 2020). Climate change as a

learning object is infused with a particular sense of urgency to transform society through education (Monroe et al., 2023). Moreover, today's complex working professional environments require higher education to prepare students to take on society's most urgent challenges (Nowell et al., 2020). Topical contemporary issues have been increasingly recognized to be multidisciplinary endeavors that rely on teamwork, communication and basic knowledge of the topics at hand; yet, classically designed curricula in higher education are still segmented by discipline in many universities (Rhee et al., 2014). As a result, problem-solving tasks traditionally remain focused on close-ended problems (Engeström, 2015) despite the fact that consequential, real world, open-ended and ill-defined problems may result in deep learning (Vest, 2008) and foster the development of collaborative problem solving competences through practical and relevant settings rife with the high dynamics characteristic of authentic situations (Jonassen et al., 2006). Grand challenges may also have a positive impact on the quality and meaning of learning experiences which may in turn have an impact on both academic success, leadership, communication and problem-solving skills (Kuh, 2012).

Framing real-world problems as runaway objects in section 1.1.1 raises several types of issues which may represent sources of ambiguity to higher education. Addressing runaway object as open-ended and ill-defined endeavors differ from problems occurring in controlled environments such as classrooms, which are usually approached in education through close-ended problems (Engeström, 2015). Yet, the complexity and fatefulness involved in climate change are *open-ended* and *ill-defined*. This raises important paradoxes: (a) runaway objects may not fit the classroom environment due to their distribution over time and space and it may elude the pre-existing educational fixed structures operating over fixed space and time. (b) The global scale of activity involved in runaway objects implies a variety of related activity; it represents

infinite potential for action, while preventing participants from undertaking action as embedded activities appear to evade centralized responsibility. (c) Addressing part or totality of runaway objects requires the collaboration of participants in a social process, as described in section 1.2.3; however, in many instances, (d) potential actions have gradually become confiscated by highly trained and specialized professionals or organizations (Engeström, 2009). While seeking development and improvement, such organizations may also marginalize publics as they involve (e) a variety of participants across institutions dealing with (e) opposition and controversy, which (f) mobilizes the ethical and moral senses of problem solvers. Finally, runaway objects are (g) dynamic and uncontrollable, with far-reaching potential effects. In section 3.2.2, describing the field of study, we further address this issue through the introduction of an intermediate object as a tangible proxy to runaway objects (Engeström, 2009).

Designing adequate learning strategies (Ferraro et al., 2015) and engaging in creative problem solving in extended and distributed collectives may represent a way forward (Nowell et al., 2020) to address runaway objects through intermediate objects, an ambiguous process that involves creativity (Sarathy, 2018, p. 2). However, addressing runaway objects such as climate change may also require the creation of effective courses of action as alternatives to dominant practices and ways of thinking; such alternatives require material transformations in collective activities and alternatives to the ways people satisfy their basic needs. Furthermore, as runaway objects cut across activity systems, they require heterogenous coalitions of participants to produce alternatives across various sectors and levels of a system over a longitudinal approach (Engeström & Sannino, 2021; Sannino, 2020). The interplay and cross-fertilization across levels required to address such issues may represent a major challenge to higher education as academic silos and declining public support and community engagement make it a tall order to meet those

challenges (Verma, 2023), in spite of their relevance to bridge the gap between academia and society (Hero & Lindfors, 2019).

We may contend at this stage after Yamazumi (2021, pp. 59–62) that runaway objects require an alternative type of learning to address distribution in time and space and allow participants to be made responsible for their learning processes from interactions with experts; such interactions may subsequently generate new types of activities and provoke opposition and controversy in ethical and responsible ways to master the challenges caused by runaway objects across multiple systems (Engeström, 2005). In this respect, the runaway of climate change may appear as a fruitful avenue, as exposed in section 1.1.1.

## **1.2 Creative Problem Solving and Runaway Objects**

In this section, we frame creativity under the perspective of open-ended and ill-defined problems relevant to the study of runaway objects from the perspective of higher education institutions; we define creative problem solving and the relevance of the notion of competency in higher education; we conclude the section with a characterization of the perspective adopted in this PhD research towards the phenomenon of collective complex ill-defined problem solving.

### ***1.2.1 Creativity: Definitions***

Joy Paul Guilford (1950) has been recognized as one of the pioneers of the argument for the scientific study of creativity (Runco & Jaeger, 2012). The academic spark lit by Guilford engendered research on creativity focused on the personality of the creator (Sawyer & DeZutter, 2009). Creativity may be defined as the ability to produce ideas or products that are original and adapted to the context and constraints of specific tasks (Amabile, 1994, 1996; Runco & Jaeger, 2012; Sternberg & Lubart, 1999) occurring in social contexts. Creativity studies have been undertaken in a variety of domains e.g., business, psychology, neuroscience or education



(Puryear & Lamb, 2020). While Guilford (1950) suggested early on a connection between creativity and learning, this relation was established in the first half of the twentieth century (Feldman & Benjamin, 2006) as Vygotsky (1967) argued that the purpose of education should be to foster creativity to prepare students for the future. Nonetheless, it has often been seen as a separate curricular goal in education without a role to play in regular education (Beghetto & Kaufman, 2009; Beghetto & Plucker, 2006) and the number of students who get the opportunity to develop creative abilities in academic settings has remained limited (Beghetto, 2010). Regardless, creativity is an important competency to be developed both in teachers and learners to foster agency and extend their respective fields of actions beyond the walls of traditional higher education to develop and nurture competences (Hakkarainen, 2013; Yamazumi, 2013, 2021).

Creativity and learning may also appear to respond to similar development over time and to be congruent to one another (Karwowski et al., 2020), as they both result from interactions between individuals, collectives and their environment (Glăveanu et al., 2019). *Creative learning* (Beghetto, 2016) stresses the dynamic relation between individual and collective dimensions as both *learning* and *creativity* may result in personal and collective new understanding and meaning at both individual and collective levels. Yet, although the intersection of creativity and learning may produce favorable conditions to transform everyday life through problem solving, research efforts aiming at changing one's circumstances in life or creating new outcomes have been under covered (Lemmetty et al., 2021), despite their relevance to understanding context-specific practices (Anderson et al., 2014). Additionally, the "relation between learning and creativity is still poorly understood, especially when creativity is taken in a collective sense" (Sannino & Ellis, 2015, p. 2). The promotion of agency and collective creativity remains an

important issue due to the increasing prevalence of networking and collaboration across organizations where partnerships with experts and relevant actors beyond the walls of higher education are increasingly needed. This field of study is still limited in scope and depth to analyze how higher education may be expanded by creating hybrid activities involving the real-life world (Yamazumi, 2021). Moreover, creativity may be conducive to collaboration and shared understanding, as well as developing professional agency in a dynamic interplay of creativity and agency (Collin et al., 2017).

As a field, creativity research has been consistent with its roots in psychology and psychometrics under the impetus of Guilford (Sternberg, 2012), while following along the 80s and 90s shift in cognitive science. This shift allowed to focus on the distribution of cognition across people, tools, and environments (Sawyer & DeZutter, 2009). The focus on idea generation and personality was subsequently widened to include more comprehensive frameworks, and a number of methodological issues were identified; for instance, the measurement of problems that require divergent thinking is inadvertently devalued by the use of standardized tests (Plucker & Makel, 2010; Runco, 2010). Much creativity was studied from an individual perspective (David et al., 2022; Romero, 2020) in psychology and focused on idea generation and divergent thinking, e. g., through the use of idea generation tasks (Torrance, 1968; Urban, 2005).

Veering from previous lines of research, this PhD research recognizes after Green and contributors (2023) the importance of defining creativity both as a *product* and as a relevant *process* whereby creativity may be interpreted as internal attention constrained by a generative goal; from this perspective, said goal state is generative, i.e. it is not held in the memory of a person involved in a creative process. Focusing on process allows to bring greater resolution on the *how* of the creative process rather than on the *what* of the creative product. Furthermore, such

process may not be understood fully outside the societal context from which it gains its value (Sternberg & Kaufman, 2010). For Kind and Kind (2007), creativity should be analyzed as a social phenomenon by examining collaboration relationships among members of a team and map out relations between individual and group interactions.

Creativity may emerge across various elements in group interactions, across various elements of a system which Lubart (2017) described as the 7 C's of creative thought. The 7 C's allow to take into consideration (1) the characteristics of a person or group of persons who undertake a creative process (*Creator*), (2) the process undertaken (*Creating*), (3) collaborations and co-creation occurring during the process (*Collaborations*), (4) environmental conditions in which the process occurs (*Context*), (5) the nature of creative work and outcomes (*Creative products*), (6) the integration or adoption of outcomes of a creative process (*Consumption*), (7) ways of developing the curricula (*Creativity development*). This line of work brings greater resolution to the phenomenon of creativity by integrating cognitive aspects, sociocultural dimensions, and contextual dimensions; as such, it lays the ground for a detailed systemic study and analysis of the phenomenon of collective creativity. This following section further interrogates the second element of the 7 C's, i.e., the creative process, focusing on *problem definition*.

### **1.2.2 Creative Process: Problem Definition**

*Problem definition* has been identified as the representation of a problem from experience (Mumford et al., 1994). For instance, Reiter-Palmon (2017) approaches *problem identification and construction* as the first step of creative problem solving, a process whereby problem solvers *identify a problem, structure an ill-defined problem and define the parameters* of the problem, followed by *information search, idea generation and evaluation* (Reiter-Palmon, 2017).

However, the process may not be accurately described by a fixed sequence of events occurring over time. Indeed, problem representation is activated by environmental cues, i.e., perception stimuli, which are activated in the problem representation process; when multiple problem representations are activated, problem solvers must create new problem representations which may result in subsequent creative solutions.

When working in teams, different experiences, knowledge, and educational background may engender different problem representations and therefore different framing for a given problem. Individuals in teams may not be aware of such differences (Cronin & Weingart, 2007), and therefore face disagreements. Moreover, heterogeneity on problem representation may lead both to greater quality and innovation (Weingart et al., 2010) and to poorer creative results (Weingart et al., 2005). Additionally, subjects engaged in problem-solving tasks are mostly unaware that other subjects may have a different problem representation than their own (Leonardi, 2011). Furthermore, prior knowledge also acts as a bias with an implicit dimension in problem solving (Gish & Clausen, 2013) which may result in participants being unable to solve the problem. The question of how teams may negotiate and reconcile contradictory problem constructions and the problems involved therefore appear as a paramount yet understudied problem (Mumford & England, 2022; Reiter-Palmon, 2017). Furthermore, *problem definition* may be a fruitful framework to describe the way information is managed in creative problem solving, through the search for facts and discrepancies to guide the process (Mumford et al., 1996; Yang et al., 2022). Moreover, the *dynamic allocation of attention* over time in creative activity further points to the question of *persistence* in creative problem solving (Grohman et al., 2017; Nijstad et al., 2010). Few studies have been dedicated to the relation between the interests and the creative goals undertaken by participants in creative problem solving, in particular about

the setting of goals in creative problem solving such as learning and performance (Mumford & England, 2022). However, creativity may also happen in collective settings (Romero, 2020), and in this respect, creative teams may be envisioned as moving entities over a process extending from *initial exploration* to the emergence of a new *process* or *product* (Mumford et al., 2008). Furthermore, this process may require assuming *flexible professional identities* while maintaining a *creative climate* under high demands, pressure, and risks. Mumford and England (2022) further question the processes involved in taking the decision to engage in exploratory work and the *identification of high value avenues* relating to the global environment of a project. Finally, further unanswered questions relate to the *selling of ideas* across organizations which require participants to gain the necessary support to sustain creative effort over time (Dougherty & Hardy, 1996). Finally, creative people in the real world may cause important disruptions of pre-established routines, which requires participants to assume a variety of roles, a topic already mentioned and developed as far as creativity research (Mumford & England, 2022).

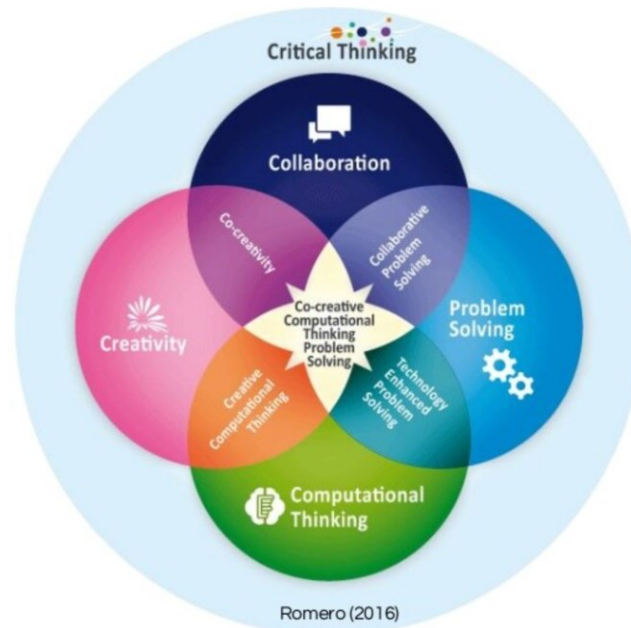
### **1.2.3 #5c21 Transversal Competences Framework: Co-Creative Problem Solving**

Romero (2017) suggests a synthesis of generic competences to define co-creative problem solving which she roots in formative, professional and social skills concerned with the preservation of democratic values. The skills identified after reviewing integrative frameworks in the literature are *collaboration*, *creativity*, *critical thinking*, *problem-solving*. The resulting framework, #5c21, puts critical thinking at its core as a generic skill with emancipatory potential that aims for the formation of independent critical judgment. Such a central position illustrates the relevance of competences related to *reasoning with complexity* (González-Pérez & Ramírez-Montoya, 2022) and systems thinking, creative thinking and scientific thinking as avenues to create new solutions to societal needs (Morin, 2015). In this respect, critical thinking may allow

for the analysis of ideas, knowledge and processes connected to a system of values and personal judgments (Romero, 2017). *Collaboration* in this context is defined as the ability to develop shared understanding and to produce work in a coordinated manner among various participants sharing a common objective. *Creativity* is a process of conception of a solution to a problem that is deemed novel, innovative, and useful. *Problem-solving* is defined as the capacity to identify a problem situation for which the process of resolution is not known in advance, determine a solution, design, and implement the solution. The model of Romero (2017) is illustrated in Figure 1 below:

**Figure 1**

*The #5c21 Framework of Competences for the 21st Century (Romero, 2017)*



*Creativity, collaboration, problem solving, and critical thinking* have overlapping components in *co-creative problem solving* (Romero et al., 2022). According to Barron (1999), all creativity is collaborative, as even eminent creativity may ultimately be understood as social endeavors (Csikszentmihalyi, 2015; Kaufman & Beghetto, 2009) where the chances of meeting the challenges posed by complexity individually are slim. Authors have stressed the importance of both cooperation and collaboration and expanding understanding through the reconciling of multiple perspectives (Hmelo-Silver & Chinn, 2016). In this context, Romero (2020) defines co-creativity as a contextual process of shared creation of design of an idea or solution which is deemed original, relevant and useful by a group of reference. However, as demonstrated in section 1.2.2, there is ample need for regulation at various levels in co-creative problem-solving efforts, when they occur in multi-systemic environments.

To Romero (2020), the description of the creative process may echo Vygotsky's concept of double stimulation, further defined and developed in section 2.1.2 and according to which learners overcome conflicting motives by making use of cultural artifacts to produce a solution that allows them to break away from problem situations. *Change*, in this respect, may be described as resulting from the mutual mediation between contradictory concurrent options as the driving force of development towards change and novelty (Yamazumi, 2021). However, whereas non-routine situations require non-routine processes (Lubart, 1994), solvers may rely on the applications of strategies similar to situations they have encountered in the past as points of references, which can be a source of errors when the problem at hand may not be solved through known means (Cassotti et al., 2016). Under this perspective, problem solving competences may be seen as *a formative construct where successful performance emerges from a range of different factors* (Funke et al., 2018, p. 42). Complex problem solving may therefore be envisioned as a behavioral and a cognitive multistep activity which evolves dynamically through a nonlinear process in which outcomes and hindrances may not be known in advance.

Westera (2001) observes a wide polysemic space in the overlap and interwoven definitions of *skills*, *competencies* and *competences*; an early definitional effort and consensus may be reported relating competence to *what one does*, competencies to *how well one does it*, while skills may more accurately describe sub elements constituting a competence in educational contexts. In this context, actions and situations trigger the acquisition and display of progressively-acquired expertise. This process impacts cognitive, psychomotor, and affective abilities in relation to specific situations. In this respect, development may occur at the intersection of education, professional experience, and lifelong learning.



Despite offering a way forward to conceive of knowledge and active learning (Musial & Tricot, 2020), competency-based approaches may also promote the stepwise applications of pre-established procedures and promote a behaviorist vision of learning (Dancot, 2016). As a result, they may not account for the development of higher order cognitive skills but rather result in the further modularization of learning into small units of information (Braun & Mishra, 2016; Franks et al., 2014); competence may manifest in behavior rather than generate the production of higher mental functions or advanced expert skills and they may therefore not account for the emergence of new identities, knowledge, attitudes and values (Dancot, 2016). However, the transformation of knowledge to solve personally or professionally relevant problems may represent a way forward to the behaviorist trend in competency-based approaches (Franks et al., 2014) as competences may develop in professional environments where interactions in ecological contexts may result in a tension between performance and learning (Martin et al., 2023), competences should at their core should be actionable towards the world (Scholkmann et al., 2023), a process which is related to emotions, dispositions and creativity and may be more accurately be described as a process rather than an outcome for higher education (Illeris, 2012); pre-defined learning outcomes may benefit from integrating multiple perspectives and systemic complexity as backdrops to the development of competences in complex social and professional learning environments (Orsino & Ng, 2019).

Although focusing on knowledge as the basis of competency development may prove to be an inefficient strategy (Tynjälä et al., 2020), it may also appear that such knowledge may be fruitfully used as a stimulus to testing and achieving new ideas, therefore showing the relation between competency, learning outcomes, innovation and creativity. Such dynamic relation may appear paramount to school and workplace environments where interprofessional collaborative

competency may be developed and reinforced through mutual exchange in interprofessional teams, e.g., in clinic training (Varpio et al., 2017).

We may therefore further consider and support Romero (2015) in her contention that the interactive and dynamic process of competency formation may not only occur beyond mere sequential processes, it may also be understood and described through analysis of the systemic constraints occurring as cognitive processes where prior knowledge, new knowledge, socio-cultural and professional settings intertwine and mediate one another in a tacit and implicit manner (Engeström, 2015). Tynjälä and contributors (2020) also recognize the importance of authentic experience and problem solving to develop vocational competency and professional expertise. In their view, excessive stress on knowledge as the main component of competency development may conceal the fact that knowledge may intersect with competency development when learners are encouraged to evolve from one context to another e.g., from school to workplace (p. 13).

In this respect, Varpio and collaborators (2017) stress the importance of the notions of agency to account for educational challenges. A CHAT-based understanding of agency may help link systemic agency development at activity level by integrating interactions with more knowledgeable professionals. This may allow for the process of competency development for an individual or a group of individuals and their interactions with the environment. It may further allow researchers to determine how social structure described above (professionals, educators, other students) may interfere with the development of personal competency while accounting for intentionality and reflectiveness involved in the process.

Martin and contributors (2023) further recognize the potential of moving beyond knowledge, skills and attitudes to include socialization (becoming a member of a professional

group) and subjectification (including reflexivity and responsibility). They argue for a shift from outcome-based practice to system-based practice by complementing learning outcomes with the development of agency in different professional or educational contexts or cultures; according to the authors, this should align with the integration of dialogue, the integration of multiple perspectives at a complex, systemic level to account for specifics of learning in given situations. From this perspective, CHAT may represent an opportunity to analyze competence development as trajectory by focusing on participants activity as opposed to as the outcome of studying through language rather than performance measurement (Scholkmann et al., 2023). Finally, Orsino and Ng (2019) argue for accounting for the complexity of developing expert practices which they envision as collective competency by helping to map the different activity systems interacting in any given social situation and help subjects identify paths and their intersection within and across systems (p. 58). Further, competences from a CHAT perspective allows for an alternative to performance-based views, by rooting development as historically and culturally rooted in language and the product of a subjective competence development trajectory.

#### ***1.2.4 Inquiring Into Creative Phenomena: a Material Perspective***

Creativity, collaboration, problem solving, and critical thinking may appear as interrelated competences in co-creative problem-solving activity (Romero, 2017). Generic competences involve complex, interactive and non-routine skills (Thornhill-Miller et al., 2023) which may be seen as a formative construct where successful performance emerges from a range of different factors (Funke et al., 2018, p. 42); this formative construct may be deeply rooted in social interactions and embedded in situations and contexts, expanded with cultural artifacts towards a shared object of activity (Romero, 2020) which should take into account the possibility of extending agency beyond the skin of the individual towards collective transformative

endeavors (Sannino, 2015b). This research intends to pursue this line of research by investigating aspects of the material world on which human actions rely and aim to transform.

Having stated the need for integrative frameworks when dealing with generic competences to study creative problem solving across a variety of fields and domains (Funke, 2021) in a learning perspective, the need to heed individual mind and agency at the level of the construct in which it manifests requires a multidimensional perspective for creativity and learning. From a sociocultural standpoint, creativity may bloom in collaborative environments (Moran & John-Steiner, 2003) when ideas are traded between members among a group or collective (Sawyer, 2012) which may also favor creative learning (Beghetto, 2021); moreover, both creativity and learning may be approached as codependent phenomena (Lemmetty & Collin, 2021) relying on context and varying across situations and environments. This research subscribes to the observation that whether framing learning and creativity as *creative* or *collaborative* learning or problem-solving activity, it is deeply rooted in social interactions and embedded in situations and contexts, expanded with cultural artifacts towards a shared object of activity.

### **1.3 Formation and Regulation of Collective Will in Potentially Expansive Problem**

#### **Finding Activity**

From a scientific perspective, empirical research on the phenomenon of collective creativity has been called for by Sannino and Ellis (2015) to analyze and understand the link between creativity and learning when understood as intertwined phenomena. However, CHAT studies of creativity remain rare occurrences (Hyrkkö & Kajamaa, 2021) despite the potential to account for the multiplicity of perspectives (Virkkunen, 2013) in the creation of novel concepts and models of work practices (Engeström et al., 2014). The process of creativity, in this sense,

requires a collective to engage in multi-voiced object-oriented discourse, and to use artifacts and concepts to support the process (Engeström, 2008; Yamazumi, 2021). Co-creative problem solving may be described as a socio-material collective phenomenon mediated by discourse, artifacts or other persons within or beyond current settings (Engeström, 2015, p. 59). The systems studied in CHAT are object-oriented, according to Engeström, and the object is what gives direction and meaning to a given system of activity. The system shifts under the pressures and tensions exerted by constant amendment and adjustments as the object may be continuously transformed (Engeström, 2008). We contend that CHAT may constitute a fruitful framework of inquiry for creative phenomena at large, in so far as it allows to unpack the efforts of collectives to reconstruct their object, an expansive movement that may lead to the creation of subsequent activity systems (Hyrkkö & Kajamaa, 2021). The authors further tie this phenomenon to the concept and cycle of expansive learning as having the potential to describe the efforts of collectives involved in shared object-oriented processes. *Object-orientation* in activities represents a tentative connection between the goals and needs of activities and the outside world (Yamazumi, 2021).

### ***1.3.1 Towards an Activity Level of Creative Complex Problem Solving***

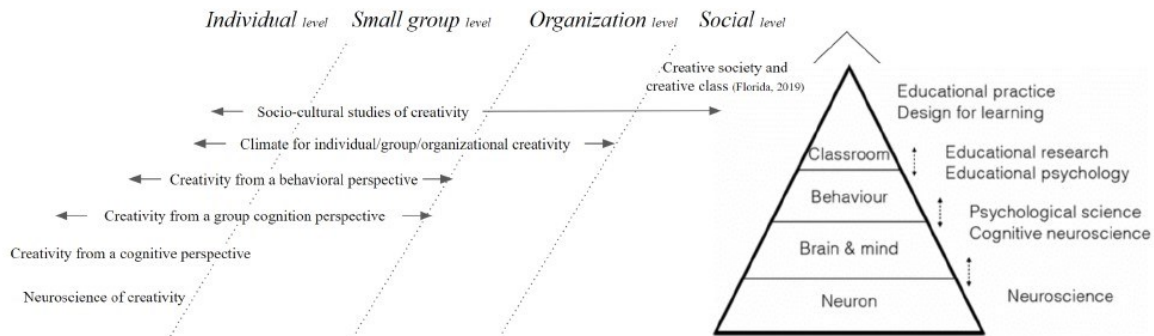
Romero (2022) suggests two lines of inquiry to advance research in creative problem solving: (a) activity systems addressing interactions between learners, ill-defined problems and resources (e.g., artifacts and concepts) analyzing problem-solving under a systemic perspective; (b) socio-cognitive and neurocognitive processes mobilized in specific tasks; both lines of inquiry aim towards understanding volitional and regulatory processes in creative problem solving. This research follows the first line of inquiry suggested above, i.e., systemic interactions between persons (*creator*), processes undertaken (*creating*), collaborations occurring over the

process (*collaborations*) and environmental conditions (*context*) involved in the emergence of a *creative product* using complex artifacts and concepts. From this perspective, we follow Impedovo and contributors (2017) who characterize artifacts as psychological tools used in cognitive development and which may be used in communication between self and others to organize activities. Concepts and artifacts are of particular importance to understand the complex interactions between several of the 7 C's described above. The importance of artifacts and concepts is further stressed in section 1.2.4.

When considering sociocultural theories Lemmetty and contributors (2021) consider pragmatism (Dewey, 1986), dialogical theories (Bakhtin, 2010), Cultural-Historical Activity Theory (Engeström, 2015) and cultural-historical theory (Vygotsky, 1980) as fruitful research avenues to study complex phenomena and to move away from individual approaches to address learning, creativity and environment in teaching, learning, or group activity. The rooting in sociocultural perspective of real-world problem solving therefore has the following implications: (a) creativity and learning are based on *change* and *uncertainty*, (b) *agency* and *autonomy* which may lead to creativity and learning and relying on (c) *cultures*, *shared goals* and *diversified methods* to support creativity and learning (Lemmetty et al., 2021, p. 13). Creative problem solving may therefore be fruitfully studied from a sociocultural perspective, as illustrated in Figure 2:

**Figure 2**

*Levels of Analysis of Creativity in Learning Sciences After Romero (2022)*



Sawyer (2012) asserts that sociocultural theories focus on group processes over time, while shying away from producing explanations based on the mental states or actions of participating individuals. Sawyer contends that processes are the core unit of social reality and suggests evolving the focus of sociocultural studies from *social practice* to *collaborative emergence* to analyze and understand group creativity. In this respect, according to Sawyer (2012), group or collective processes are understood as situated social practices involving individual acts, interactions over time and emergence of collective group creations. Collective processes of co-creativity may therefore involve different levels from individual to collective dimensions, while integrating environment: Sannino (2015a) suggests pushing this evolution further by extending notions of agency to include aspects of the material world as the environment humans rely upon and aim at transforming, extending agency to include a collective level of transformation.

It therefore appears reasonable to suggest taking the initial problematic state or situation as a trigger for conflicting motives exerting tensions on resources used to reach a desired state (Romero, 2022) where sustained willful effort is needed to foster learning and develop new

concepts that have relevance in a cultural context (Engeström, 2011; Sannino & Ellis, 2015). The decision process that is thus fostered in the intermediate steps involved in designing a solution is therefore a function of initial state, intentions, perseverance, process, and properties of the solution.

Due to the contextual nature of creativity as occurring across field, domain and either individual or collective subject (Csikszentmihalyi, 2015) to acquire both criteria of *novelty* and *usefulness* (Runco & Jaeger, 2012), creativity may fruitfully be inquired as an emergent phenomenon suitable to occur in 21<sup>st</sup> century education and promoting related competences (Henriksen et al., 2016) which may be fruitfully approached from a socio-cultural perspective. Romero (2022) further asserts that collective iterative efforts of production of creative outcomes to a problematic situation may be characterized as a non-routine problem-solving process. Hakkarainen (2013) stresses the contrast between novelty and routine in a learning environment as engaging in social practices that may allow novice problem solvers in a field to pursue various and complementary problems requiring innovation and exploration. As such, the mobilization of communities outside the current work practice may provide access to cultures of innovations as pools of collective creativity that may bridge the gap between academic experiences and shared knowledge practices.

Miettinen (2013) frames collaborative and creative interactions as a product of the meeting of a *need* and an *object*, triggering motivation and agency, a line of thought initially suggested by Leontyev (1977), branching away from individualistic approaches by considering the concept of need as emerging from contradictions in human activities. A joint object thus may be regarded as a hypothesis for the resolution of contradictions. Miettinen (2013) also highlights the complementarity of knowledge and resources in explaining the emergence of collaborative



agency. He further elaborates by defining collaborative agency as “the mutual development of a joined vision of a new product or service and a joint commitment to a project to realize the vision in practice” (p. 159). As a result, the author asserts creativity as relying not only on the participation of individuals but locates the interaction of needs and objects as determinants to the outcome of the process. This raises the question of the randomness of the association of shared needs and objects, doubled by the essential complementarity between individuals for creative agency to emerge.

The collective activity system heuristic used in CHAT implies human cognition, learning, emotion, and volition as intertwined socio-historical processes occurring in culturally mediated activity systems (Yamazumi, 2021). According to this view, both the mind and consciousness are situated and distributed across the poles of an activity system oriented towards its object.

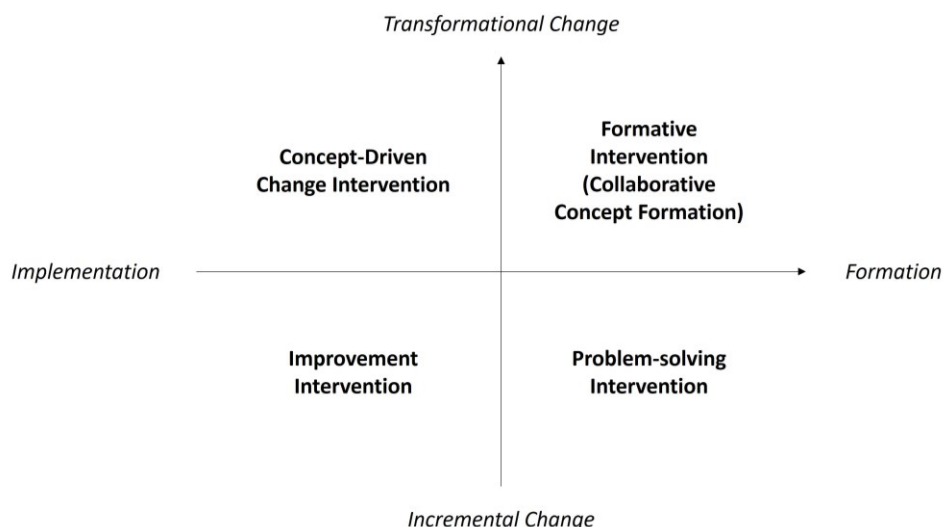
Although the notion of distribution may appear as problematic in some situations, we follow Engeström (2008) who focuses on the distribution of agency—rather than mind—in temporary formations in which problems may be solved and decisions made by allowing the movement of changing attributes in a system to be followed moment by moment in hybrid forms of learning activity (p. 208). In this respect, problem solving may be understood as problem finding (Sannino, 2023), which may be described as object orientation in an activity system through volitional processes. In this respect, we follow Lund and Vestøl (2020) according to whom *transformative processes* may involve the interplay between volitional action and use of resources to break out of problematic situations (p. 2). By contrast, Blunden (2023) pointed the risk of incoherent, pointless activities when no shared object is identified in a collective; to the author, this situation may cause the collective’s effort to produce sterile results as participants *comply*, i.e., do not aim at building a shared object but to follow a predetermined course of

action. We take this as a serious risk in higher education settings and we therefore recognize problem finding and modeling of a shared object as major challenges to be overcome.

A few additional observations are in order as some overlapping may be signaled between CHAT and co-creativity to the extent that CHAT itself may be considered a co-creative method; in more ways than one, it is exemplified by a body of scientific literature resulting from the use of formative intervention method such as the change laboratory methodology in recent years (Virkkunen, 2013). According to the authors, there are different ways to solve problems according to various methods of intervention, as illustrated in Figure 3 below:

**Figure 3**

*Four Types of Interventions Methods (Virkkunen, 2013)*



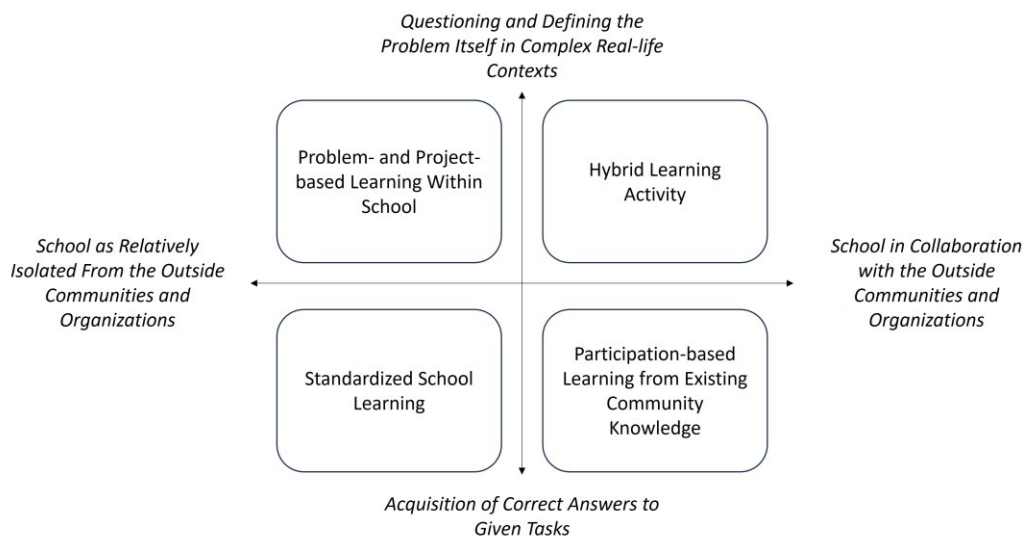
We may describe efforts in higher education to promote generic competences in otherwise compartmentalized curricula such as academic service learning (Tiippana et al., 2022) as *interventions* which Virkkunen (2013) defined as “a purposeful intervention from a human agent to produce change and effect an actor’s actions so that the activity finds a new direction through the use of a special plan or method, understood as a planned procedure or set of steps to perform tasks” (pp. 3-4). Still following Virkkunen (2013), we distinguish two dimensions—illustrated in Figure 3—that interventions may vary over: *order of change*, on the one hand, stretching from incremental improvements to transformation of the whole activity system; and *type of intervention process*, on the other hand, varying in scope from implementation of pre-existing solutions to creative reframing of problems and forming novel solutions. Although this model was initially designed to apply to work environments, we consider it as a valuable tool to categorize interventions in higher education; the tension and possible paradoxes between these interventions and the intent of CHAT as a co-creation method is illustrated in the right-hand part

of Figure 3, in which a solution to a problem is pursued and created; the other end of the spectrum describes transformational change and the creation of a new concept of an activity.

When addressed in this way, change should come as a response to the obsolescence of the object of an activity which prevents it from meeting its societal need, thus provoking a crisis which cannot be avoided by making incremental changes or acting individually. Contrasting with Figure 3, Figure 4 below suggests an articulation of the various possible methodologies adapted to education, following Yamazumi (2021, p. 115) who focuses on agency and hybridity:

**Figure 4**

*Two Dimensions of Expansive Development in Schools After Yamazumi (2021, p. 115)*



While Figure 3 maps intervention across dimensions applicable to change in organizations and aiming at formative interventions, Figure 4 zooms in on educational institutions and maps expansive dimensions in school across *involvement with outside communities* and *ability to question and define the problem itself*. Although *formative interventions* such as change laboratories and hybrid learning activity are hardly comparable in scope, we contend that (a) both models rely heavily on problem definition as the object of activity is not given in advance, resulting in an open-ended, ill-defined scenario and (b) both formative interventions and hybrid learning activity afford participants with wide decision and activity margins thus relying on agency to reach a satisfactory goal state. Finally, (c) while typical formative interventions ideally rely on a stable group of participants, hybrid educational activities are open to outside influence *from complex real-life contexts* (Figure 4) and may therefore entail a societal dimension leading to historical transformation either in school or in real-life contexts. However, historical transformation in organizations through formative

interventions may require cycles of expansion typically occurring over long time spans (Sannino et al., 2016). Hybrid learning activities, on the other hand, are ruled by different time constraints relative to school curricula and organization, echoing the characteristics of runaway objects exposed in section 1.1.3. They may more realistically result in *expansion* from the school perspective, rather than true historical transformation (Yamazumi, 2009). This comparison of both models stresses the importance of embedding activities under a critical reviewing process. Such a process of careful analysis may eventually lead participants to taking responsibility for their progress, a key characteristic of hybrid learning activities: the ability to not follow a predefined course may lead to the attempt to accomplish an expansive transition involving a novel process (Yamazumi, 2021).

One implication of the comparison between problem solving methodologies and hybrid learning activities from this perspective stresses the dialectic between *agency*, i.e., the ability to amend the frame of action to transform it (Virkkunen, 2006) and *hybridity*, i.e., the combination and interpenetration of two or more *worlds* causing tensions and conflicts (Engeström, Rantavuori, et al., 2022b, p. 2). This requires *agency* or the ability to exert free will through voluntary actions in multi-activity *hybrid* coalitions relying on collaborative and transformative expertise. The two dimensions of *agency* and *hybridity* may involve intersecting trajectories as the objects of learning (i.e., types of problems) vary depending on the types of organizations involved in the process. From our perspective, the case which is the focus of this research connects both models above: it is both relevant to problem solving intervention and to the collaborative formation of concepts. Section 3.2.1 provides further details on the *problem* suggested to be addressed by the activity, which we contend to be wide and deep enough to allow for the modeling of a new object. In this sense, the object to be worked with is not a

complete blank slate, it is one step removed from societal needs by first-hand participants, and it is a fully hybridized activity according to the description of Yamazumi (2021): it is fully dedicated to questioning and framing the problem according to authentic contexts, relying on extramural collaboration to realize it. Intense collaborations involving actors from different systems concerned with problem solving under the impulse of a partially shared object may allow the generation of new types of agency by engaging with objects shared by activity networks (Yamazumi, 2013): hybrid learning activities evoke distributed and emergent agency polylogs occurring across boundary crossing, hybridized activity systems which we interpret as conducive to the emergence of *agency*.

### ***1.3.2 Volitional Processes as Regulation Processes***

For Romero (2022), creative behavior in creative problem solving requires creative intention and perseverance, as the process alternates between *divergent* and *convergent* phases to advance towards either resolution of a problem or discontinuation of the process altogether, in a dynamic complex process. However, creativity may not be reduced to idea generation in successive divergent and convergent exercises (Vinchon et al., 2023). It also relies on the identification of the problem to be addressed, the exploration, identification and definition of the object of creativity (Csikszentmihalyi, 1988). Moreover, it involves an estimation of originality and effectiveness (Corazza & Agnoli, 2022) which are essential to sustaining the efforts, to the *perseverance* necessary to complete any creative endeavor. Problem finding and assessment of the value of the creative output or product involve regulation efforts to develop and refine outputs (Ivcevic & Nusbaum, 2017). Collective regulation allows for the merging of ideas and incorporation of feedback which may benefit the overall originality of a creative process (Zielińska et al., 2022).

*Self-regulation* may be defined as individual processes aiming at an individually motivated purpose or goal which occurs through contextual and interpersonal feedback (Jackson et al., 2000) allowing students to learn from modeling thought patterns, strategies and behaviors (Schunk, 1990). *Coregulation* may be defined as a transitional step in self-regulated learning occurring over a shared problem-solving plane, and during which one participant may acquire self-regulation through interaction, e.g., with a more knowledgeable other (Hadwin & Oshige, 2011). This view is strongly reminiscent of the development of higher psychological functions as socially embedded processes, or internalized through social interactions (McCaslin & Murdock, 1991). Finally, *socially shared regulation* describes processes of regulation of collective activity through the co-construction of goals and standards by multiple subjects. The desired outcome is socially shared cognition (Hadwin & Oshige, 2011). In research concerned with socially shared regulation, the unit of analysis is collective, and therefore groups are considered as a collective entity of shared regulators. In this respect, it equates with collective processes within group interactions, negotiations of meaning and evolution of ideas. Each model of self-regulated learning emphasizes different aspects of volition, motivation and cognition (Pintrich, 2000).

Authors have stressed the prevalence of research dedicated to studies on well-defined goals relying on exercise routine (Delose et al., 2015). However, creative goals have been defined as ill-defined (Lubart, 1994). In this respect, research in regulation, and in particular in self-regulation has been operationalized as a trait, which may not predict everyday creative behavior and achievement (Grohman et al., 2017) due to the fact that creative individuals possess the ability to persist against obstacles (Helson et al., 1995). Simultaneously, a high level of adaptability is required, as established by research on problem finding (Abdulla et al., 2020). Sharing much with open and ill-defined problem solving, Ivcevic and collaborators (2023) argue



that the regulation of creativity represents a unique challenge and should be addressed as creative metacognition to understand creative thinking. Furthermore, Ivcevic and colleagues (2022) identified the following research inquiries to the area of regulation and creativity: process expectations dealing with changes and revision of initial ideas, openness to new perspectives in the face of obstacles, negotiation of goals regarding the level of challenges and risks involved in a creative process, and the ability to change course of actions and persistence in the face of obstacles. Persistence in this case entails to weigh risks and deal with uncertainty in a process in which participants are aware of recurring cycles involving difficulties, obstacles and failures (Glaveanu et al., 2013) requiring a constant balancing effort between concurrent options or goals in the collective processes involved (Ivcevic et al., 2023).

Engeström (2015) defines double stimulation as concerned with the formation of higher mental functions, a process in which a subject tries to overcome a paralyzing conflict of motives, considered as first stimulus. Sannino (2015b) expands further the notion of conflict of motives as “a clash between different opposite aspirations or tendencies which occur in situations involving uncertainty about the situation in which one is or about one’s own conduct, and requiring the courage of deliberate choice” (p. 8). In the Vygotskian tradition, the bridge between will and conflicts of motives is established through auxiliary motives. Vygotsky (1967) describes the emergence of self-control by means of auxiliary stimuli involving a conflict of motives as its principal component. We believe conflicts of motives to be pervading in ecological settings, which involve the solving of complex problems and to represent complex constructs which are relevant to co-creative activities. Indeed, as the model of TADS by Sannino (2015b) in Figure 7 below shows, the conflict of motives phase is instrumental to the generation of a variety of artifacts for its resolution when the “real” conflict of stimuli is satisfactorily identified and

subsequently triggers an adapted reaction. Through the identification and up taking of auxiliary stimuli, the action engendered further gains agentic potential (Sannino, 2015b, p. 11).

The processes dedicated to mastering a situation through an auxiliary motive to resolve conflicting motives may be described, according to Romero (2022), as *creative intention* or *volitional orientation* (p. 3) which must be sustained through creative perseverance to maintain intention across the task. Maintaining or evolving creative intention over time is sustained by volitional orientation towards a certain outcome through metacognitive monitoring of divergent and convergent thinking processes. This process may be supported and described through the lens of a decision-forming apparatus in situations of uncertainty through the up taking of an auxiliary stimulus to overcome an initial cognitive dissonance between conflicting motives and resources in a situation characterized as ambiguous and uncertain (Sannino, 2015a, 2015b, 2022; Sannino & Laitinen, 2015). Under this perspective, self-regulation opens a door for creativity in learning context to be studied under an agentic perspective (Zielińska et al., 2021): learning and creativity are most effective when participants in a creative problem-solving activity are convinced of the value of the activity at hand and of the value of the answer they can bring; it requires to take into account people embedded in a world of objects interacting with other people, become part of creative acts (Lemmetty et al., 2021, p. 3). On the other hand, Yamazumi (2021) suggests creative action may be the most central object of pedagogy and the formation of human beings, described as a dialectical process for overcoming ideas from a societal and historical point of view. The author also recognizes double stimulation as an important principle of volition that underlies higher mental functions and integrates conflictual aspects such as conflicts of motives. Furthermore, double stimulation aims at fostering agency among participants (Postholm, 2020), which is consistent with the outcome of socially shared regulation

which aims at socially shared cognition; double stimulation may offer a fruitful research avenue to achieve this goal.

### ***1.3.3 Co-creative Problem Solving as Expansive Problem Finding***

Research focusing on expansive learning to analyze creative learning happening at systemic level remains marginal in the literature (Hyrkkö & Kajamaa, 2021). Nevertheless, when adopting a sociocultural stance, creativity may be studied as an object-oriented process relying on shared practices based on innovative knowledge communities and their network (Hakkarainen, 2013). Creativity in this perspective revolves around novelty, innovation, agency, and the transformations undergone by *systems* of collective activity unified around a shared object and exerting changes and modifications at any of the poles of an activity system. Creativity may therefore be described as expansion of a shared object of activity and subsequent transformation occurring at poles of activity systems. When framing creative collaborative problem-solving under the societal imperative to deal with grand challenges, the setting is necessarily the societal material world of practice. When framing problem solving activities as multi-voiced involving a potentially considerable number of participants over various time scales, the process may require prolonged effort from hours to months, depending on the number of scales across which systems are expected to *learn* what is not yet there. This learning equates with processes of formation of agency through the development of learning activities which may develop in temporary coalitions of actors engaging in multi-voiced dialogue, contradictions, cognitive conflicts to develop new systems by connecting the learning contexts of criticism, discovery and practical social applications to education (Yamazumi, 2021). This may in turn result in the *de-encapsulation* of school learning (Engeström, 1991) which questions the strict assignment of teaching to teachers and learning to students (Nummijoki et al., 2018). In this

sense, *de-encapsulation* may be described as an attempt to “push school knowledge out into the world by making it dynamic and theoretically powerful in facing practical problems”

(Engeström, 1991, p. 251). In this research, de-encapsulation is interconnected to the concept of hybridity as a principle of collaboration across activities that create new transformations. In this sense, Gutiérrez and contributors (1999) describe *hybridity* not only as the inclusion of racial, ethnic and linguistic elements but also as diversity in the mediating artifacts, roles and activity systems themselves, a point further developed in section 2.1.5.1.

*Learning*, in this instance, amounts to meeting the conditions for change to happen, i.e., to meet the conditions for *novelty*, i.e., how change may happen in a system in a process of adaptation. Engeström (2015) suggests novelty stems from a combination of the possible and the actual, fueled by the need to expansively generate new activity structures, a process that rests on double binds. “A double bind may now be reformulated as a social, societally essential dilemma that cannot be resolved through separate individual actions alone—but in which joint cooperative actions can push a historically new form of activity into emergence” (p. 131). In this context, being creative amounts to operating changes in the instruments used in an activity system to resolve its inner contradictions. According to Morselli (2022), the nature of expansive learning is to solve real-world problems *that have materiality in the socio-cultural world*. Expansive learning may therefore be asserted as a mode of creativity aiming at the *assimilation* or the expansion of learning through creativity to offer solutions to cogent problems in education settings and beyond. In this view, dialectics and remediation may engender creative solutions to historically developing problems and affecting organizations at large as a primarily creative endeavor.

## 1.4 Object of the Research

This section aims at tying concepts of CHAT to problem finding, and to state the object of the research. We follow Engeström (1993) who, in the following quote, establishes the tight relation between *object of activity* and *problem space*:

In the model, the subject refers to the individual or subgroup whose agency is chosen as the point of view in the analysis. The object refers to the “raw material” or “problem space” at which the activity is directed, and which is molded or transformed into outcomes with the help of physical and symbolic, external, and internal tools (mediating instruments and signs) (p. 67).

Whenever a variety of actors participate in managing part or totality of a problem, as is necessarily the case in systemic issues, framing the problem space may result in ambiguous interpretations. We follow Sannino (2023) according to whom participants involved in a problem solving activity should be able and allowed to exert *agency* regarding the definition and presentation of a problem. Moreover, when creativity is involved in the solving of real-world problems, problem definition may be viewed as the most important component in the creative process, either when problem solving in the real world (Okuda et al., 1991) or in creative problem solving (Mumford et al., 1994, 1996; Reiter-Palmon & Robinson, 2009).

Sannino (2023) establishes problem finding as playing a significant role in handling societal problems collectively through collective learning and the exercise of agency, whereby the way problems are formulated is more important to creative endeavors than how problems are solved. The approach is paramount regarding the current research as human agency may be discouraged by the complexity and wickedness of runaway objects and issues or “cross-sectoral problem domains in which key problems and their solutions are not known ahead of time”

(p. 203). Problem finding may therefore be understood as a means of navigating a wide and ambiguous problem space. It may indeed be argued that runaway objects point towards the limits of knowledge and require an effort to envision their potential caveats (Verma, 2023).

In other words, problem definition, a crucial step of problem solving, remains an understudied area of creativity research, while the allocation of attention and factors guiding choices in creative activity of problem solving has also been under studied, while persistence also remains under addressed. Furthermore, complex problem solving may involve the interplay of professional identities in collectives, a topic which is also under addressed, especially when regulation is required in collective settings.

This section intended to tie connections between creativity understood under a socio-cultural perspective and under a CHAT perspective; double binds appear as an idiosyncrasy of CHAT that ties the quest for novelty as a conditional process with a potential to crash into regression; two additional remarks are in order. The CHAT perspective on novelty forbids serendipity and accidental forms of creation; any act of novelty creation or expansion is the fruit of the determined contradiction manifesting in the double nature of commodities, being both abstract and concrete or use value and exchange value. Under this perspective, the integration of excluding and dependent sides is the essence of the double binds which are at the root of novelty creation. As a result, the present research focuses on the formation and regulation of collective will in collective creative problem finding through TADS in a potentially expansive micro cycle of modeling of an object of hybrid learning activity in higher education on sustainable development with a potential to expansively resolve conflicting motives in higher education.

## 2 Chapter 2: Conceptual Framework

Runaway objects require a social process involving interactions between humans and their environment. During this process, collaboration equates with the competency to develop shared understanding and coordinated work over a shared objective; it is embedded in situations and contexts and uses artifacts to reach a shared object. Co-creative activity may therefore be described as a socio-material collective phenomenon mediated by discourse, artifacts, concepts and physical person (Engeström, 2015, p. 59) to bridge the needs of activities and environments, settings and situations (Yamazumi, 2021). We may further contend that such activities involve constant change, uncertainty, agency and autonomy to foster creativity and learning (Lemmetty et al., 2021). This requires a specific learning activity, defined after Yamazumi (2009) to address time and space constraints inherent to runaway or intermediate objects (Engeström, 2009), one which may not involve a predefined course of action (Virkkunen, 2013; Yamazumi, 2021), and may lead participants to take responsibility and action where power to exert agency was not previously available. We therefore contend that the regulatory processes occurring through the use of the socio-material environment allows collectives to support attempts at transforming conflicting situations which cannot be amended through incremental changes or individual action. The creative perseverance required to sustain such processes to address conflicting situations may be regulated through material artifacts and foster volitional orientation (Romero, 2022). Learning and creativity may therefore be studied by focusing on collective agency and the ability to transform problem situations through resources.

Understanding creativity as a *process* (Green et al., 2023) occurring *over time* requires to adopt a research paradigm taking into account historical development of an activity occurring in collective settings and riddled with ambiguous and mixed information and messages, i.e.,

fundamentally *contradictory* and *debated* among a variety of participants therefore involving a multiplicity of voices (Engeström, 2015). Furthermore, the opportunity to transform the very process occurring when dealing with complex multi-systemic objects such as runaway or intermediate objects implies the ability to adopt and adapt to the needs of complex interaction patterns with a potential to result in specific types of learning involving epistemic actions. Furthermore, the interactions across coalitions or heterogeneous groups from which such epistemic actions result implies the ability to analyze interactions among a variety of participants and organizations.

Accounting for the need for a systemic and holistic vision of creativity and competence development (Boelt et al., 2022) from an activity perspective described in section 1.3.1, generic competency development and collective regulation devices, this research adopted a Cultural Historical Activity Theory perspective. This chapter consequently details the conceptual framework on which this research relies and aims at fulfilling three objectives. First, it introduces the prevalence and characteristics of CHAT through a DWR framework; specifically, it highlights the importance of contradictions. The second section describes the tentative inquiry framework inspired by literature on TADS and its coverage. We question further the importance and role of contradictions, TADS, and expansive learning to higher education in scientific literature. Finally, this chapter aims at investigating the use of *channels* (Sannino & Laitinen, 2015) and their complementarity to the concept of *knots* (Engeström, 2008) occurring in hybrid learning activities (Yamazumi, 2013). The chapter is closed with research objectives and questions.



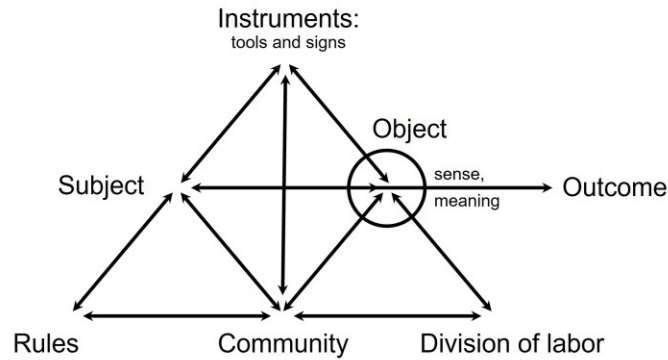
## 2.1 Cultural-Historical Activity Theory

CHAT is both a theory and a research methodology, and it has been used in a variety of domains to understand situated, contextualized mediated human activity (Bligh & Flood, 2017; Grimalt-Álvaro & Ametller, 2021). It is radically engaged in practical human creation and aims at emancipation of the human creative potential to address and transform human collective challenges (Yamazumi, 2021). CHAT has been used to investigate and understand the connection between *learning*, *development* and *transformation* (Sannino, 2015a; Thorne, 2015). In this respect, research has been pursued to understand emergence and evolution of agency over the transformation of society (Bal et al., 2019, 2021; Hopwood, 2022; Hopwood & Gottschalk, 2017, 2020; Lotz-Sisitka et al., n.d.; Sannino, 2016; Stetsenko, 2023). Following Vygotsky and Marx, CHAT considers humans as active meaning makers and active builders of the world and society they are a part of. They produce and use cultural tools to take power of their relations to society and among themselves through volitional actions. The cultural tools produced and used are constitutive of the emergence of transformative agency. They are used as mediational means through which they can transform activity and constitute stimuli to break out of conflicting motives (Hopwood & Gottschalk, 2017; Sannino, 2015b, 2022; Stetsenko, 2023). The use of mediational means to break out of conflicting situations provokes movement in the emergence of transformative agency, a social process described by Sannino (2022) as TADS and which results in the emergence of a second stimulus.

Engeström (2015) identifies five principles of interacting activity systems; they are (a) *collective*, (b) *artifact-mediated*, and (c) *object-oriented* systems. The multiplicity of actors involved in interacting systems implies (d) *polyphony* or *multi-voicedness*: each system carries its histories materializing into the artifacts, rules, and conventions of the system. Finally,

interacting activity systems focus on (e) *overcoming contradictions*, between and among *subjects*, *mediating artifacts* and *object of activity* which may lead to expansive transformations.

An activity system may be formalized in the triangular heuristic displayed in Figure 5 below:

**Figure 5***Activity System Adapted From Engeström (2015)*

The standard unit of analysis in third generation CHAT is interacting activity systems (Engeström, 2015) which remains one of the most used in the research community (Lund & Vestøl, 2020). In this research we focus on a *hybrid educational activities* (Yamazumi, 2021) emerging from networks of interacting activity systems occurring over different timescales (Engeström, 2015), and we consider that interconnected systems may generate qualitative transformations at their poles or by reframing their object. In this respect, the expansion of an object of activity may trigger its transformation (Barma et al., 2017). Furthermore, hybrid forms of educational activity may provide a way to overcome fundamental contradictions of education within capitalist society (Engeström, Rantavuori, et al., 2022b; Jóhannsdóttir, 2018) e.g., giving meaning to education in the context of society through definition of a common object (Nilsson & Wihlborg, 2011).

DWR is based on CHAT, and it is dedicated to the analysis of transformation and learning in work, technology, and organizations. DWR aims at the rediscovery and expansion of use value in runaway objects (Engeström, 2005); to address this ambition, it rests on the foundation that human beings may exert motivation and agency to collaborate, learn and create

their lives and futures to act and exert power. Systemic contradictions are at the heart of DWR and they may be described as potential sources of transitions as the inner contradictions of existing dominant activities are a dynamic source to the transition to new activities (Yamazumi, 2021). Inner contradictions, in other words, may signal the origin of the development of human activity (Engeström, 2015). Following Marx, Engeström identifies the origin of contradictions as interconnection of *use value* and *exchange value*. Each commodity is subjected to a double existence and to a double set of subsequent values as *the total societal production* and as one *production among many* (Engeström, 2015, p. 66). This contradiction manifests as a clash between actions making up the total activity system. Leontyev (1977) sees the opposition between use and exchange value as a feature of the scientific study of activity in capitalism. They are not one-dimensional; they are both positive and negative and competing opposite forces in capitalist labor activity. New activities may therefore emerge to satisfy needs and transcend the contradiction between use and exchange value, therefore helping to create new use value. Creativity, according to the standard definition of Runco and Jaeger (2012) is a process or a product displaying *novelty* and *usefulness*. From a CHAT perspective, *novelty* and *usefulness* may manifest as expansion at the poles of an activity system, resulting from the pressures exerted by *contradictions*. Indeed, “We could almost describe creative collaboration as the moment when different people come together to understand and especially address ambiguities” (Massari et al., 2023, p. 21).

### **2.1.1 Systemic Contradictions**

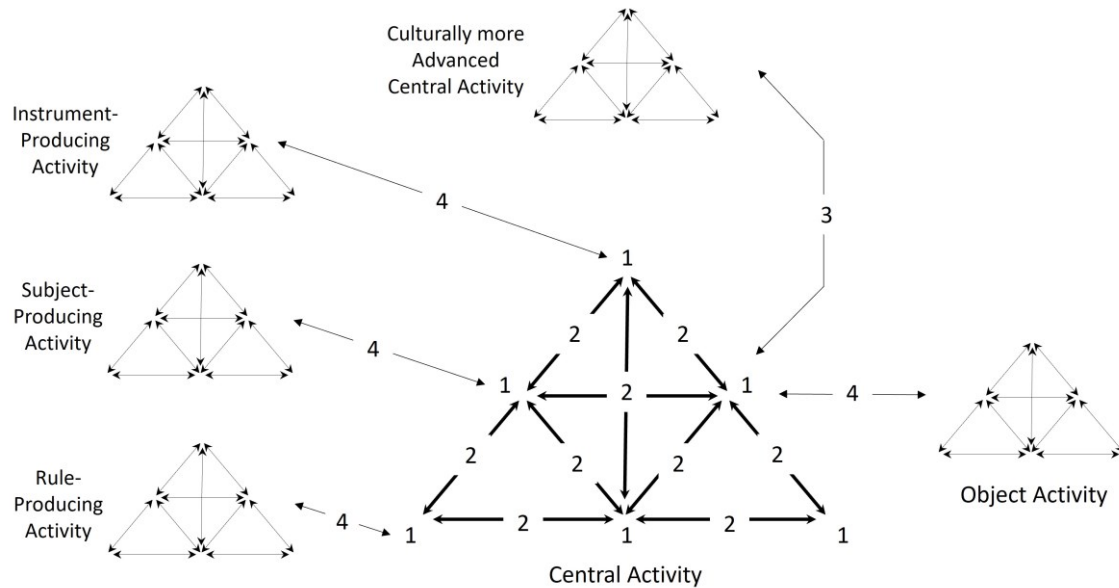
Miettinen (2009) identifies four levels of contradictions. The primary level of contradiction in capitalist activities is the conflict between exchange value and use value *within poles of the triangle of activity*. Secondary contradictions appear *between the corners* e.g., stiff

hierarchical division of labor. Tertiary contradictions appear when the object of a culturally more advanced activity is confronted by the central activity. Quaternary contradictions emerge between the central activity and the neighboring activity in their interaction which usually fosters additional conflicts and resistance. The four levels of contradictions are pictured below in

Figure 6:

**Figure 6**

*Four Levels of Systemic Contradictions* (Engeström, 2015, p. 71)



The four levels of contradictions are important sources of creative progression in activity systems as “new qualitative stages and forms of activity emerge as solutions to the contradictions of the preceding stage or form. This in turn takes place in the form of ‘invisible breakthroughs’” (Engeström, 2015, p. 73). This illustration of the importance of CHAT and DWR is covered as such in the literature (Engeström et al., 2015; Ivaldi & Scaratti, 2020; Sannino & Engeström, 2017). However, as illustrated in Figure 6, we identify two groups which illustrate how contradictions are used: *internal* to an activity system (primary and secondary) and considering contradictions from an *external* perspective, i.e., interacting activity and potentially activity-

generating tertiary and quaternary contradictions. However, our review<sup>3</sup> showed little use of the terms “primary” and “secondary” contradictions and none regarding tertiary and quaternary contradictions despite their methodological interest to advance CHAT studies (Postholm, 2015).

From the perspective of activity systems, for Ivaldi and Scaratti (2020), knowledge produced across new qualitative stages may evolve through the dynamic collective development of the object of activity; systemic contradictions may generate a complex, adaptative and multilayered *problem* in activity systems where contradictions may be generative (Cakir et al., 2022, p. 2). In this context, analysis of contradictions and conflicts of motives may appear as a fruitful means to unpack the layers of complex problems. Furthermore, in collective settings, *discursive agency* and *transformative action* are interrelated and connect subject and organization through their historical evolution (Sannino, 2008a) in which contradictions appear as inherent drivers of transformation *within* activity systems by channeling the energy they engender (Sannino & Engeström, 2017). The authors also note that contradictions manifest “in terms close to the conflict of motives expressed by the participants” (p. 86), further establishing the connection between both contradiction and conflict of motives.

The dynamic relation between contradiction and conflict of motives may further be described as the channeling of energy as a *push* phenomenon from contradictions, aiming at the future orientated concept exerting a gradual *pull* (Sannino & Engeström, 2017, p. 94). The push and pull dynamic represent a gradual movement from *contradiction* to problematic *first stimulus* triggering a *conflict of motives* to a tentative *second stimulus*. The process allows a collective to

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<sup>3</sup> We applied the following research strategy to Google Scholar on 2022/08/04: (contradiction OR tension OR conflict) AND (“cultural-historical activity theory” OR “CHAT” OR “Cultural-Historical Activity Theory”) which resulted in a selection of 27 articles.

break out of a *paralyzing conflict* and to map a *zone of proximal development* eventually leading to the emergence of a *germ cell*, i.e., a new theoretical idea or concept in the form of an abstract explanatory relationship oriented towards the building of a new model (Engeström, 2015, p. xx). In this research, the push-pull dynamic is operationalized through double stimulation.

### **2.1.2 Double Stimulation**

The method of double stimulation is rooted in Soviet psychology (Ploettner & Tresseras, 2016). According to Blunden (2021), the method of double stimulation came as a reaction to the difficulty to understand human behavior without understanding consciousness, which cannot be observed directly. As physiology and behavior are observable, this methodological conundrum was tentatively resolved by Vygotsky and Luria through the experimental method of double stimulation to bridge the symbolic and concrete and investigate reasoning abilities and through cultural tools (Kucirkova et al., 2015).

Sannino (2015b) further describes double stimulation as a method, a process, a theory-method, and a principle. In CHAT, it is described as a method, i.e., a generative principle relying on the exposition of subjects to a set of two stimuli. The second stimulus is described as an artifact or a model engaging participants in redesigning their activity (Ploettner & Tresseras, 2016) and as such it may represent a promising way to understand how individuals and collectives may transform their conditions (Sannino, 2015a) through a double apparatus of decision-making (Figure 7). Hopwood and Gottschalk (2017) further stress the difference between double stimulation and technical mediation. Double stimulation aims at investigating the motives for conducting certain types of activities, the origins of said activities and their connections to society. In the perspective of this research, it makes accessible the learning process through which collectives may engage in collaborative problem solving. The gaps of



knowledge on such processes over extended time frames have been stressed (Graesser et al., 2018; Sannino et al., 2016) as double stimulation has been treated in the literature in a fragmented way (Isaac et al., 2022; Sannino, 2016; Sannino & Laitinen, 2015) despite its foundational value in a deep tradition of formative interventions.

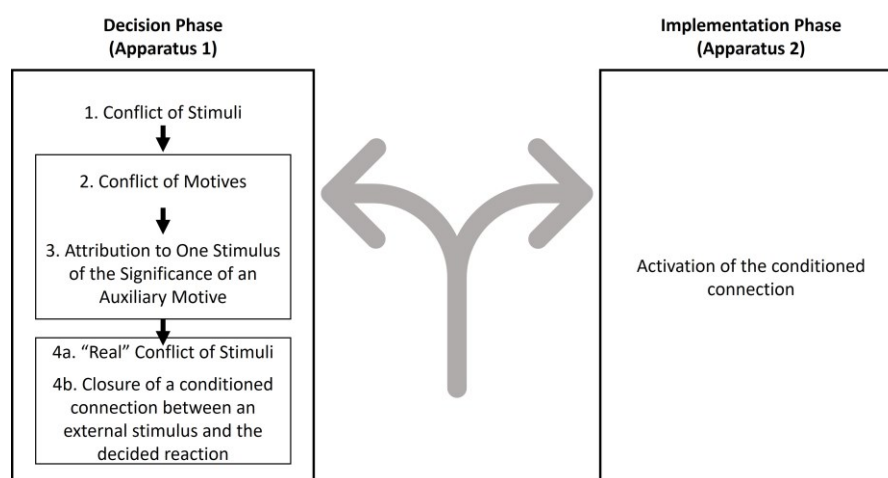
### ***2.1.3 Transformative Agency by Double Stimulation***

Transformative agency may be described as “... breaking away from the given frame of action and taking the initiative to transform it” (Virkkunen, 2006, p. 49). For Mäkitalo (2016), agency corresponds to the capacity for agents to act upon and transform the meaning of situated activities (p. 64). Although learning and agency have been questioned in research endeavors (Thorne, 2015), the agent—artifact dialectical relationship remains at the center of the transformative process, both as far as problem situations and agents engaged in this process. Artifacts involved in the process may be of various natures (material, digital, discursive) and they are both interwoven in and constitutive of transformation (Lund & Vestøl, 2020). However, agency cannot be understood as a discrete phenomenon, and transformative agency is deeply rooted in disturbances, conflicts and contradictions (Lund & Vestøl, 2020); through the process of transformative agency, such disturbances are progressively transformed through epistemic learning actions such as *explicating* and *envisioning new possibilities* (Engeström et al., 2014; Haapasaari et al., 2016). As such, it is *transformational* in that it seeks to go beyond situations and actions, emerging over time through polylogs and negotiations producing a new vision to be later implemented. Double stimulation may afford a framework suited to the emergence of volitional action (Engeström et al., 2014) out of conflicts of motives through an *auxiliary stimulus*, i.e., an artifact filled with meaning and turned into a sign. Both definitions of transformative agency point towards action aiming at transforming the object of collective

action. Indeed, transformative agency may be best analyzed through negotiation, contestation and collaboration across two or more agents engaged in dealing with a challenging object (Nummijoki et al., 2018). TADS may therefore usefully capture *the process of formation of will* towards societal transformation and embody a *principle for changing practices* by encouraging subjects to expand their understanding of the object thus creating learning opportunities for collectives to not only understand but expand their object (Yamazumi, 2021). TADS connects volitional acts that break away from conflicts of motives through agency and auxiliary means used over time to allow people to “form willful actions aimed at changing their circumstances and shaping their uncertain futures” (Sannino, 2015a, p. 1). Conflicts of motives are central to TADS, which offers a means to analyze agency from inner psychological properties towards external artifacts that may become second stimuli and enable transformative actions. In this respect, we may follow Bandura (2001) to distinguish *individual* agency, focused on the setting up of objectives while *collective* agency aims at improving a situation, e.g., sharing goals and beliefs, transforming the environment, emergence of communities and their development through collective effort). The model of TADS is more primarily concerned with the latter, and it is illustrated below:

**Figure 7**

*Transformative Agency by Double Stimulation Adapted From Sannino and Laitinen (2015)*



Engeström (2020b) further asserts the prevalence of the method of double stimulation to educational approaches and of the importance of promotion of agency in education settings. According to the authors, an increasing number of challenges in education may no longer be formulated as closed problems but as open-ended ones which require instructional methods to overcome conflicts and break out of problem situations over disturbances caused by interactions with external systems.

Learning may be understood as a process of internalization and control of knowledge and competences that may result in both new understanding and new competency (Alexander et al., 2009) which is expected to change the behavior and cognition of the learner (Engeström & Sannino, 2010). As a result, learning in school may appear disconnected from practice; under this perspective, learning “makes sense” at a different time, in a different context than the time of exposure to knowledge (Nilsson & Wihlborg, 2011). In this respect, hybrid educational activities emerge from the interaction of two interacting activity systems involving dialogue, negotiation of multiple perspectives and voices (Yamazumi, 2021, p. 34). Hybrid educational innovation

stemming from this process is “a process aiming at creating advanced networks of learning based on the collaboration among a variety of participants both inside and outside a school, gradually transcending the school’s institutional boundaries” (Yamazumi, 2013, p. 61). This process aims at fostering cycles of expansive learning to promote creativity and for participants to exert agency.

### ***2.1.3.1 The First Stimulus (S1)***

TADS is a model composed of two apparatuses involving the interplay of two sets of stimuli; when considering stimulus 1, conflicts of motives play a decisive role: “conflict of motives denotes a clash between opposite aspirations or tendencies which occur in situations involving uncertainty about the situation in which one is or about one’s own conduct and requiring the courage of a deliberate choice” (Sannino, 2015b, p. 8). According to Sannino (2022), TADS allows collectives and individuals to break out of conflicts of motives and change their circumstances by forming *auxiliary motives*, or *second stimuli* (S2), and implementing them. According to Sannino, problematic situations may provide conflicts of motives, or first stimulus (S1). To either solve or cope with the problem triggering conflicts of motives (S1), learners turn to artifacts (S2) to gain control over and transform the problematic situation into one that is understandable and manageable (p. 10). In that sense, TADS is a model of agency that allows to inform concretely lived change processes, according to a dialectical rationale that allows for its conceptualization in terms of processes, and it contributes to the creation of conditions to enact concretely agency.

#### ***2.1.3.1.1 Conflicts of Motives***

Vygotsky defines a motive as a complex formation involving reactions to stimuli:

As motive, we understand a complex system of stimuli connected with the construction, formation, or selection of one of the reflex curves... intruding into a certain system formed to evaluate the set-up and habits... this complex, reactive formation crystallized around the stimulus is a motive... The motive is, in a certain sense, a reaction to a stimulus (Vygotskiĭ, 1997, p. 214)

Leontyev (1977), on the other hand, described motives as “motivational spheres of consciousness” (p. 62) which determine the object of activity as there cannot be “non-motivated” activity (Leont’ev, 1977, p. 63). However, motives may be conflicting as *concurrent goals* (Charron & Koechlin, 2010). Conflicts of motives have been identified as key components of the genesis of will at individual and collective levels (Engeström et al., 2015; Morselli & Sannino, 2021); however, despite the strong developmental dimension asserted by Vygotsky, Sannino and Morselli link the rising of conflicts of motives to situations entailing ambiguity and necessarily implying the taking of a willful decision as a condition to the emergence of volition. Conflicts of motives are therefore framed in this PhD research as a condition to meaningful advancement. Indeed, ambiguity and open-endedness are seen by the authors as “the outset through which the individual willfully acts to influence his or her environment” (p. 3). The authors identify these conflicts as manifesting through DMC (Engeström & Sannino, 2011). Building from these elements Sannino and contributors (2021) suggest a three-step process to analyze TADS: identifying (a) a conflict of motive, (b) second stimulus (c) new forms of practice.

One additional aspect of the relevance of conflicts of motives is revealed by *expansive transitions*, as described by (Engeström, 2015; Engeström et al., 2014) and subsequently put in practice by Ivaldi and Scaratti (2020). They are described thus: (a) from systemic contradictions to experienced conflicts of motives, (b) from conflicts of motives to auxiliary stimuli and (c)

from second stimulus to implementation of solutions. The authors subscribe to the same framework as Sannino and collaborators (2021) on DMC (Engeström & Sannino, 2011).

#### 2.1.3.1.2 *Discursive Manifestations of Contradictions*

Morselli and Sannino (2021) link contradictions (see section 2.1.1) and DMC (Engeström & Sannino, 2011); the sum of elements made accessible by paying close attention to DMC—otherwise not directly available—may in turn be used to enrich the description participants of critical events to detect underlying contradictions (Ivaldi & Scaratti, 2020, p. 3). The generative and creative aspect of a dialectical framework based on DMC is developed for instance by Li and colleagues (2022) according to whom it allows participants to understand a phenomenon based on the principles of *change*, *contradiction* and *wholeness*, fostering broader cognition and creativity as it allows to hold conflicting perspectives while considering them both as correct. Indeed, contradictions are *dialectical* (Deslandes et al., 2016) in that they constitute unity of opposite forces or tendencies (Engeström & Sannino, 2011). Although contradictions are used in a variety of ways, most of the research studies surveyed have focused on a generic use of contradictions and do not make explicit their position and role in the analysis provided. Their role is rarely made explicit. Few studies have focused on the generative potential of systemic contradictions in activity systems, and many studies tend to group *systemic contradictions*, *conflicts of stimuli*, *conflicts of motives*, under the *stimulus 1* label without specifying the role they play in the field or in the data collected. Consistent with these observations, Sannino and collaborators (2016) mark the difference between analysis devoid of the prevalence of conflicts of motives and volitional aspects, which are discriminating factors to distinguish simple mediation from double stimulation processes (Hopwood & Gottschalk, 2017).

### 2.1.3.1.3 *Expansive Resolution of Conflicts of Motives*

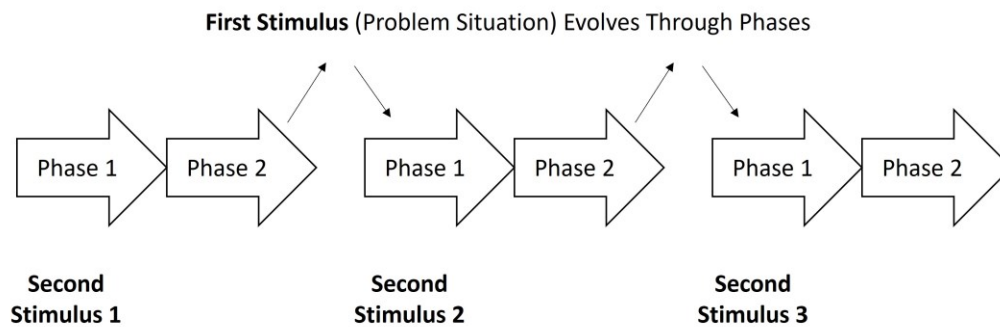
In line with research questions and objectives in this research, this section deals with the concept of expansive resolution of conflicts of motives. First spotted in the literature in the work of Barma and colleagues (2015), *expansive resolution of conflicting motives* (p. 9) refers to the expansion of conflicting motives leading to the emergence of subsequent new conflicting motives caused by the subsequent expansion of the object as motives and object evolve to match. In this study, the authors analyze development cycles through double stimulation which seek to resolve tensions producing struggles, obstacles, tensions, and clashes. The authors note that conflicts of motives may intersect and overlap; the study reveals a deep interplay of the volition formation process with conflicting motives: as a result, the expansion of certain poles of an activity system engenders new conflicting motives.

### 2.1.3.2 *Stimulus 1 ↔ Stimulus 2 Pathways*

To illustrate the concept of transformative agency and its relation to conflicts of motives, transformative agency may be described to depend on three elements: situation of contradictory motives (S1), construction of an auxiliary motive stimulus-means (S2), practical action to transform the situation (Engreström & Sannino, 2020). The combination of these elements makes up agentic actions, as illustrated in Figure 8 below:

**Figure 8**

*The Emergence of an Agentive Action as Mediational Chains (Engeström & Sannino, 2020, p. 91)*



Conflicting elements (S1), stimulus-means (S2) and practical action come together in successive steps, which the authors describe as *mediational chains* (p. 91) leading to agentive action, i.e., expressions of transformative agency. Far from being a once-occurring process, it is an iterative process of redefinition of the problem conducted through a sequence of intentional actions. Additional new meaning coming from previous chains influence both S1 and S2 in the following chain: “Chaining is thus a progressive elaboration of the evolving problem situation through the use of multiple auxiliary mediating means and new meanings on the conflict” (p. 91). The formation of will is therefore described as a longitudinal process evolving over time and subject to negotiation and changes rather than a decisive moment.

The *mediating social relations* need to be articulated in educational settings as modalities of human agency (Jalasi, 2020; Sannino, 2022). Specifically, the authors study in this paper the emergence of emancipatory TADS as resting on motives and unfolding over *process pathways* (p. 4) bridging first stimuli analyzed as conflicting motives and second stimuli in the shape of agreements, management plans and tools. In this framework, emancipatory agency involves a mediation process that produces a second stimulus addressing contradictions and conflicts of



motives, which needs to be developed collectively in transforming power relationships, specifically (Lotz-Sisitka et al., n.d.).

Elaborating further the point risen by Hopwood and Gottschalk (2020), Sannino and Engeström (2017) also stress the importance of both conflicts of motives and second stimulus as preconditions for *ascending from the abstract to the concrete*; indeed, the authors focus on an analytical framework articulated around *contradiction, conflict of motives, first and second stimulus, zone of proximal development, germ cells and emerging concept* (p. 85). A critical point raised from this research stems from the fact that the degree of aggravation of a contradiction or a conflict of motive does not predict the results, outcomes, or processes of an intervention.

Hopwood and contributors (2022) distinguish experimental settings, i.e., the waiting experiments and its various iterations and ecological contexts in which TADS may be taking place; according to the authors, the processes engendered are messy, temporally dispersed, and iterative by nature (p. 3), particularly when the problematic situation implies chronic reactivation of a conflict of motives. To account for such unruly and messy processes, the authors settle on an analysis grid that is rooted in *conflicts of motives, auxiliary motives, kedge anchors, throwing/searching actions, taking over/regaining actions, breaking out/moving away actions* (p. 9). Interestingly in this view, contrasting with e.g., Waermö (2016), transformative agency still emerges due to a conflict of motives, yet the author locates the conflict of motives *at the level of the first stimulus*, which contrasts with the two previous frameworks described above. The three following categories can be identified: conflict of motive as first stimulus, emergence of transformative agency through negotiation in a situation (p. 25). The distinction is important,

as it points to the fact that conflicts of motives may trigger problem situations or may in some situations *encapsulate* the problem situation.

One important point risen by Engeström and Sannino (2016) is that the actions undertaken in a double stimulation process are not driven by systemic contradictions systematically; *systemic contradictions* rather need to be turned into *personal conflicts of motives* (p. 409). Taking this a step further, Ivaldi and Scaratti (2020) frame *contradictions* and *conflicts of motives* experienced discursively through their manifestations as essential components of the stimulus 1. Augustsson (2021) refers to conflicts of motives as conflicts articulated by participants, and offers the following analysis grid: *contradiction, conflict of motives, first and second stimulus, zone of proximal development, germ cell and emerging concepts*.

Barma and collaborators (2015) published the results of a study that is closer in the theme chosen to the preoccupations of the present PhD study; not focusing solely on the constitution of higher mental functions, the authors focus on conflicting motives as a central principle of double stimulation, and it is therefore a powerful tool to agency emergence in response to a problem involving a conflict of motive; in this interpretation of the theory, the problem (i.e., S1), contrary to previous operationalizations, is not merged with conflicting motives. As such, it may be closer to our stance as researchers. The model suggested to describe the decision forming process in teachers' decision forming process as one of (a) *acceptance of the impossibility of finding a consensus as far as environmental issues*, (b) *choice to approach environmental issues in a different way*, (c) *decision to debate controversial issues*, (d) *engaging in planning a teaching sequence*; this sequence may be summed up in the following way: *acceptance, choice, decision, engaging in agentic actions*. In the case of the designing of a novel teaching sequence, the authors frame agentic actions as resulting from the *expansive resolution of conflicts of motives*

which would lead to subsequent new challenges characterized by conflicts of motives involving larger communities (p. 36). Unfortunately, although the research is concerned with the use of controversial issues in environmental or sustainability issues, it does not address the potential for students to develop agentic actions in the face of highly ambiguous open-ended problems.

Van Amstel (2021) studied the role of games and gamification in developing and mediating transformative agency while facing conflicts of motives in education, work and design activities; Van Amstel rests on a position where she identifies games and gamification as contemporary approaches that allow the introduction of conflicts of motives about the learning process, hoping to challenge students to master the contents; although we perceive the interest and meaning of such an endeavor, we remain skeptical whether the conflicts of motive mentioned by Van Amstel would rather fit in the primary contradictions framework, e.g., as an instance of a primary contradiction of the activity of school going (Engeström, 2015, p. 82).

Impedovo (2022) focuses her interest on transformative agency in discourse and actions in envisioning new patterns and models for the current activity. The author focuses on Italian migrant workers in France and their narrative accounts. In so doing, the author leans onto examining dilemmas, conflicts, and contradictions *in* and *in between* activity systems; thus, the author focuses on the notion of *interest* resulting from the emergence of transformative agency in the personal accounts of the migrants. The analysis centers on displaying *conflicts of motives* and *interest conflicts* as components of transformative agency. At its analytical core, the study uses the categories of *place, conflicts of motives and action*.

Romero and Barma (2022) further investigate temporality and dynamics of ill-defined problem-solving activity through a microgenetic approach of a practical problem-solving activity. The authors investigate the relation between subjects in a task of manipulable visuo-

spatial constructive play objects. Stressing the formation of will, the authors stress the nonlinearity of the decision-forming apparatus based on conflicts of stimuli, conflict of motives, and interactions with artifacts, which according to the authors materialize the problem-solving process.

Finally, Barma and her collaborators (2023) focus on the expansive resolution of *conflicts of motives* in a team of teachers over a seven-year period during which secondary education teachers were supported in the application of normative regulations through a DWR methodology. The framework suggests a dialectical mode of analysis according to which DMC (Engeström & Sannino, 2011) combine with ELA (Haapasaari et al., 2016) in learners. The originality of this work comes from the association of both frameworks to spot and rebuild actions from participants in the study. This framework is therefore in line with the frameworks highlighted in this section. The originality of the paper is to unify the frameworks under the umbrella of the concept of *perezhivanie* (p. 10) by including emotions to their analytical framework while framing the concept of *perezhivanie* to work over conflicts. As a result, their tentative framework opens a way to bridge the qualities of the individual and the characteristics of their environment, the *social situation of development* (Veresov & Fleer, 2016) with a potential for criticality. Data collection and analysis are performed through the use of dialectical analysis of DMC (Engeström & Sannino, 2011) and expressions of transformative agency (Haapasaari et al., 2016). Again, in this PhD study, the authors found that the resolution of conflicting motives triggers new ones, therefore pointing towards further potential development cycles.

This research relies on a dialectical unit of analysis based on double stimulation after Lund and Vestøl (2020). We chose to study phenomena involving transformative agency in

higher education, and therefore needed a unit of analysis to capture dynamics and dialectics. We therefore chose a unit of analysis that captures the dialectic between problem situation and resources mobilized for its solving (described in section 3.3.2.) while recognizing the importance to consider the object of expansion processes through S2.

### **2.1.3.3 *The Second Stimulus***

Although this research recognizes the importance of contradictions, tensions, and conflicts of motives by focusing primarily on S1, it is also concerned with S2 and the dialectical relation between the two stimuli. According to the definition of Engeström (2011), a second stimulus requires four characteristics: (a) it is *intentionally designed*, (b) it is *formulated vaguely* initially and its meaning is progressively enriched over time. (c) It functions as an *anchoring device* which is stable over time and (d) it addresses the challenge caused by *aggravated contradictions*. Structural and historical tensions are connecting elements between the two stimuli.

The categories described in this section find their purpose as methodological instruments allowing for close examination and understanding of discursive manifestations displaying the categories exposed: *epistemic encounters* are occasions for the circulation of knowledge through interaction, on the one hand, and the production of concepts and models have the potential to become boundary-crossing artifacts between activity systems, on the other hand. In this PhD study the potential boundary-crossing quality is identified as producing a qualitative change as to the nature of the object, whether the level of the system, or at the level of its object. As a result, the production of a second stimulus through the transformation of an activity system's structure also represents a transition to a new motive, and this transformation or expansion of the activity structure may lead to new relations between and among the subjects (Yamazumi, 2021).

According to the author, this transition is twofold: (a) from one or several people's deviation, from the specific to the universal i.e., the *abstract* to the *concrete*, or (b) from individual subjects to collective subjects.

#### ***2.1.3.4 Transformative Agency by Double Stimulation: a Synthesis***

The models reviewed in the previous section are summed up in Table 1 below which displays the various models and applications of TADS:

**Table 1***Models of investigation of TADS in the literature*

		Decision phase			Implementation phase	
Sannino (2022): the TADS model		S1: conflict of motives	S2: auxiliary motive	S1 + S2 reactivation	Implementing S2	
Sannino and Laitinen (2015)	Conflict of stimuli	Conflict of motives	Second stimulus	Real conflict of stimuli	Closure of a conditioned response	Implementation
Engeström et al. (2014)	Expansive transition 1: from systemic contradictions to conflicts of motives	Expansive transition 2: from conflicts of motives to potential auxiliary motives			Expansive transition 3: from S2 to systematic implementation	
Barma et al. (2015)		Acceptance	Choice	Decision	Engaging in agentive actions	
Hopwood & Gottschalk (2020)	Activity	Stimulus motive Conflicting stimuli Conflicting motive				
Augustsson (2021)	Contradiction	Conflict of motives First stimulus	Second stimulus			Zone of proximal development Germ cell Emerging concepts New forms of practice
Sannino et al. (2021)		Identifying a conflict of motives	Second stimulus			
Hopwood et al. (2022)		Conflicts of motives	Auxiliary motives	Kedge anchors	Throwing/searching actions, taking over/regaining actions	

Impedovo (2022)	Place	Conflicts of motives dilemmas		breaking out/moving away actions action	
Barma et al. (2023)		conflict critical conflicts double binds		Criticizing questioning explicating envisioning committing and taking consequential actions	
Sannino & Engeström (2017)	Contradic tion	Conflict of motives	First and second stimulus		Zone of proximal development Germ cell and emerging concept Channel intervention Channel wider life
Hopwood & Gottschalk (2017)	Conflict of stimuli	Conflict of motives	Auxiliary motive		
Grant (2022)	Conflict of stimuli	Conflict of motives	Auxiliary motive	Real conflict of stimuli	Closure
Romero & Barma (2022)	Conflict of stimuli	Conflict of motives	Second stimulus	Real conflict of stimuli	Closure Implementation

Table 1 allows us to note the variety of approaches in CHAT through the literature, while at the same time noticing the common features from every framework used. We are aware the authors may tailor and assemble concepts to suit their research objects and needs, despite relying on a common framework. We see our intent in this research as distinct from those described in the previous sections and therefore for practical reasons, we chose to rely on the original model from Sannino (2015b) composed of *conflict of stimuli*, *conflicts of motives*, *auxiliary motives*, *real conflict of stimuli*; in the following sections and results, we swapped the lengthy *closure of a*



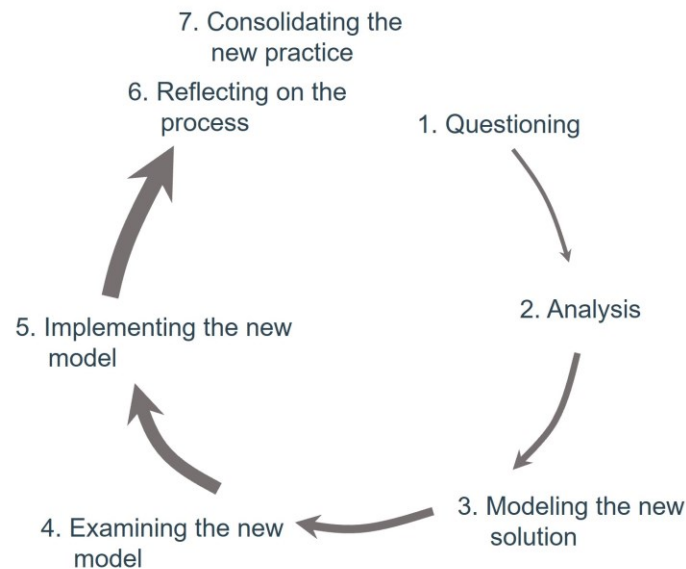
*conditioned connection between an external stimulus and the decided reaction* (Sannino & Laitinen, 2015) for the more readable *stimulus 2*; we intended to present our results in tables and therefore opted for the more simple label although we set on maintaining the original more complex model due to the resolution it affords to analysis in ecological settings. Furthermore, due to the prevalence in multifactorial complex settings of the interplay of problem definition and problem-solving phases, we anticipated the necessity to use a framework that would incorporate the possibility to account for conflicting stimuli, i.e., conflicting situations.

#### **2.1.4 Expansive Learning**

For Engeström (2015), *learning* happening at activity-level results in a theoretical reconstruction of the object which results in analyzes and connection of discrete elements with their systemic activity contexts. These elements are then transformed into contradictions demanding creative solutions which may expand and generalize into a qualitatively new activity structure. In further stages, instruments of learning activity are models that objectify the essential relations of the object; the construction of *models* is accomplished via a *methodology*. This process is essential to the line of thinking in this work: learning activity is a two-way expansive movement from models to the methodology of making models (p. 99). Furthermore, the transitions between epistemic learning actions in the expansive model may contrast with the instructional guidance usually encountered in traditional learning and offer a way to trace the evolution of contradictions in the object of the activity being transformed (Miettinen, 2009). The cycle of expansive learning cycle is depicted below:

**Figure 9**

*Expansive Learning Cycle Adapted From Engeström (2015)*



At its core, given the importance given to *collective subject* in activity both from a CHAT perspective and from a co-creative problem-solving perspective, expansive learning is “learning in which the learners are involved in constructing and implementing a radically new, wider and more complex object and concept for their activity” (Engeström & Sannino, 2010, p. 2). In this respect, we follow Yamazumi (2021, pp. 59–62) who envisions expansive learning (a) as a historically *new type of learning*, (b) emerging as a system of *object-oriented* and *instrument-mediated* collective activity, (c) as an *activity-producing activity*, (d) as learning based on *dialectical change* and development of human activities driven by their inner contradictions, (e) as learning that causes a transition from *individual actions* to new *collective activities*; (f) finally, it emerges through the creation of *instruments* that are conducive to and promote the expansive development and mastery of new activities. Spinuzzi (2018), on the other hand, stresses the importance of the gradual modification of the mediators in a system to produce new collective

designs and therefore activities. In the cycle displayed above, *modeling* is a centrally important learning action and is at the center of the analysis offered here. This position was also assumed by Hyrkkö & Kajama (2021) and is the one we follow here; for Engeström (2014), the modeling phase is particularly central because it articulates a new tentative idea of solution to a problem and therefore have potential to mediate between action and activity levels.

#### **2.1.4.1 *Expansive Learning Actions***

According to Haapasaari and contributors (2016), learning actions may be defined as manifestations of agency developing in activity systems: transformative agency is therefore about working out contradictions in an activity system collectively over time (Nummijoki et al., 2018). Haapasaari and colleagues (2016) define five epistemic learning actions that delineate the emergence of agency (p. 236): (a) *resistance* to the intervention, the management or the process taking place, (b) *explication* of new possibilities in the activity aiming at the object of activity or potential following steps or actions to be undertaken, (c) *envisioning* new patterns or models of the activity from mere suggestions to whole models of activity, (d) *committing* to concrete actions to change the activity and finally (e) *taking consequential actions* to change the activity.

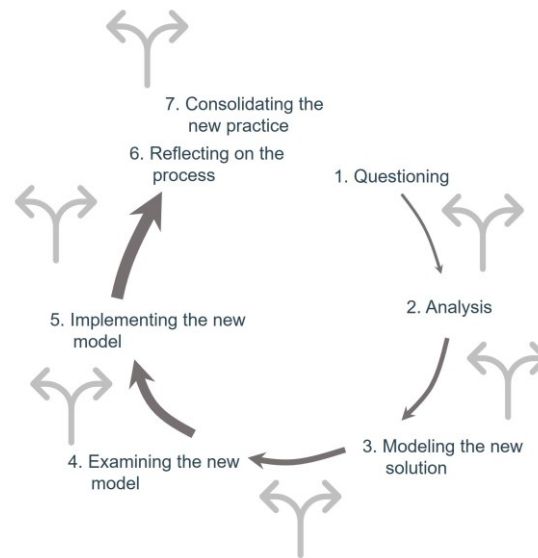
#### **2.1.4.2 *Expansive Learning and Transformative Agency by Double Stimulation as***

##### ***Intertwined Phenomena***

Of further interest in the context of the present investigation, the hybridization of the cycles of expansive learning and TADS is illustrated below, after the work of Sannino (2023). We illustrated instances of TADS in Figure 10 below under the double-headed arrow symbol to symbolize the double apparatus of decision-making described in Figure 7 above:

**Figure 10**

*Integrated Processes of Expansive Learning and Transformative Agency by Double Stimulation  
After Sannino (2023)*



*Note.* Double-headed arrows represent instances of TADS as instances of the implementation of the double apparatus of decision forming in Figure 7.

### **2.1.5 Channels: Intervention and Wider Life**

Sannino and Laitinen (2015) built on the waiting experiment from Lewin to trace the origin of conflicting motives to a movement between “life activity-related actions with mobile phones” and the experimental setting (p. 13). In this experimental setting, the authors report a dual competing source of stimuli between two channels: the *life activity channel* and the *immediate environment* channel. This concept enables the authors to establish the stimuli as coming from channels clashing from the subjective experience of the participants, on the one hand, and the direct environment in which it is experienced. In the context of the waiting experiment, this has the effect of mitigating the effects of the conflicting motives of *staying* vs. *going*. As a result, the concept of *channels* allows for a more comprehensive understanding of

the interplay between phases of the double stimulation model. The following section exposes the coverage of the concept in the literature.

Hopwood and Gottschalk (2017) used an adapted model in an ecological setting dedicated to the transformation of breastfeeding techniques in young mothers and therefore renamed the *experiment channel* to *intervention channel* (p. 25). They analyze data based on the Vygotskian model of transformative agency from Sannino (2015b) applied to the emergence of volitional action in professional-parent interactions and added the two channels described above. The conclusion of the study shows that contrary to the waiting experiment, which is historical, double stimulation happening in ecological context is a recursive, multithreaded, and nonlinear process during which stimuli are in a flux of constant negotiation focusing on breaking away from previous conceptions connected to experiences. The authors note the importance of productive deviations, a concept borrowed from Sannino and colleagues (2016) and note that threads derived from *channels* may be a defining feature of double stimulation in ecological settings.

Grant (2022) uses a model of analysis inspired by Sannino and Laitinen (2015) which also expands the model of double stimulation through the use of *channel intervention* and *channel wider life* coupled to a basic analysis of types of agentive actions (Haapasaari et al., 2016) in the context of a school intervention in South Africa. The authors identify four instances of double stimulation from their data, which they identify as rooted to a defined conflict of motive in each case. The authors also point to the prevalence of channel wider life and of conflicts of motives in student-lead tool making.

### 2.1.5.1 *Knotworking*

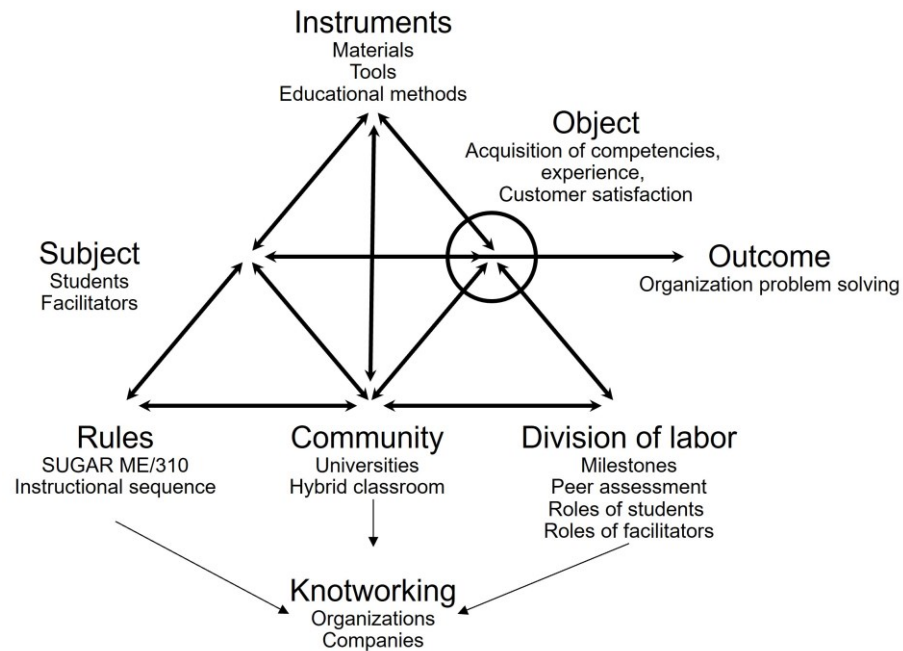
While studying double stimulation *in the wild*, Hopwood and Gottschalk (2017) have suggested *channels* as a potentially defining feature of double stimulation in ecological settings thus confirming the validity of channels occurring in double stimulation processes of will formation (Sannino & Laitinen, 2015). Channels outside of the intervention or experimental setting therefore appear as constitutive of the agentive reframing and repurposing of a problem situation by bringing outside elements into the main activity. In this sense, we contend that *knots* may fulfill a similar function in a hybrid educational activity and expand the possibilities for agents to influence and master their relations to problem situation and master their relation to the environment beyond the system they evolve in by adapting tools available to them. We contend further that critical and potentially creative encounters may fulfill this function and may be considered as defining elements of expansion in hybrid educational activities. Creative encounters may bring cultures of higher education in close contact with professional cultures to engage students in deliberate creation of knowledge early in their higher education curriculum (Hakkarainen et al., 2004). They may also bring participants to grapple with learning that is *tacit*, *intangible* by nature as non-conscious learning operations and actions are embedded in other activities (Engeström, 2015).

Activities at the junction of work and school have been described by Yamazumi (2013) as a transition operated from *transmitting and preserving cultural forms* to *transforming and creating culture* in educational institutions; indeed, educational institutions have little direct impact on society (Admiraal et al., 2019). As a reaction, *hybrid educational activities* seek to create activities in the real world, i.e., to co-create objects of learning across school organizations and outside communities by means of *knotworking*. *Knots* may be defined as temporary

spontaneous collaborations between otherwise disconnected activity systems (Engeström, 2008, p. 194); *knotworking* refers to these collaborations when participants engage in problem solving over short periods of time depending on the correspondence of the object of their activity (Yamazumi, 2013, p. 62). We may illustrate hybrid educational activities and knotworking according to Figure 11:

**Figure 11**

*Knotworking in a Hybrid Educational Activity Adapted From Yamazumi (2021) and Engeström (2008)*



In this respect, *knotworking* may translate at the socio material level to *relation* and *interplay* between elements of practice which may participate in constructing the collective reality (Cleland et al., 2020). In this respect, knotworking may involve both a *horizontal* dimension (e.g., peers, co-subjects in an activity) and a *vertical* dimension (e.g., culturally more advanced activity, senior experts) (Olsen et al., 2019). Expansive learning in knotworking aims at constructing a new object and concept for collective activity and implementing the new object in practice. This includes practices, goals and understanding of why participants do things the way they do. Expansive learning therefore involves an *agentic layer* (Engeström, 2008, p. 62) which relates to the way agents create intellectual, emotional and moral judgments through intentional transformative actions translating these changes to real-life worlds; in this respect, agency is the expression of subject potentialities connected to the creation of new tools and



forms of activity through which humans transform both inner and outer worlds and master their social conditions. On the other hand, engagement in deeper organizational and collective social environment provides a potent incentive to creativity (Vygotsky, 2014; Yamazumi, 2021) e.g., community revitalization, cultural production, economic activation or citizenship activation. As a result, learning, agency, and collective creativity may appear intertwined in collective, future-making, and transformative processes.

For Yamazumi (2013), hybrid activity and knotworking may provide opportunities to generate new types of agencies that mobilize *networks of agents* with an emerging shared object in *networks of activity*; knotworking may allow for the emergence of distributed agency in polylogs across hybridized activity systems. As a result, knotworking-type integrated learning, may occur as a type of learning activity that allows for the emergence of collaboration and creative learning activities across knots: teaching staff and outside partners representing different activity systems may come into contact and recombine motives and goals in horizontally organized movements i.e., between peers and co-subjects. It therefore offers an opportunity to expand *school activity* into *learning activity* involving both the object and the organization. However, collective creativity and learning is a complex and elusive phenomenon which may involve paradoxes, struggles and tensions as regular occurrences along a co-creative problem-solving process (Sannino, 2008b; Sannino & Ellis, 2015) and be better approached from its products. Further, for Nawab and their colleagues (2021) outside influence i.e., from interactions in knots occurring over different types of *encounters* are major sources of disturbances.

#### **2.1.5.2 Critical Encounters**

Considering the importance of knotworking and hybrid educational activities in this research lead us to characterize further the function and impact that *encounters* occurring in

temporary coalitions—in knots—among distinct categories of people whose interests may be congruent. Engeström and contributors (2015) point to the notion of *critical encounter* as “an event in which two or more relevant actors come together to deal with a problem with a potential shared object of activity and at the same time a conflict of motives” (p. 49). The authors equate this potentially shared object with a corresponding *conflict of motive*. As such, *critical encounters* represent opportunities for learning i.e., formation of transformative agency and emergent concepts and may trigger learning and stimulate creative agency through a *conceptualization effort*, i.e., the articulation of an idea or characteristic that has integrative potential for setting a direction to a solution to the perceived *conflict of motive*.

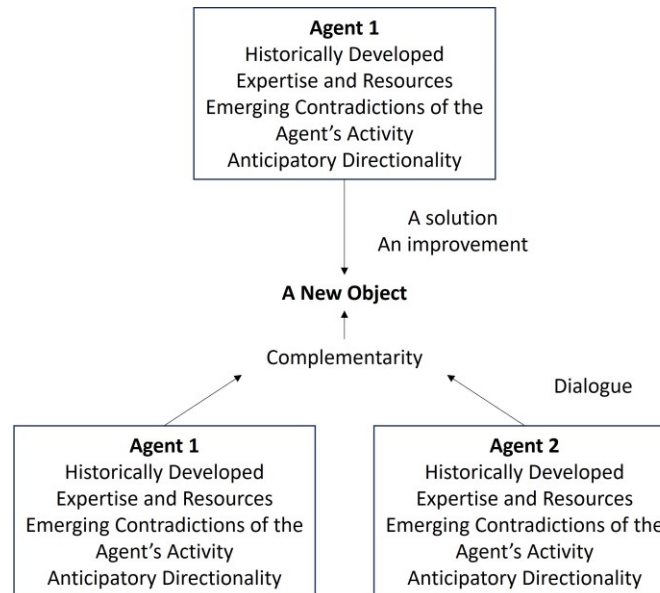
### **2.1.5.3 Creative Encounter and Collaborative Agency**

Miettinen (2013) complements the notion of *critical encounters* as a category of *epistemic encounters* which allow for the circulation of knowledge between stakeholders involved in the process (experts from the field or domain, participants, sponsors, partners, facilitators, etc.). Understood as a continual process of rich interactions, it is conducive to the creation of *epistemic objects*. Miettinen (2013) defines such *creative encounters* as *epistemic encounters* i.e., attempts to circulate knowledge between epistemic frameworks or approaches (p. 161). These encounters represent critical events that tie together spatially distant, institutionally complex, and culturally distinct activities that produce generative dialogic encounters. Within the context of co-creative real-world problem-solving activities, what is generated in such dialogic encounters are epistemic objects defined as representational artifacts such as concepts and models which are instrumental to the advent of change in human practice (Miettinen & Virkkunen, 2005). This concept is further added to the present framework to account for the creative nature of these objects as epistemic boundary-crossing objects which

carry over ideas, concepts, and instruments from unrelated domains into the domain of focal inquiry (Engeström et al., 1995). *Creative encounters* (Miettinen, 2013; Miettinen & Lehenkari, 2016) are of further importance to characterize interactions in knots as they may root the emergence of creative solutions to complex problems involving a variety of stakeholders and participants. The model of collaborative agency is described in Figure 12 below for reference:

**Figure 12**

*Creative Encounter Adapted From Miettinen (2013, p. 162)*



This model stresses the importance of motives involved in an activity, understood as the match between needs and objects. Accordingly, as far as the process of agency is concerned, Miettinen (2013) describes the unfolding of collaborative agency according to the following steps: (a) the recognition of a *contradiction to the construction of an artifact*, (b) the recognition of a *contradiction of an activity*, (c) the formulation of a *constructive problem*, (d) the development of an *inventive idea*, (e) the development of a *product*. This *extraordinary meeting* of an object with a motive echoes the work of Leontyev (1977) and is identified by Sannino (2023) as foundational for expansive learning and TADS whereby participants in an activity sharing the same needs take on a challenging phenomenon as the object of their activity.

## 2.2 Research Objectives and Research Questions

The matching of *need* and *object* in an activity system described by Miettinen (2013) informs the rationale for this research. Our aim is to investigate a *co-creative problem-solving*

*activity related to the runaway object of climate change* happening in an ecological setting across higher education and professional organizations. We chose to focus on the sustained efforts produced by participants over the *modeling* phase of a *shared object of activity* which may be associated with creative and collective *problem finding*. We focus on the processes involving the regulation of collective will through TADS in an activity ruled by contradictory tensions. From the perspective of TADS, we focus on co-creative problem solving at a socio-material level mediated by discourse and artifacts through concepts, signs, or physical persons participating in gaining mastery over problem situations (Engeström, 2015, p. 59) as detailed in section 1.3. The introduction of consequential topics e.g., environmental issues in higher education is aligned with global societal and cultural expectations (European Commission, 2012, 2017; OECD, 2018). We describe the activity analyzed in this research as a *hybrid learning activity* in higher education involving *knotworking* i.e., interactions with a variety of individual or collective agents from a variety of fields and domains as a built-in element of the instructional sequence; the outcome of this process may display the attributes of *novelty* and *usefulness* (Runco & Jaeger, 2012) as an emergent quality occurring across *domains, fields, person* and *press* (Sawyer, 2012).

### **2.2.1 Research Objectives**

The research objectives pursued in this PhD study are further detailed below, and follow the premises detailed in the previous section according to which needs emerge from contradictions in human activity resolved through the emergence of a shared object which acts as a hypothesis for resolving contradictions (Miettinen, 2013). From this perspective, solving a real-world problem requires (a) *transformative agency*, is a process ruled by (b) *contradictions* as primary privileged sources of development, occurs over (c) gradual steps of *negotiation* and

*regulation*, and it aims at (d) the emergence of a *common vision* and commitment to develop a product or a service. The general objective of the research is (a) to document the emergence of regulation processes of collective creative problem finding and solving in a hybrid educational activity in higher education through TADS; this research seeks to (b) describe the interplay and relations of temporary coalitions to the object of activity and (c) to provide a thick description of  $S1 \leftrightarrow S2$  pathways at intermediate and macro levels of analysis.

### **2.2.2 General Research Question**

This research seeks to describe and analyze the processes of collective regulation of will at the *socio material level* and therefore asks the following general research question:

*“How does a collective involved in a complex learning environment may build a shared object of activity when faced with real-world open-ended and ill-defined environmental issues while collaborating in a collective project across higher education and work?”*

Having chosen to rely on a CHAT framework, we can therefore reformulate the general research question above in the following way: *“How may collective will emerge and evolve in a higher education hybrid activity of creative problem finding through TADS in an expansive micro cycle of modeling of an object of activity aiming at the development of artificial photosynthesis technology?”* In subsequent sections and in verbatim excerpts participants refer to APT as *artificial leaf*, the artifact that was presented during initial working sessions, illustrated in Figure 56. Subsequent research questions are further specified in the following section.

### **2.2.3 *Research Objective 1: Emergence of Agency and the Creation of a Shared Object of Activity***

The first research question in this research is dedicated to the emergence of agency, i.e., the origin of agentive actions and their evolution over time. The following research questions ensue:

Research question 1: How does Transformational Agency by Double Stimulation emerge in a Hybrid Educational Activity?

Research question 2: How does Transformational Agency by Double Stimulation evolve over time in a Hybrid Educational Activity?

### **2.2.4 *Research Objective 2: TADS and Knots in a Hybrid Educational Activity***

This research contends the prevalence of the community pole where temporary coalitions are a defining feature of a hybrid educational activity (Yamazumi, 2021) and a peculiar instance of knotworking (Engeström, 2008). This research question therefore seeks to identify the role played by knots in the emergence of TADS and the function of *interactions in knots*. The following research question ensues:

Research question 3: What is the role of knots in the emergence of TADS?

### **2.2.5 *Expected Contribution***

This doctoral research aims at documenting and understanding the underpinning volitional processes and the conflicting motives at play in problem-solving activities. It may also help to understand the way stimuli triggering responses in potentially conflicting motives may emerge for a collective subject through conflicting motives, decision-forming processes, agency and at activity level. As such, this research aims at expanding the scope of research produced on creativity from a CHAT perspective by scaling the framework to authentic, ecological, real-

world activities of problem finding and solving in the social plane of human activity. Further, it aims to investigate the potential for expansion in multi-voiced activity systems involving students, facilitators, and professionals. However, transformation across the boundaries of organizations requires time, and longitudinal studies of expansion and transformation in ecological settings have been highlighted as blind spots in research (Engeström, 2020b; Haapasaari et al., 2016; Sannino, 2015a). In this respect the connection between learning, emergent creativity, collective activity through potentially expansive processes and pathways may appear as a valid and complementary addition to creativity literature, CHAT and TADS, while contributing to environmental consciousness education. Furthermore, formation and regulation of collective will in potentially expansive problem finding in a micro-learning cycle of modeling of a sustainable development activity through TADS may uncover the importance and interplay of stimuli during a longitudinal approach of problem-solving activities in higher education, thus helping to understand the role of conflicting motives in a problem-solving hybrid educational activity. Additionally, it may contribute to understanding problem finding processes in authentic, ecological, real-world activities. Finally, this PhD research may serve to illustrate problem construction in complex, ill-defined and open-ended problem solving as shared object definition activity through double stimulation.

### **2.3 Conceptual Premises**

We frame problem solving of societal issues in the real world as an activity of problem identification (Sannino, 2023). Problem identification may occur in hybrid educational activity (Yamazumi, 2013, 2021) in temporarily forming coalitions of knotworking (Engeström, 2008; Engeström & Sannino, 2021). The object of activity may be defined through collective phases of regulation of learning actions which may result in the expansion of its object (Engeström, 2015).



We hold the position that the shared building of an object of activity is a possible and realistic endeavor in complex learning environments (Yamagata-Lynch, 2010) through hybrid educational activities involving the community pole of the activity system (Engeström, 2008; Yamazumi, 2021). Overcoming contradictions and dilemmas may produce qualitative changes (Lund & Vestøl, 2020) either in the object of activity or at any of the poles of the system involved. Double stimulation as a method (Sannino, 2015b) may be a fruitful conceptual and methodological framework to use in highly complex, ambiguous and contradictory situations. We have identified activities involving intermediate objects such as climate change (Hickel, 2019). We contend such activities may shed light on processes of collective creative processes involving divergence and convergence phases aiming at the production of novelty and usefulness across interacting activity systems. The trajectories involved may be described as expansive pathways (Jalasi, 2020; Lotz-Sisitka et al., n.d.). Moreover, such pathways may provide a way to describe the creative process of problem finding while addressing societal challenges through expansive resolution of conflicting motives (Barma et al., 2015, 2023). Hopwood and Gottschalk (2020) further associate double stimulation as closely related to the necessity of volitional action brought to resolve situations involving conflicting motives.

### 3 Chapter 3: Research Design and Methodology

This chapter presents the methodological framework used in this PhD study to address research objectives and questions. The previous sections have allowed us to establish that complexity inherent to higher education hybrid activity may trigger competing motives (Engeström & Sannino, 2011) as collectives engage in uncertain processes of ill-defined and open-ended problems resolution (Sannino, 2016; Sarathy, 2018). Simultaneously, conflicts of motives may be understood as constitutive of the realization of qualitative change in activity systems (Lund & Vestøl, 2020) through TADS (Sannino, 2015a, 2015b, 2016; Sannino & Laitinen, 2015). The strong focus on transformation in this research exposed three corresponding methodological challenges. First, collective learning in expansive cycles may be considered an elusive phenomenon, which may partly account for the relative scarcity of studies in the literature in higher education apart from formative interventions. Following Engeström (2020b) and Lund or Vestøl (2020), we decided to adopt a naturalistic inquiry paradigm while assuming a DWR stance unlike much work done on the topic of TADS relying on formative interventions. In this respect, Kerosuo (2017) showed the principle of double stimulation to be conducive to transformative agency through unintentional interventions involving knotworking. This challenge is addressed in sections 3.1 and 3.2. The second challenge relates to the choice of a data analysis method to produce a thick description, while including numerical data to provide finer grain resolution on the expansive processes occurring over time. This issue is addressed in section 3.3.1. Third, a challenge was posed by the choice of a unit of analysis that accounted for double stimulation processes in hybrid educational activities. We addressed this challenge by adopting a dialectical unit of analysis including stimulus 1 (problems situations) and stimulus 2 (resources mobilized). This allowed us to inquire into fuzzy open-ended wicked problems where

problem situations may be reconstructed to as not to resolve to abdication (Blunden, 2023) or passivity (Lund & Vestøl, 2020) but enable action and forward movement. Although activity systems may be suited to capture transformation in organizations over time, they may not be equally suited to capture smaller scale expansion of situation or practice. This issue is addressed in sections 3.3.1 and 3.3.2.

### **3.1 Methodological Approach**

#### ***3.1.1 Ontological and Epistemological Stances***

The paradigm in use in this research rests on the ontological view that reality exists and can be apprehended but never fully known (Hatch, 2002); in this respect, researchers work to capture close approximations of reality while maintaining an objective position to the phenomena studied. From this perspective, the only *reality* is human beings in action (Aranzadi, 2023). Furthermore, we subscribe to the view of Grimalt-Álvaro and Ametller (2021) who describe *activity* in science education as ontologically significant and relating consciousness and the physical world, individual and society; in this respect, consciousness is to be connected yet not reducible to physical systems. It was decided to adopt a post-positivist research paradigm. Nonetheless, this research does not aim at generalizing results or predicting phenomena. Taking on a post-positivist stance, the research aims at identifying patterned behavior that participants use to make sense of their surroundings from the systemic analysis of data. From a post-positivist paradigm, scientific research is “interested in capturing participant perspectives but in rigorously disciplined ways” (Hatch, 2002, p. 15).

#### ***3.1.2 Naturalistic Inquiry Paradigm***

All data collected in this research was collected according to a naturalistic inquiry data collection methods (Lincoln & Guba, 1985) to fit the purpose of observing phenomena in

ecological settings. To their author, naturalistic inquiry may serve as an umbrella term for ethnographic studies, field studies, case studies and participant observation (p. 65). The characteristics underlined by Lincoln and Guba (1985) and further developed by Yamagata-Lynch (2010) are reported in Table 2 below, which indicates the sections in this chapter that address each item:

**Table 2**

*Comparison of the Characteristics of Naturalistic Inquiry Adapted From Lincoln and Guba (1985) and Yamagata-Lynch (2010)*

	Lincoln & Guba (1985)	Yamagata-Lynch (2010)	Related section
1	Natural setting	Natural setting	3.2.1 Focus of the Research
2	Human data collection instrument	Investigator as a highly adaptable data collection instrument	3.1.3 Investigator Role
3	Utilization of tacit knowledge	Intuition and observation produce rich understanding about participants	0 Trustworthiness
4	Qualitative methods	Qualitative data collection	3.2.1 Focus of the Research: Collective Processes of Co-creative Real-World Problem Solving
5	Purposive sampling	Purposive sampling	3.1.2 Naturalistic Inquiry Paradigm
6	Inductive data analysis	Inductive methods of data analysis	3.3 Data Analysis
7	Grounded theory	Thematic analysis of the data	Data Analysis
8	Emergent design	Emergent research design	3.2.1 Focus of the Research: Collective Processes of Co-creative Real-World Problem Solving
9	Negotiated outcomes	Negotiated outcomes of the study with participants	3.2.4.4 Research Instruments and Techniques
10	Case study reporting mode	Thick description of observations	4 Chapter 4: Results and Analysis
11	Non-generalizable	claims	3.1.1 Ontological and Epistemological Stances
12	Tentative application	Tentative nature of findings	3.1.1 Ontological and Epistemological Stances
13	Focus-determined boundaries	Clear focus based on the research questions	2.2 Research Objectives and Research Questions
14	Special criteria for trustworthiness	Identify, apply, and report procedures based on trustworthiness	3.3.7 Trustworthiness

### **3.1.3 Investigator Role**

As stated in section 2.1.1, contradictions may represent fruitful avenues for the analysis of complex systems dedicated to the solving of complex open-ended problems, and as drivers of

creativity and development in collectives. As such they may represent value in the context of educational systems (Nawab et al., 2021). The authors contend that the concept of contradiction for learning in educational contexts may represent a missed opportunity due to the negative value often associated with the term; contradictions in their view may serve to break from cultures of conformity and compliance in teaching, learning and assessment to counter memorization and reproduction of text as dominant practices (Engeström, Rantavuori, et al., 2022b; Nilsson & Wihlborg, 2011), where creativity and critical thinking may appear as deviances from the norm. However, such deviances may be channeled by interactions with outside systems. Engeström and contributors (2015) further establish a direct connection with the notion of *critical encounters* as a potential site for the emergence of an object under the constraint of a conflict of motive rooted in *historically accumulated systemic contradictions* (p. 50). Nawab and contributors (2021) further characterize these deviances as potentially emerging from the *multiplicity of stakeholders* involved in an activity, i.e., the *participation of external participants*, the *intervention of an external source* and the *involvement of novices*. Our position as researcher involves lending attention to such deviances and contradictions as important drivers of development in ecological settings, when relating to open-ended and ill-defined situations such as runaway objects and the many contradictory values they may convey and bring about in educational settings.

Our position as investigators was informed by the will to preserve intentionality and conscience of participants in context, as well as their evolution over time. We chose to remain observers of the activity and to maintain its ecological nature to preserve its dynamics and to favor means to maintain access to information. We sought to remain intentional regarding the data we collected and relied on observation as our primary source of data according to an *observer as participant* stance. This posture allowed us to ensure trustworthiness of investigation

while maintaining ecological conditions: the *observer* stance refers to a quiet, observant, unobtrusive location in the field trying not to interfere with activities. By contrast, in the *participant* position, investigators become members of the community (Glesne, 2016). In the context of this research, remained *observer as participant* according to which investigators interact with participants while conducting research. In this scenario, participants identified us primarily as investigators conducting observations. We sought to experience activities by witnessing those activities during investigation under an outsider perspective. However, researchers took part in some activities related to actions or operations aiming at the object of activity. We generated web conference links, helped with the setting up of working spaces and we sat in in-presence meeting. This way, we gained first-hand experience of the emergence of a shared object of activity in an object-oriented activity in an ecological setting. We chose this position to preserve internal validity of the data and to prevent the perspective of the researchers to influence the perspective of the participants. We also sought to preserve the role of the facilitators intervening in the process as distinct from the one of the researchers.

## **3.2 Data Collection**

### ***3.2.1 Focus of the Research: Collective Processes of Co-creative Real-World Problem***

#### ***Solving***

This section sets the focus and point of entry of the research (Grimalt-Álvaro & Ametller, 2021). Complex learning environments and hybrid educational activities describe situations in natural settings in a single or multi-organizational context (Yamagata-Lynch, 2010). The context may provide naturally occurring phenomena (Miles et al., 2018) while focusing on the contents of exchanges and conversations happening in a creative problem-solving activity (Bender-Salazar, 2023; M. K. Foster, 2021). We have therefore framed co-creativity as a social activity

after Romero (2020) aiming at real-world problem solving in a complex learning environment. The present research has been designed as a qualitative research project, aimed at describing the subjective experience of participants in a social situation (Flick, 2014); we therefore set to inquire into experiences and interactions in natural context to highlight their specificities, as occurring in material settings (Flick, 2018). This research was therefore designed to be applied in an ecological setting which implies relying on the three following levels to guide data collection: *attention to people and environment as they interact, teaching and learning as an interactive process and centrality of attitudes and perceptions of the actors* (Hamilton, 1983, p. 151).

We inquired into collective mediated actions towards the pursuit of an explicit goal with the intent to discern causation and interrelations while analyzing longitudinal trends (Flick, 2014). Following Grimalt-Álvaro and Ametller's CHAT approach to design research in science education research (2021), we approached hybrid educational activity from a *relational perspective* between problem situations and the resources mobilized to overcome these problem situations through TADS. We chose to first specify the focus of this research as *collective strategies of co-creative real-world problem solving in a higher education setting*, understood as *material regulation of collective will in problem solving activities through TADS*. Therefore, we chose to focus on the regulation of collective will in creative problem finding in a potentially expansive micro cycle of modeling of an object of hybrid learning activity across higher education and work. We set the focus of the PhD study at the collective level by observing the back-and-forth movements between distinct types of activity and meetings, on the one hand, and the interactions between communities such as companies and potential private sector partners in *knots*, on the other hand. In this respect, the *point of entry* of the study was identified as the *genesis of collective will* while facing ill-defined open-ended problems. We seek to document



and study potentially expansive processes occurring through decision forming over time (Grimalt-Álvaro & Ametller, 2021) in a complex learning environment (Yamagata-Lynch, 2010) involving both higher education and work.

Methodologies based on activity systems analysis (Sannino et al., 2009; Yamagata-Lynch, 2010) may untangle complexities of real-world situations but may not be adapted to studying transformative agency (Lund & Vestøl, 2020) which may be understood as a quality of expansive learning (Kerosuo, 2017). Yet, most studies on transformative agency rely on activity systems analysis (Engeström, 2011; Sannino & Engeström, 2018). As a result, we consider the principle of double stimulation to be best adapted to illustrate agents' endeavors to transform problem situations (Lund & Vestøl, 2020). When focusing on expansive learning cycles or micro-cycles, the processes involving mediated goal-directed actions should be the focus (Postholm, 2015).

### **3.2.2 *Field of Study***

We sought to identify avenues for participation in multiple systems of problem solving or item creation allowing different forms of agency. According to Granados-Sánchez (2023), agents should create *spaces*, *programs*, or *structures* to foster sustainable practices and bring about transformation through collective efforts. Such spaces, programs or structures may be encapsulated as *complex learning environments* (Yamagata-Lynch, 2010) aiming at participants' learning and engagement (Yamazumi, 2021) as they engage in an activity rather than being exposed to fragmented learning actions. Participants may therefore create collective learning activities involving more than a single activity simultaneously. Complex learning environments may be described as "*situations in natural settings where multiple individuals are involved in shared activities within a single or multi-organizational context*" (Yamagata-Lynch, 2010, p.

vii). Co-creative real-world problem solving in a *hybrid educational environment* (Yamazumi, 2013, p. 61) sets a variety of participants in interaction both from within and from beyond education. In this case, the hybrid educational environment is structured as a design course aiming at problem-solving in the real world, with the purpose of identifying solutions while developing both tangible and intangible design artifacts (Yamagata-Lynch, 2014).

We decided to favor a single-case study aiming for an information-rich case to favor depth of study (Patton, 2002); having established an agreement with the Innovative Center for Entrepreneurship (ICE)<sup>4</sup> at Université Côte d’Azur, we considered the courses offered during the 2021–2022 academic year. Access was granted to the researchers to an intermediate selection of two programs involving problem-solving activities, namely *invent@uca* and *SUGAR/ME310*. The latter presented the advantage of involving students with a project related to sustainable development while requiring collaboration with companies. *Invent@uca* was coming to the end of its initial funding, and it allowed its participants access to courses dedicated to problem-solving and co-creation processes; however, it did not grant access to authentic settings as students were attending lecture in groups with minimal interactions planned in the lecture plan. Finally, the last criterion was the duration of the program; studies in the literature have signaled the lack of longitudinal studies on the development of agency, particularly in higher education (Engeström, 2020b; Haapasaari et al., 2016; Sannino, 2015a). Indeed, *invent@uca* lasted one semester, while *SUGAR/ME310* lasted the whole 2021–2022 academic year.

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<sup>4</sup> <https://ice.univ-cotedazur.fr/>

SUGAR<sup>5</sup> is a global *network* dedicated to the promotion of innovation between academic institutions and private sector companies to solve real-world challenges and produce user insights and creative solutions according to design innovation techniques<sup>6</sup>. It brings together corporate partners and students from twenty-five universities representing four continents. The program offers to solve complex problems in international settings using a human-centered design method in practice-based learning. The program lasted for the whole 2021–2022 academic year. In the meantime, twenty projects were offered to university student teams on themes such as optics, sensors and semi-conductors, chemical materials, finance, food, insurance, technology, health, mobility, blockchain or sustainable development and energies. We identify the program as an instance of *academic service learning*, i.e., a program that “engages students in tackling real-life problems in their community as part of the formal curriculum, and, thereby, contributes to solving vital community problems and societal issues” (Tiippana et al., 2022, p. 3). The SUGAR pedagogy is built around the four main concepts illustrated below in Figure 13:

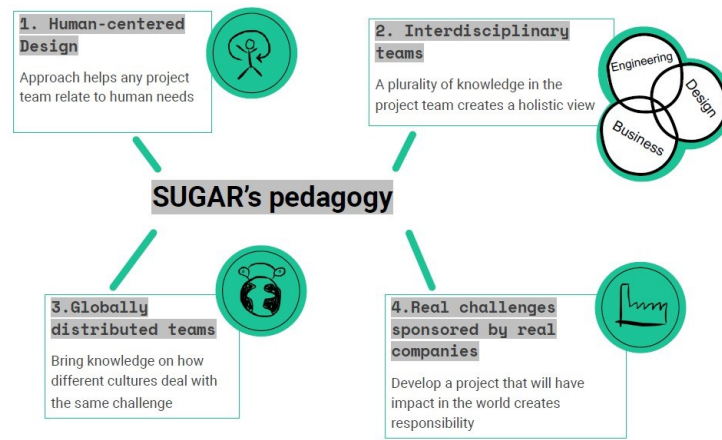
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<sup>5</sup> <https://sugar-network.org/>

<sup>6</sup> <https://expe.stanford.edu/index.php/Main/SUGAR>

**Figure 13**

*The Sugar Pedagogy Model (p. 10 of the “Welcome to SUGAR/ME310” Booklet)*



The SUGAR program is structured according to a design thinking methodology based on prototyping, testing, developing, and implementing original solutions to authentic design challenges from multinational corporate sponsors. The SUGAR network appointed Université Côte d’Azur (UCA) through the ICE service to manage organization and logistics, while Università di Bologna (UniBo) appointed its Almacube<sup>7</sup> offices. The program was instantiated through a minor program format in both universities. At UCA, minor programs<sup>8</sup> are offered to students at graduate level in the Digital Systems for Humans (DS4H<sup>9</sup>) graduate school and research, to diversify and customize students’ curricula coming from five major master programs. The project was initiated by the Istituto Italiano di Tecnologia<sup>10</sup> (IIT) as a *tech-push* challenge dedicated to the development, acceleration, and transfer of an emerging carbon capture

<sup>7</sup> <https://www.almacube.com/>

<sup>8</sup> <https://ds4h.univ-cotedazur.eu/education/minors>

<sup>9</sup> <https://ds4h.univ-cotedazur.eu/>

<sup>10</sup> <https://www.iit.it/>

technology. The challenge was presented as follows: “*How Might We Develop an Innovative Service Based on the 'Artificial Photosynthesis Technology and Create a Business Opportunity Out of It?*” The design brief was presented as follows: “*In collaboration with the technology transfer office of the Italian Institute of Technology, the research project aims to design an innovative service based on a technology capable of converting carbon dioxide (CO<sub>2</sub>) into chemical energy. This technology is named 'Artificial photosynthesis technology' since its working principle is based on solar energy and recalls the system adopted by plants to create oxygen from CO<sub>2</sub>. The IIT team strongly believes in the potential of this technology which allows the sustainable production of energy starting from a limitless source such as (CO<sub>2</sub>), whose impact and diffusion can positively influence many sectors.*” In this respect, we consider this challenge to correspond to the *implementation* of APT, characterized as an uncertain process and requiring creative adaptation to needs and circumstances (Nummijoki et al., 2018). As a result, implementation is a learning process, which requires its object to be modified, expanded, and transformed.

The constant shaping of new instruments is the result of interaction with an *object of activity* over time. Despite their tangibility, runaway objects are hard to bind in space and time, being ambiguous phenomena evading a sense of centralized responsibility. The objectification or “objectedness” of runaway objects requires a specifically focused and decentralized attention to delimit fields of potential actions which have gradually become confiscated by highly trained and specialized professionals. This tends to disengage other publics—applying in this sense a strict division of labor by ostracizing people who nonetheless do suffer from the same consequences. To prevent this phenomenon, Engeström (2009) suggests the use of *intermediate objects* (p. 329) to bring publics stripped from their potential for action into productive activities.

In this doctoral research, we have chosen an intermediate object as the focus of our study at the boundaries of higher education, science, and work. We believe this object to be a fruitful exemplar to inquire into the deep-reaching intricacies of teaching, studying, working, and changing reality in the face of pressing adversity. We therefore chose to observe and study the expansive pathways related to a benign object in higher education in the form of a carbon capturing electrochemical device built on Artificial Photosynthesis Technology (APT).

Yamagata-Lynch (2010, p. 69) stresses the importance of relying on an adequate setting to conduct research. Dealing with large objects may mean the *activity* cuts across multiple organizational boundaries that embed multiple activities. According to the third generation of CHAT (Engeström, 2015; Engeström & Sannino, 2021), programs operating at the fringes of work and school present an opportunity for learning activities (Engeström, 2015). Such programs may therefore represent opportunities to de-encapsulate learning and development in higher education (Engeström, 1991; Engeström, Rantavuori, et al., 2022b; Jóhannsdóttir, 2018). As a result, this study is articulated around the study of a program that satisfies the following criteria: (a) it offers interaction between school and professional practice, (b) it is concerned with environmental issues, and (c) it offers an opportunity to work collaboratively across disciplines and profiles.

### **3.2.3 Participants**

The sample in this PhD study is a homogeneous sample (Hatch, 2002) composed of three types of participants that share common characteristics and are all involved in the same activity: *students, facilitators, and professional researchers (liaison)*. The description of the characteristics of participants may be accessed in Appendix 1. The main project offered by IIT was designed during the 2020–2021 academic year and resulted in a partnership between UCA

and UniBo to facilitate jointly the program. Student participants were recruited at the beginning of the 2021–2022 academic year by ICE, based on their belonging to one of the eight thematic graduate schools of the Digital Systems for Humans, their availability from 2022/09/21 to 2022/06/22 and their fluency in English. The selection of participants was also based on the production of a two-minute presentation video to assess their communicative abilities.

Although interactions in *knots* (Engeström, 2008) are integral to the program, this research omitted interactions in knots in the data, due to non-disclosure agreements required by private sector partners. In this respect, participants taking part in interactions in knots are represented in the data even though they do not belong to the study sample.

### **3.2.4 Data Collection Process**

Gathering data about problem solving from a CHAT perspective implies a deep dive into the fabric of activity and into the strategies used by students and facilitators to solve ill-defined open-ended real-world problems. This research focuses on systemic contradictions and mediating artifacts through the study of in-presence and online interactions complemented by interviews with students and facilitators.

#### **3.2.4.1 Time Frame of the Research: The Modeling Phase of a Potentially Expansive Cycle**

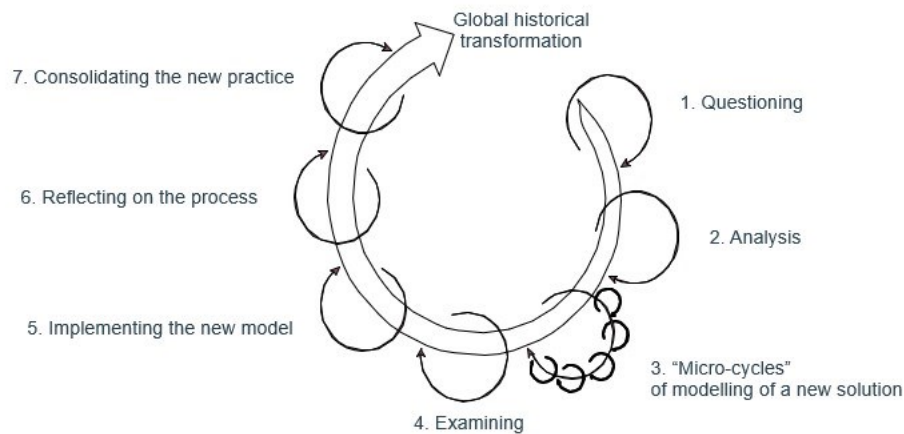
The learning actions occurring over an expansive cycle in this case encompass facilitators, students, and researchers (liaison). Transformations from a sociocultural perspective may occur over cycles of expansive learning which may last years. These efforts are notoriously hard to sustain in the middle and the long run (Sannino et al., 2016), especially as complete expansive cycles aiming at historical transformation may last over a decade. Full cycles of expansive learning may be described as composed of smaller micro-cycles of learning actions that may under certain circumstances produce expansive results. However, such micro-cycles

should occur over longer spans of time to produce expansive results which require deliberate effort and time. In this case, the research focuses on a miniature cycle of development (Barma et al., 2017; Engeström & Sannino, 2010; Nummijoki et al., 2018). Micro-cycles occurring over a potentially expansive cycle may be illustrated thus in Figure 14:



**Figure 14**

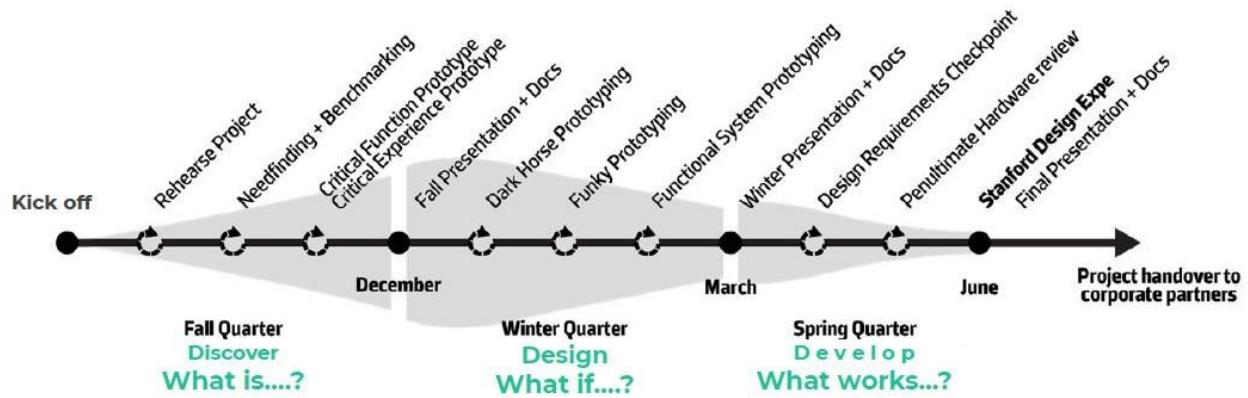
*Micro-Cycles of Modeling Learning Actions and Their Place in the Expansive Learning Cycle After Engeström (1996)*



Examining such a cycle from the perspective afforded by Sannino (2023), we envision it as intertwined and embedded expansive learning micro-cycles in which instances of TADS may occur and symbolizes an instance of the double decision-making apparatus described in Figure 7. Furthermore, the processes involved in an expansive learning cycle are far from linear or predictable (Sannino & Engeström, 2017); it was therefore decided to favor a sequence of three months, considering that the sequence had started three months prior, and would finish three months later; the expected phases of the program are illustrated in Figure 15 below:

**Figure 15**

*SUGAR/ME310's Timeline Process (p. 12 of "Welcome to SUGAR/ME310" Booklet)*



We favored direct observation through systematic video recording of problem-solving working sessions over a 13-week period. The main outcome was the emergence of a shared object in a virtual online course; this research therefore echoes other studies lead in classroom contexts in CHAT studies (Engeström, Rantavuori, et al., 2022b; Jóhannsdóttir, 2018). We further provide a description of what is entailed by each sequence described in Table 3 below:

**Table 3**

*Steps of the Instructional Sequence adapted From Svalina and collaborators (2022)*

Phase		Description	Function in the sequence
1	From October 2021 to December 2021	Need finding and benchmarking of potential fields of application	Diverging: design space exploration
2	From January to March 2022	Critical functions and critical experience of users	Diverging: first prototypes creation
3		Dark horse prototyping	Diverging: creating a prototype with neglected constraints
4		Funky prototyping	Diverging: merging the best ideas
5		Functional system prototyping	Converging: shaping the idea according to final requirements
6	From March to June 2022	Design requirements	Converging: formalization of key functionalities that meet customer needs
7		Hardware review	Convergence: final meeting and agreement with customers validating the product

#### **3.2.4.2 Preparation: Preliminary Observation**

Extended engagement has been ensured from the onset of the project to produce a thick description and ensure that the researchers spend enough time on the field to collect appropriate data (Hatch, 2002). In this respect, full access to the field was negotiated from the onset of the project, and complete access was granted to a complete cycle of activity in the SUGAR/ME310 program; as such, access was granted to the Large Group Meetings (LGM) and some Small Group Meetings (SGM) from October to December 2021 by the facilitators to ensure a smooth transition into the data collection phase, starting January 2022. This immersion phase allowed the researcher to get familiarized with the global methodology of the project and the preceding phases of work undertaken by participants.

### 3.2.4.3 *Research Planning Challenges*

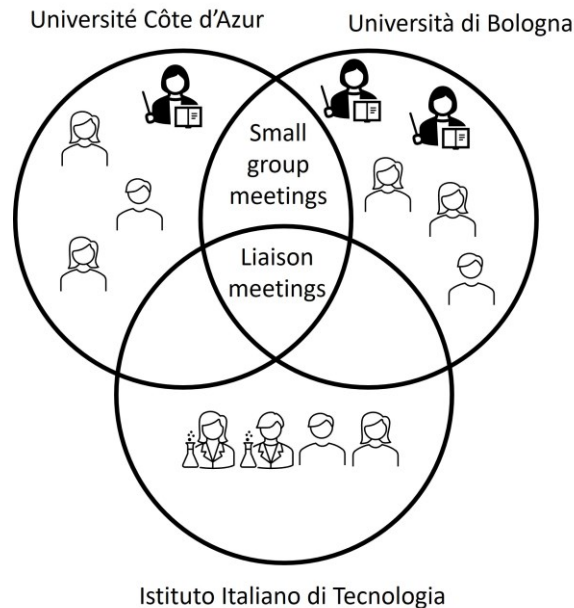
Formative interventions and ill-defined open-ended problem solving share *ambiguity* and *indeterminacy* of outcomes (Engeström et al., 2014): neither researchers nor participants involved can approximate either the outcome or the time of conclusion of the process. The initial planning anticipated the object of activity to be defined by the end of March 2022; facilitators warned all participants that the term of each sequence could overlap significantly over the following one. For this reason, it was decided that the data collection would last until the term of the program in principle; nevertheless, data relating to the last phase of the process, namely the *definition* phase dedicated to formalizing and refining the new object while establishing a possible business model was excluded due to the emergence of an object of activity by the end of the month of March 2022. Participants then moved on to apply this new activity model systematically and applied the newfound object to the activity system. Subsequent work was then dedicated to establishing a business model; the time being invested in client auditing, SGM, LGM and liaison meetings were subsequently suspended to free time for what was perceived to be the main priority of the project. As a result, this phase of the project was subtracted from the data corpus, notwithstanding the diminishing number of working sessions. In this respect, the design of the research may be described as *emergent* (Ravitch & Carl, 2019) regarding the time frame of the data collection process. We set outcomes flexibly to make sure to capture adequate data.

### 3.2.4.4 *Research Instruments and Techniques*

Having established a qualitative research paradigm to be consistent both with the epistemological positions specific to a CHAT conceptual framework described in chapter 2, it was decided to optimize the potential for triangulation in the data by relying on different types of

data. Yamagata-Lynch (2010) identifies the most prevalent data collection methods for qualitative studies related to CHAT as *interviews*, *observations*, and *document analysis*.

Observations provide first-hand experience of everyday activities; although time-consuming, they allow for the observation of situations in which participants engage in goal-directed actions and object-oriented activities that may involve a variety of participants from a variety of places. Although no one observation event may be identified as the entirety of object-oriented activities, they allow for a finer understanding of context. Moreover, goal-directed actions fit into object-oriented activities (Yamagata-Lynch, 2010, p. 71), which is the reason we chose to make them the primary source of data in this research. Participant observation and working sessions recording were facilitated by the full availability of working sessions in video format propelled by the sanitary COVID-19 crisis. According to Hatch (2002), participant observation fieldwork involves a set of data collection strategies that can be utilized within any of the qualitative research paradigms; in the context of the present PhD study, the data set is thus primarily composed of video recordings of working meetings. The organization and composition of the participants in the types of meetings involved are as follows:

**Figure 16***Composition of Meetings*

The details of data collection agendas, timelines, and types of data may be accessed in Appendix 2. Data collection instruments are detailed in Appendices 5, 6, 7, 8 and 9.

### 3.3 Data Analysis

Both quantitative and qualitative paradigms may have veered towards certain types of orthodoxy (Yanchar, 2011). As a result, researchers should be open to using methods that are suited to their questions and purposes (Yanchar & Williams, 2006). Interpretive quantitative methods may help to understand new aspects of practical activity, lived experience and self-interpretation (Yanchar, 2006). Indeed, we contend after Yanchar (2011) that numerical data may enrich qualitative accounts of human phenomena in the real world. The main critic addressed to the use of numerical data rests on its disconnect from practical involvement in ordinary human life. On the other hand, all research account is limited by their inability to encapsulate phenomena outside of perspectives afforded by the setting in which they occur.

Yanchar (2011) identifies two types of uses of numerical data used by Engeström: (a) clarify and support the accounts offered in the research presented, (b) clarify the background context of the activities. This research was inspired by the first option. As an example, Engeström (2002) tested the prominence of the themes they identified through frequency counts over different phases of the research. To Yanchar (2011), this procedure allowed the researchers to remain faithful to the lived experience of participants through practical discourse and practical involvement, and therefore served the purpose of the research. Engeström and Sannino (2011) observed and presented frequency analysis of DMC, a strategy also used by (Engeström, Rantavuori, et al., 2022b). Haapasaari and colleagues (2016) used a comparable strategy to present types of expressions of transformative agencies, while some authors (Barma et al., 2015, 2023) have used both. In these examples, numerical data is used to make sense of transformation as it occurs over time and provided insights into the discursive practices and transformation processes experienced by participants (Yanchar, 2011). Since this research is concerned with the emergence and unfolding over time of TADS in a higher education hybrid educational activity, we were therefore drawn to using numerical data from practical discourse in contextual inquiry. This research therefore answers the plea of Yanchar (2011) for research designs that emphasize the persons-as-agents and their doings in natural authentic situations in a case study strategy through numerical discourse analysis. In this sense, we sought to combine quantitative and qualitative data to identify trends and relate findings to theory (Ponce & Pagán-Maldonado, 2015).

### ***3.3.1 Data Analysis Method: Qualitative Content Analysis Method***

We chose to rely on a qualitative content analysis method relying on a deductive phase to ensure codes to be relevant with the research objectives; as a result, the present research is

focused on applying CHAT concepts to understand volitional processes from the perspective of the principle of double stimulation and TADS. It was therefore decided to expand the naturalistic inquiry framework (Lincoln & Guba, 1985) with a deductive phase of theory analysis before the coding phase. Following Elo and Kyngäs (2008), we contend that using a structured matrix of analysis in the shape of a well-defined coding scheme (see section 3.3.3) allows us to distinguish aspects from the data that fit the prior categorization and identify those that do not. Resulting from the complexity of analysis, categories may be described as conceptually *and* empirically grounded, therefore ensuring optimal coverage of the data with regards the research objectives.

Analysis means organizing and interrogating data to allow researchers to identify patterns, themes, relationships from which to produce explanations, interpretations, critiques, and theories (Hatch, 2002, p. 148). One of the potential caveats of qualitative analysis is the biases involved in the analysis of data; particularly as e.g., systemic tensions or conflicts of motives are rarely explicit and manifest in discourse (Engeström & Sannino, 2011; Miettinen, 2009). According to Chi (1997) the importance of in-context observations is related to the use of external aids and tools and incorporating them to the analysis of verbal transcripts. Accounting for the subjectiveness of the observational methods, Chi advocates for an approach of verbal data integrating elements of both *qualitative* and *quantitative* analysis.

Bryman (2012) defines content analysis as document analysis aiming to quantify content according to predefined categories in a replicable and systematic way. The authors point to the fact that it is an unobtrusive and non-reactive method that is particularly well indicated to track changes over long time spans. Among the various types of qualitative content, qualitative content analysis asks the question of the way the themes are extracted from the data; various methods have been described in the literature: Mayring (2014) advocates for a systematic, rule-bound



procedure structured by categories aiming at objects of study and guided by a strict theory-guided analysis that integrates quantitative steps of analysis.

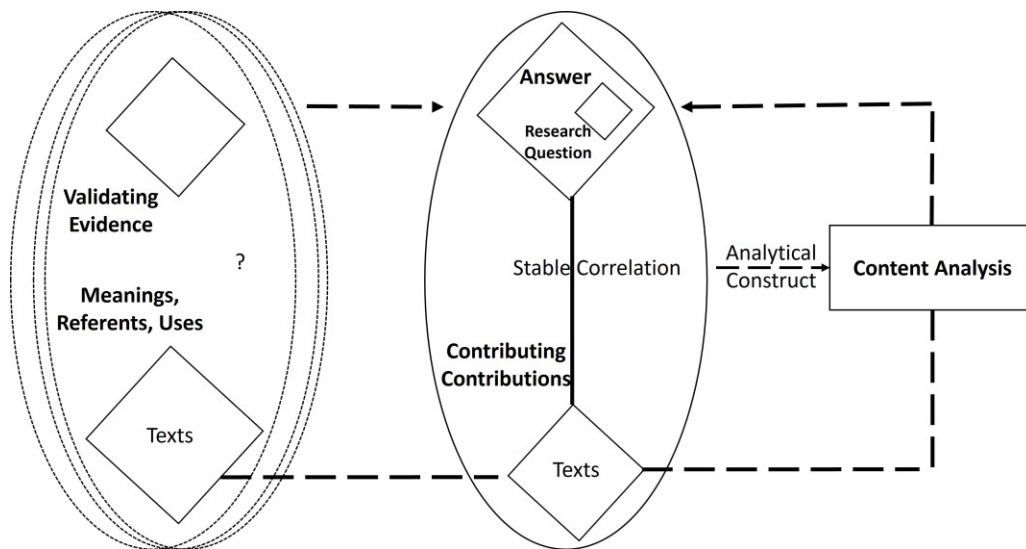
Hsieh and Shannon (2005) also stress the origin of the method as initially a quantitative method with text coded into explicit categories and described using statistics. Evolving from this initial definition, they define it as “a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns” (p. 1278). They identify three approaches to qualitative content analysis: *conventional content analysis* in which researchers avoid using preconceived categories and rely on an inductive method of coding; *directed content analysis* in which prior theories already exist and researchers might as a result use a deductive phase of theory-based analysis to validate or extend a theoretical framework. Finally, Hsieh and Shannon (2005) identify *summative content analysis* as a third type of qualitative content analysis which is based on the identification and quantification of textual content and which refers to manifest analysis which is subsequently followed by *latent content analysis*, i.e., interpretation. Using such a method allows for the discovery of underlying meanings of the content and allows the identification of patterns in the data, the contextualization of codes, and the interpretation of context associated with the use of a word or a sentence while providing basic insight into words usage.

We follow Krippendorff’s definition and initial rationale on qualitative content analyses (2004). According to the author, qualitative content analysis may be most successful when focused on facts emerging in language through the very texts that the content analysts are analyzing. Such linguistically constituted facts of interest here are concepts, attitudes, beliefs, intentions, emotions, mental states, and cognitive processes which manifest in verbal attributes of behavior as they are not observable directly. For Krippendorff (2004), qualitative content

analysis relies on a body of data, a research question, a context within which to make sense of the data, an analytical construct, inferences to answer the research question and validating evidence. This structure is illustrated below:

**Figure 17**

*Global Framework for Content Analysis (Krippendorff, 2004, p. 30)*



Complementarily, we present the components suggested by the author to structure the process in the sections below after Krippendorff (2004, p. 83). In Krippendorff's model and terminology above, texts are the data collected in the form of working sessions transcribed verbatim. The analytical constructs are the conceptual framework and are described in the coding book in section 3.3.3 below. The research questions are exposed in section 2.2. The context of the study is the SUGAR/ME310 program as described in 3.2.1. Finally, the validating evidence is gathered during interviews at several points in the data collection process as described in section 3.2.4.

### 3.3.2 Unit of Analysis: $S1 \leftrightarrow S2$

This section seeks to define the basic unit of meaning to the analysis of discourse through video transcripts. Due to the implicit nature of the levels of analysis involved, the present PhD study relies on themes as its unit of meaning in discourse, which implies identifying and looking for the expression of an idea in utterances occurring in transcripts (Minichiello et al., 1990).

Furthermore, change may be generated through talk in polylogues and be considered and analyzed through consequential actions (Haapasaari et al., 2016) and DMC (Engeström & Sannino, 2011). For Chi (1997), a unit of analysis is analogous to a single trial in an experimental design. For Neumann and colleagues (2002), a unit of analysis is the unit a researcher uses when measuring, which they expand as a data category common across compared settings. As such, each instance represents the construct that is the focus of the relevant research question. Postholm (2015) contends that to understand complex forms, it is necessary for the researcher to build developmental phases and transformations through collective reflection and transformation of activity, which requires to identify the germ cell of the system being studied (Virkkunen & Ahonen, 2011). For Säljö (2009), a unit of analysis carries theoretical and analytical essentials that have explanatory power when examining a phenomenon. Jornet and Damşa (2021), following Vygotsky, we advocate for a unit of analysis that displays *all the basic characteristics of the whole* (p. 4), i.e., salient characteristics of the phenomenon under study, which involves considering the social and psychological processes involved in learning as wholes. Blunden (2021) further asserts the importance for Vygotsky of considering a unit of analysis that represents a concept as a whole i.e., the accumulation of *units of analysis* (p. 10). Kerosuo (2017) argues that transformational agency is a quality of expansive learning that manifests relative to *structure* and *human praxis*: capturing transformative dynamics requires to consider various levels: discursive, systemic and agentic (Lund & Vestøl, 2020), which may be afforded by the principle of double stimulation (Sannino, 2015b). However, consistent with previous observations (Isaac et al., 2022; Lund & Vestøl, 2020; Sannino, 2015b), few studies have used double stimulation as a unit of analysis to transcribe the transformative dynamics used by agents to break away from problem situations as it links double stimulation,

agency and transformation (Engeström, 2011) outside a formative intervention. Such a unit of analysis can be used in research designs based on observation where participants may identify, experience, and analyze stimuli 1. In this respect, an  $S1 \leftrightarrow S2$  unit of analysis provides an avenue for conducting research in complex and technology-rich environments. In such contexts, participants are confronted with multiple resources and an  $S1 \leftrightarrow S2$  unit of analysis may allow us to explain how participants make sense of complex tools (e.g., digital technologies) as stimulus 2 through the principle of double stimulation. Lund and Vestøl (2020) suggest envisioning agency as emergent across human and artifacts to transform first stimuli through a dynamic process in time and in iterations.

Such a unit of analysis affords the perspective to focus on situations of challenges, dilemmas, conflicting motives, and difficult choices in which the outcome cannot be known ahead of time, while providing students with the opportunity to become agents of their learning and development. Additionally, the processes involved may be continuous or interrupted, take many directions, and therefore involve different manifestations, i.e., different *pathways*. For this reason, we use an  $S1 \leftrightarrow S2$  unit of analysis in a longitudinal way, inspecting a series of instantiations along a trajectory to describe the unfolding of developmental and longitudinal aspects of transformation. As such, it allows to capture students' agency and the dialectical relations both with peers and artifacts; therefore,  $S1 \leftrightarrow S2$  relations have explanatory power to understand relations between a problem situation, the resources used to break away from such situations and to understand the transformation of the problem situation into further action. In this context, concepts are understood as verbal artifacts and exist in rich tapestries mixing social, cultural and material dimensions (Markauskaite et al., 2021). Problems can therefore be framed from multiple perspectives and need to be enacted through practical material actions; *constructed*

*knowledge objects* and *object-oriented practices* are therefore the main point of focus of this research.

### 3.3.3 *Levels of Analysis*

Morselli (2021) identifies three analytical levels to analyze a phenomenon under double stimulation. The macro level refers to the process of problem-solving and involves first stimuli (S1), conflicts of motives, second stimuli (S2); in this respect, participants encounter and build a first stimulus (S1) as a shared consciousness of the problem to be solved (Virkkunen & Newnham, 2013, p. 49). The second stimulus (S2) at this scale is a key artifact aiming at the future of activity and aiming at actions; agency manifests at this level for the collective change effort. In this research, the macro level is concerned with the building and sharing of a common object. Still following Morselli (2021), the intermediate level corresponds to the level of sessions of teamwork, and deal with (a) the step-by-step process of definition of a problem and (b) the progressive building of a new model of activity. At this level, we address disturbances, critical incidents, challenging problems stemming from the activity using artifacts suggested by the facilitators and the methodology towards the building of a second stimulus (S2); this level is therefore particularly important to artifacts potentially acquiring the status of *auxiliary motives*. Finally, the micro level represents the transcripts of the teamwork sessions to look for instances of double stimulation and the distribution of auxiliary motives (Engeström & Sannino, 2011).

This research uses double stimulation it in the lineage of Sannino (2016; 2015a; 2015) or Sannino and Laitinen (2015) as a principle and analytical tool used in an ecological setting to investigate volitional action and the emergence of TADS. To Lund and Vestøl (2020), such a unit of analysis may be used to analyze data produced outside formative interventions. Thus, we use it as the main unit of analysis of the research design, and it informs the levels of analysis

illustrated in Table 4. In studying all mediational elements, only the top two elements were considered (activity and actions) while operations were discarded. Although the intent to use S1 ↔ S2 units of analysis was to limit the quantity of data to analyze, some sequences organized in the instructional sequence were recurring within subsequent sequences, albeit with a different tooling set, or with different rules, or aimed at a different community or aiming at a different outcome; as a result, those were considered as *different* activity systems, or *embedded* activity systems. The following levels of analysis ensue:

**Table 4***Levels of Analysis of the Data*

Level	Scale	Terminology	Elements/concepts	Agency
Level 1	Micro	S1	DMC	TADS
Level 2	Intermediate	S2	Artifacts and auxiliary motives	
Level 3	Macro	S1 ↔ S2	Expansive pathways ELA	Collaborative agency/problem solving
Level 4	Macro	Activity systems	Object-oriented and goal-motivated actions	-

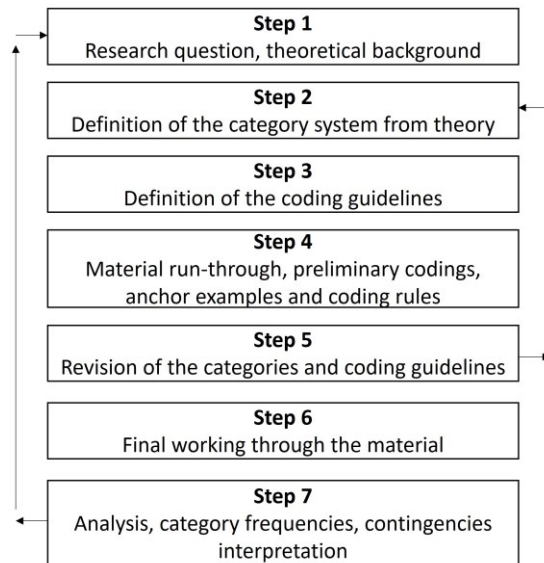
**3.3.4 Coding Procedure**

Qualitative research is an interpretive endeavor (Denzin & Lincoln, 2008). However, constructs such as *object of activity*, *contradictions*, *expansive learning* or *agency* can only be approached and inferred through theory (Morselli & Marcelli, 2022). This research was therefore designed around a deductive category application, working with prior formulated constructs, and connecting them from their appearance in data. The qualitative aspect of analysis consists therefore of a methodologically controlled attribution of a theoretical category to an excerpt of text (Mayring, 2014). The analysis scheme applied to our data is illustrated in Figure 18 below:

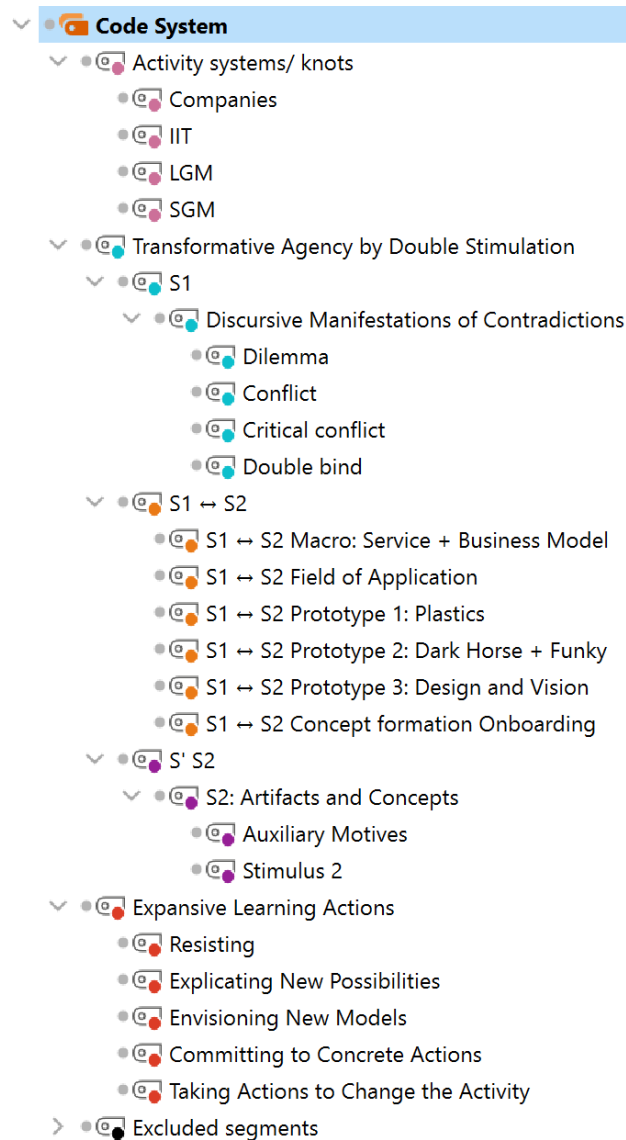


**Figure 18**

*Deductive Category Assignment Adapted From Mayring (2014, p. 96)*



Once the corpus of data was coded, the following complementary analyses were undertaken: (a) co-occurrence of concepts from word co-occurrences, (b) frequency of concepts or analytical constructs over time, (c) distribution of concepts, (d) frequency of co-occurrence of concepts. The corpus of selected data was integrated and analyzed through the MAXQDA Analytics Pro 2022 software. Each transcript was integrated and subsequently coded. Further analysis implied the sorting of units of meaning emerging from the data, and further categories which are exposed in the following section and are connected to the subsequent levels of analysis.

**Figure 19***Coding Scheme Screenshot*

### 3.3.5 Analysis Procedure

At the inception of the data collection process, the object of activity had not been identified yet; as such, the instructional sequence facilitated stresses the importance of identifying opportunities and maintaining a solution space which is consistent with the problem space inquired in through the object of activity. For reference, the general structure of the

instructional sequence over the data collection is described according to definitions and descriptions from Svalina (2022) in Table 3 and Figure 13 in section 3.2.4 above.

Data collection took place from January to March 2022 over fourteen consecutive sessions recorded and analyzed in chapter 4. The data was transcribed to text, and speaking turns were identified and anonymized. The data was then analyzed and  $S1 \leftrightarrow S2$  (Lund & Vestøl, 2020) pathways at intermediate levels were identified and coded according to the contents of the instructional sequence, which constituted the first level of coding. A second level of coding was subsequently conducted according to the typology of DMC (Engeström & Sannino, 2011), and frequencies of occurrences were computed over the whole data set and over each previously identified  $S1 \leftrightarrow S2$  pathways. In a third round of coding, the elements of TADS (conflicts of stimuli, conflicts of motives, auxiliary motives, real conflicts of stimuli, stimulus 2) were identified at intermediate level after the model of Sannino (2015b). The fourth round of coding was conducted to identify manifestations of agency as ELA (Haapasaari et al., 2016), and subsequent frequencies of constructs (resisting, explicating new possibilities, envisioning new models, committing to concrete actions, taking action to change the activity) were subsequently computed. In a fifth round of analysis, the modeled shared object of activity was identified and data not satisfying inclusion and exclusion criteria were excluded from the corpus. Finally, the  $S1 \leftrightarrow S2$  pathway and corresponding elements at macro level were identified. A summary of the analysis procedure and of the coding schemes may be exemplified in Table 5 below:

**Table 5***Data Analysis Steps*

Steps of analysis	Procedure
1	Transcription verbatim
2	Anonymization
3	Coding S1 ↔ S2 pathways at intermediate levels
4	Coding DMC
5	Coding TADS
6	Coding of ELA
7	Identification of a modeled object
8	Coding S1 ↔ S2 pathway macro level
9	Code frequencies
10	Code co-occurrence
11	Clustering through multidimensional scaling method

**3.3.6 Limits of Selected Method**

Hsieh and Shannon (2005) identify three potential caveats to using qualitative content analysis; the first one stems from the centrality of the substantive theoretical framework which may involve a strong bias towards the data analyzed. Overemphasis on theory can also mitigate the importance and effect of contextual aspects of the phenomenon studied. Finally, the design of the research may lean on validating evidence through interviews; the authors also point out that participants may get cues from questions asked and therefore produce biased responses towards the theoretical framework.

Serafini and Reid (2019) further identify qualitative content analysis as a restrictive method focusing on textual content by comparison with qualitative analysis paradigms which may align better with interpretivist paradigms (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005). As a result, qualitative content analysis may be limited as far as theory development and accounting for concrete lived experience is concerned, because the conceptual relations which make findings difficult to infer from. As a result, it may be better suited to concept development and model building (Lindkvist, 1981). Lincoln and Guba (1985) identified such limitations as

relating to *confirmability* or *trustworthiness*, which are the object of the following section which describes the steps undertaken to ensure the maximum level of credibility within the naturalistic inquiry paradigm.

### 3.3.7 *Trustworthiness*

Trustworthiness of the results was ensured by following the steps offered by Yamagata-Lynch (2010) and which rely on prolonged *engagement* in the field, persistent *observations*, *triangulation* of the sources of data, creation of a study database, maintenance of *a chain of evidence*, *peer debriefing* and *member checking*. The present section details this chain of evidence.

Prolonged engagement was granted by conducting an activity observation sequence prior and posterior to the data collection. This allowed for meeting face-to-face at the onset of the program with the participants, explaining and clarifying the objectives of the research, getting acquainted with the participants and finally and allowed the researchers to gain access to multiple sources (Glesne, 2016). Persistent observation was ensured through longitudinal engagement with the field: observations started three months prior to data collection and finished beyond the term of the limits suggested by selection of data criteria described in previous sections. One hundred and eighty (180) hours were spent on the field either in online or in-person meetings.

We used two types of triangulations in this research; *data triangulation* was performed as access was granted from the gatekeepers and participants to all the files, folders and data repositories used by the participants during the activity. *Theoretical triangulation* was ensured through the use of a deductive step of analysis to treat, analyze and interpret the data as described in sections 3.3.4 and 3.3.5. Finally, regular member checking was organized throughout the

analysis phase of the data with the facilitators to present the results of analysis and findings gradually, and negotiate the results and meanings associated to them with the researchers, which allowed the researchers to check the meaning and values of interpretations (Yamagata-Lynch, 2010). Progress of the analysis was subsequently discussed and negotiated over four hours of member checking with one of the facilitators in UCA. These informal meetings happened on 2022/10/31 and 2023/03/10 and served to discuss and negotiate the advancement of the analysis of data, preliminary results, and their credibility regarding the lived experience of participants.

### **3.3.8 Ethics**

All participants in this research were duly informed of their rights at the inception of the observation phase. Subsequent approbation was granted by the Committee on Ethics for Non-Interventional Research<sup>11</sup> (CERNI) at UCA, the organism concerned with research involving human beings excluding therapeutic purposes and invasive methods. The application was made in December 2022, and all participants involved subsequently were informed at the inception of the data collection phase of the motives and intents of the research, their rights to withdraw from the research, the conditions of length of data storage according to CERNI and Data Protection Officer (DPO) recommendations at UCA. All participants solicited agreed to sign the consent form, and at the time of writing, neither requested to withdraw data nor to benefit from the remediation procedure offered at inception.

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<sup>11</sup> <https://univ-cotedazur.eu/ethical-and-academic-responsibility/ethics-and-scientific-integrity>

#### **4 Chapter 4: Results and Analysis**

In this chapter, an  $S1 \leftrightarrow S2$  unit of analysis is analyzed longitudinally, based on the analysis of a series of five instantiations in co-creative problem-solving activity. Our objective is to document the emergence and development of TADS over time. We set out to capture participants' agency investigating problem situations (S1) and resources used to break away from them (S2). We envision the process after Markauskaite and colleagues (2021) as object-oriented and manifesting in verbal artifacts across social, cultural and material dimensions. Our results aim to document the transformation of problem situations by considering three phases. The first phase stems from an analysis of stimulus 1 and the dominant contradictions attached which are further discussed in section 5.1; it relies on the analysis of five  $S1 \leftrightarrow S2$  sequences at intermediate level which are detailed in sections 4.2 to 4.5. We expand on Table 3 above by incorporating the sequence in Table 6 below:

**Table 6***Description of Schedule, Objectives and S1 ↔ S2 Units*

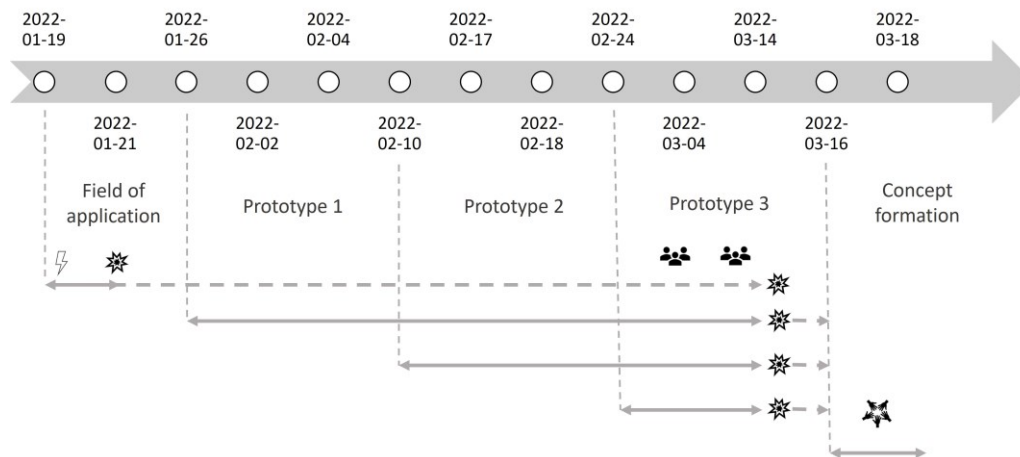
Phase	Time frame	Description	Intermediate problem	S1 ↔ S2	Inclusion/exclusion
1	From October 2021 to December 2021	Need finding and benchmarking of potential fields of application	Diverging: design space exploration	S1 ↔ S2 field of application	Included
2	From January to March 2022	Critical functions and critical experience of users	Diverging: first prototypes creation	S1 ↔ S2 prototyping 1	Included
3		Dark horse prototyping	Diverging: creating a prototype with neglected constraints	S1 ↔ S2 prototyping 2	Included
4		Funky prototyping	Diverging: combining and merging the best ideas	S1 ↔ S2 prototyping 3	Included
5		Functional system prototyping	Converging: shaping the idea according to final requirements	S1 ↔ S2 concept formation	Included
6	From March to June 2022	Design requirements	Converging: formalization of key functionalities that meet customer needs		Excluded
7		Hardware review	Convergence: final meeting and agreement with customers validation of the solution	-	Excluded



We identified five problem situations in the instructional sequence, presented to the participants as intermediate steps to tackle, which were designed as a progression towards a tentative shared object. The corresponding timeline, relative to the working sessions in the data collection is illustrated in Figure 20:

**Figure 20**

*Timeline of the Instructional Sequence per S1 ↔ S2 Unit*



The process described in Figure 20 is determined by its cumulative aspect: each step is designed to build upon the previous one, each subproblem meant to inform and participate in resolving the following *problem situation*; eventually, mastering the final problem should turn into the final object of the activity and produce a response to the initial  $S1 \leftrightarrow S2$  at macro level; it illustrates the embeddedness and sequential nature of the instructional sequence's initial design as a preliminary structure.

#### 4.1 Chapter Structure

Each of the following sections analyzes the process through an  $S1 \leftrightarrow S2$  unit of analysis; the first section seeks to present results in response to *research objective 1* to describe and characterize the emergence of agency in the creation of a shared object described in section 2.2.3 through TADS. To answer this question, we describe the *pathways* that lead to the modeling of a new object of activity at an intermediate level of analysis (described for reference in Table 4). The analysis presented in response to *research question 1* relies on close analysis of intermediate levels. The results related to research question 1 may therefore be consulted in section 4.2 in this

chapter, which characterizes the general expansive pathway followed by participants over a micro-cycle of object modeling. Faithful to the TADS model exposed in section 2.1.3, we present the main *conflicts of stimuli*, *conflicts of motives*, *auxiliary motives*, *real conflict of stimuli* and *stimulus 2* we identified for each sequence at intermediate and macro levels.

Additionally, we complement the analysis of emergence of TADS with the evolution over time of auxiliary motives in section 4.7.3.1 and of stimulus 2 in section 4.7.5.1. The channels of double stimulation retained are (a) *intervention*, i.e., the instructional sequence structuring the SUGAR/ME310 minor course, and (b) *wider life* understood as interactions occurring over temporary coalitions in knots (Engeström, 2008; Yamazumi, 2013).

In response to *research objective 1* and *research question 2* presented in section 2.2.3 addressing the evolution over time of TADS, we characterize and present DMC (section 4.8.1) and their evolution over time (section 4.8.2), and the evolution of ELA over time (section 4.8.3). We subsequently present in section 4.8.5 the association of DMC and ELA and S1 ↔ S2 problem solving units. Finally, we conclude the section by exposing three critical and creative encounters which we believe to be decisive to the evolution over time of TADS, which we present in section 4.9.2.

Finally, we address *research objective 2* and *research question 3* in section 4.9; The third and last section of the chapter is dedicated to the evolution of interactions in knots over time, as we contend that they represent important sources of qualitative expansions in the process we aim to characterize; we also contend they play a major role in the emergence of a stimulus 2, a point further discussed in chapter 5, in particular in sections 5.3.2 and 5.3.3.

## 4.2 S1 ↔ S2: Identifying a Field of Application

The main contradiction operating through this episode is one concerning the object, as all actions in this sequence are aimed at defining a shared object of activity. This section is characterized by the oscillation between safety and risk, novelty and usefulness and it is therefore an episode rife with conflicts of stimuli and conflicts of motives revolving around a dilemmatic choice. The tentative fields of application identified through the first phase are *waste treatment, cement industry, maritime shipping, plastic industry* and represent various levels of risk and opportunity which have been identified through rounds of analysis and careful comparisons through interviewing potential stakeholders during the three months prior. The two meetings reported here are composed of an open-heart exchange of opinions and reflections at the beginning of the session, in preparation for the collective decision-making process of choosing one field of application.

Additionally, we identify the main double bind relating to the development of a technology as being explicit from the beginning of the sequence. We deem worthy for the remainder of the analysis to expose it as a background process operating throughout the sequence. The double bind is relative to the development of a technology characterized by its open-endedness and by a high level of ambiguity characterized by its representing a *benign object*. The double bind may be expressed in the following way: "... it's very hard to get specific feedback about the technology and the product desirability as long as you don't have a proper product to talk about (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 48)." We understand this double bind to point towards the *object* pole of activity, while also displaying energy towards the *community* and the *instrument*. At such an early stage of the modeling process, the outcome—understood here as an attempt to make sense of the role and expected

contribution of the participation of students—may be best encapsulated in the following quote from one of the facilitators: “And then in an ideal word, if you think you could get everything so super-realistic and creative idea that would be happy.” (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 80). Table 7 shows an overview of the S1 ↔ S2 unit:

**Table 7***Overview of S1 ↔ S2 Field of Application Unit*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2
Intervention	Lack of a clear focus	Learning ambitions vs. performance	Cement	Outcome of the project: tried and tested solutions vs. potential new opportunities	Plastics
	Comparison with other groups		Plastic		
	Clashing feedback		Maritime shipping Wastes		
	Misalignment with instructional process		Decision criteria		
Wider life		Risk vs. reward	Plastic subsidies		

#### 4.2.1 Discursive Manifestations of Contradictions

##### 4.2.1.1 Dilemmas

We were able to identify two main dilemmas occurring in this S1 ↔ S2 pathway; the main recurring dilemma occurring over this phase may be characterized as *novelty* vs. *usefulness*, a label we borrow from the standard definition of Runco and Jaeger (2012) and which we exposed in section 5.1. Both appear as dialectical unities of contrary unities, steering the activity according to the path taken by participants. The following two quotes illustrate how tightly the role of students in this hybrid educational activity is tied to a divergent, creative representation, and their expected contribution to the modeling of the object:

F002: I had that discussion, with Italian Institute of Technology with the researchers. It's something we do like after each milestone just to see how they're feeling about the

project and what they were super satisfied in general, and they were super satisfied about all the fields of application because some are less ready to be used than others but they were all interesting because some of the field of application, where things they didn't think about and it would have never thought about without you so they were super interested about it, and they also realize that it's very hard to get specific feedback about the technology and the product desirability as long as you don't have a proper product to talk about. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 48)

P002: um yeah um yeah, I guess I'm kind of wondering... it... like how realistic we are supposed to be. The only reason I ask that is because, like... the reason they're coming to students, I assume, is because they want like more creative solutions and less like, super analytical I mean, obviously we have to be realistic to a certain extent, so that's kind of what I'm wondering. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 77)

On the other hand, although the object of activity should be novel "enough," the stress is also pointed on the need to turn in a project that is useful:

F002: And then in an ideal word, if you think you could get everything so super-realistic and creative idea that would be happy, but I would say I don't know it also depends on you actually so I kind of reverse the question a bit. So, it depends on you how much you want to train your creativity, but risking to arrive at the end with something which is not immediately applicable and maybe doing something which is more realistic and won't be any way immediately applicable, probably, but more ready to be applicable one day.

(2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 80)

#### 4.2.1.2 Conflicts

As the need to identify a common field of application to root a potential shared object on is more urgently felt by the participants, we were able to identify the following two conflicts arising in the data set. The first one is connected to the time available to complete the project, while showing concern about reaching a possible satisfactory outcome:

F003: What do you expect from this program so if we really want to take a risk or if we want to go more on our, I don't know, feelings or more for the easiest way so it's hard because right now we didn't really get to a convergence I don't know and we have many, many thoughts so. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 95)

The time constraints and focus on a *macro* activity level is further asserted in the following excerpt:

F002: Again, just to tell you that, because it's nine months I know it's a lot of time I know it's a lot of efforts. And I know that also the fact of working a lot on something, then leave it aside, it can be... you didn't show any concern about it, but sometimes the previously in previous projects with something we're a little bit stressed about it, so if you have these kinds of concerns feel free to speak about it, too, because they are normal. And it's better to don't keep it for yourself. If you look like, I mean you're, of course, tired out because you have worked a lot but it looks like you're kind of in a good mood, but if you need those to talk about I mean I'm not going to be a psychologist, but if you need to talk about the mood of the project, how to make it more fun to make it more... beautiful for you as I also as an experience feel free to do that, that said, of course, physiologically there are some moments in which you are more overwhelmed more tired



and so on, so... Ok, just to tell you that the feedback channel is open. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 116)

#### **4.2.1.3 Critical Conflicts**

The pressure to converge further pushes participants to question the motives of the project, directly putting in question the outcome and the rationale of the project. In this respect, the following quote displays elements of tension between the community and the tentative shared object of activity:

P003: Yes, I was thinking that probably I don't know what the company like IIT is expecting from us because I'm feeling like that from for me, we could not like have the whole project and right application I don't know I'm feeling like that right now. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 34)

This feeling is further aggravated in the following three excerpts that display conflicts crossing over to having an impact on feelings in one or several participants that materializes in discourse, all of which concerned with time and the proximity of deadlines:

P004: I think it's kind of impossible to find something concrete for July and I don't know I feel like in the time it really it's not a lot of time and I'm very worried about that and also, I think that, yeah. It will be interesting to focus on every application we have, because I think, they are all very interesting, but we should narrow it down because in this way we can work all together in one and maybe have more ideas, the more convergent I don't know. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 44)

#### **4.2.1.4 Double Bind**

The most important double bind expressed in this section regards the inability to overcome unpredictability connected to the open-endedness and the lack of clear definition of an object or an outcome. This double bind initially materializes in the following manner:

F002:... it's very hard to get specific feedback about the technology and the product desirability as long as you don't have a proper product to talk about. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 48)

Subsequent difficulties experienced by the participants are further recognized thus:

F002: It's a lot about making the decision where you don't have the elements to make this choice [...] That's the big problem of innovation projects and it's something everybody struggles with even people live in professionals who are working on that since years, so if you feel it's difficult it's because it's difficult. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 90–92)

#### **4.2.2 Distribution of Discursive Manifestations of Contradictions Over S1 ↔ S2 Field of Application**

One hundred and eighteen (n=118) instances of DMC were identified over this S1 ↔ S2 unit, and their distributions may be illustrated in the following manner in Figure 21:

**Figure 21**

*Distribution of Discursive Manifestations of Contradictions in the S1 ↔ S2 Field of Application Unit After Engeström and Sannino (2011)*

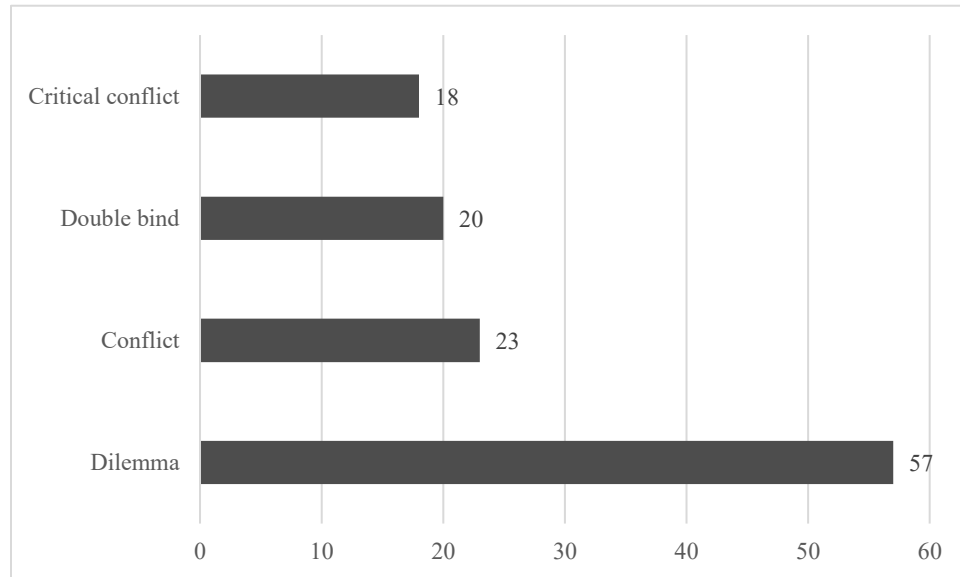


Figure 21 displays the number of DMC occurring over S1 ↔ S2 prototyping 1 unit; the figure shows the prevalence of *dilemmas* (n=57), *conflicts* (n=23), *double binds* (n=20), and *critical conflicts* (n=18). The tendency in this sequence shows the prevalence of *dilemmas* as the collective searches out to solve its first subproblem in the instructional sequence, an achievement—or milestone. This milestone seeks to establish an operating field, i.e., restricting the problem space to advance the sequence. Additionally, the need for an committing decision towards building a shared object is the source of many expressions of dilemmas, which we think is reflected in this distribution. Finally, it is worth noting that the whole sequence is overturned by an unexpected decision to choose the most open and creative potential object despite the votes of participants being in favor of the opposite option, i.e., the most useful option. As a result, the selected application turns out to be plastic over cement, a source of further dilemmas.

### 4.2.3 *Conflict of Stimuli*

This phase in the problem-solving sequence is characterized by multiple conflicting stimuli experienced by the participants. The lack of a stable field of application serving as a stable problem space to move into is perceived as a serious hindrance preventing the process from unfolding. The sources of such hindrances are detailed below and relate to comparison with other groups resulting in a sense of competition, time constraints, lack of a clear focus or definition of the object of activity, misalignment with global method of instruction and dissonant feedback gathered from stakeholders.

#### 4.2.3.1 *Lack of a Clear Focus: Tensions Generated by an Undefined Object*

The fact of trying to keep up with the demands of several potential applications forces participants to sustain too many leads and a large energy and time expenditure that is experienced as a hindrance to the process of problem solving in general, as well as to the creativity potentially displayed by participants:

P006: A lot of ideas that we had for the fall presentation were like very similar to each other, so the fact that we now have to come up with really crazy wild ideas that aren't necessarily directly in line with the technology, but a little bit more out there, a little bit more creative it's something that I find really interesting but also really hard to do for so many subjects. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 38)

The need to focus on fewer topics and to direct the focus of the whole team of participants onto one topic is further described below:

P005: Because we are, yeah, I don't know, trying to focus on all these different applications, so we cannot really work as a team in a way, so if we could focus on one thing, I think we could bundle our energies which would help us and also like this, yeah,

In LGMs F004 tells us: “Find your prototype and test it,” but for us it’s not so easy to, ok, contact the company and say “Ok let’s test our prototype” next company, so prototype. We... yeah, it’s more difficult, in my opinion. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 43)

#### ***4.2.3.2 Comparison With Other Groups Resulting in Competition***

Furthermore, recurrent biweekly meetings with other groups working on different challenges allow for both positive and negative emulation on the part of the participants; this next excerpt sets the tone of the first meeting in the data collection:

P002: I was just saying that we’re feeling pressure to converge, I think, especially when we’re compared to the other teams, like teams, and we have to do the same, like. Like, we had to do the prototyping, I found it very difficult because we had like six different topics that we could prototype on I was trying to cover all one topic I don’t know; it’s complicated. But yeah, it could just be because we’re comparing ourselves to other teams. I don’t know. You know? (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 25)

The contemplation and summing up of conflicting stimuli at this stage leads to the observation and hypothesis that the instructional method may not be adapted or relevant to the specificity of the challenge faced by the students:

P001: I think our team activities don’t generally slot in nicely into the [LGM] activities. I think I’m grateful that we’re here because I saw what P003 and P004 and P005 will go through, because last time they were telling us. But we didn’t really understand what they needed, and now I can see more of what they were going through with their LGMs, so I think I find it useful in meeting new people and new perspectives, but also not useful in

that it's scary that it doesn't fit ours. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 37)

#### **4.2.3.3 *Time Constraints and Deadlines***

Time constraints and the perceived necessity to cope and satisfy with the objectives of the project may in turn cause critical conflicts, such as the one experienced by P004 at this stage:

P004: Yesterday I realized from the interview I had with P003 that probably the technology is too early and I don't know I think it's kind of impossible to find something concrete for July and I don't know I feel like in the time it really it's not a lot of time and I'm very worried about that. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 44)

#### **4.2.3.4 *Clashing Feedback From Potential Stakeholders***

Despite regular interactions with the researchers responsible for the development of APT, the confrontation to the needs and negating points of view of potential stakeholders is a further source of conflicting stimuli for participants, as exemplified in this excerpt:

P003: For example, yesterday, P004 and I had an interview with a person who works in a company that installs biogas plants, and it was something that we wanted to study more because it was something that the company, said it would be probably interesting to have the technology in that sector but yesterday he was very honest with us, and he said that the main problem probably would be the cost and anything that is connecting with the economic value of the technology, because he said that could work in a biogas plant, but only if could... only if the company could really benefit from the technology, so... Yes, I was thinking that probably I don't know what the company like IIT is expecting from us because I'm feeling like that from for me, we could not like to have the whole project and

right application I don't know I'm feeling like that right now. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 34)

These confrontations during interviews, although considered an essential part of the process, may have a negative effect on student motivation and outlook as far as the outcome of the project is concerned, including the threat of potentially not complying with the objectives of the project, and therefore failing with the intent to build a shared object of activity:

P001: We had the interview last week and ever since we had the interview, I've been...

I've been less thinking about being less creative about our technology and more thinking is this... are we actually going to have something by the end of this? (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 37)

#### **4.2.4 Conflict of Motives**

Although in the initial phase of data collection, several conflicting stimuli appear in the data, we were able to identify two main corresponding conflicts of motives echoing the last dilemma described in the previous section. We interpreted these two sets of conflicting motives as belonging to two distinct channels: *intervention* and *wider life*.

##### **4.2.4.1 Conflicting Motives in Intervention Channel: Learning Ambitions vs. Performance**

Adding to the dilemma of being creative, understood here as on a continuum from *novel* to *useful*, the dilemma is doubled up by a *learning dilemma*, one according to which participants need to decide, or be aware of how much they ambition to “train their creativity.” The outcome is therefore described as being a product of the responsibility and ambition of the participants:

F002: So, it depends on you how much you want to train your creativity, but risking to arrive at the end with something which is not immediately applicable and maybe doing something which is more realistic and won't be any way immediately applicable,

probably, but more ready to be applicable one day. (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 80)

#### **4.2.4.2 *Conflicting Motives in Wider Life Channel: Creative Gamble***

Although from the perspective of a hybrid educational activity, learning ambitions may appear as a relevant concern, from the perspective of *wider life*, the stakes are framed under a different set of perspectives along the *novelty* vs. *usefulness* primary contradiction. Namely, researcher participants are subject to a dilemma; their initial respective positions in the choice of a field of applications are leaning on the *usefulness* end of the spectrum as illustrated in the following quote:

S001: While you were discussing I was considering that I think that also this is the same for S002 so half of my head, would like to be very free to select what is very challenging and very promising as a citizen and the rest of myself is strongly biased on what is feasible, at least in the framework of the project. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 65)

#### **4.2.5 *Auxiliary Motives: Decision Criteria vs. Emerging Subsidies***

The main auxiliary motives or auxiliary stimuli used to make sense of the dilemma of finding a field of application under the contradiction of novelty vs. usefulness is spread across four tentative fields of application: cement industry, plastic and plastic upcycling, maritime shipping, and waste treatment. We consider these elements to be auxiliary motives used during the process of building a shared object, and as such to reduce the problem space in which participants evolve. The decision is mediated by the following agreed upon mediational tools: technology readiness level, contacts, stakeholder engagement, potential, risk. Yet, despite the voting happening in real time during the activity on an interactive white board, an element



emerges in the conversation that turns the table from participants' expectations and the consensus being built according to which usefulness is prioritized. Despite cement industry emerging as the most shared upon reasonable choice, a turning point happens:

P006: The EU is implementing a plastic tax, which means all new virgin plastics that are being produced are taxed so it's going to be so much more expensive to produce new plastics, and if you can use old plastics in... if you can use like already being used plastics, in combination with recycled b-produced virgin plastics, that means less carbon tax has to be paid, and it also creates a value to waste, which means probably a lot less plastic ends in the environment because it can actually be reused for something valuable. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 57)

Further, the difficulty to rely on stakeholders' feedback, a point detailed in further relevant subsections, as co-configuration is identified as a potential element to resolve the double bind of not being able to prototype a tangible product:

F001: So yeah, it's actually really, really hard to like to co-define, like, how can we calculate these risks? (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 101)

#### **4.2.5.1 Outcome of the Project**

Considering the difficulties to define a field of application in which to embed the object, the global outcome of the project is mobilized to mediate the decision process by confronting participants and suggesting they take a stance:

F002: To be honest, I have more reflection about... but it's a further point about the goal we want to achieve with SUGAR, so the big contrast between a stronger feasibility or more innovation and creativity, which is already there on the table, this is a huge reflection we have to make, and also maybe S004 can help us with that, to be sure we can

come up with an output, which is useful for you after SUGAR. It would be nice to reach a decision altogether, but I also think your point of view with respect to these reflections is interesting so maybe S001 do your consideration, then we open this discussion.

(2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 64)

The outcome is called upon a second time at speaking turn 95:

Since we have like 15 minutes left, and we really want to converge to one or at least two fields and we started with the most voted one that was the waste, but right now we have like very strong opinions about plastics and cement. And maybe it's really time to put on the table huge criteria that might be the... I don't know, our goal for this project for the sugar program because we can tell that maybe the cement production might be the easiest way, but we also have good feelings on the waste so maybe it's time to, I don't know, answer a question and put on the table a discussion about what we really want to do in this program and what you S001 and S002 and S004, what do you expect from this program so if we really want to take a risk or if we want to go more on our, I don't know, feelings or more for the easiest way. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 95)

#### **4.2.5.2 Consulting a Fellow Chemist Researcher: Extending the Knot**

As the decision process shifts from *cement industry* to *plastics*, participants push through a condition to solidify a tentative decision:

S001: First, we assess internally with the colleagues with which we work. How much would be the impact in a polymeric industry to have carbon monoxide, we just make an internal assessment that just because we have organic chemists here, and we are not organic chemists, so we just need to assess if this can be a very good opportunity for the

polymeric sector, and this is one possibility and another, that is not excluding the first is that, at the end of this is a project that can also explore, something that is maybe more challenging and maybe not let's say their strongest successful, as assured no? (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 99)

#### 4.2.6 *Real Conflict of Stimuli*

The dilemma identified earlier is further addressed as a direct acknowledgement of the double bind quality of having to make a choice where no data is available to back the decision up. As a result, one of the facilitators warns the participants about the difficulty to make a final informed decision: "It's a lot about making the decision where you don't have the elements to make this choice (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 90)." Facing the difficulty to break from the safety of a useful already tried and tested solution, both researchers lean towards a *useful* field of application:

S002: The reason I choose the cement is that we already proved that it is feasible to do it, due to this project and use the fact that the cement plants are among the largest CO<sub>2</sub> producers, so they are surely committed in trying these kinds of technologies. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 19)

S001: I selected the cement application because as S002 was mentioning, we know that is feasible and we have the evidence that this can work and in it's a short time can also be something economically viable for the company. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 65)

P006: If you can use like already being used plastics, in combination with recycled b-produced virgin plastics, that means less carbon tax has to be paid, and it also creates a value to waste, which means probably a lot less plastic ends in the environment because it

can actually be reused for something valuable. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 57)

The enthusiasm to bring a creative touch and enlarge the scope of the solutions that have been considered thus far is eventually welcomed and championed by S001, the most senior researcher, whose enthusiasm overtakes the voting process; this enthusiasm is illustrated in the two following quotes:

S001: But maybe this is the project in which the fancy takes place in the most interesting ways, so why not considering different scenarios that what we share me and S002 may be completely different if you feel that the stakeholders are very interested in and also because you feel that this can be successful, we have not that the answers for all, we just have feelings on based on our work so and you have had another point of view, so what we told is what we feel could be more successful or more interesting in thinking in an application that means that the company will invest and pay money to have a technology but apart what we told that if you feel that the waste or the other selection can be more successful, I think that this is a good project to try. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 99)

#### **4.2.7 *Stimulus 2: Plastic Upcycling***

As a conclusion to the process of choosing a field of application, the initial *usefulness* priority is overtaken through the uptake of two distinct auxiliary stimuli or auxiliary motives: a tentative evolution of plastic subsidies in Europe, an idea that may be summed up in the following description by one of the participants; the switch from a useful and safe field of application is endorsed for good in the following quote: a point of no return is reached and the overtaking of the collective vote is complete:

S001: Given the discussion with either now, I have a preferential application, because I, I see that that... that we have the chance to, to have good results for some reason I don't know if I can express my really preferred application now after this discussion. I can proceed F002? Ok, so. At this point, I think that the plastics will be the more interesting selection. [...] So maybe, considering that time, in which the project has to be concluded this can be a discussion that can be more effective, with the company because... give some evidence that may be the costs are not lower than the oil-based components, but there is let's say a good starting point that to develop a new technology and to have a parallel or alternative way to have the same molecules. So, if I have to vote now, I will vote plastics. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 90)

Yet, S002, her researcher colleague remains on the fence, in a dilemmatic and paralyzing position:

S002: I'm a little bit... how to say, "torn in two." For sure in... yes, what you said is interesting, is intriguing. I maybe I will also vote for the cement application, I don't know. I'm torn in two. For sure that will be something different, and new for us to try to move in the... in the plastic scenario. I don't know, I will say 50/50 among the two. For different reasons. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 92)

Finally, the opportunity identified by S001 which triggered her sudden change of heart is further detailed; it could be considered a tentative germ cell, and it aims at the valorization of by-products of industrial processes:

S001: And they do not care about the product that they just want to sell whatever product is coming from this technology that someone will consider and reuse, in that case, also for them the technology will be winning technology, because they, they valorize the

waste and they can sell a product, so they have any income from this technology from one of their waste. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 65)

Finally, although a tentative decision has been made, one that represents a risk, as described by participants, alternative plans are devised in case this path proves unsuccessful to account for potential undetected risks:

P001: We start with plastics and until we hit a no-go roadblock that will absolutely, we can't move forward, and then we go to the second one, because then that way we kind of can work together rather than separately. I don't know if it's feasible, we have like months, but I don't know. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 101)

#### ***4.2.8 Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Field of Application***

One hundred and thirty (n=130) instances of ELA were identified over the S1 ↔ S2 field of application unit, and their distributions is illustrated in Figure 22:

**Figure 22**

*Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Identifying a Field of Application Unit*

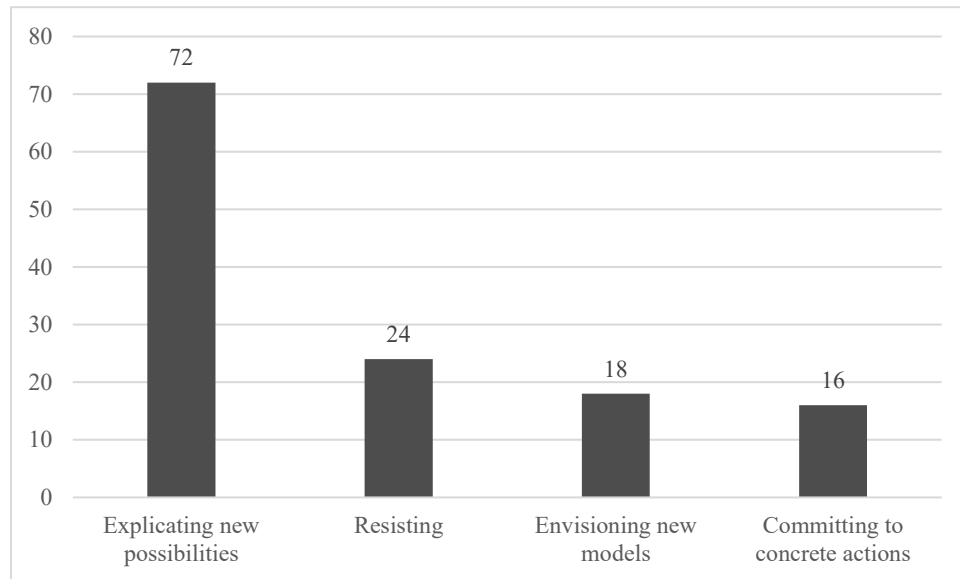


Figure 22 displays the total number of ELA occurring over S1 ↔ S2 identifying a field of application unit; the figure shows the prevalence of *explicating new possibilities* (n=72), *resisting* (n=24), *envisioning new models* (n=18), and *committing to concrete actions* (n=16).

### 4.3 S1 ↔ S2 Prototyping 1

The main contradiction addressed in this sequence keeps revolving around the *novelty* vs. *usefulness* primary contradiction already identified in the previous sections. The main elements according to the TADS model are displayed in Table 8:



**Table 8***Overview of S1 ↔ S2 Prototyping 1 Unit*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2
Intervention	More usefulness, less novelty	Centricity vs. systemicity	APT technology as the object, instrument, or outcome	Make positive environmental impacts visible	Visualization
Wider life			Interviewing to prototype vs. prototyping to interview		Co-design

### 4.3.1 Discursive Manifestations of Contradictions

As the sequence further advances, a reaction is taken against the creative push that is the defining feature in the previous sequence. As a result, participants veer towards more usefulness and pit their initial prototypes against material, concrete elements.

#### 4.3.1.1 Dilemmas

Consequently, the process spirals into abstraction as the nature of the ideal company is evoked but also introduces the issue of the costs involved. As a result, the size dilemma translates as a dilemmatic chain involving costs, therefore calling forth the feasibility of tentative prototypes:

S001: I agree just to be clearer, sorry, maybe I was misleading if you go to the big company alone can decide to implement the technology the very small one and S002 is very right we are collaborating with a small technological company for example to implement the technology they are not producing carbon dioxide they build the system they are quite small company medium media small they would like to invest in that what they can what they will be able to invest they will but in this case maybe there are other

instruments let's say financial instrument like the European projects to be supported in introducing new technologies or government finance meant to introduce that new technology in the production chain not paying 100 percent inside the company so there are several tools let's say financial tools that can be exploited to be honest yes I support more what S002 said in the sense that the very big companies usually would like to have the technology fully paid by the government because they say ok you are imposing me, uh, taxes or to change my technological approach ok but just pay me because, uh, I don't want to do any step in this direction and usually the governments are paying the small ones maybe are more, uh, sensible to this topic and, of course, they in this case they are more those that need this the financial support and but, uh, by comparing with the big, uh, sometimes they are more willing to try to invest in something that today is not known if there would be it would be a success or a complete failure this is not the climate change is a reality we have not, uh, let's say any chance to say ok we are joking that is not the climate change but this is not completely true for the technologies. (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 81)

The issues related to costs push the participants to devise solutions centered on the valorization and capitalization of wastes and integrate them to the economic model to cover the costs of construction:

S001:... so the second very important point for a company is to say you have a waste normally you have to treat the waste for some kind of waste it's some... there are possible technologies to use to or to substitute part of the components that you are using in your production chain or to be able to sell another product that is coming from the carbon dioxide valorization or to make kind of joint, joint scenario in which the

companies with different productivities, make an agreement and one is collecting the carbon dioxide producing another product that is exactly the product that is needed from the second company so the product can be sold. The product can be used internally or there can be the possibility to make some kind of agreement with other companies we are not in competition with the first to take both value from them from these products so this is what I feel that for a company should be clear to see which can be the future, uh, way to have money from the waste at the end this is what they need they need to gain more money no? (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 79)

#### **4.3.1.2 Conflicts**

The process of materialization of a developing technology and answering questions about costs is aggravated and reinforces difficulties:

P003: We tried to also find touch points but also stakeholders that are involved, in a way, during the process and it was a bit difficult because we tried to study every phase of the process of plastic um recycle and so um trying to find I mean, what type of users are involved and where the artificial leaf can be put. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 71)

This phase in the project also signals issues regarding the conduct of interviews and the difficulty to identify relevant sources of information:

P002: Yeah, I guess, I mean I'm... I think a lot of us are having trouble because I'm... Like the leaf gets you know... when we put it into the process... it's just kind of like, I mean, I think we need to have more interviews for sure, with plastic companies. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 94)

The difficulty to identify relevant companies to feed relevant information further reinforces the difficulties identified to manipulate a relevant prototype of APT and use it in joint interviews to trigger and retrieve relevant information, as illustrated below:

P005: Honestly, I would love to try all the prototypes with companies and stuff and continue prototyping, testing, iterating and stuff but for us interviews is really a rare uh a rare like uh how do you say, a rare thing, so like for example if we consider the interview with from the C010 guy, if we do one prototype with him and it turns out to not be useful I don't think that we would have another interview with him and then yeah the iterating process is stopped and then there's no other... (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 115)

#### **4.3.1.3 Critical Conflicts**

Echoing previous difficulties related to the identification and hiring of interviewees, a critical conflict is articulated as frustration caused by the lack of enthusiasm of potential partners to take part in the study:

P005: Yeah, but you're saying this, like... this like getting interviews is so easy and we have so many, right, emails and I rarely get an answer. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 82)

The aggravated tension caused by the open-endedness and lack of definition of the problem-solving pathway is further reinforced through recognizing the difficulty and ambiguity of the situation, as facilitators recognize they ignore what the best path to a solution is:

F003: It's hard for us to... Can I come out with that we don't have like the solution, so it's really... that's why maybe you see us, kind of you know, stuck, because it's very

difficult topic. And, and I see your concern about this step, and it's very smart that you... that you find it out. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 100)

#### **4.3.1.4 Double Binds**

This sequence allows participants to experience several variations of double binds which we describe below. Participants are encouraged to break the rules and breach previously agreed upon elements hoping to trigger new insight in interviews through not following the rules:

F003: Because sometimes you really got to go—not against them—, because it's not against them, but they you were hired for this also to... not follow what they say. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 106)

The double bind caused by the inability to transfer a lab artifact to an industrial environment is further developed as participants are encouraged to push the process towards certainty when addressing more knowledgeable others:

F002: So, it's a bit... it's just a feeling. I see... I felt like you really you were waiting to have certainty before the interview, uh it should be the other way around, which, of course, means that you do one interview that may be the first interview that you understand is not, uh, wasn't that useful but then when you, uh, managed to contact the right person uh you are definitely going to save a lot of hours of research and that's also... this is already a prototype and a very simple way to test it is to show it to the person. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 79)

#### **4.3.2 *Distribution of Discursive Manifestations of Contradictions over S1 ↔ S2 Prototyping***

##### ***1***

A total of one hundred and nine (n=109) instances were identified over this S1 ↔ S2 unit. The distribution of DMC is illustrated below in Figure 23; as the proportion of dilemmas is lower than in the previous section, the proportion of conflicts and critical conflicts is significantly higher, testimony to the difficulties encountered by participants, and to the emotional reactions they may face as a consequence.

**Figure 23**

*Distribution of Discursive Manifestations of Contradictions in the Prototyping 1 Unit After Engeström and Sannino (2011)*

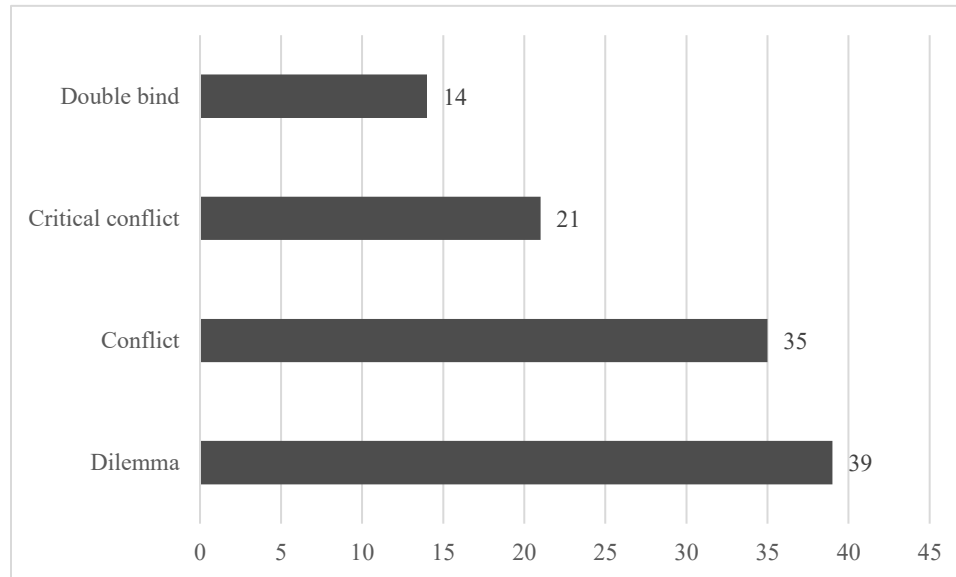


Figure 23 displays the number of DMC occurring over S1 ↔ S2 prototyping 1 unit; the figure shows the prevalence of *dilemmas* (n=39), *conflicts* (n=35), *critical conflicts* (n=21), and *double binds* (n=14).

#### **4.3.3 Conflict of Stimuli**

Given the strong divergent push characterized in the previous section, the initial conflict of stimuli identified in this section may appear as a reaction to this divergent pull, which we interpret as an attempt to refocus on a concrete object of activity to give gravity, inertia, or grounding to the system. As a result, despite experiencing a phase dedicated to ideation and prototyping in which the participants are encouraged to lean on the *novelty* end of the spectrum, a contrary impulse towards more usefulness and less novelty is favored by grounding the forthcoming conversations by pulling on the perceived needs of the stakeholders:

F002: I would like to ask you a question, maybe it is trivial to answer you, answering with a question, like in your opinion, which is the need of the... of S001?

P006: That the artificial leaf is going to be used by multiple companies.

P002: Yeah, I mean I was going to say something about like um... because they... I think they need from us a creative process of, like, ideas that will make their leaf viable or necessary. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 23–25)

#### **4.3.4 *Conflict of Motives***

##### **4.3.4.1 *Leaf as the Object vs. Leaf as the Instrument vs. Leaf as the Outcome***

As the following work sequence is initiated, participants follow ideation techniques to gather ideas about potential prototypes answering the main challenge of designing a service and a business model. An important conflict of motives emerges early in the process questioning the ideal place APT should occupy in the process. This conflict, as to whether it should be front and center as the very object of activity itself, or as the object of an emerging system of activity itself is illustrated below:

P002: I do have a question I've been wanting to ask, because when I've been doing sort of some brainstorming on plastic, you know, and like basically all of the applications that we have, we have to create like... we have these multistep processes and even like one of the... one of the advice, like the advice that we got was that we could look into the different points of the... of that system. And so, I was, like, coming up with like... ideas for, like, different points about like plastic collection, or about like creating something out of this plastic and I'm just wondering... how... because, like where the technology fits in is a very specific point in that process where they mix the virgin plastic that's been



created with the artificial leaf with the upcycled plastic now. I'm wondering like whatever we come up with, does it need to be like... should it be completely I'm...

P006: Based on the leaf? (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 16–17)

The response is both clear and ambiguous:

F002: So, like the final solution should definitely be something which revolves around the leaf. The prototype you were mentioning before, so these baskets to like... to the plastic triage, as it can be used as a prototype to explore a need. And it can be part of the solution, if your stakeholders say, "I'm cool with everything and just really concerned that people... that this whole system is not going to work because people are not able to collect properly the plastic." (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 26)

#### 4.3.4.2 *Interviewing to Prototype vs. Prototyping to Interviews*

Having taken on the risk of an uncertain gamble to steer the potential object of activity towards *novelty* rather than *usefulness*, the imperative to maintain alignment with the community of potential stakeholders is renewed. In this respect, the *instrumentalization of community* potential to extract information and orientate the process is also one of the major conflicts of motives i.e., to gain clarity and certainty towards a shared object:

F002: So, it's a bit... it's just a feeling. I see... I felt like you really you were waiting to have certainty before the interview, uh it should be the other way around, which, of course, means that you do one interview that may be the first interview that you understand is not, uh, wasn't that useful but then when you, uh, managed to contact the right person uh you are definitely going to save a lot of hours of research and that's also... this is already a prototype and a very simple way to test it is to show it to the person

P003: So, you suggest starting doing interviews even though we don't have like a prototype with just sharing the process and...

F002: That's already a prototype, that's something; this... this thing... it's a... at this point prototypes for you are still conversation triggers. Yeah, because you don't have ideas right now, I mean proper ideas also... because, uh, you're still trying like you should be more into the mindset of critical functions, critical experience prototype. I don't know if all of you, uh, remember that. So, it's important that you understand as soon as possible whether plastic is doable or not. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 79–81)

The previous excerpt is fundamental as it describes a process whereby prototypes of potential objects may serve as stimuli to gather further information and insight about a given product. This is an important statement, as it alludes to the role of potential stakeholders in knots coming from a given community while also hinting at potential instances of spontaneous double stimulation instances. Although the interview process is burnt into the sequence, it nonetheless emerges as a response to the main conflict of motive in the sequence, detailed further and interpreted as a double bind.

#### ***4.3.4.3 Acknowledging the Double Bind: Prototype From a Technology that has not Materialized***

The double bind of having to work and build upon an artifact that is not yet materialized eventually reaches the point of an aggravated tension deeply embedded in the interview process:

P001: My confusion comes from testing and even when we reach a point of testing which I don't think is going to be now—and I don't and we weren't ready to test—even a few weeks ago when um during the LGM we were asked to but when we eventually reached

that how do we test... like because we have so many prototypes and the thing is, we're going to need a lot of resources, I think. So, the more we converge on a just the prototype, the fewer resources we will need to test you know. So, I'm a bit confused about this process of... this part of the process. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 62)

We define this double bind as aggravated in the sense that it disrupts the normal process of the instructional process occurring at *intervention* channel level and requires participants to resolve to alternatives to sustain the progression.

#### **4.3.5 *Auxiliary Motives***

This section investigates the main auxiliary motives or auxiliary stimuli used by the participants to produce prototypes they may use to anchor the process on a viable and desirable chain of prototypes. This section addresses the first batch of prototypes suggested by the participants in response to conflicts of stimuli and conflicts of motives.

##### **4.3.5.1 *Capitalization of Wastes***

As a result, what is initially thought of as being a positive step regarding sustainable development moves a step further towards the valorization i.e., the capitalization of wastes:

S001: I, uh, address at least a bit of the climate change issue but for the company this is not working because they have to get money from their productivity so the second very important point for a company is to say you have a waste normally you have to treat the waste for some kind of waste it's some... there are possible technologies to use to or to substitute part of the components that you are using in your production chain or to be able to sell another product that is coming from the carbon dioxide valorization or to make this kind of joint, joint scenario in which the companies with different productivities, make an

agreement and one is collecting the carbon dioxide producing another product that is exactly the product that is needed from the second company so the product can be sold. The product can be used internally or there can be the possibility to make some kind of agreement with other companies we are not in competition with the first to take both value from them from these products so this is what I feel that for a company should be clear to see which can be the future, uh, way to have money from the waste at the end this is what they need they need to gain more money no? (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 79)

#### ***4.3.5.2 Valorization of CO<sub>2</sub> Through Plastic Upcycling***

The initial stream of auxiliary stimuli originates in the idea of a potential opportunity guided by the impulse on behalf of participants to create a systemic virtuous cycle of plastic recycling:

P006: Well, if you have this contaminated stream of plastic then, if that were upcycled that would also... that would already be great. But if you can actually improve the quality with a carbon negative so... because the plastic traps carbon, with carbon negative produced polyethylene or polycarbonate and the waste would have way more value and also, because it's already a green process the recycling to improve the quality in another green way would be a great marketing tool for these companies to sell the most environmentally friendly plastic that is available because it both uses waste and traps new carbon that's being emitted. (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 24)

#### **4.3.5.3 *Plastic Collecting Basket***

A direct consequence of the place the technological artifact should occupy in the process is illustrated by the first prototype idea to emerge in the system. This prototype, however, fails to satisfactorily integrate APT:

P002: Yeah, but like... yeah... and like... what if, like... we pick a step in the process, like, we come up with an amazing like plastic collection basket that can like detect the different types of plastic that's in it, or something you know, whatever um... does that work? But because, like, I'm wondering if it wouldn't work because it doesn't necessarily need the leaf. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 20)

#### **4.3.5.4 *Gamification App***

The concept of an application designed to foster public awareness and engagement emerges as a thought experiment. It illustrates further the perspective offered by a plastic sorting artifact involving a corresponding tentative activity system:

P002: I feel like one need is like the public understanding of like what plastic can be recycled and what plastic can be recycled and how much each type of plastic or other, you know other materials like have an impact on the planet, so maybe that could be part of that APP the team was talking about when you receive money, but you also know which plastic you're supposed to put on which bin. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 71)

#### **4.3.5.5 *Marketization of Wastes Through an App***

One further tentative to apply a market perspective to recycling is expressed in the shape of a digital application to measure and monetize the quantity of plastics recycled by future users:

P006: Yeah, and on the app, you can also see not only the amount of money you receive for this... for this plastic actually positive but also the amount of plastic and maybe it could also be that if you... If you go to a certain page if you tap that number of the amount of plastic that you deposited that it shows the amount of carbon that is being saved by returning this. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 72)

#### ***4.3.5.6 Turning Carbon Dioxide into Cryptocurrency to Capture Co2***

The concept of public engagement and awareness is further refined in the following excerpt in which cryptocurrencies may be used to capture and store carbon dioxide:

P001: So P005 came up with the... an idea which we haven't discussed but I was doing a bit more research into it and I just thought it was so smart that... to reward people... using the leaf to bring people to capture carbon dioxide... um... was to make it into a cryptocurrency. That way, the amount of carbon that they've captured can be converted to like a Biocoin or something. Um the reason... the reason I really like this idea is because it incentivizes people to capture carbon dioxide which I watched your video, P005, which you can build a little box in your back garden and it's... it's like very cool but the thing there are a few problems with it: you can't capture a lot uh a significant amount of carbon yet. The technology that underlies cryptocurrency is blockchain, um, and blockchain is a whole different issue that we... if we decide to go down this route, it's a cool thing. It will take way longer than we have, though, um, and then connecting the artificial leaf to the reward aspect, uh, means that the leaf will need to be small and personal to each person, and that's another barrier because one of the very first questions we asked the scientists was "Can we make it smaller in a few years?" or whatever "Can it be more personable?" and they said "It's made to be stacked with other leaves" um so

they said “No” to that but that you know we don’t know what more R&D will do to the leaf but... this is a potential prototype the Biocoin which combines... which combines cryptocurrencies with capture device. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 103)

#### 4.3.6 *Real Conflict of Stimuli*

The real conflict of stimuli orienting this S1 ↔ S2 pathway relies on the formulation of a germ cell as it illustrates the importance of *representing*, *illustrating* and *visualizing* the effect APT may have for participants within their activity system and beyond; as such, this double bind responds both to the *object* and to the *outcome* of the activity system: in order to have an impact on the contradiction of *preserving vs. developing*, the tentative impact of the technology may not be perceived. One of the benefits of the framing of the object within a foreign emerging activity system seems to have brought forward a real conflict of stimuli as the need identified does not fit yet the current state of thinking and it influences the subsequent emerging stimulus 2. The relevant conflict of stimuli may be illustrated thus and combines the previous auxiliary motives of *visualization* aiming at *public engagement*:

P002: Yeah and I think we did find out a little bit about like I mean a lot about like the whole system um and how like the way that we represent the system is like really important to people’s understanding of how necessary the leaf is um, so I think, like, I guess, I was just having this thought when you’re talking that was like um I think we need to really show the amount of carbon that would be like sucked up and utilized like I think we need to show like the positive environmental impact that the leaf has more so than we need to show like the system. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 40)

#### 4.3.7 *Stimulus 2*

The following excerpt displays the gradual shift from using premade data or tools to trigger feedback and insight from stakeholders, to promoting and adopting a more open and constructive or participative attitude in which stakeholders are invited to take an active stance in the process. This requires an open attitude based on adaptation and an unfreezing of the previously used tools (*user journey* in this instance) towards *co-configuration*. This shift informs subsequent attempts and may be illustrated thus:

S001, you were also suggesting not going to the interviews with, uh, already-made user journey, right? So maybe guys as prototyping is also, you know, co-designing with the interviewee you can also build the user journey with them so it's a way to ask them, "What's your process?" and give them the possibility to really talk about what... how it works, their process in the... in the company and to find together a place to where to put the artificial leaf, so S001 just tell me if I'm wrong, but take... Ok, thank you, taking advantage of this, um, of this feedback guys you can, you know, build new prototypes... (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 46)

#### 4.3.8 *Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 1*

One hundred and twenty-six (n=126) instances of ELA were identified over the S1 ↔ S2 prototyping 1 unit, and their distributions is illustrated in Figure 24 below:



**Figure 24**

*Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 1*

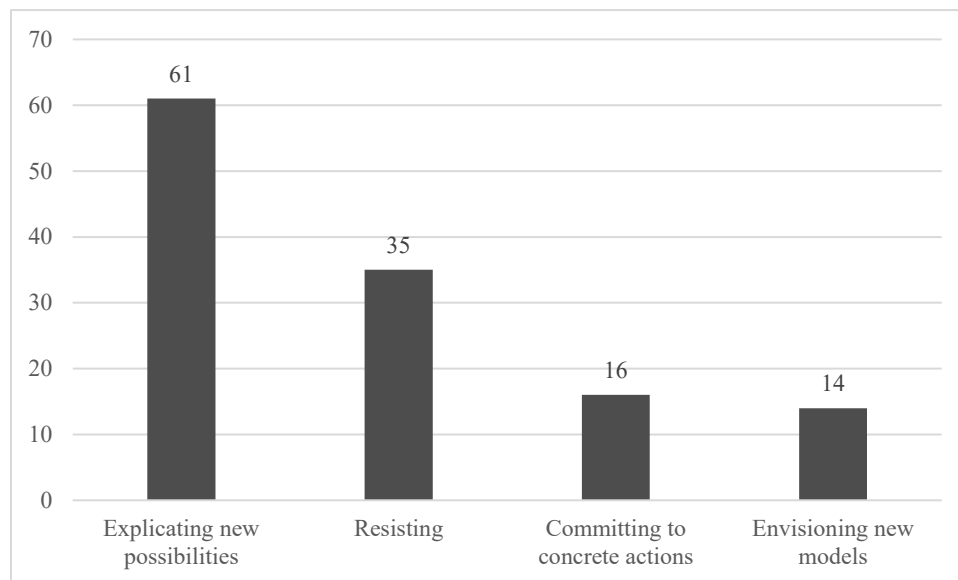


Figure 24 displays the total number of ELA occurring over S1 ↔ S2 prototyping 1 unit; the figure shows the prevalence of *explicating new possibilities* (n=61), *resisting* (n=35), *committing to concrete actions* (n=16), and *envisioning new models* (n=14).

#### **4.3.8.1 Students' Manifestation of Agency**

The present section allows for disruptions of processes that we would like to account for and report: this section thus looks at discontinuities and interruptions which we have deemed important to the process as they represent agentic attempts to break free from problematic situations or events. Although the previous section showed how researcher participants were able to break free of the suggested frame of action, this section is divided into *students' manifestation of agency* and *facilitators' manifestations of agency*.

*Rebelling against the process*

The dilemmatic tensions engendered by the need to visualize and generate data on APT, a developing technology, triggers resistance with the very process—the instructional sequence—followed by the participants. The project is perceived as being of a different nature than other projects followed by other groups, and participants therefore point the discrepancy out by targeting the steps of the process suggested by the facilitators:

P001: Like F003, like it... it's what they have is a lab prototype and what we are building is something that works in the real world. We are skipping, like the scientists said, three levels of research and development to reach a point which is fine, you know, for the future and it's good for us but that's what makes it so hard. And then we'll present... and when you understand those restrictions we have and we're presenting towards the LGM, but the feedback we get is something that will not help us you know because we're not at the level as the other teams, we don't have the same, um, we don't have the same priorities or path. So, when we are in those, well, at least for me I'll speak for myself when I'm in the large group meeting, I'm like... I love the feedback you're giving me. I can't do anything with it, you know, and that's what's frustrating for me at the prototyping level. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 110)

Interestingly, the two channels of *intervention* and *wider life* collide in this instance, displaying a perceived discrepancy between *the lab* and *the real world*.

### *Interviewing processes*

Furthermore, the lack of reactivity from potential stakeholders is pointed out as an additional point of difficulty, as illustrated by P005: “Yeah, but you're saying this, like... this like getting interviews is so easy and we have so many, right, emails and I rarely get an answer (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 82).”

Eventually, the very double bind of not having the possibility to act based on physical interactions with prototypes is further criticized:

P005: Honestly, I would love to try all the prototypes with companies and stuff and continue prototyping, testing, iterating and stuff but for us interviews is really a rare uh a rare like uh how do you say, a rare thing, so like for example if we consider the interview with from the C010 guy, if we do one prototype with him and it turns out to not be useful I don't think that we would have another interview with him and then yeah the iterating process is stopped and then there's no other... (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 115)

#### *Resentment with researchers*

The difficulty to produce valid stimuli to gather valuable feedback and insights from potential stakeholders is further reported, which we identify as a direct consequence of the dilemmatic force of the double bind which ends up producing resentment with the researchers and the intangibility of APT:

P005: But I really struggle with the prototyping because it's so tough especially here to put something practical because we also do not have access to their prototype, they actually have a prototype. It would be even a success to test their prototype of the company, right? I mean at the end the company would like to see whether the prototype actually works outside of the lab, and we are thinking about additional... uh... prototypes that stimulate the experience the company would have used the prototype. But not really yeah this is...

F003: But that's good, why do you say it's frustrating? Sorry, yeah...

P005: It's just tough, in my opinion. I would like to have their prototype see how it...  
 how big it gets when it's really yeah under operating conditions. (2022-02-02, SGM [S1  
 ↔ S2 prototyping 1], Pos. 107–109)

#### **4.3.8.2 Facilitators Manifestations of Agency**

##### *Enforcing the rules*

The response from the facilitators results in the enforcement of existing rules and steps of the process, as shown in the two following excerpts:

F003: Um, maybe my suggestion might be to force yourself to follow that suggestion to try to fit that process because actually, I know we have different challenges, whatever. But still, it's an innovation challenge so what is going on during the SUGAR process also can fit, of course. But I know it's hard to do that and the only thing we can do is trying and not stick to the way we think it's right because actually neither me, F002 and F001 sometimes know what is right or not and that's actually the... you know... fun part.  
 (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 112)

The idea of pushing through the discomfort zone is also described in the following excerpt:

F001: I have to leave the meeting in one minute but, um... also yeah the other thing just to wrap up I try to suggest you to think uh... to not think as the team IIT but to really think as a SUGAR team [...] try to force yourself to follow the process because maybe this is going to help you open your mind and not stick to the tech process with the tech functions with the old tech stuff we already said because you actually did a great job until now with research and you really understood the technology uh. Right now, try to really,

you know, also force yourself doing something that maybe it's not so comfortable for you to do. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 120)

*Admitting not knowing the answer ahead of time*

The open-endedness of the process, its complexity and the uncertainty attached to it also attract reactions on behalf of the facilitators:

F003: But yeah sorry, but that was... That was it. It's hard for us to... Can I come out with that we don't have like the solution, so it's really... that's why maybe you see us, kind of you know, stuck, because it's very difficult topic. (2022-01-26, SGM [S1 ↔ S2 prototyping 1], Pos. 100)

*Time to "not give a fuck"*

Having gone at length over the many discontinuities and difficulties experienced by the participants, the following sequence is dedicated to more extreme divergent and ideation phases are set under the following tone:

F003: So, I really suggest you to, like... I know it's... uh... hardcore... uh... to say but maybe this is the right time to not give a fuck on the researchers, and the research itself. So, like, you are really sometimes... but it's... I understand it you're really thinking like the researchers so, we should dig it... maybe we have to do research on it or whatever, but this is the time you can really... Ok... you can really... um... put yourself in the shoes of a crazy designer and sometimes also to not listen to the researchers. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 106)

#### 4.4 S1 ↔ S2 Prototyping 2

The second sequence is dedicated to prototyping in a more extensive, deep, and divergent fashion; participants are encouraged to iterate and test prototypes at the limits of their potential uses, to uncover new properties, features, or functionalities. In this sense, this sequence seeks to expand the tentative object of activity through validation of the new features with the community. An overview of the sequence is illustrated in Table 9 below :

**Table 9***Overview of S1 ↔ S2 Prototyping 2 Unit*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2
Intervention	Technical speak	Developing an intangible object	Plastic sorting apps	Inability to work “to size”	Complex simulation, visualization, funding, and 3D modeling online platform
Wider life	Lack of funding	Lack of numbers and figures	Funding apps		
	Skepticism		Simulation websites		

#### 4.4.1 S1 ↔ S2 Prototyping 2: Discursive Manifestations of Contradictions

##### 4.4.1.1 Dilemma

As iteration cycles progress, the need to account for viable sources of funding is further discussed and debated, putting in perspective both the object and the outcome through dilemmatic options. One illustration is offered below contrasting benefits and the marketing value of having environmentally friendly processes:

F005: Ok, but I think that there are these two tracks to consider at the same time, one is really when you speak to a producer that is interested in reducing costs and so on, and then there might have a commercial department and you could speak to them saying, “Look, you could have helped the adoption, the implementation of the solution, because there might be some benefit also in terms of marketing. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 184)

The same dilemma is further reinforced in the following excerpt:

F002: So, what if you also can have this reduction on taxes? What if you can ease on reputation so try to really investigate, which are the point to leverage with them? Whether it’s just money. Maybe we discover that for them space is super important maybe we

discover that the reputation is more important than ever, because they will be like for the transformation is happening in this field. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 208)

The dilemmatic impulse to favor either *company gains*, or collective and citizen awareness further emerges in the process and is expressed in the following excerpt:

P003: It's because the main topics of our prototypes that really worked were the... I mean the simulation, the fact that company could really invest on the technology and the other part was about awareness in general and education so it could be a little part in which maybe not only companies but also citizens and people who want to, in a way join the project could do these challenges. The previous prototype was about people that collect plastic waste and received... receive rewards and points but yeah, the topic is the challenge or some activity that can involve the public but maybe it can also be uh transformed in a way or not, like there is here... like how it is here, um... (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 115)

#### **4.4.1.2 Conflicts**

In this sequence, two sources of conflict are identified. The first one echoes directly the double bind expressed above on the intangibility and apparent lack of transferability of a developing technology. In this instance, the facilitator is particularly struck by the inability to picture and think “to size”:

F005: But this part is clear for me, and I think that if you consider the huge factories, because maybe of their core business and so on, they have availability, it is usually built maybe where it's sunny, outside, you have water, because they need... all the ingredients let's say should be there. But, my point is, can you reduce, I mean just to understand, is it



something that benefits from economies of scale, you know, the fact that the bigger it is, the better, the more efficient is the solution or not? Should we go for a huge solution or not? (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 135)

The second instance identified as a conflict is rooted on the predominance of digital applications and the possibility to expand benefits to unexplored ways of generation, such as cryptocurrencies and their potential deficiency in sustainability, experienced in this case as a clashing instance to the values of the participants:

P001: I agree with you P004 we can uh yes ok we can talk about it tomorrow um, but I think that I've been thinking about what you're saying. But I think that we shouldn't be so quick to say something that's complicated so we shouldn't think about it because, even if we found an application that's straightforward like the plastic thing is also complicated. We don't know how it really works and you know... so we do need to, well, I'm not very quick to kind of um think of um digital currency as not real but I do understand what you're saying and that's not sustainable. But there are sustainable ways it's just not mainstream yet. (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 189)

#### **4.4.1.3 Critical Conflicts**

This section offers three different types of critical conflicts experienced by participants undertaking a divergent phase of iteration: visualization, lack of knowledge. First, the inability to visualize the environment and operating conditions of APT are further addressed in the following critical conflict:

F005: I cannot represent myself exactly this artificial leaf solution what... where you can put... ok in a building inside the room outside the, in the, in the countryside or in the city or in the desert? (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 133)

Second, a discrepancy in both competency and scientific knowledge relating to the instantiation of APT puts tension over the process and triggers a critical conflict among participants with regard researchers. The critical conflict renders the process of interviews tedious and puts the participants in a position of incompetency in the absence of the more knowledgeable others supposed to fill the competency gap:

P005: But regarding all these technical questions... like we asked and because it's also tough for us to really picture the technology because we never can visit it tested, see it and yeah, the scientists have not shared a detailed specification sheet, they only responded to questions of ours. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 145)

An additional gap in knowledge or competency is signaled as a potential aggravated conflict and superimposes the previous ones:

P004: Yeah, that's my worry too it's not that you cannot get into there, but I think you may need some help to understand a little bit how the market works especially in ethics uh or in sustainable energy, yeah. (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 183)

This lack of competency and knowledge on cryptocurrencies is further addressed and causes experienced senior participants to apologize for their own perceived lack of expertise, questioning their very relevance to treating the matter at hand:

S001: Yes, I agree completely. Sorry for my continuous comments and I understand that, sometimes, maybe the discussion goes in the wrong direction, so as you, as you know, I am kind of continuously flowing when you talk, I think, and I return immediately so sorry for that, because maybe this is a bit limiting your discussion so... Thank you, because this is a very good job, and this very precious point of view. (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 115)

#### 4.4.1.4 *Double Bind*

This sequence offers the most precise articulation of the already mentioned double bind above as it touches upon potential customer understanding and skepticism, the need for visualization to gain convincing strength, the absence of relevant data to answer recurring questions in interviews and trigger relevant feedback to advance the project, and the moral and ethical dimensions of producing scenarios that may only be relevant to a certain extent. Finally, the inability on the part of the researchers to produce such figures is finally voiced for the first time.

Already mentioned several times, the lack of a visualization option is alluded to and voiced in the following excerpt:

F002: So, F005, like I didn't get for real your concern. Your concern is that the current prototype is not really possible for the stakeholder to understand, to visualize whether its technology would be applicable to their plant, is that your doubt?

F005: Yes, this is something that I think that the visualization because it's considered that, as we say, an image is worth 1000 words when you communicate to a company and you start to speak, you have to spend the time to say 1000 words instead of putting an image, ok? So, also in terms of an efficient communication, so you put images and use you speak two minutes less there is more information, so I think that you need to have visual tools that can provide elements that you can move and adapt to a specific situation.

(2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 155–156)

The specific need for a visualization tool is reasserted in the following excerpt, showing a reframing effort in terms of the impact of the double bind in the conduct of interviews and interaction with the community in knotworking:

P002: I also feel like every time there's a new person it's really hard to like to explain the project very quickly, so I think this would be a really important exercise for us just like explanation purposes, but also like to have a graphic that we can just show. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 200)

The possibility to work on mockup data and numbers is also considered as an option to overcome the double bind, insofar as it is backed up by experienced people i.e., more knowledgeable others:

P004: And now it's fine because I'm done, I don't know um they gave us numbers that are like lab numbers. And they are not like really what is going to be on the market, so I don't know how to take them, I really don't know I can... I can try to ask some of my professors if they happen to evaluate. I think like this, I can do that I know very good people at numbers but, otherwise, just for us to make them up it's us it's useless, I think. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 205)

Another instance is described below:

P004:... I think that it's very useful that we understand that, because it also happened to us that during the interview obviously people were interested and couldn't really focus without having such numbers or size, because we have to keep them in mind, but the problem is, we cannot make them up. I believe, so I think it's very useful, but if they if the scientists don't let us know better, but they don't know better, so I think it's kind of a steal, because... (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 203)

The inability to produce numbers is further described below:

S001: I know, but in the following panel in 30 or 20 years, sorry -in frame 37, the costs there, how we calculate this cost. In frame 37, I don't know who is sharing. Sorry, ok.

Sorry. Here is kind of cost how we count this cost. We, as SUGAR group, how we count this cost? (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 84)

The inability is voiced and recognized further in the discussion, as illustrated below:

S002: Because actually, this is what my previous comment, we do... we cannot provide numbers, real numbers. (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 95)

#### **4.4.2 *Distribution of Discursive Manifestations of Contradictions over S1 ↔ S2 Prototyping 2***

Ninety-nine manifestations of contradictions (n=99) were analyzed in this sequence and are presented in Figure 25 below. The most salient features of this problem-solving pathway rely in the fact that although dilemmas remain stable, double binds seem to increase to their highest point, signaling intense efforts to narrow down on the main fundamental issues being faced by the collective. Critical conflicts remain stable, signaling highly emotional involvement in the face of the contradictions being faced by the collective.

**Figure 25**

*Distribution of Discursive Manifestations of Contradictions in the Prototyping 2 Unit After Engeström and Sannino (2011)*

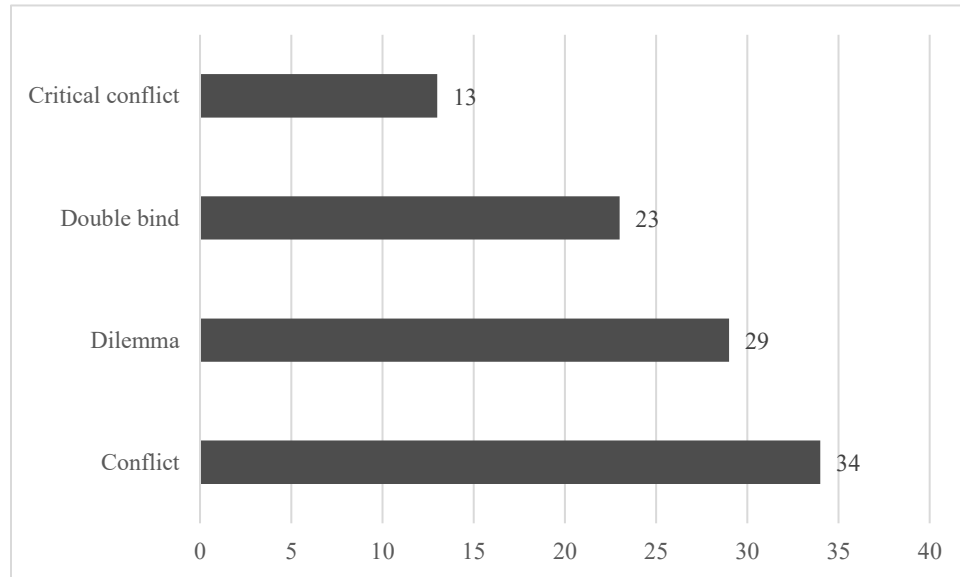


Figure 25 displays the number of DMC occurring over S1 ↔ S2 prototyping 2 unit; the figure shows the prevalence of *conflicts* (n=34), *dilemmas* (n=29), *double binds* (n=23), and *critical conflicts* (n=13).

#### **4.4.2.1 Primary Contradictions: Object and Outcome**

In this phase in the instructional sequence, we were able to identify the primary contradiction surrounding the object of novelty vs. usefulness to be pervasive, it appears doubled up by an aggravated contradiction at the outcome, related to the contrary impulse of *developing* vs. *sustaining*, a tension displayed in the following quote:

P002: Yeah, so there are two ways. We haven't decided which way to pursue, um, but yes cryptocurrency would be one option. I'm a little bit nervous about that because cryptocurrencies are not very sustainable obviously. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 116)

### **4.4.3 *Conflict of Stimuli***

As the contradiction and the focus at the activity level both widens and deepens, so the number of conflicting stimuli accumulates and is identified as lack of funding, on the one hand, and skepticism on the other:

P002: So, the problems that we're trying to tackle this is the lack of funding to implement the leaf and skepticism about the technology, people being worried about investing in something they don't understand. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 99)

#### **4.4.3.1 *Technical Speak vs. Layman Speak***

One particular caveat mentioned by participants is the increasing load on the division of labor, i.e., on skills exerted during interviews which impede the expected process of gathering feedback and possible insight from the interaction:

P002: Actually, I had one question I wanted to ask you, so we had an interview today with C015 and for most of us... most of us his... like way of even just talking about the project was very high-level technical chemistry, so that, like, I can maybe understand, maybe 7%. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 46)

### **4.4.4 *Conflict of Motives***

#### **4.4.4.1 *Recurring Conflicting Motives***

The very same dilemma related to the impossibility and incapacity to illustrate and materialize prototypes is described as one of the most limiting factors experienced by the participants while investigating stakeholders in interviews:

P004:... it also happened to us that during the interview obviously people were interested and couldn't really focus without having such numbers or size, because we have to keep

them in mind, but the problem is, we cannot make them up. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 203)

The resulting inability to answer satisfactorily while interacting with stakeholders and potential partners results in a reassessment of the division of labor and potential discrepancies in skills:

P002: But he was asking us a lot of questions which we don't have the answer to because we're not scientists and we're not THE scientists that work on the project... (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 46)

Eventually, the opportunity to design premade scenarios involving numbers, figures and data emerges, and the possibility to call upon external help—to create a new knot—is raised:

P004: And they are not like really what is going to be on the market, so I don't know how to take them, I really don't know I can... I can try to ask some of my professors if they happen to evaluate. I think like this, I can do that I know very good people at numbers but, otherwise, just for us to make them up it's us it's useless, I think. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 205)

#### ***4.4.4.2 Lack of Data Regarding Size and Output***

The double bind is further mentioned in a challenging work session in which the prototypes and ideas from participants were particularly pushed and stretched; this session in particular, as shown in the excerpt below, is gaining additional details and precision as it becomes more explicit over time:

F005: My idea... my difficulties now is, ok, let's consider that, as I told you, I didn't attend to the last meeting, but I don't really have... I don't have any numbers in terms of size and in terms of output. Ok, and I think it's relevant to size, the equipment in



industrial context or even in commercial contexts eventually like for the 3D printing, there might be some companies that focus on this one and I think it's useful if you want to communicate with them, to have a clear representation in terms of size and in terms of numbers to say how much you need for instance, water. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 131)

#### **4.4.4.3 *Lack of Representation***

The previous articulation of the double bind is further refined and detailed in the following excerpt, as it is expanded through a variety of illustrations and examples:

F005: Yeah, then I start to speak about the water but, in general, I cannot represent myself exactly this artificial leaf solution what... where you can put... ok in a building inside the room? Outside the... in the, in the countryside or in the city or in the desert? The desert as far as I know, no, because you need water... Ok so, is it better to put in Iceland? Is it better to put in the Alps, or in the south of Italy? Ok, I'm just taking as an example, Italy because you have from North and South, very big differences in terms of water availabilities. Is there a problem, eventually, with water? We are having problems now of water more and more so... What I miss currently but maybe you have a clear idea is really... and also, if you have to communicate with this company in 3D printing company, ok? Here, I think that we cannot be generic and say we have a solution, no. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 133)

#### **4.4.5 *Auxiliary Motives***

The previously described conflicting stimuli of *funding*, on the one hand, and *lack of a material artifact* to use during interviews is addressed by the auxiliary stimuli offered during this step of the process. As the need to visualize and provide material grounding to a tentative shared

object, a variety of objects emerge from the process of ideating prototypes according to the instructional sequence. In this intermediate stage of ideation and iteration of potentially shared objects, the following themes emerge: (a) cryptocurrency, digitization, investment, (b) education, (c) public perception and marketing (d) home and community devices, among which emerge the subtheme of plastic sorting and plastic sorting apps. We present potential auxiliary stimuli under three categories: *plastic sorting apps*, *investment apps*, and *websites*.

#### **4.4.5.1 *Eco Plastic***

As a direct response to issues risen in the previous S1 ↔ S2, the production of environmentally friendly plastic from recycled wastes, and in particular fumes, remains at the center of the process, despite presenting several scientific issues regarding its feasibility:

P002: But in general, we're like with this... with this application we're talking about installing the carbon capture on the... on the chimneys of a factory of a good distance and so it'd be a plastic upcycling factory, so outside on the chimneys. But then the leaf would then be able to source would be able to transform the carbon that it is taking in, and it would then start to make virgin Eco plastic so here's like a... This is... This is the leaf creating Eco plastic, which is done next with recycled plastic and then turn into a product... (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 134)

#### **4.4.5.2 *Plastic Hunters***

Further, echoing the issue of the systemic integration of APT to a *system* with the ambition of serving civic purpose, the possibility to produce a plastic sorting basket is further refined in this sequence using a gamified application:

P002: Um so F003 came up with this APP called plastic hunters so really like it's just like... the idea that ok like you can collect wastes, scan it and it'll tell you ok, it's this

type of plastic, you can put it in this container and the container will alert you “Ok put it in here,” and you get money on a personal card, depending on how much faster cycle there are challenges and that kind of thing. And then, P006 had the idea of like ok, it could even be like a Pokémon Go...

P006: Like augmented reality that you can walk around with your phone in your hand.

Like if you see something that sets a specific set of challenges with it. It becomes a little more interactive and fun. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 169–170)

#### ***4.4.5.3 Investment Applications***

*Investment apps* are devised as means to circumvent the funding issues relative to the use of an underdeveloped and a potentially financially risky technology:

P002: Yeah, exactly, so, um, there are three different ways and we’re looking at, like, basically an investment type of approach, but the one that we’re like sort of at least like leaning towards targeting more, we have to discuss this as a team, but it’s called “bio coin” and basically it’s an investment app so people will invest in... will invest in the classic upcycling companies and they invest in them so that these companies can pay for the leaf. And so, then, once that company implements the leaf... slowly people who have invested in the company get a small portion of the profits that comes from the leaf. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 101)

#### ***Investment app 2***

P002: Another one along the same genre is called “adopt a leaf,” and so this is like... actually, P003, want to talk about yours?

P003: Yeah, it’s similar to the previous one, and here companies and people in general can adopt a leaf so invest and invest on it and see its progress, so its benefit... the benefit

that can give to the company, and so they basically can follow its life and it's more like a game, but I also added a part in which a company can really invest and give money to have their own leaf, that is yeah for them and it is a way to be more involved in the process. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 103–104)

### ***Websites***

Progressively, the double bind and previously risen issue of providing means to visualize the project and its potential outcomes is devised and emerges among participants. Here we report two successive iterations across a seven-day period:

#### ***4.4.5.4 Simulation Websites***

P002: So, this is a prototype that I might even share like if it's applicable, but I guess the thought was ok, what if we made a website where you can go in and be like, ok, click here to compare with a negative plastic offsetting plant, and it can have a list of specs on the product which is the leaf. How to install the product and like show something like when you're talking about more concrete like this is where it would go this is how it would link up with your... with your current production. And then, how much it will save, so your input, the amount of plastic that you're currently producing which is kind of like your carbon emissions in a way. Input your location of business because I think that different countries are going to have different carbon taxes and different plastic taxes and then output would be the savings that you would get from implementing the leaf. So, I mean, I don't want to talk about this one too much with the team, but maybe it could be useful... (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 188)

Although the germ cell of an online tool to bridge the execution gap between a tentative project and its implementation emerges, the idea is refined over time, and further functionalities are added, which morph from a visualization to a simulation tool:

P003: Ok yeah thank you yeah so, this idea was about helping companies and people in general, but we are talking more about companies that want to invest in our... in the technology. And I came up with this idea after our discussion of last week, because one of the main problems let's say is that companies can't really imagine how big the plant of the artificial leaf could be to be really... to really get benefit uh from it. So, I uh could you zoom um more? Yeah on the... yeah ok thank you. So maybe the platform could help them to visualize and simulate the implementation of the leaf and so they could, for example, insert their space that is um that is free in their in the company, and for example how much CO<sub>2</sub> is uh produced by the company. So, the simulating part would be it would imagine in a way how big the plant would be how much... Ok thank you... how much um it would cost and so on... (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 103)

Eventually, the potentially shared object of a visualization and simulation platform gets added to and turns to a multilayered object by assimilation of features that have been suggested in different phases of the process:

P002: Yeah, so um the way that P003 like kind of set up the website it could have multiple different um subject areas. So, one could be the simulation. Um another one could be if you're interested, here's how you can invest maybe an app you can download, um another one could be like um and about us and here we could implement for instance uh the plastic hunter's idea where you could like join challenges just learn about the

project. So, I think that's where the idea of like taking all the different elements could come into play. (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 111)

Not only the simulation platform gets elaborated upon and gains in complexity, but it also becomes an integral and total solution accounting for all perceived needs up to this point in the modeling phase of the process:

P001: So yeah, so if you imagine F003 the platform itself will be like everything about the leaf. So, the simulation is for companies to see if the leaf is feasible for their advance and their company. And then we can also engage the public through things like challenges, maybe an educational game one of which is the plastic hunters and then it would contain other things as well like multi... it's layered but it's all about the leaf and one of the layers is also investing... in that investment it could be one of our cryptocurrency ideas we could make a token that is attached to the platform you know.

This is very ambitious but what we're thinking is "everything about the leaf" and it would target our end user as in the people the companies and also um could be used to teach.

(2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 117)

#### **4.4.6 *Real Conflict of Stimuli***

The articulated conflicting stimuli emerging in this sequence is further detailed over two distinct quotes in this section; the need for communication through visual representation is established as being a priority to advance the process and be prototyped:

F005: Can we help them to visualize to have a kind of a representation of these objects?

And how it works and discussing with them to size, I mean to understand what are their request, if it is enough or not. This, I think it's personally an important on the activity that I suggest doing as you were saying you need to communicate through visual

representation, and I think you have to really spend some time because it's a first prototype of the visual representation or drawing. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 133)

Second, the counterintuitive impulse caused by the double bind is reframed as a tentative reversal whereby missing data to produce a satisfactory and realistic simulation is overcome by the tentative idea to present a prototype with the ability to mediate information with potential stakeholders to find a balance or point of agreement to investigate an acceptable efficiency level.

F002: It could work, even though you, like, miss a lot of data, but it could work like even though you already started some assumptions. Which could be the amount of efficiency which could be interesting for the company like how much are they willing to give in terms of pain space for how much in terms of money, so this kind of tradeoff, yeah.

(2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 199)

#### **4.4.7 *Stimulus 2***

The simplistic idea of a linear step by step process for the integration of technological artifacts to industrial facilities is therefore reinforced and enriched to turn into a three-dimensional simulation and visualization tool:

F005: Ok, and at this level, I think that it's not just a simple diagram the combination, also 3D combination of elements that can give you an idea of where to put the... if there are pipes where to put... where you can pass things through, I don't know... building, outside the building just the leaves me because you need the sun and the water in another place. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 133)

Eventually, this potentially shared object gains enough traction despite the preestablished impossibility to produce numbers and gets further developed and enriched:

P001: Um, I just wanted to like again simplify things, real quick, with our idea for the simulation. First the simulation is not connected to investment, the investment would just be in another part of the website where users can invest. But if we move away from investment for now simulation will be built, just for the companies to understand what the leaf does, and if it fits with their industries last thing we agree with is this, right? So, imagine like we want to hire builders to build a house, you know we will never have exact numbers... they... people like me will put “I want this I want that that that that” and the algorithm will give out a number, a quote, a rough estimate about what to expect that will lead to a call to a more exact thingy, but our idea to help you talk to connect to companies... is to help companies imagine the leaf in their industry. So, it would be like “how much CO2 do you emit, how much space do you have, do you have access to direct light, yes, no, yes, no,” this is what you can do. (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 99)

The costs assessment issues represented by APT are further detailed in the following two excerpts as illustrations of the double bind tying the activity system:

S001: So, this part is not trivial because also from our side when we have to make this estimation, is very difficult... and you say it depends on if the company will wait for the return of the investment maybe it will be not so quick. Because there is not only the technology but it's also the infrastructure so and also it is an investment from the company... from the company side, and so I don't want to add the complexity, because it's really complex still like as it is. But we need to consider that there is not only the leaf, that is, everything that is around, also, that is requiring an investment. (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 82)



The double bind is further asserted in the following quote:

S002: Because actually, this is what my previous comment, we do... we cannot provide numbers, real numbers. (2022-02-18, liaison meeting [S1 ↔ S2 prototyping 2], Pos. 95)

Yet, despite the incapacity to produce numbers, the need for visualization is further reasserted:

F002: So, F005, like I didn't get for real your concern. Your concern is that the current prototype is not really possible for the stakeholder to understand, to visualize whether its technology would be applicable to their plant, is that your doubt?

F005: Yes, this is something that I think that the visualization because it's considered that, as we say, an image is worth 1000 words when you communicate to a company and you start to speak, you have to spend the time to say 1000 words instead of putting an image, Ok? So, also in terms of an efficient communication, so you put images and use you speak two minutes less there is more information, so I think that you need to have visual tools that can provide elements that you can move and adapt to a specific situation.

F002: So, a sort of visual vade mecum for the stakeholders, sort of? (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 155–157)

#### ***4.4.7.1 A New Emerging Consequential Double Bind***

The double bind is further reinforced beyond its initial formulation by adding a moral and ideological dimension in the following excerpt:

F002: P004, you are our economist in chief... What do you think?

P004: That's right. I wouldn't define myself such but... so, I think that it's very useful that we understand that, because it also happened to us that during the interview obviously people were interested and couldn't really focus without having such numbers

or size, because we have to keep them in mind, but the problem is, we cannot make them up. I believe, so I think it's very useful, but if they... if the scientists don't let us know better—but they don't know better—so I think it's kind of a steal, because... (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 202–203)

#### ***4.4.7.2 Criticizing, Questioning and Moving Back While Setting to Ascend to the Concrete and to a New Model***

Interestingly, the pressure and indecisiveness caused by the double bind leads to agentive affirmations whereby participants question anew the relevance of the project they are advancing with respect to pre-established and agreed upon decisions, e.g., the field of application which is debated again considering the latest evolutions in the following excerpt:

P004: But yeah that's right I don't want to discard the idea it was just um some thinking I made out of it and I don't know I think we have a lot even because um I was talking to P003 before and I was like "I don't know how this thing about plastic... whatever we really decided."

P001: No clue

P004: Yeah, that's right. So, we're thinking about like a platform uh for plastic, but it could be uh we could apply this platform for every field that we choose, if you think about it so... I don't know I really would like to understand better with the scientists uh the plastic thing. (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 190–192)

This extract appears to us as extremely meaningful for two reasons: despite appearing as an aporia whereby no further development might appear to benefit participants in the solving of a double bind, it foreshadows the progressive giving up of the field of application initially chosen and decided upon, while at the same time showing all qualities of ascending from the abstract to

the concrete by establishing a model that represents a potential solution to various fields of applications. As a result, while translating a regression at face value, it may be interpreted as a potent expansive development in the process.

#### ***4.4.8 Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 2***

One hundred and twenty-five (n=125) instances of ELA were identified over the S1 ↔ S2 prototyping 2 unit, and their distributions is illustrated in Figure 26:

**Figure 26**

*Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 2 Unit*

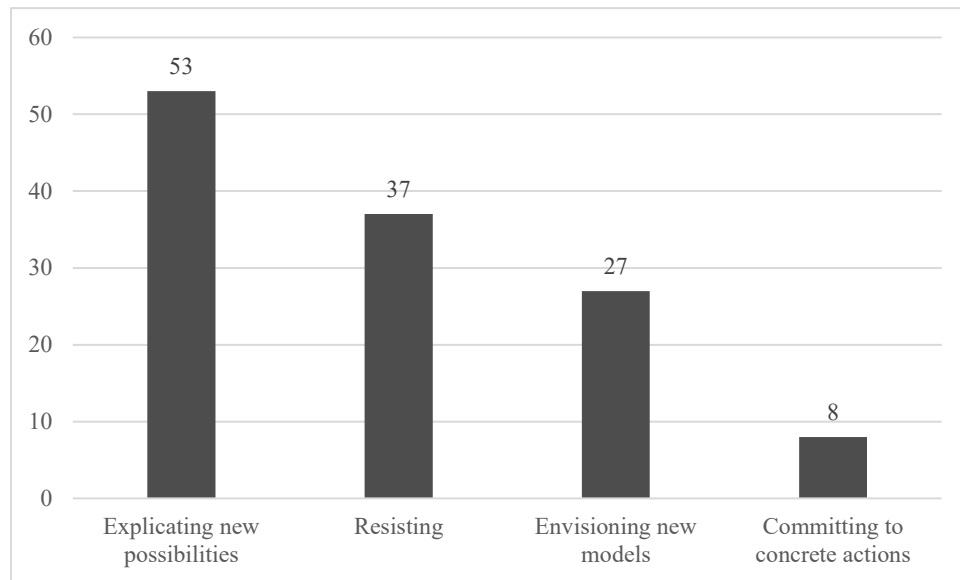


Figure 26 displays the total number of ELA occurring over S1 ↔ S2 prototyping 2 unit; the figure shows the prevalence of *explicating new possibilities* (n=53), *resisting* (n=37), *envisioning new models* (n=27), and *committing to concrete actions* (n=8).

#### 4.5 S1 ↔ S2 Prototyping 3

As the sequence advances towards one additional round of iterative modeling of the object, the main contradictions to the activity remain regarding the object as a balance between *divergence* and *convergence* (novelty vs. usefulness) is reasserted. Following the previous section and the apparent insolvability of the double bind between the need for tangibility as a reaction to the impossibility of producing data, the contradictions deepen across the poles of the activity system to include outcome (ecology vs. growth) and subject (preserving vs. developing): participants further question their roles and agencies in the process. The double bind from the previous section has not been resolved and keeps looming large over the whole activity system, and as a result, we consider the conflict of stimuli and the conflicts of motives to be the same in this section as they were in the previous one, with a few developments detailed below.

**Table 10***Overview of S1 ↔ S2 Prototyping 3 Unit*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2
Intervention	Being optimistic vs. being pessimistic	Having a field of application vs. not having a field of application	Easy peasy slotting Interactive infrastructure	Subject Rules Division of labor	Onboarding
Wider life		Making headway vs. not having a result by the end/not making a difference	Unity is strength Benefits to the surface Optimization Planet first Certifications	Community	Co-configuration

#### **4.5.1 Discursive Manifestations of Contradictions**

This sequence of iterations aims at crystallizing the features, functionalities and ideas gathered over the course of the previous sections into an abstraction, a vision; we interpret this phase of iteration as an intent to reach an ascending dynamic from abstract to concrete towards a model, even though the instructional sequence and the facilitators do not frame the exercise in this way. The cost of this ascending process may be considered as coming at the price of an unexpected switching of fields of application due to scientific unviability of the initial plastic upcycling attempts.

##### **4.5.1.1 Dilemma**

The dilemmas related to this pathway focus on efficiency in some way and are described below. Efficiency is first contrasted to desirability and states the principle of efficiency as one of the most important to base the object:

P002: So, like... like our goal, like one of our design visions, is to create something that's like the most efficient, so if it's something that you know, like, it's cool but it's not necessarily actually like the most efficient way of going about it, like perhaps we need to come up with them directly, described as the output, rather than...

P006: Yeah, there are multiple forms of efficiency, you know. For example, like you can make fuel out of it, but that will immediately put the carbon back into the air, so it is very easy to do so that makes it efficient, but it doesn't this efficient going for like climate change and then you have [...], which is very inefficient in regards of output, but very efficient if you combine it with discarded plastics, because then you need a very small amount of it. And so yeah efficiency can go in multiple directions. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 125–126)

#### **4.5.1.2 Conflicts**

Interviews may be considered as decisive trigger generators to major evolutions. A major conflict arises as the scientific unviability of the plastic fields of application is reported from an interlocutor in an interview:

P002: I mean, so we did send the scientist his report, so I think it would be his paper. I think it'd be interesting to see if they have a different view. But I think if they also like to read the paper and they're like: "yeah it's not feasible," then maybe even rethinking plastic.

P001: I think it's very, very possible that we might have to rethink plastic. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 109–110)

The prospect of switching field of application so late in the process triggers comments that show participants may border on critical conflicts:

S002: I can see, just a feeling of sadness, but I don't want you to be sad. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 167)

An attempt is made at converting disappointment and pessimism into optimism, showing high emotional involvement in this phase:

... it's not necessary to be so like pessimistic avoided, we should be still the ones who are optimistic. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 120)

#### **4.5.1.3 Critical Conflicts**

F003: But it's kind of it's also like hard for me to get it like even when we explain it it's still like I have to do that kind of effort with my mind I don't know I think it's the toughest part of the process, but when it comes it's like satisfaction. (2022-02-24, SGM [S1 ↔ S2 prototyping 3], Pos. 74)

P001: I mean I don't... I don't... I kind of understood... Ok so I'm just going to try. So, his interview was particularly important to us because I think he made it very clear to us that it's not going to be viable or feasible to use the leaf or polyethylene. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 106)

#### **4.5.1.4 Double Binds**

In this section the main double binds emerging are variations of the previously described double binds; in this respect, they become more specific and detailed by incorporating subtler issues. As an illustration, the concept of efficiency is derived as an iteration in which under certain circumstances it may produce adverse consequences such as producing further carbon emissions e.g., through fuel production. It is therefore framed as a polysemic term that might need to be disambiguated to satisfy the intent of a principle to be followed at object level:



P006: Yeah, there are multiple forms of efficiency, you know. For example, like you can make fuel out of it, but that will immediately put the carbon back into the air, so it is very easy to do so that makes it efficient, but it doesn't this efficient going for like climate change and then you have Atlanta, which is very inefficient in regards of output, but very efficient if you combine it with discarded plastics, because then you need a very small amount of it. And so yeah efficiency can go in multiple directions. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 126)

This observation is further reinforced thus:

P006: It's using fossil fuels... using carbon to recreate fossil fuels and that's what the artificial leaf does, all right? Yeah. (2022-03-14, SGM [S1 ↔ S2 prototyping 3], Pos. 36)

The following excerpt highlights the contrary incentives to be both generic and specific to be convincing:

S002: So, just correct me if I'm wrong, so you your guide, your rule should be to try to when you will speak with the companies, just to start giving them as one of the first things which benefits they can have, by implementing the leaf technology.

P001: Yeah, exactly.

S002: You thought that in some cases, it is not immediately clear to them.

P001: Yes, exactly, because we would because right every industry has different priorities right and different numbers on what they're dealing with so, for example, if we're talking to a cement industry in comparison to a plastic industry they have different numbers of different frameworks, right? So, the better, so this design principle is for us to keep in mind to make a personable solution that people can imagine the leaf in their industry, no matter where we go. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 18–21)

The contrary of managing a developing technology as opposed to a fully functional solution is stated as one of the major sources of tensions:

P005: Yeah, but that's my point right, we need investors to develop the technology that the technologies in any way not written.

P006: Yeah, I agree P005, because if the technology worked perfectly then literally every company would want it.

P005: Yeah, exactly. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 122–124)

The necessity to visualize the material configurations of APT is further addressed at this stage:

P005: Yeah and I think one thing that that forced us a bit to also asking you, these difficult questions was that I think F005 wanted us to really visualize companies, the impact the leaf would have on them right: space, scalability, costs everything, and if you are not able to give me that I, to give us this information, yeah I would not be right to give the company some assumptions right, for example, if they if they have photovoltaic plants we should we say them, "Yeah you, you can use the space." I am not a photovoltaic plant, but... (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 52)

#### **4.5.2 *Distribution of Discursive Manifestations of Contradictions Over S1 ↔ S2 Prototyping***

##### **3**

One hundred and nineteen (n=119) DMC emerged from the data in this sequence.

Although the proportion of dilemmas remains stable over this sequence, double binds increase as well as conflicts. The rise in double binds may signal expansive potential as the object of activity gets more closely critically inspected and debated. The increase in conflicts signals the involvement of participants and the liveliness of polylogues in multi-voiced settings. Although

this situation may lead to critical conflicts, the proportion is lower, which in our understanding may signal better fluency within the collective. The distribution of DMC is illustrated in

Figure 27 below:

**Figure 27**

*Distribution of Discursive Manifestations of Contradictions in the Prototyping 3 Unit After Engeström and Sannino (2011)*

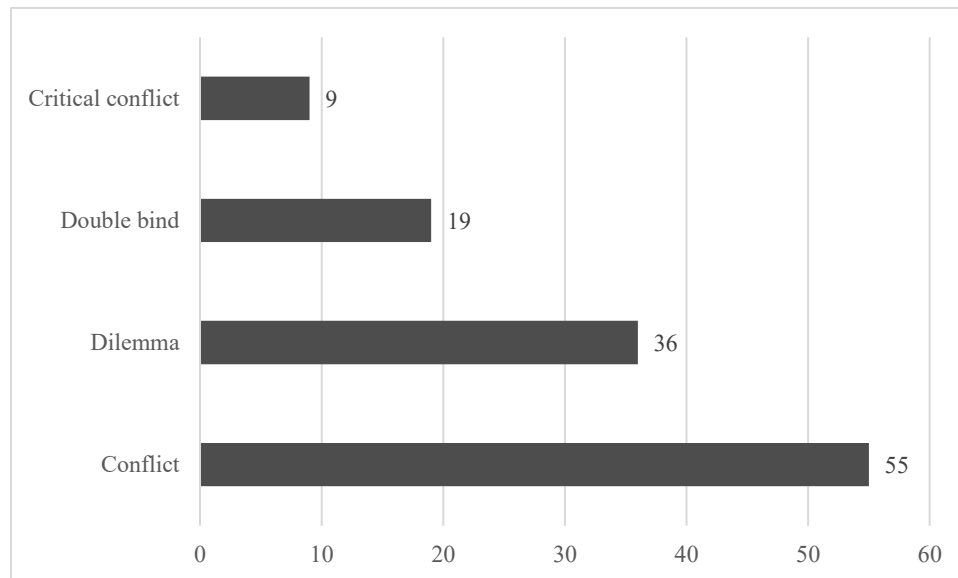


Figure 27 displays the number of DMC occurring over S1 ↔ S2 prototyping 3 unit; the figure shows the prevalence of *conflicts* (n=55), *dilemmas* (n=36), *double binds* (n=19), and *critical conflicts* (n=9).

#### **4.5.3 Conflict of Stimuli**

As stated earlier, the double bind is reframed so the quality of the missing data for the simulation and subsequent visualization of the process of integration of the APT to an industrial infrastructure is flipped: the resolution of the information expected is lowered to tentatively let an acceptable performance level emerge from interactions with stakeholders.

Despite the reversal mentioned above, critical encounters happen through interviews which push skepticism with respect to the viability and feasibility of the application of APT to a productive industrial activity:

P005: And I just opened the article again and the conclusion he says, could be pasted here: “Electrochemical convergence is needed and could be of interest, but several breakthroughs are needed” and I think we are... it’s not necessary to be so... like... pessimistic avoided, we should be still the ones who are optimistic. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 120)

#### **4.5.4 *Conflict of Motives***

The previous section displayed tensions between the field of application which was shown at the beginning of the data set, and the doubts and potential conflicts expressed by the students with regards the solidity and viability of ideation and prototyping in the field of plastics; this dilemma illustrated the fear of not complying with the objectives of the project, which were also expressed as conflicts and critical conflicts in the first phase of the sequence. The researchers try to circumvent any sign of frustration or discouragement by shifting from the focus of the activity to a prospective, future-oriented activity and removing the necessity or fear of not delivering the expected service and corresponding business model:

S002: Obviously, just to be clear, we are, we are very happy on the work that you did up to now just to be clear. As maybe F003, if I remember well, said, yours is a research work, ok? You are not selling anything to anybody, you are doing research, if a research from the one but it’s also... but it is anyway it’s a research so... and you did an excellent work in finding, also companies that at least are interested in the... (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 82)

#### **4.5.5 *Auxiliary Motives***

The present section offers an overview of some principles that have been issued during the process of ideation and prototyping. They are treated as germ cells containing an abstraction

(an *insight*) to the resolution of a contradiction (a *problem*), and they are used to mediate the process of problem solving according to the guidelines provided by the instructional sequence. They mostly play as thought experiments to refine and improve potential designs during the process. We therefore interpret those episodes as micro development cycles, the smallest unit dealt with in this PhD study as far as time is concerned. They are described in the next section as micro S1 ↔ S2 units.

#### **4.5.5.1 *Easy Peasy Slotting***

The first principle addresses the problem of funding and optimization of installation costs, and we understand it as being directly influenced by the outcome of the primary contradiction of *ecology vs. growth* as it established the funding of the object and its material dimension:

P001: The first one is easy peasy slotting. So, this one, the insight we got for this one was that the leaf is an expensive undertaking for factories to shell out money for, so to save money um the need was to make sure that the leaf kind of slots into existing factory framework. So, the design principle is easy peasy slotting in that the leaf will slot into existing infrastructure to show popularity with industries, you know, make it competitive. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)

#### **4.5.5.2 *Interactive Infrastructure***

The *interactive infrastructure* principle establishes a relation between company ecosystems and the public at large; it interrogates the outcome (*ecology vs. growth*) to ensure the moral and ethical dimension of the development of the object:

P001: And the second principle was an interactive infrastructure and this was based on the need that we need public support and public engagement which means that we need to

ensure that there's a symbiotic relationship between companies and the public, and that the leaf strengthens that. So, another design principle was an interactive infrastructure, which means it allows a relationship to occur between the public and the companies with the leaf, in the middle, and the second one. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)

#### **4.5.5.3 *Unity is Strength***

The third principle establishes a community on the funding of an object by sharing costs between cooperating actors; it therefore calls in question both the ethical and moral dimension as well as the material one:

P001: The third one is unity is strength and here I think this was this is an insight but based on an assumption, and this follows the same line of thought that it's an expensive thing for companies to just shell out money for so. If we manage to create an ecosystem of stakeholders that will work together and maybe invest in the leaf together and then reap its benefit together that's more doable for everyone. Um so the design principle here is unity and strength. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)

#### **4.5.5.4 *Bringing Benefits to the Surface***

*Bringing benefits to the surface* is the principle that most directly addresses the dilemmas and double binds covered so far in this section: it stands on the need to visualize and translate the features and functions of APT into palatable practical facts in an industrial environment:

P001: And number four is bringing benefits to the service, and this was based on the need that, a lot of people understood what the leaf was doing in terms of benefits that will bring to the production line and to the industries, so we decided that the insight was to make it clear to make communication more transparent and then, so this is where it came

from bringing benefits to the surface. Making it clear that the benefits of the leaf will help stakeholders, um. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)

#### **4.5.5.5 Optimization**

The *optimization* principle is performance oriented and responds to the *preserving vs. developing* primary contradiction according to which financial and economic performance are the most central tenets of a potentially share object:

P001: The fifth one is optimization, so this is one of the more technical ones, maybe for the future research and development and it was based on the need that the leaf needs to measure up to an already existing system. So many industries and companies already have some sort of a leaf but some soft technology that mimics your leaf, but your leaf would need to be even more optimized for them to take up the leaf, for example, like with efficiencies of the products um. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)

#### **4.5.5.6 Planet First**

This principle again addresses the outcome of the activity by stressing the ecology vs. growth contradiction, stressing again the moral and ethical dimensions:

P001: And then the last design principle is the planet first the this came across in many interviews that even though... even some of the most in... unsustainable companies wanted to be sustainable and also this kind of reflects our values as a team, we want for the planet first so making any step that we take sustainable and efficient and to create a circular model and benefit us and future generations. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 13)



#### 4.5.5.7 *Certifications as Means to Onboard the Public at Large*

“P004: Well, it’s a bit confused because I also thought while I was writing it like that if a company, for example, is uh... recognized for adopting the leaf for example as we said once, maybe more than once. As we said for example if they have like kind of certification then the final user will be like... um... will uh... acknowledge the fact that um, they’re doing some effort. (2022-02-24, SGM [S1 ↔ S2 prototyping 3], Pos. 35)

#### 4.5.6 *Real Conflict of Stimuli*

This section demonstrates through various quotes how the double bind manifests across the channels of intervention, ruled by the shape of the global instructional sequence, and how it is shaped and modified over time by *tertiary contradictions* in the shape of fully developed industrial or organizational systems which challenge the ability of the participants to provide concrete answers to material issues. The main conflicting stimuli consistently manifesting throughout the sequence is therefore related to the ability of participants to bridge that gap satisfactorily and the skills gap that materializes thus, provoking a zone of proximal development whereby collective learning is therefore needed. The double bind is further exemplified in the following excerpt, and hints at ways to take advantage of tentative interviews to involve and empower stakeholders to take part of the process of defining and coming up together with participants to a new shared object in the shape of acceptable performance standards; as such, *co-configuration* becomes both a potential shared object and emergent activity system with a potential to resolve the tensions reported in this section:

F002: How you can make the need behind this question satisfied, even though you don’t have... you cannot have, by definition, clear answers maybe the question is to like... the answer is to develop a trial strategy where you test the technology before you can develop

it, so you can actually... you can actually find the answers together. So how can you create reliability without being able to actually provide specific answers about the...?

(2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 5)

#### 4.5.7 *Stimulus 2*

Emerging from previously pointed discontinuities in the pursuit of a shared object, the concept of *onboarding* is voiced as a tentative Stimulus 2 effort. We report this formulation in the following excerpt:

F002: So, like uh... I think one very helpful thing you could do, would be to create a tool and activity that could enable uh the scientists to onboard a new partner in the future. So, this relationship that you are building with C012 is a sort of a prototype for you to understand according to this situation which are the needs of a company to implement the artificial leaf and understand it and how to ease this process in the future and it's also about strategy. So how can the prototype we build with a company become a showroom for future companies, so it's really a sort of a strategy user experience design so it's very transversal. According to this experience you're having, next time if you had to present the artificial leaf to another company, which doesn't really matter the field I think um... how would you approach it? Because I... for example, I felt that the conversation we have today with them was really insightful because there was kind of a lot of trigger questions the scientists weren't... not that ready to answer to. I mean they weren't trivial, but they were the logic questions a company would do... practical questions a company would do, practical questions a company would do, like Ok 'what's the efficiency?'

(2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 1)

This excerpt may be the densest quote in this section and it requires to be unpacked; it establishes the object of activity as a *tool* or *activity*, the outcome of which is to *onboard* potential partners, an emergent concept addressing the need to co-configure and let stakeholders be involved in the process of building potential new objects of activity, i.e., to be integrated within the collective subject of the new activity and its shared object. The concept shows a potential for ascending from an *empirical* to a *theoretical* concept by acquiring *transversal* i.e., being generalized to a variety of stakeholders. In this respect, it therefore turns the necessity to address a unique field of application obsolete. The tentative new concept jumps from instrument to object of activity and gets labeled “showroom” by analogy with a tertiary contradiction experienced prior. Finally, the *creative encounter* is experienced as a resolution to the conflicting stimuli and motives experienced by participants: the corresponding aggravated tensions and double bind represented in the excerpt above act as *trigger questions* producing dead-ends dialogic situations for all parties involved. The double bind of developing technologies therefore represents a way out of the double bind, which is suggested as the ability to *onboard* and co-configure i.e., involve stakeholders in the process. In this new vision, a secondary contradiction is also called into question as the *instrumentalization of the community* in the activity is expanded: stakeholders from the field are no longer perceived as recipients of tacit knowledge to be investigated through the thoughtful and relevant triggering or stimulation via *prototypes* or *tools* but their roles and attributions are expanded to give them *integral subject status*.

#### **4.5.8 Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 3**

Ninety-three (n=93) instances of ELA were identified over the S1 ↔ S2 prototyping 3 unit, and their distributions is illustrated in Figure 28:

**Figure 28**

*Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Prototyping 3 Unit*

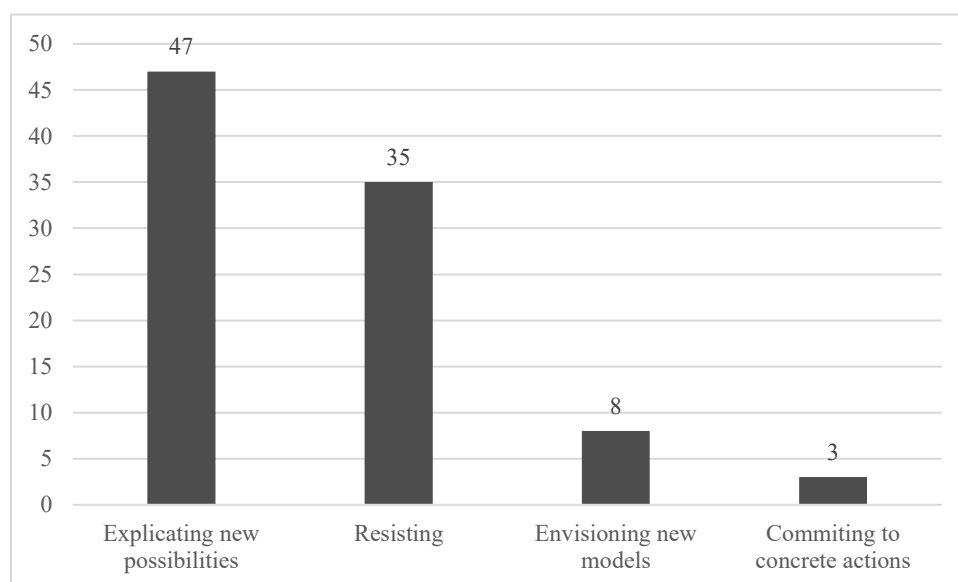


Figure 28 displays the total of ELA occurring over S1 ↔ S2 prototyping 3 unit; the figure shows the prevalence of *explicating new possibilities* (n=47), *resisting* (n=35), *envisioning new models* (n=8) and *committing to concrete actions* (n=3).

#### 4.6 S1 ↔ S2 Concept Formation

The main primary contradictions manifesting in this section are consistent with the ones described in previous sections. They manifest as *novelty* vs. *usefulness* in the gradual emergence of a shared object of activity over several iterative and cumulative cycles. This emergence evidences the gradual appearance of tensions on a dialectical unity of *ecology* vs. *growth* as far as the outcome is concerned. Additionally, the unity of *preserving* vs. *developing* also gradually emerges in this sequence. A gradual global shift is observed from initial moral ethical shifts from creativity, ecology, and preservation towards a more conservative stance of usefulness, development and economic growth under the pressure exerted by accumulating aggravating tensions occasioned by unsolvable and contradictory values. An overview of the S1 ↔ S2 unit is suggested in Table 11 below:

**Table 11***Overview of S1 ↔ S2 Concept Formation Unit*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2	Agentive action
Intervention		Reliability vs. developing technology	Onboarding “Co-design” Showroom	Ascending from plastics	Digital showroom	Giving up on plastics
Wider life	Fitting existing systems		Digital showroom			Influencing decisions Heckling researchers

#### 4.6.1 Discursive Manifestations of Contradictions

##### 4.6.1.1 Dilemmas

The previous section evidenced the dead end of plastics as a tentative field of application of APT; however, the extract below exemplifies how the disruption of ongoing processes may be considered as a generative episode thanks to which participants *ascend* from a particular instance to a generic model that may be applied to further fields of applications:

P005: Let’s focus on the plastic sector, right? We all agreed on focusing on the plastic sector. But then during the interview with C012, we realized that it’s more important that we... that it’s more important to focus on the collaboration between IIT and other companies to find a way to find answers to their questions, and that we can apply this in every sector. So, we decided to open up again to every sector, not only plastics. (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 17)

#### 4.6.1.2 *Conflicts*

As the concept of *onboarding* emerges and is further refined, its wider applicability is praised by participants who appreciate its potential to widen the basis of potential participants that may as a result be involved in the process:

F002: Yeah, but I think it's less and less related to plastic specifically. It's more related in general how to uh onboard partners in the technology. To make it accessible and understandable. So, this is also the thing I would like your question what we should do to help IIT. This is the big question you should ask to IIT after the second milestone...

(2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 7)

#### 4.6.1.3 *Critical Conflicts*

Resentment towards researchers further manifests in critical conflicts with a potential for aggravation in which they momentarily are depreciated as to their ability to answer predictable and commonsense questions:

P005: "Would you like uh... how would you like a co-design session next week uh... in two weeks?"

F002: So, you can make this question, I'm just not sure they are able to...

P001: They won't answer.

[inaudible]

F002: They prepare the technology, they don't invest, or they don't really know what to do with it... the questions they were asked today were kind of predictable, and they were completely... what was it about the unit of measure... the measuring unit? (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 42–46)

#### 4.6.1.4 *Double Binds*

Tensions emerge at subject level regarding the division of labor and the object of the activity, and the double bind is articulated again under an agentive perspective as P001 articulates the unresolvable tensions emerging between laboratory and ecological contexts. The new meaning and sense of activity are conveyed in the last sentence and as a by-product of the emergence of the *onboarding* concept as an auxiliary motive:

P001:... even though we told them it's only lab-based, they expected us to also know the numbers for a normal factory. So, I guess those are I from what I got, those are not things that we should know, that's not our area. And even if it was, I don't think I would like... it's so much detail I would never... and even the scientists themselves didn't know the numbers. So, I understand what you're saying, almost, but like how can we communicate something that even the experts themselves who invented it don't know yet to accompany... (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 2)

#### 4.6.2 *Distribution of Discursive Manifestations of Contradictions*

A total of fifty-one (n=51) instances of DMC were identified over the S1 ↔ S2 concept formation unit, and their distribution is illustrated in Figure 29:



**Figure 29**

*Distribution of Discursive Manifestations of Contradictions over S1 ↔ S2 Concept Formation Unit*

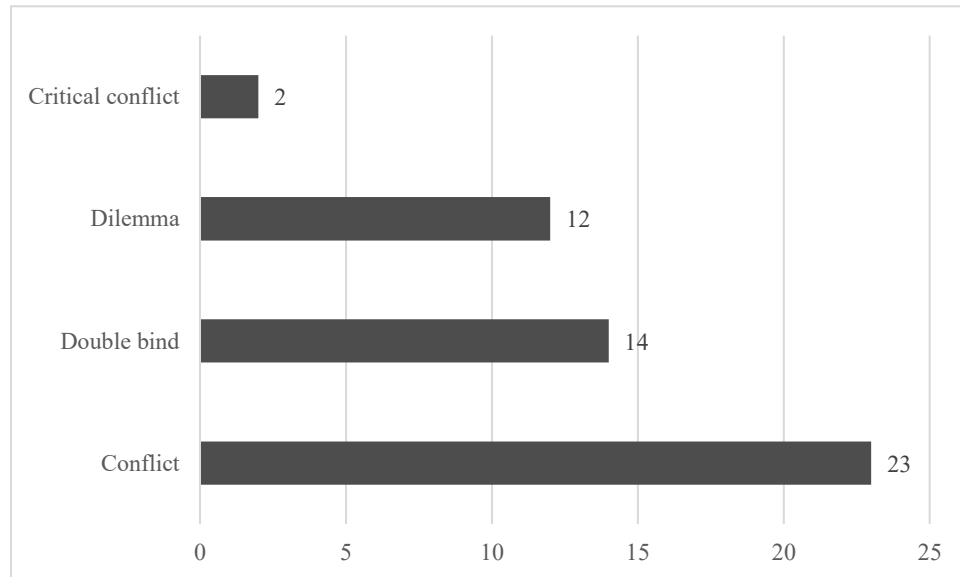


Figure 29 displays the number of DMC occurring over S1 ↔ S2 concept formation unit; the figure shows the prevalence of *conflicts* (n=23), *double binds* (n=14), *dilemmas* (n=12) and *critical conflicts* (n=2).

#### **4.6.3 Conflict of Stimuli**

As the activity progresses and a tentative Stimulus 2 is articulated, the main conflict of stimuli in this section shows the fusing of both the double bind and previous conflicting stimuli, as well as a new expansion of the moral and ethical dimension as they *merge* with the spatial-temporal one. This mutual reframing is illustrated in the following excerpt in which a summing up of the tensions and aggravated conflicts relative to the conduct of the activity up to this point is exposed; the situation is acknowledged as complex. We interpret this excerpt as reflecting a tentative reframing and new expansion of the dialectical unity of *preserving* vs. *expanding* reframed under the perspective of *ecology* vs. *growth*:

S001: Because you tried to look for an application and you know that it's difficult for you and also for us and for everyone. What you observed on Wednesday is exactly what we do each time we have a company to discuss with, so they want to, as they were doing with were asking them, 'How can [I] imagine this in my company?' And it's difficult because first we do not know the company arrangement or by-products or the characteristics of the company so for us it's difficult to imagine how to apply this technology on one side. But also I understand that they need more numbers to decide that uh 'Ok I want to invest money in this technology without knowing if there will ever really be a return, because it's the very beginning of this technology or in the climate change technology, circular economy technology, all the companies are so willing to say, "Ok part of my economic return, I want to invest this in promoting new technology because I believe this is the future." Very few! (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 25)

#### **4.6.4 *Conflict of Motives***

We consider this stage as being the final stage of the modeling phase; the double bind is directly reflected in the conflict of motives addressed in this sequence; we consider this a fusion of double bind and conflict of motive as a distinctive feature of this sequence is both aligned and addressed by participants:

F002: I think a greater *how might we* is "How can you, uh, create reliability towards a technology when you cannot provide specific answers to specific questions?" (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 166)

#### 4.6.5 *Auxiliary Motives*

At this stage, all auxiliary motives emerging in activity among participants are dealing with *onboarding* as an initially emerging concept which progressively and increasingly gets filled with *co-designing* or *co-configuring*. The following excerpts illustrate this emerging trend within the activity.

##### 4.6.5.1 *Material Relations With the Community as the Expansion of an Object*

The materialization of relationships between participants and community remains at the center of collaborative processes, though reversed from previous iterations in that the situation. The fruitful interactions and conditions are extracted from a spontaneous episode so as to be abstracted into a model, a process peculiar to the present section which we identify as a manifestation of *ascension from the abstract to the concrete* (Davydov, 1990). The first step therefore is abstraction in the shape of objectification or prototyping of this relationship:

F002: So, this relationship that you are building with C012 is a sort of a prototype for you to understand according to this situation which are the needs of a company to implement the artificial leaf and understand it and how to ease this process in the future and it's also about strategy. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 1)

##### 4.6.5.2 *Co-Design as a Favorable Vision*

The abstraction is further reinforced by encouraging a potential positive or exemplary co-design situation to extract features and functions from:

F002: So, I don't know if you will find that absurd for tomorrow, but if you mention co-design, it's already an insight, a good design vision because you cannot solve this vicious circle if they don't collaborate. And a future prototype for you could be a good design session. A really solid design session between them. Maybe you can say "like in two

weeks we are going to organize it,” then tomorrow or Friday you will collect the info you need to do it. So, it could be a way to get prototypes going. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 38)

#### **4.6.5.3 *A Showroom as a Transitional Mediatlional Space***

As the concept of *onboarding* is further expressed and exchanged upon by participants, it gets enriched by a layering process through which reference elements stemming from tertiary contradictions are gradually abstracted and mixed with the initial concept. Thus, the concept of a showroom lifted from a critical encounter producing a tertiary contradiction gets superimposed over the *onboarding* as a tentative shared object or an outcome of activity systems, while the concept materializes in co-design as an instrument. In this sense, the following excerpt illustrates a future orientation in the activity:

P005: No, no, no, I think it could be a really cool idea if we could in a way convince IIT to already try to create this showroom. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 6)

#### **4.6.5.4 *From Showroom to Communication Platform***

The object and instruments get further expanded with linking features to create correspondences between prospective stakeholders and researchers:

P001: But what do we do? And I feel like the way you see [it] is like math and we’re done.

P005: No, no, no, but I’m uh... on your side with the... with the showroom also.

P001: We could create it ourselves.

P005: Yeah also a communication platform to inform every uh important stakeholder... not only stakeholders but I mean in the company like the engineers, economic guys blablabla.

P001: Yeah, exactly. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 13–17)

#### **4.6.5.5 From Concept to Model**

Finally, after diverging and layering the object of activity with both pre-existing features and newly emerging ones, the simulation object mentioned above in previous phases of the modeling phase is used to reframe, recenter and refocus the scope of the object; it also displays elements of aggregation of the spatial-temporal (optimization) dimension and the ethical moral one (honesty) along the *preserving vs. developing* opposites:

P001: So, we're trying to help companies best imagine and work together with you, right? So, we can do a simulation of this, and we can do a model of this, yeah? And then we can include like the little numbers and stuff. But the optimization comes after the simulation, after the working table.

P005: Exactly, that's right. At first it is important to show them the current state yeah... and then when we can... and we can say, it can be optimized but this is the current state yeah... so to be honest, ok?

S001: Exactly, it's true, we cannot promise but we agree. (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 73–75)

#### **4.6.6 Real Conflict of Stimuli**

At this stage again in the process, the real conflict of stimuli is aligned with the double bind expressed in previous sections, and as representative and relevant in this section, further

justified by the endorsement and demonstration of the inability of the researchers to provide certain answers and data:

F002: Because I, for example, I felt that the conversation we have today with them was really insightful because there was kind of a lot of trigger questions the scientists weren't... not that ready to answer to. I mean they weren't trivial, but they were the logic question a company would do practical question a company would do, practical questions a company would do, like ok "what's the efficiency?" (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 1)

#### **4.6.6.1 Transitioning From Plastics**

From the previous observation, a second conflict of stimuli emerges due to a tertiary contradiction pushing the activity system towards an enlargement of its object by enlarging its potential community. This contradiction shifts its center of gravity from creating a service and a corresponding business model for APT to shifting the object of activity so APT integration becomes the *outcome*; thus, co-configuration becomes the main shared object:

P005: Let's focus on the plastic sector, right? We all agreed on focusing on the plastic sector. But then during the interview with C012, we realized that it's more important that we... that it's more important to focus on the collaboration between IIT and other companies to find a way to find answers to their questions, and that we can apply this in every sector. So, we decided to open up again to every sector, not only on the plastics. (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 17)

#### 4.6.7 *Stimulus 2*

##### 4.6.7.1 *A Potential Model Emerging From a Critical Encounter*

The following quote is a tentative articulation of the aspects discussed in this section as a Stimulus 2 lands across activity systems in reaction to the primary contradictions. The stimulus 2 also bridges the gap and synthesizes various aggravated aspects by grounding them into the materiality of a lived experience and the gap opened by a tertiary contradiction. The generalization and germ cell emerging in response are illustrated in the following quote:

P001: The last interview was a moment of clarity for us, but we've noticed patterns in all the interviews and that they always ask the same questions, very detailed questions, and that... and then but this was the first interview that IIT was there, decided you guys were in and talking with them, right? And we were there from the background, and we were noticing that maybe it's not so helpful that we need to design something specific into a factory. Maybe what our role here is making companies feel like they can trust um the process. So, so here we said "create a system of reliability" when we don't have solid numbers. We don't know what the artificial leaf would look in the factory but maybe we can create those moments where you and the company can brainstorm and productively and come up with these house ideas or whatever. So that's why we changed it to that. So, we're thinking "how can we make it easier for companies to join you with artificial leaf" does that make sense or...? (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 24–25)

##### 4.6.7.2 *Make it sexy!*

The concept previously established and described above is further detailed, refined and enriched by being layered with a potential auxiliary motive in the shape of a *digitalized model* to

enhance the attractiveness of the previous materialized concept; it is worth noting that it also introduces conflicting stimuli as far as the division of labor: participants understand that the ambition may surpass the current level of skills represented at this stage in the activity system:

S003: Maybe we can try to find a way to digitalize the model and to make some interaction, not simulation is too much, I mean I think that we are using very complex software and stuff like that, but we can try to summarize some numbers that you already get that you got from your experiments and use it combined to the 3D “sexy” model to present to them

P001: [inaudible] that’s what you want, right?

S003: Yes, we need to make the leaf sexy. And this is very hard work! (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 108–110)

#### ***4.6.8 Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Concept Formation***

Eighty-two (n=82) instances of ELA were identified over the S1 ↔ S2 field of application unit, and their distributions is illustrated in Figure 30:



**Figure 30**

*Distribution of Expansive Learning Actions Undertaken in S1 ↔ S2 Concept Formation*

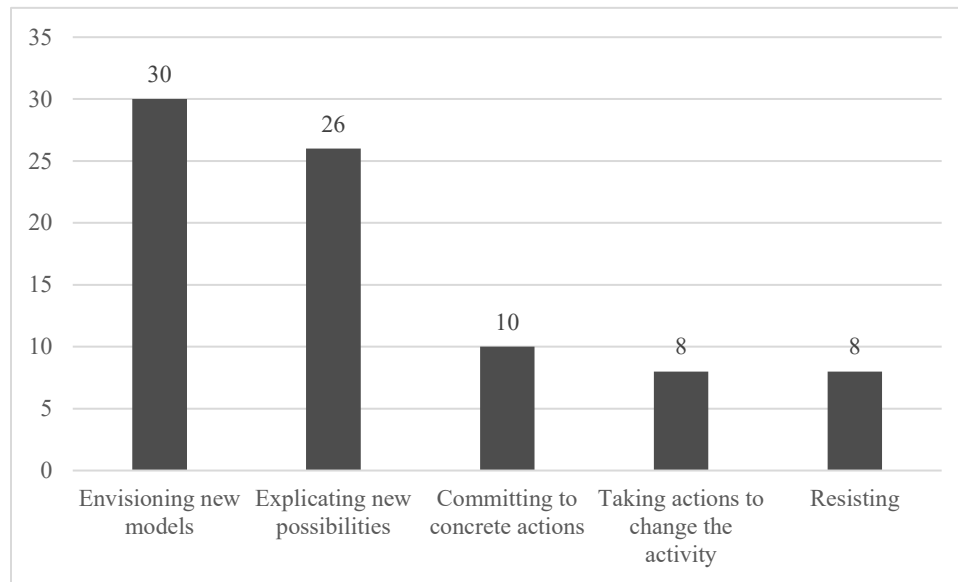


Figure 30 displays the total of ELA occurring over S1 ↔ S2 concept formation unit; the figure shows the prevalence of *envisioning new models* (n=30), *explicating new possibilities* (n=26), *committing to concrete actions* (n=10), *taking actions to change the activity* (n=8) and *resisting* (n=8).

#### **4.6.8.1 Ascending From the Abstract to the Concrete: Sacrifices and Gambits**

While discussing whether to include the newfound concept of *onboarding* and shifting the object of activity towards co-configuration, a *novelty* aspiration emerges in the group whereby participants are willing to trade on the moral and ethical dimension of development and optimize the decision process towards their preferred application. In this following excerpt, participants discuss the organization of a major milestone presentation to the researchers of the project, which catches them discussing and strategizing the way to favor their options to influence the final decision.

#### 4.6.8.1.1 *The Costs of Ascension: “Burning” Plastics*

P001: I think we should use this as a strategic move

P005: To burn the plastics...

F002: Never put, maybe you don't need to burn, plastic but just acknowledge that it is not really about the field but it's about the company, it's about uh onboarding companies and partners... so plastic could be an example. But... (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 120–122)

This next excerpt further details the same principle:

F002: So, like prepare the presentation the way you would like it to be. First of all... think, first of all, about what you want to discuss with them, what is important from IIT side. And then build the design vision according to it.

P001: And make it better than the rest so that we are forced to choose that one. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 117–118)

#### 4.6.8.1.2 *Criticizing the Researchers*

On a different level, participants get doubtful about the sincerity and integrity of researchers to share information, while doubting their skills and competencies to comply with certain parts of the process, tainted with ill will and suspicions of information hold back:

F002: So, you can make this question, I'm just not sure they are able to...

P001: They won't answer.

F002: They prepare the technology, they don't invest, or they don't really know what to do with it... the questions they were asked today were kind of predictable, and they were completely... what was it about the unit of measure... the measuring unit?

P005: Efficiency?

P002: Oh yeah, the kilowatt?

F002: But I mean if they behave like this there is a reason, of course, so...

P005: Yeah but it would have been like, I don't know, they always held back information in this way. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 43–51)

The previous observation holds for the following quote, whereby strategizing the presentation of results is seen as favoring one class of participants over another:

F002: Yeah, exactly but I... at least in that way you can ask them to prioritize something.

So, when you think about the design vision, you can just be a little bit selfish about what you need to be progressing with the project. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 9)

Eventually, a disconnect within the activity system is felt, as participants start to manifest a temporary disconnect with the object of activity, despite the object being finally as defined as it ever was:

P001: I really love that onboarding... thing, actually. Because I think that's their problem, really. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 61)

#### **4.7 S1 ↔ S2 Problem Solving Pathway at Macro Level: Create a Service and a Business Model**

This section presents our analysis of the macro S1 ↔ S2 pathway encompassing the analysis presented in sections 4.2 to 4.6. We chose to report results at the macro level according to levels of analysis presented in Table 4 according to the model of TADS exposed in Table 1.

The sequence may thus be described in Table 12 below:

**Table 12***Overview of  $S1 \leftrightarrow S2$  at Macro Level*

Channel	Conflict of stimuli	Conflict of motives	Auxiliary motive(s)	Real conflict of stimuli	Stimulus 2
Intervention	Intangible object	Reliability vs. developing technology	Cryptocurrency		Complex simulation
			Digitization		Visualization
			Investment		Funding
			Education		
			Public perception marketing		3D modeling online platform
			Home and community devices		
			Plastic sorting		
Wider life	Competency gap experienced in interviews		Onboarding Co-design	Giving up on the field of application and creating a generic model	

#### 4.7.1 *Conflict of Stimuli*

The core of the process at macro level described in this section may be described as a micro-cycle of object modelling, as described in section 3.2.4.1; one of the main objectives of the sequence is to align needs and object through the production of prototypes. These prototypes are supposed to be tested in interviews with experts, clients, or potential partners; in this sense, the prototypes are suggested to be used as stimuli to interactions in knots. However, an

aggravated tension appears around the difficulty to align prototypes and stakes of participants during interviews; we interpret the following excerpt as an illustration of the difficulty to prototype services around an intangible object:

P005: But I really struggle with the prototyping because it's so tough especially here to put something practical because we also do not have access to their prototype, they actually have a prototype. It would be even a success to test their prototype of the company, right? I mean at the end the company would like to see whether the prototype actually works outside of the lab, and we are thinking about additional... uh... prototypes that stimulate the experience the company would have used the prototype. But not really yeah this is... (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 107)

As a direct consequence of the choice of a challenging field of application over a safe one, the risk and tentative fear of encountering a fatal roadblock is also evoked:

F002: What they don't know is what it means to build a service which is usable and desirable so even if at the end of the story the service you build is not that usable in plastic they can kind of replicate it in another field. So, uh but I also fear like I also fear that maybe we discover that plastic is not doable I prefer to understand it like leaves you with this feeling, no? (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 121)

#### **4.7.2 *Conflicts of Motives***

The main conflict of motive occurring at the macro level relies on the impossibility to provide stable data during interviews with experts and potential partners. This situation impedes interactions in knots and provokes frustration and conflicts. The main double bind manifesting in the following excerpt materializes the need for reliability and tangibility on behalf of all participants involved in the central activity as well as in knots:

F002: You cannot have by definition have clear answers. Maybe the question is to like... the answer is to develop a trial strategy where you test the technology before you can develop it, so you can actually... you can actually find the answers together. So how can you create reliability without being able to actually provide specific answers. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 5)

#### 4.7.3 *Auxiliary Motives*

Participants frame the contradictions and double bind expressed above over multiple iterations and instances, as the contradiction manifests at various levels depending on the phases of the modeling process participants find themselves in. The main concept used as an auxiliary motive is the one of *onboarding*:

P003: Like, the onboarding phase is the first phase we need to face in order to not sell but develop the technology with the companies and the other steps are farther from us, so we discussed that probably the onboarding phase was the perfect phase to start with. So... yes. (2022-03-31 stimulated recall interview, Pos. 101)

It is noteworthy to observe the vivid impression left on participants and the contrasting state of the working session during which it emerged:

P001: We were frustrated and hu, and P006 was sick, and P005 was losing his shit and we kept taking turns talking to understand... to each other that there was like a huge breakdown in communication, I think, but we didn't get angry about it. We were trying to get through it and then the minute F002 drew this, everything just kind of calmed down. Because it contextualized what we were all saying but not hearing probably? And then when F002 drew that, P005 understood, I understood, P002 and P006 understood. And

then we started saying to F002 about how are we going to explain this whole process to P003 and P004? (2022-03-31 stimulated recall interview, Pos. 115)

#### ***4.7.3.1 Evolution of Emergence of Auxiliary Motives Over Time***

To complement previous observations, the evolution of emergence of auxiliary motives over time is further characterized by Figure 31 and Figure 32 below whereby tentative auxiliary motives increase in the first phase of prototyping and decrease over the following  $S1 \leftrightarrow S2$  thereby showing a gradual reduction of the problem space.

**Figure 31**

*Distribution of Auxiliary Motives at Macro Level of Analysis*

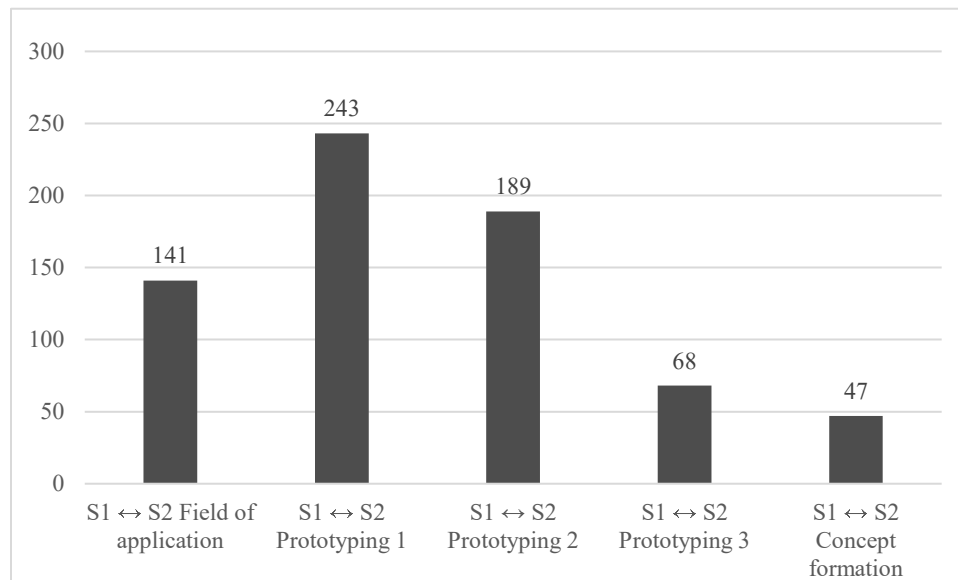


Figure 31 displays the distribution of auxiliary motives per  $S1 \leftrightarrow S2$  unit. The beginning of the sequence ( $S1 \leftrightarrow S2$  field of application,  $n=141$ ) is followed by a rapid increase in  $S1 \leftrightarrow S2$  prototyping 1 ( $n=243$ ) followed by a progressive decrease in  $S1 \leftrightarrow S2$  prototyping 2 ( $n=189$ ),  $S1 \leftrightarrow S2$  prototyping 3 ( $n=68$ ), and  $S1 \leftrightarrow S2$  concept formation ( $n=47$ ).

#### **4.7.4 Real Conflict of Stimuli**

The real conflict of stimuli occurring at the macro level of the sequence is triggered by information shared by an interlocutor during a knot interaction which invalidated the initial choice of the development of a service centered around plastics and plastic upcycling. Once this prospect was scientifically invalidated, it forced participants to salvage the parts of the work done already that could be applied to another field of application. Though stressful, it triggered the emergence of a generic model by extracting features potentially applicable to other fields.



This may be considered a major shift and leap forward in the process. The difficulty and unviability of plastics is reflected upon in the following excerpt:

F002: And at the end they decided to go for the plastic one which was the most fascinating, the most charming, I guess, but the most difficult so I remember we specified to them, many times that they should be aware of this choice, there were choosing the hardest and... It may be the only real concern was... about them not really be aware of what it means to go for a field of application, where you don't have any contacts and where you don't have any element, so they were kind of an underestimating the innovation process in that... in that part. (2022-07-04, facilitators interview, Pos. 12)

#### **4.7.5 *Stimulus 2***

The stimulus 2 described in this section comes from circumstantial events occurring in knots (further described in section 4.9.2.2) over a critical encounter experienced as a third-person event under the joint effect a visit to the showroom of a major company in the field of sustainable development and a critical encounter. Both events were identified by participants, as demonstrated in the following excerpt:

P006: I feel like there's two triggers for going for onboarding. First one was our first interview with C012, because over there, we saw that we were participating with the scientists and there were so many people from a company present as well. And during that interview like none of the students really talked because IIT was just explaining the technology and company was asking questions and just went back and forth, back, and forth, and after that, the day [inaudible] Where they're really interesting as a way of using this technology, one which we couldn't think of ourselves because we don't know the technology as far as IIT does. And so that really shows how valuable a good onboarding

process can be if you can co-design and collaborate together. And also, the second big trigger I feel like was our visit, when we were in Bologna or was it in Turin? To that one company that has a sort of a showroom that shows all the impact of the technology, and they have a lot of screens that show numbers on the carbon emissions and electricity use and all of that really engages someone to invest in the technology like that, so that also showed us like “Oh actually in order for people to use this technology, we need to really visualize how it works and what it is capable of.” So those two are the big triggers I think. (2022-07-05, students interview, Pos. 23)

The following quote brings further detail on the circumstances of the emergence of the stimulus 2 across the activity systems involved. The stimulus 2 emerges pushed by primary contradictions as well as bridging the gap and synthesizing various aggravated aspects by anchoring them into the materiality of the lived experience and the gap opened by a tertiary contradiction. The generalization and germ cell emerging in response are illustrated in the following quote:

P001: The last interview was a moment of clarity for us, but we’ve noticed patterns in all the interviews and that they always ask the same questions, very detailed questions, and that... and then but this was the first interview that IIT was there, decided you guys were in and talking with them, right? And we were there from the background, and we were noticing that maybe it’s not so helpful that we need to design something specific into a factory. Maybe what our role here is making companies feel like they can trust um the process. So, so here we said “create a system of reliability” when we don’t have solid numbers. We don’t know what the artificial leaf would look in the factory but maybe we can create those moments where you and the company can brainstorm and productively

and come up with these house ideas or whatever. So that's why we changed it to that. So, we're thinking "how can we make it easier for companies to join you with artificial leaf" does that make sense or...? (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 24–25)

The final iteration of the solution and the way it addresses the contradictions experienced by participants is expressed below:

P003:... I think that, in general, Colab it's like... a tangible way of... it's something tangible, but all the information is already there like it's the communications between companies and it already like are there, but we are just making everything tangible and we also try, we are also trying to in this way collect the data from companies and on the other end from IIT. (2022-07-05, students interview, Pos. 39)

The direct connection between contradictions and stimulus 2 is further confirmed below:

P004: So, in this way, we're kind of saying that what we created was like an answer to... The problems we experienced during the process. To make sense and then it's like a circle so. (2022-07-05, students interview, Pos. 48)

#### ***4.7.5.1 Emergence of Stimulus 2 at Macro Level of Analysis***

Conversely, the emergence of stimulus 2, identified in the data as relative to the mention from participants of *onboarding*, increases progressively over the sequence and signals clearly the emergence of a stimulus 2 over the S1 ↔ S2 concept formation unit, as illustrated in Figure 32:

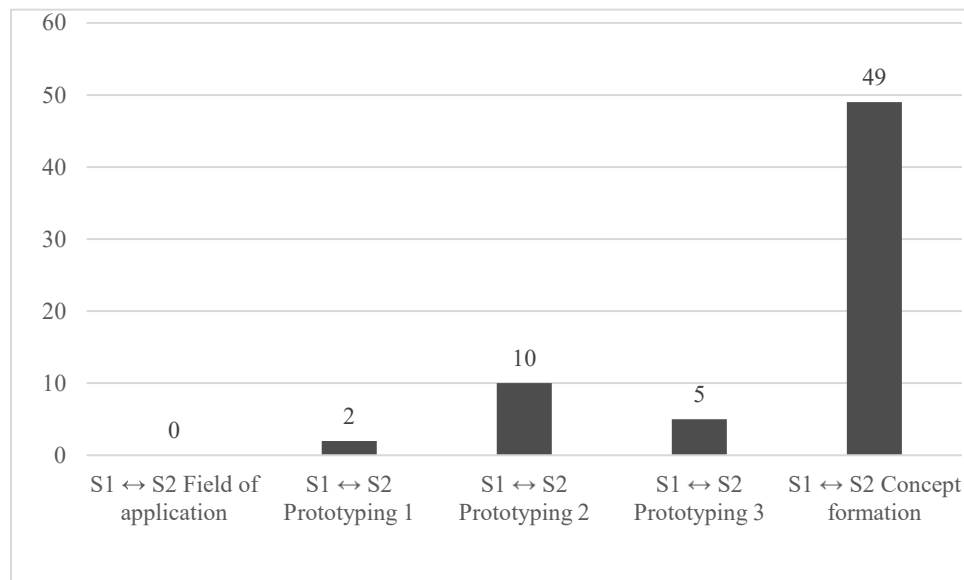
**Figure 32***Emergence of Stimulus 2 Over the Macro Level of Analysis*

Figure 32 above displays the distribution across each  $S1 \leftrightarrow S2$  unit; the graph shows no stimulus 2 over the  $S1 \leftrightarrow S2$  field of application ( $n=0$ ), with a small increase over prototype 1 ( $n=2$ ) and a steeper frequency over prototype 2 ( $n=10$ ).  $S1 \leftrightarrow S2$  Prototyping 3 shows 5 instances of stimulus 2 while  $S1 \leftrightarrow S2$  concept formation shows rapid increase due to the consensus on a shared object ( $n=49$ ).

#### **4.8 Evolution of Transformative Agency by Double Stimulation at Macro $S1 \leftrightarrow S2$ Level of Analysis**

The evolution of TADS is the outcome of intertwined transformative actions (Haapasaari et al., 2016). To account for this evolution and intertwining, this section seeks to frame  $S1 \leftrightarrow S2$  pathways under the perspective of DMC and ELA; we chose to apprehend those pathways with an initial characterization of  $S1$ , or problematic sequences, followed by the frequency distribution of codes for each sequence. The corpus of data presented comprises over 14 hours of

video recording for a total of close to 3100 speaking turns once transcribed. Because of the high level of ambiguity, the development of a service and a business model based on APT, our data allowed us to identify expressions of DMC (n=496). In this sense, close to one in six speaking turns on average contains a DMC. While this might be understood as being caused by disturbances in the instructional sequence, it might also point to the fact that participants display very high levels of agency, as stimulus 1 may be understood to aim at resolving the contradiction through resources, and therefore as starting points to  $S1 \leftrightarrow S2$  pathways. To understand better stimuli 1 occurring over the pathway leading to a shared object of activity, we present the distribution of DMC over the process, and their evolution over time.

#### ***4.8.1 Characterization of Discursive Manifestations of Contradictions***

In this section, we seek to illustrate the way DMC plays out in our data in  $S1 \leftrightarrow S2$  problem solving sequences at intermediate level. The distribution over the macro sequence may be illustrated in Figure 33 below:

**Figure 33**

*Distribution of Discursive Manifestations of Contradictions at Macro S1 ↔ S2 Level of Analysis*

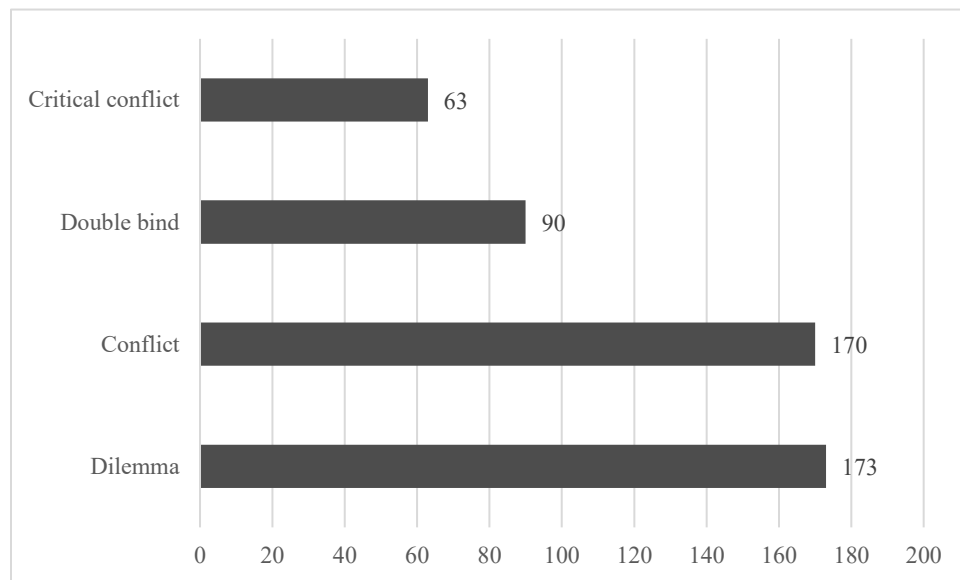


Figure 33 displays the total of DMC at macro level; the figure shows the prevalence of *dilemmas* (n=173), *conflicts* (n=170), *double binds* (n=90) and *critical conflicts* (n=63). In the following section, we attempt to describe the macro phase of S1 ↔ S2 analysis as interwoven and interlocked clashing values, ideas, goals, or motives. Excerpts presented in this section were selected in interviews lead with participants rather than during work session to favor depth and reflexivity. To provide relevant information regarding the analysis, we identified two dilemmas as overarching and specific to the case studied, i.e., *novelty* and *usefulness* which echoes the standard definition of creativity (Runco & Jaeger, 2012). The dilemma may manifest in different ways regarding the processes and may cause relative strain on the team to comply with opposing values:

P005: Also, the one object... object like being creative versus being effective, no? Yeah, I felt like sometimes we could have been way more effective, but we were forced to be

creative and that slowed everything down and confused everyone. Huh yeah. (2022-07-12, students interview, Pos. 10)

The difficulty to reach a balance between novelty and usefulness is also reported as a learning opportunity at collective level:

P001: I think it's very funny because the type of people that were in our team half of us being very creative and half of us, being very effective, me falling to the effective side versus being creative made it so that it was always a struggle between the two. I think SUGAR kind of contributed to that and it did contribute to that, but I think it was mostly us like at what cost do we give up some creativity or at what cost the week of active to me that was always like going on it. (2022-07-12, students interview, Pos. 13)

The efforts and tradeoffs to bridge both *novelty* and *usefulness* emerge as personal dilemmas involving competences and questioning the division of labor:

P002: So, I feel like I feel like we were trying to find the right balance between the two, and our project and effectiveness are really important, like creativeness for me comes much easier than effectiveness so, like, I always try to like circle back to that.  
(2022-07-08, students interview, Pos. 19)

The second set of dilemmas in this section are connected to *preserving* and *developing* as far as the actual sustainability of the outcome is concerned. The process at macro level is reflected upon as evolving from one end to the other of the continuum in the following excerpt:

P006: Oh yeah, yeah. It's kind of switched around at some point. In the beginning, at least for me, I was like "Ok, what can this technology do for... to combat climate change?" I was really looking into the ecological aspects, but later it shifted more into, as you know, how can companies use this technology? So, the climate benefits became more

of a secondary thing, and it was more about finding an outlet for the technology and how can we get to this point, so... that's switched around a little bit during the process but also if we find an outlet that is going to make a difference, so I still feel like these two parts are connected in a way.

P004: Yes, I agree, I agree with P006 and also like how the challenge was proposed to us, it was to find a business opportunity. So that's the key that I think... Maybe we're very excited at the beginning for the technology and we couldn't really understand it, so we had to go through this process of research in order to understand it. And maybe we got a bit lost in the making of the different parts so... actually find a way to really implement it, but we could not really realize, as a team, I guess, the idea was to not "sell" but... was to... Yes... make the technology available to the market so that's where we may be... We may have gotten lost, but it was a very useful process getting lost so. At the end, it was, yeah, fine.

P003: Yeah I totally agree with this... With the situation that we experienced because it was at the beginning, quite challenging and I also like... personally at some point, I thought that we, we were really making a difference in a way I was, I was like dreaming that in June, like for the final presentation, we really could like present something innovative, but it was... it was, but not in, not in the way that I thought in the beginning. (2022-07-05, students interview, Pos. 10–12)

The same feedback is further developed by a different group of interviewees below:

P002: Yeah, um... I mean so like the whole team, we actually are really aligned on this, we wanted to make sure that the technology would be used in a way that wasn't like any sort of greenwashing and that would really be like, used in the most sustainable way but,



IIT kind of was more like we just want our technology to be bought and we want it to get moving and developed so that's where like the team versus IIT had differences and how we wanted the technology to end up.

R001: Do you feel you managed to bridge that gap between the student team, on the one hand, and IIT on the other?

P002: Ah, I wouldn't... I wouldn't say so, I mean... it wasn't like we weren't... yeah, I mean I wouldn't say so, because we really just focused on like on what IIT needed which was like getting their projects onboarded but like now that we have, you know, created that application for them the software um they're going to do with it what they want, and I don't think ...' I don't think that we really changed their mindset too much, honestly.

(2022-07-08, students interview, Pos. 27–29)

Leaning on *developing* brings a different sort of dilemma regarding competences and the division of labor involved in the process of promoting a utilitarian motive that may have run contrary to the initial aspiration of the participants:

P003: For me at least, it was very hard. Because even though we did it, we were not asked to know everything about the technology, because we are not—apart from P005-like technical people so, we were not asked to know everything but we... at the same time, we, we have to, we had to because, while dealing with the companies and facing that they were asking like technical questions all the time and we were there, like having basically no answers... we experienced like what also innovation processes and people in the field experiences. So, it was very hard, because we at least again, personally, I was trying to really understand the technology, because I couldn't like communicate with the

people that we were interviewing. So yeah it was challenging... (2022-07-05, students interview, Pos. 14)

A major conflict involving competences and division of labors in knots is reflected upon in the previous section as far as the collective subject is concerned, and a subsequent competency gap emerges as the dilemma of assuming different roles (students or professional knowledge transfer officer in charge of APT) is reflected upon in the following excerpt:

P006: Yeah, so it was definitely hard switching from the student role to a sales representative role because, like P003 said, we weren't fully understanding, all of the aspects of the technology. But I do feel like if you send an email to a company and you mentioned that you are a student, they are a lot more willing to participate and to be a little bit milder if you don't have all the answers, so I do... you... think have our being a sales representative, but also being a student at the same time can really help companies, open up because they don't feel like... All the information they're giving away is immediately going to some company that's going to exploit it, but more to students that are curious, and they are doing research, so I do feel like it is an interesting role to have as a student, but also as a sales representative yeah it's hard at times that you don't have all the answers for them, and sometimes yes, that was very... sorry? (2022-07-05, students interview, Pos. 16)

The conflicts depicted above, however, may also be interpreted as bringing learning opportunities that may reinforce the *exchange value* of the experience, as illustrated in the following excerpt:

P004: Ok no, my point is more about, you don't know what happens to you when you are in a working situation. So, in the moment you... your... we experienced this stressful

situation, and we could not really be effective, it taught us, maybe how to get... like... [inaudible] in the situation. I'm just saying that that could be a situation that could come again in the future, and then we're going to be more ready, since we already experienced the thing, but it's just a personal experience like for me, I think it helped me in this way, but it's not something that's very concrete, you know? It's just some learning I can take out of it, but still, the difference between student and sale representative was hard to manage. (2022-07-05, students interview, Pos. 21)

Creative solving of real-world problems may be described as occurring in knowledge-rich contexts (Yang et al., 2022), i.e., requiring the reorganization of prior knowledge acquired and retained at different stages of one's experience, and retained over variable lengths of time. One critical conflict that emerged at macro level was the lack of fluidity in outcomes, rules, and division of labor, which we identify as an aggravated conflict as far as the exchange of information is concerned with potential to become a critical conflict as it questions the whole activity system:

P005: One thing I don't agree with the... with our coaches and scientists, how they manage this is how they... as I sometimes felt like they were keeping back information, and are still keeping back information, and I think. I hope they will prove me wrong, but I sometimes feel that this could backfire and not the smartest approach. I would have found it better to share information directly with us and. But like yeah. (2022-02-24 interview, Pos. 7)

The predominant double bind emerging in the modeling of a new object of activity stemmed from the difficulty to interact satisfactorily in knots with potentially more

knowledgeable others; the ways in which the stimulus 2 addresses those issues may be illustrated thus:

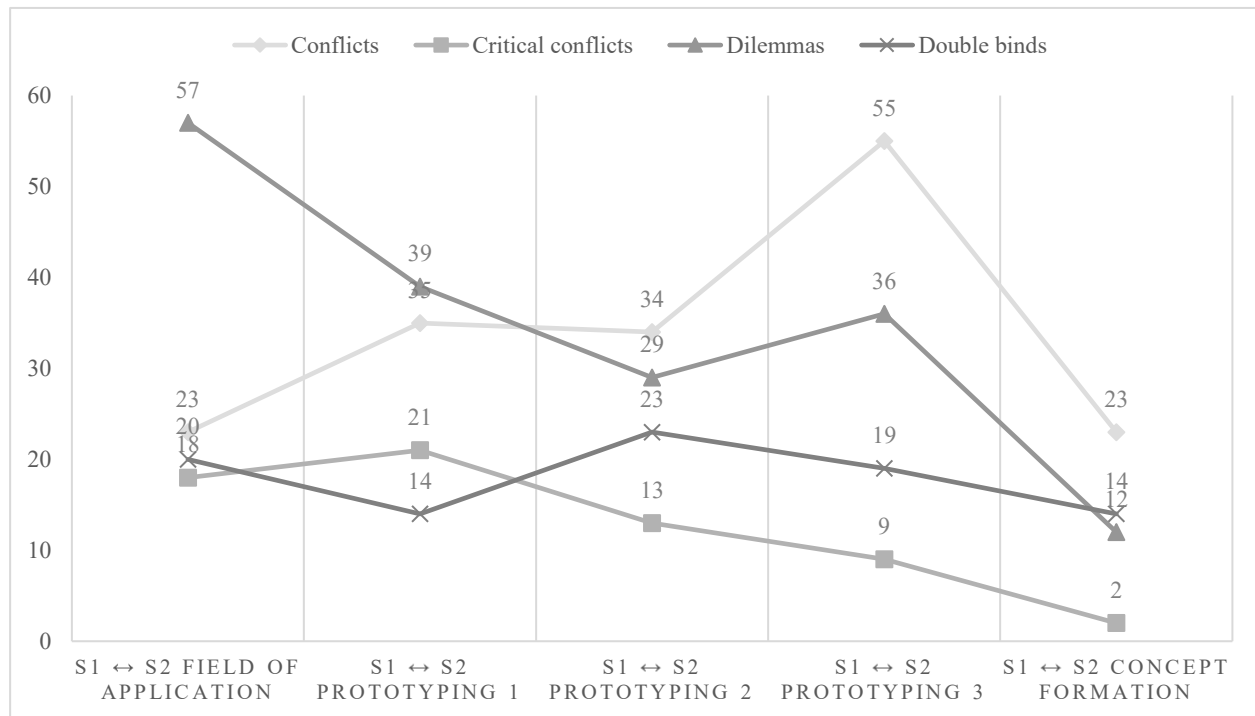
P001: Um yeah so. The features are like we were seeing... so there were some numbers at the beginning. There were some like elements to our research, that are theoretical and that we got from interviewing companies about their innovation process. So, we got knowledge from them, but I would also argue, we were witnessing in real time, the problem with onboarding slash innovation processes with C012. And C012 didn't work out and actually ended weirdly. And we saw that in real time they could not... that there was communication at many points that even both spoke Italian, but there was still a miscommunication because C012 or the client could not imagine and so... from witnessing it in real time and we decided, with these features which were some things worked out well, like the survey was inspired because C012 and asked us to answer a few questions about the technology and we were like oh great let's take that on and kind of flip it so that there's no miscommunication about the limitations, when the client from the get-go, you know from the first step. (2022-07-12, students interview, Pos. 95)

#### ***4.8.2 Evolution of Discursive Manifestations of Contradictions at Macro S1 ↔ S2 Level of Analysis***

The evolution of DMC over the macro level of analysis involving the main S1 ↔ S2 problem-solving unit at activity level may be illustrated in Figure 34 below:

**Figure 34**

*Evolution of Discursive Manifestations of Contradictions at Macro S1 ↔ S2 Level of Analysis*



The manifestations of *dilemmas* decrease from S1 ↔ S2 field of application (n=57) to S1 ↔ S2 concept formation (n=12), which we interpret as relative to both the global refining over time of a potentially shared object of activity and improving interactions and teamwork gaining fluidity and focus over time. The number of *critical conflicts* occurring subsequently decreases dramatically from S1 ↔ S2 field of application (n=18) to S1 ↔ S2 concept formation (n=2). This may be interpreted as relative to the emergence of a stimulus 2 shaped by the concept of *onboarding*. *Double binds* are also subject to the same dynamic over the sequence, albeit on a smaller scale, at the macro level of analysis (from S1 ↔ S2 field of application [n=18] to S1 ↔ S2 concept formation [n=12]), as the perceived specificity and complexity of the object are opposed to other groups; This perceived discrepancy may be gradually toned down from the constraining of the problem area, bringing focus and satisfaction caused by the gradual

emergence of a shared object of activity. *Conflicts* follow an inverted evolution ( $S1 \leftrightarrow S2$  field of application [ $n=23$ ], reaching a peak over  $S1 \leftrightarrow S2$  prototyping 3 [ $n=55$ ]) due to the late switch of the field of application resulting from an interaction in a knot in  $S1 \leftrightarrow S2$  prototyping 3 (further detailed in section 4.5).

However,  $S1 \leftrightarrow S2$  prototyping 3 displays an increase in manifestations of *dilemmas* ( $n=36$ ) and *conflicts* ( $n=55$ ) which may be the result of the sudden realization of the unviability of the field of application and its subsequent giving up of plastics, which forces participants to reconsider gradually a new field of application, closer to the deadline. The following excerpt displays both instances of a dilemma (keeping or giving up plastics) and critical conflicts (sarcastically rejoicing at the prospect of having to start over):

P001: Um and it got me thinking whether we need to move away from that.

F003: Plastics or from...

P001: Not plastics, not plastics in like the bigger picture, but maybe from ethylene yes, I don't know what other people think, but that's the main thing I got from this interview.

P002: I mean, so we did send the scientist his report, so I think it would be his paper. I think it'd be interesting to see if they have a different view. But I think if they also like to read the paper and they're like "yeah it's not feasible," then maybe even rethinking plastic.

P001: I think it's very, very possible that we might have to rethink plastic.

F003: Great. (2022-03-04, SGM [ $S1 \leftrightarrow S2$  prototyping 3], Pos. 106–111)

The sequence above may be characterized by a gradually shrinking problem area over the first three phases prior to a sudden widening in  $S1 \leftrightarrow S2$  prototyping 3 which caused a disruption in the ongoing process of modeling of a shared object. This disruption produces a sudden rise in

(a) conflicts and (b) dilemmas. The last unit ( $S1 \leftrightarrow S2$  onboarding) is, on the other hand, characterized by the emergence of a stimulus 2 which may explain the global shape of decreasing manifestations of contradictions at macro level. Notwithstanding major disruptions exposed in section 4.9.2 below, the wider and deeper the problem space, the greater the number of contradictions as a sign of uncertainty and ambiguity. Once an object is identified, the number of occurrences of manifestations of contradictions diminishes. Furthermore, the interactions experienced in knots are refined over time, as participants in knots are more skillfully selected to match the needs of participants, who in turn switch expectations and expand their interviewing techniques, a point developed further in section 4.9.

#### ***4.8.3 Characterization of Expansive Learning Actions at Macro $S1 \leftrightarrow S2$ Level of Analysis***

The dominating ELA over the  $S1 \leftrightarrow S2$  pathway at the macro level are *explicating new possibilities* and *resisting*. We interpret this tendency as related to the various cycles of iterations and elaboration which characterize  $S1 \leftrightarrow S2$  prototyping 1 to 3 to model a shared object of activity. The corresponding learning actions are related to elaborating and combining potential solutions and the corresponding interacting and challenging assumptions and tentative auxiliary motives over the process. The corresponding learning actions characterizing the sequence may be illustrated in Figure 35:

**Figure 35**

*Distribution of Expansive Learning Actions at Macro S1 ↔ S2 Level of Analysis*

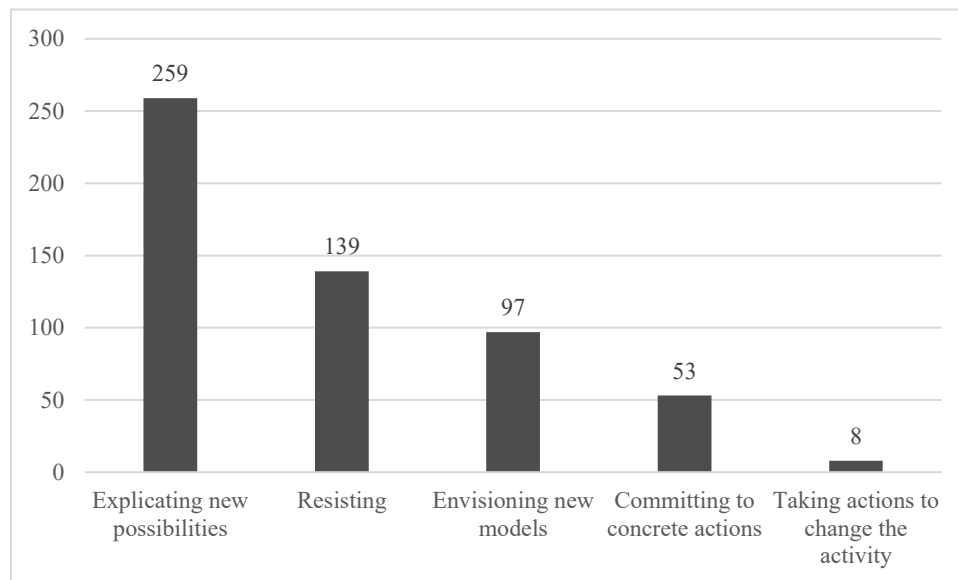


Figure 35 displays the distribution of ELA at the macro level of analysis which shows the prevalence of *explicating new possibilities* (n=259), *resisting* (n=139), *envisioning new models* (n=97), *committing to concrete actions* (n=53), and *taking actions to change the activity* (n=8).

The activity was framed under a creative pitch by choosing an ambitious field of application over a safe one: as a result, participants address a wide problem space and as a result engage in polylogs about features, functionalities, or properties. In this elaboration process, participants *resist* or criticize them; as result, suggesting new possibilities, arguing in favor or against such may lead to a progressive refinement of ideas and solutions. For example, the interplay of *explicating new possibilities* and *resisting* may be illustrated below in the following excerpt where the second speaking turn from P006 displays a new perspective on by-products of the production of plastics through APT while challenging the status quo of established by-products identified by initial specifications of APT; furthermore, the participant further call onto a knot,



representing a professional company, to confirm, i.e., “gain insight,” a point further detailed in section 4.9:

P006: For a thing like polyurethane, you need a lot more different chemicals to synthesize this plastic.

S002: Ok.

P006: It’s just a smaller building block but it’s still very interesting to look into because carbon monoxide has a huge efficiency, right? That’s why it’s more interesting to have another conversation with C015, because they were talking about using carbon monoxide to produce plastics, so it might be interesting to get some more insights from them.

(2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 121–123)

#### **4.8.4 Evolution of Expansive Learning Actions at Macro S1 ↔ S2 Level of Analysis**

Another important aspect relating to the evolution of ELA over time lies in the fact that these learning actions relate to the modeling of a shared object i.e., to a micro-cycle of the expansive development cycle. *Committing to actions* and *taking actions to change the activity* remain little represented as they theoretically would occur in subsequent sections of a typical expansive cycle. The evolution of learning actions over time is presented in Figure 36 below:

**Figure 36**

*Evolution of Expansive Learning Actions at Macro Level of Analysis*

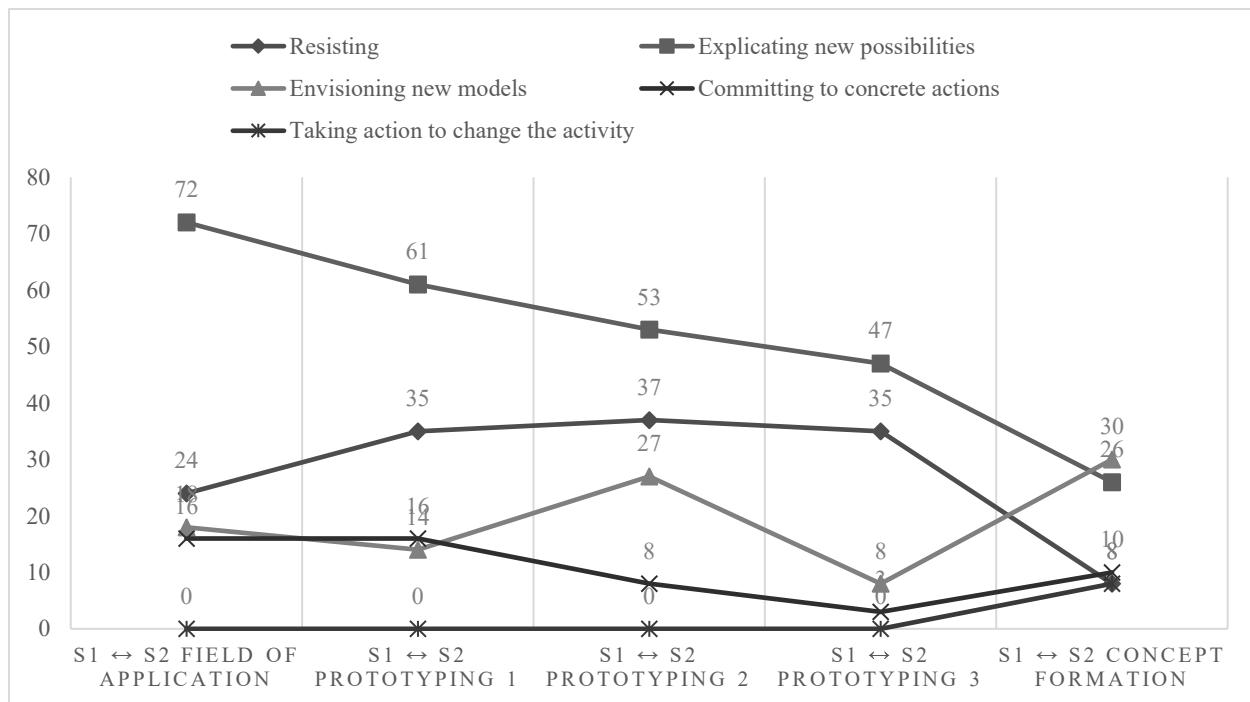


Figure 36 displays a global decrease in ELA, the most prominent being in *explicating new possibilities* from S1 ↔ S2 field of application (n=72) to S1 ↔ S2 concept formation (n=26); two ELA, on the other hand, show an inverted dynamic: *envisioning new models* (from S1 ↔ S2 field of application [n=18] to S1 ↔ S2 concept formation [n=26]) and *taking action to change the activity* (from S1 ↔ S2 field of application [n=0] to S1 ↔ S2 concept formation [n=8]).

As mentioned above, *explicating new possibilities* and *resisting* are numerically the most frequent ELA in the data, the most prominent being *explicating new possibilities* from S1 ↔ S2 field of application (n=72) to S1 ↔ S2 concept formation (n=26). *Resisting* appears as a defining feature of the sequence from S1 ↔ S2 field of application (n=24) to S1 ↔ S2 concept formation (n=10). This may be explained by the prevalence of diverging prototyping activity over a process

dedicated to the modeling of a shared object. Both frequencies of learning actions decrease in our data set beyond S1 ↔ S2 prototyping 3 phase due to the emergence of the concept of onboarding leading to the emergence of a stimulus 2.

*Envisioning new models*, (from S1 ↔ S2 field of application [n=18] to S1 ↔ S2 concept formation [n=26]) may seem like a poorly represented learning action in the context of an object modeling development cycle as it oscillates over the three first S1 ↔ S2 phases. It is interesting to note that as soon as a tentative concept is identified, polylogs become generative in the sense that they trigger new models prior to the emergence of an S2.

*Committing to concrete actions* decreases slightly over the macro sequence, from S1 ↔ S2 field of application (n=18) to S1 ↔ S2 concept formation (n=10) whereas *taking actions to change the activity* raises over the two last pathways S1 ↔ S2 prototyping 3 (n=0) and S1 ↔ S2 concept formation to S1 ↔ S2 concept formation (n=8), due to the emergence of a shared object.

#### **4.8.5 Association of Discursive Manifestations of Contradictions and Expansive Learning Actions**

Figure 37 displays the association of DMC and ELA over the macro cycle of analysis:

**Figure 37**

*Association of Discursive Manifestations of Contradictions and Expansive Learning Actions*

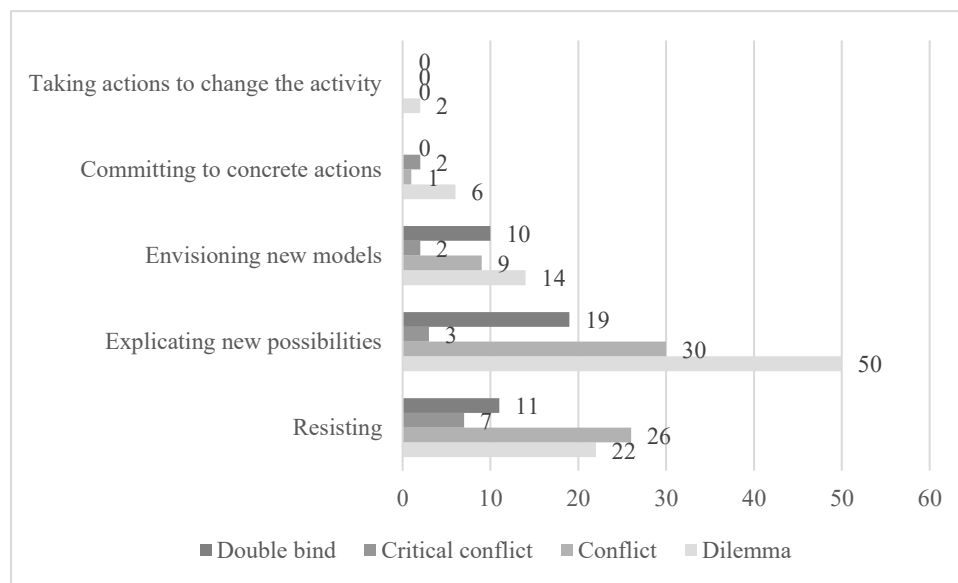


Figure 37 allows us to identify four pairs of DMC and ELA in a micro-cycle of development which we consider characterizing the progressive emergence of agency on behalf of participants. It stresses the prevalence of *dilemmas* in relation to *resisting* (n=22), and of *conflicts* in relation to *resisting* (n=26); similarly, the same tendency may be observed regarding *explicating new possibilities* with *conflicts* (n=30) and *dilemmas* (n=50). We refine further the association of DMC and ELA as dynamic pairs characterizing the emergence of agency in the following section.

#### 4.8.5.1 *Clusters of Codes at Macro Level*

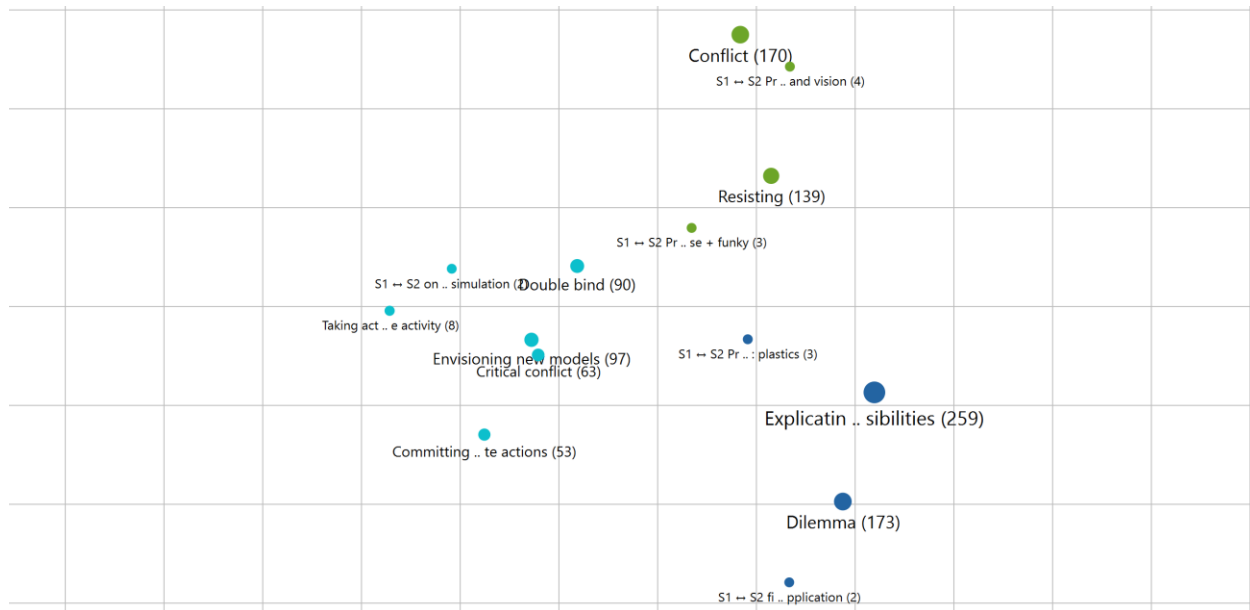
A code map was produced in the MAXQDA Analytics Pro 2022 software and allowed us to identify three *clusters* of code<sup>12</sup> which may be illustrated in Figure 38 below and in the following figure:

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<sup>12</sup> Clusters were calculated using the multidimensional scaling method: a similarity matrix was calculated according to code relations and subsequently converted to a distance matrix in three steps : (a) the column sums was calculated to determine the frequency of co-occurrence of codes, (b) the maximum of these column sums was determined and (c) the similarity of two codes is subtracted from this maximum.

**Figure 38**

*Map and Clusters of Codes at Macro Level of Analysis*



This method of analysis allowed to detail further the results exposed in section 4.3.4 by suggesting sequences of the most often co-emerging DMC and ELA over time by suggesting matches of  $S1 \leftrightarrow S2$  units, DMC, and ELA.

#### 4.8.5.1.1 Cluster 1: $S1 \leftrightarrow S2$ Field of Application, $S1 \leftrightarrow S2$ Prototyping 1, Dilemma, Explicating New Possibilities

In this section we intend to illustrate one instance of the association of *dilemma* and *explicating new possibilities* as representative of cluster 1 in  $S1 \leftrightarrow S2$  field of application. The dilemma between *novelty* and *usefulness* experienced by participants over the choice of a field of application may be further detailed through the following example as it triggers further sub dilemmas among participants; a topic of particular importance in this section is the setting of learning ambitions as a further necessity to produce prototypes that are aligned with this

ambition; in this sense new possibilities emerging from interactions in the activity may be directly related to the will of participants to set their own ambitions:

F002: Most of the time it happens, like this, but it also depends a lot on you, what do you want? What do you want to learn as well? You want to learn like how to create a real business case with a real business model or if you want to like try to be more creative... (2022-01-19, SGM [S1 ↔ S2 field of application], Pos. 80)

The adjustment of *novelty* to *usefulness* is a gradual process progressively refined over time, as the approach used during interviews expands to match the needs of participants and encourages them to inquire for the right information to keep propelling the process. The initial dilemma therefore has repercussions that require their expansion through *explicating new possibilities*, as illustrated below:

S001: Yeah in this... in the second example it was very completely different approach and yes it is showing let's say that indeed let's say you're um let me say your, uh, approach to interview has been more, uh, yeah it's different and I see that as exactly what I was, uh, asking to try to figure out so exactly this I feel that this is a good way to approach the company to... we have not to sell anything but to convince because we are really convinced that not because we just want to joke but is someone that we are developing something that is interesting for the company at least that but not only also maybe for some politicians we have to say ok, the new concept of today is that the waste has a value you have not only to pay for the waste management you can have a kind of value the value can be first and this should be I guess the first preference but is not this is not the case as human beings we should say ok this is the value is that I, uh, address at least a bit of the climate change issue but for the company this is not working because

they have to get money from their productivity. (2022-02-04 liaison meeting [S1 ↔ S2 prototyping 1], Pos. 79)

#### 4.8.5.1.2 Cluster 2: *S1 ↔ S2 Prototyping 2, S1 ↔ S2 Prototyping 3, Conflicts, Resisting*

The two sequences involved in the second cluster identified in this section are related to sequences dedicated to specific prototyping phases. In the *S1 ↔ S2 prototyping 2* phase, participants are expected to generate extra features through divergent exercises, and to subsequently match those features by combining them in relevant groupings applicable to a predetermined object. During *S1 ↔ S2 prototyping 3* phase participants are encouraged to generalize these feature ensembles into principles—rules—to be respected and demonstrated in the final solution considered. The main DMC and ELA identified at this stage are *conflicts* and *resisting*. We identified three instances of combination of *conflicts* and *resisting* through these iterations phases which we report below. Each of these instances is heavily impaired by the double bind of the intangibility of APT, as illustrated in section 4.9.2.1.1.

One instance of the conjugation of *conflict* and *resisting* emerges from the reaction to a prototype suggested by participants, which we believe to characterize the polylogs surrounding the various iteration cycles; in this case, the conflict arises as the preservation of time dedicated to the production of prototypes to be used as conversation triggers during interviews which emerges in conjunction to resisting perfectionism related to the completion of satisfactorily advanced artifacts; again, the maximization of outcome is evoked under a creative perspective:

F002: Ok, it's a lot for a prototype. Yeah, I mean, I see that you really take care of the graphics. In that stage, you're... you're kind of at the mood-finding stage now. You have identified your sector so you're now... here we go again through the whole process but faster, because you have a specific sector, finally... so like this kind of prototype you can



really do them... throw them in a piece of paper and pasting them. I mean, I say that for you done. Because, in that way you can save time and it's maybe you're more, like, stimulated to be creative by drawing or doing this kind of stuff. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 108)

While ideating, and particularly when exercises and activities are expected to draw on divergent exercises, discrepancies regarding relevant information may be expressed by participants: in this case, they try to frame a tentative artifact with respect to the perceived size of a tentative industrial recipient of APT. *Resisting* manifests as the discrepancy of information perceived during an interview is evoked while manifesting a conflict expressed as the potential impossibility to come up with a realistic solution:

F005: Yeah and one thing just to... other aspects, first of all, as far as I have understood the last time when we speak, I asked a lot of things. My impression is that this technology is just feasible because of the constraint, because it can operate only in a specific range of temperature and so on only in huge plants. I don't think that is feasible for a small uh I mean in yes not all usages not only for plastic. (2022-02-17, SGM [S1 ↔ S2 prototyping 2], Pos. 124)

The conflict expressed in the previous excerpt is further developed and reinforced in this following one where a *vision* gets endorsed while *resisting* to previously expressed disagreement during an interview; although the following excerpt may be characterized as an instance of *resisting*, it also displays a *conflict* between personal point of view and adhesion within a knot, i.e., winning over a potential partner in an interview:

F002: But wait a second, sorry, I also wanted to give feedback on the one of P002 uh it's more um... of the kind I was uh talking about before. But she did uh something else that

could be a strategy or could be what could be a downside you will choose. She focused a lot on the interconnectivity and the ecosystem part of the leaf, ok? It's not wrong at all it just means you have just to be aware that you are stressing a lot this specific aspect of the leaf. Which is not bad because you take position, like you state something specific but then you have to make to be aware that your solution uh will have to contain these ingredients, ok? Not only will have to contain this ingredient, but you are also setting a priority even in design principles. So, you are here you're saying that artificial leaf is the thing which actually activates the sustainable ecosystem through the capture uh carbon dioxide capture with the vision you really make a statement about what you want to do, and it's ok I mean I always told you that I like the ecosystem idea. Uh but that's a person it doesn't mean it's right it's my personal point of view so, you have to be aware that this design vision is very uh like directed in this direction which is good because uh it's not too vague because sometimes design vision can be very vague, "Uh, going to happen beautiful things in the future [thanks to this] idea we have but what exactly we don't really know" but it's going to be cool so it's very specific I can really picture this thing in my mind "but" it's um and it's not about and it's uh just be aware of it. ok. (2022-02-24, SGM [S1 ↔ S2 prototyping 3], Pos. 78)

#### 4.8.5.1.3 Cluster 3: S1 ↔ S2 Onboarding, Double Bind, Critical Conflicts, Envisioning New Models, Committing to Concrete Actions, Taking Actions to Transform the Activity

The last S1 ↔ S2 sequence is dedicated to the refinement of the concept of *onboarding*, used as an auxiliary motive to the emergence of the stimulus 2 of *Colab*, an integrated platform dedicated to facilitating co-configuration among potential partners. A point further developed in section 4.9.2, disruptive perturbations may emerge from interviews in knots, and the

impossibility to produce realistic simulations due to lack of reliable data is evoked, thus reinforcing the double bind:

S002: It makes it fit in. It makes visible big values. If you allow us to... refer to the paper sent from the guy from C012, and ask him, it's not about the consumption, it was 200 megawatts, was it from the old day, actually get in touch, ok I have a new tool I can show you on. On the contrary, honestly, I don't know if these numbers can... since the numbers are really bad obviously... (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 94)

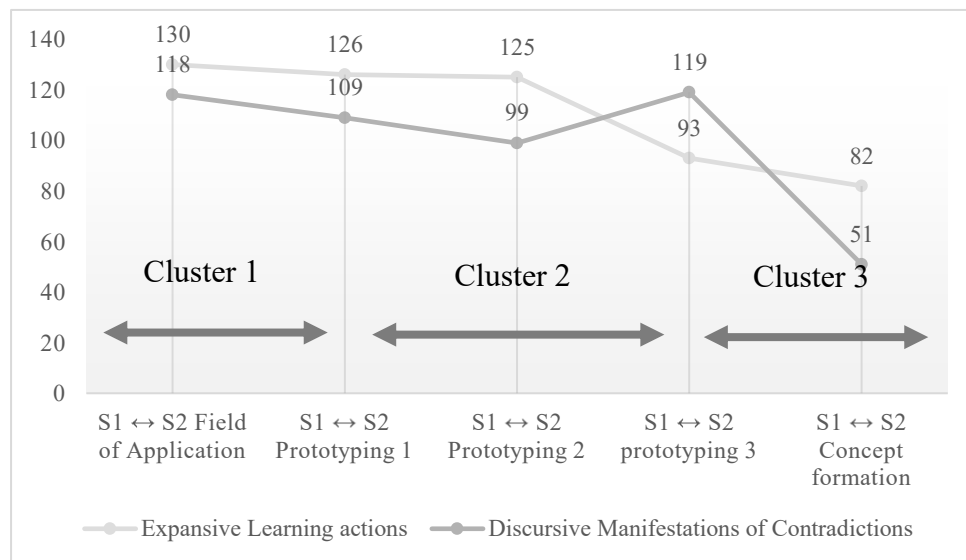
While the overarching double bind of intangibility of a developing technology is directly addressed through the emergence of the concept of onboarding and its subsequent integration to an all-in-one online application, new models appear under the effect of both, in this case as the modeling of interactive digital artifacts designed to improve the onboarding process:

P001: Uh that could be more technical.

F002: Yeah then I mean here you could go to a UX company and ask them to do it like, how to onboard companies, how to create an iterative uh... process to improve the technology, see something. I don't know if they could be translated in visual like to create an iterative process to improve it with the client uh... to onboard the client, this is the... what do you need? What you can do for them? What do you need to know for them? Also, there is the whole point about viability which I didn't represent... (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 63–64)

#### 4.8.5.1.4 *Summary*

Figure 39 below represents the sum of ELA and DMC in three clusters over time playing over the  $S1 \leftrightarrow S2$  unit at macro level. We further discuss the implications of this sequence in section 5.2.4.

**Figure 39***Evolution of ELA and DMC at Macro Level*

A similar tendency is observed in Figure 39 as in sections 4.8.2 and 4.8.3: DMC decrease from cluster 1 ( $n=118$ ) to cluster 2 ( $n=109$ ) and ELA decrease slightly from cluster 1 ( $n=130$ ) to cluster 2 ( $n=126$ ). Cluster 2 shows a more pronounced decrease in ELA ( $n=93$ ) and an increase in DMC ( $n=119$ ). Finally, cluster 3 shows a faster decrease in both DMC ( $n=51$ ) and a slower decrease of ELA ( $n=82$ ). We interpret the shift from cluster 2 to cluster 3 as a consequence of critical encounters described in sections 4.9.2 triggering the emergence of a stimulus 2 described in section 4.7.5.

#### 4.9 Knotworking in Hybrid Educational Activities

One of the most prominent features of hybrid educational activities in the case studied in this research is the prevalence of *knots*—or temporary coalitions—in activity. In this instance, knots occur over interviews conducted on a regular basis with experts from various domains in the field of energy and carbon capture in industry. These interviews are conducted

collaboratively by students to try and maintain alignment of both problem identification and tentative solutions envisioned (Kopenhagen et al., 2021). These coalitions may further be conceptualized as serendipitous encounters orchestrated by both facilitators and students and their respective research and pre-existing networks. These encounters through interviews may result in temporary forms of collaborations with a potential to result in *critical encounters* (Engeström et al., 1995). Although these coalitions or knotworking opportunities may only be loosely connected, they allow heterogeneous partners to engage in solving problems or co-configuring solutions according to the current state of the object or to influence this object and expand it altogether. Interchanging and trading resources and potential contacts allows for the emergence of new instruments, and potentially new cultural tools. Knotworking in interviews also provides learning opportunities, albeit temporary ones. Although these interviews are beyond the scope of the data collected in this research (as detailed in section 3.2.3), thirty-six (36) potential stakeholders appear in the data, which translated to an estimated forty interviews in total.

#### ***4.9.1 Evolution of Knots in a Hybrid Educational Activity Over Time***

The following section presents an analysis of the role of interviews as the main locus of interaction and knotworking. Engeström (2015) contends that control of action means control of interaction between people; as a result, the objects to be worked on by a collective are “molded into artifacts by means of instruments” (p. 44). Yet, Engeström adds a twist to the classic Vygotskian tradition of tool mediation by framing *activity* based on *material production* mediated by technical tools, psychological tools *as well as by other human beings* (p. 59). The following analysis relies on this premise, and as such stresses the importance of interactions in knots as the main tools of problem solving in hybrid educational activity. In this respect, the

purpose of the following section is to trace the emergence and modeling of a shared object of activity; we contend that by focusing on interactions occurring at the community level allows us to identify and describe all necessary features later materializing in the modeling of a shared object. Although initially, the main process of expertise is threefold: extract expertise and investigate tacit knowledge from gatekeepers and experts in a given field of application, identify opportunities for potential partnerships and finally gain insight from implicit or explicit realization through artifact- or concept-mediated interactions. The details of such interactions evolve over time, and Figure 40 below offers an overview of the evolution of knots over the process at macro level:

**Figure 40**

*Distribution of Knots According to S1 ↔ S2 Units*

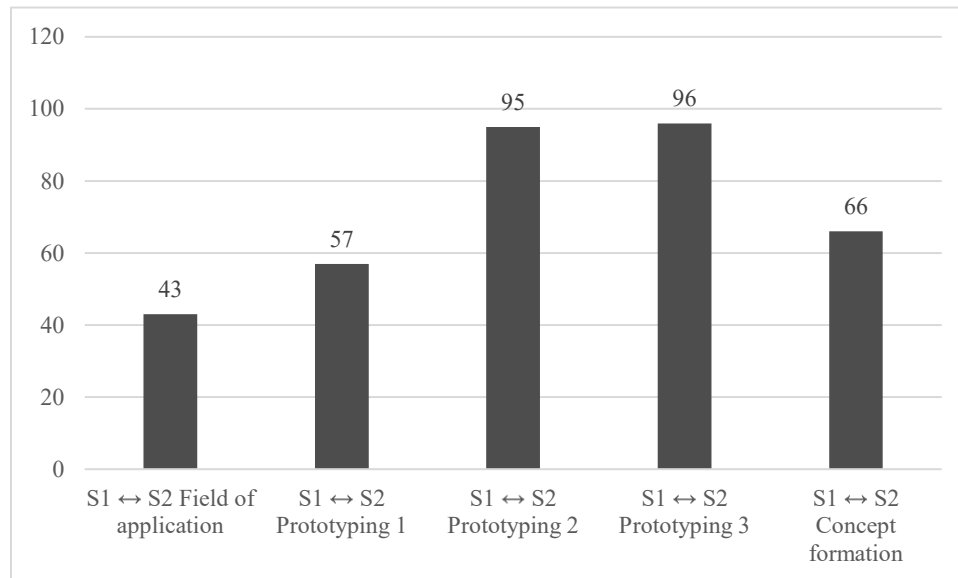


Figure 40 displays an increase in the frequency of mentions of companies or clients from interactions in knots from S1 ↔ S2 field of application (n=43), S1 ↔ S2 prototyping 1 (n=57), S1 ↔ S2 prototyping 2 (n=95), S1 ↔ S2 prototyping 3 (n=96) before a decrease in S1 ↔ S2 concept formation (n=66). However, this does not equate with absolute number of interviews. Instead, it shows the growing interest and the increasing conversation and polylog generated according to each stage of the process. In this respect, it is a better representation of the influence and importance of knots in the process, which further requires characterizing the role and function of interactions in knots. Contrasting with section 4.8.1, which showed *dilemmas* and *conflicts* were the two most common sources of DMC over the data, Figure 41 shows that the DMC associated with knots dealt with *dilemmas* and *double binds*:



**Figure 41**

*Co-Occurrence of Discursive Manifestations of Contradictions Associated to Knots Occurring in the Activity*

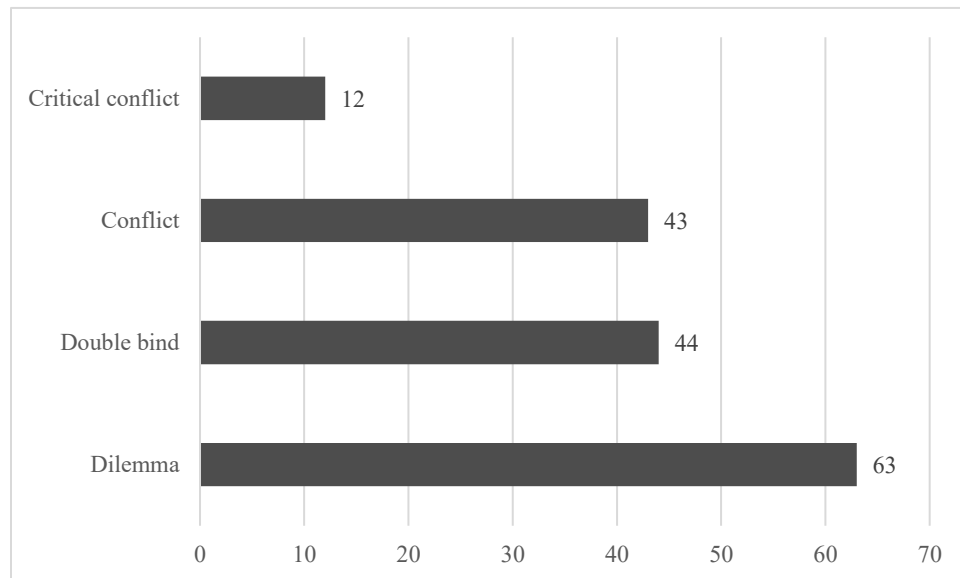
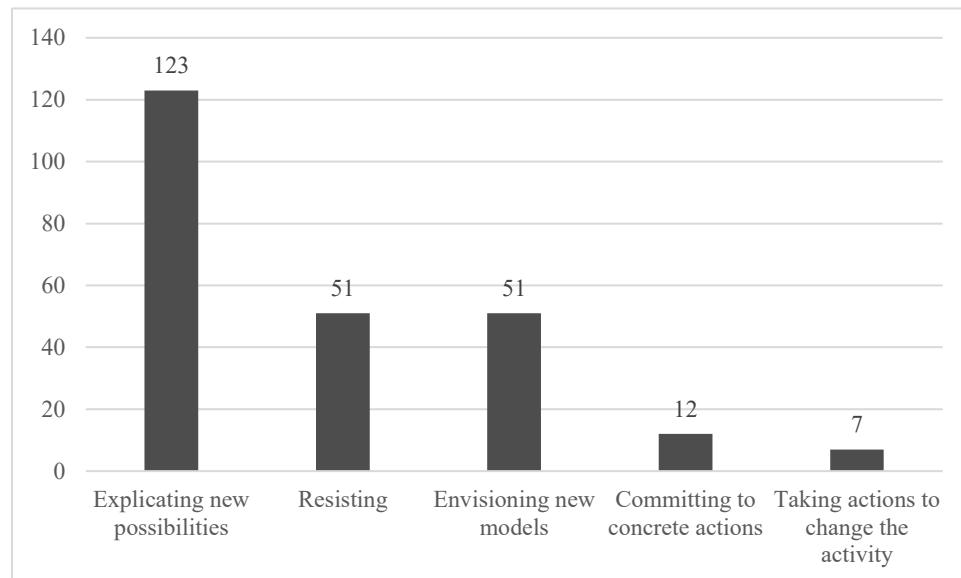


Figure 41 displays that *dilemmas* are the most represented DMC associated to knots (n=63), followed by *double binds* (n=44), *conflicts* (n=43) and *critical conflicts* (n=12). Further, the ELA associated to the mentions of knots in speaking turns are related to *explicating new possibilities* (n=125), *resisting* (n=51), and *envisioning new models* (n=51), *committing to concrete actions* (n=12), and *taking actions to change the activity* (n=7). These actions may therefore point to a slightly different role than the tendency over the whole sequence, as illustrated in Figure 42:

**Figure 42**

*Co-occurrence of Expansive Learning Actions and Knots*



We contend that the effect of both the prevalence of *explicating new possibilities* (n=123) and *resisting* (n=51) closely followed by *envisioning new models* (n=51) associated with *dilemmas*, in particular *double binds*, may account for the generative nature of interactions in knots. This point is further developed by accounting for the changing nature of knots over the course of a hybrid educational activity. This evolving and generative nature of interactions in knots is described in the following sections.

#### **4.9.2 Critical and Creative Encounters**

Participants are encouraged to create low-resolution prototypes of tentative solutions (Khalaf et al., 2013; Mitchell et al., 2020) or objects, and present them to the interviewees to collect insightful thoughts and potential insight or breakthroughs; in a certain sense, prototypes fulfill the function of first stimuli to co-configure, or co-create features or functions that may

become part of the object later on. As the difficulty to materialize an intangible technological artifact due to lack of data, prototypes are expected to emerge *from interactions within a knot*:

F002: So, it's a bit... it's just a feeling. I see... I felt like you really... you were waiting to have certainty before the interview, uh it should be the other way around, which, of course, means that you do one interview that may be the first interview that you understand is not, uh, wasn't that useful but then when you, uh, managed to contact the right person uh you are definitely going to save a lot of hours of research and that's also... this is already a prototype and a very simple way to test it is to show it to the person.

P003: So, you suggest starting doing interviews even though we don't have like a prototype with just sharing the process and...

F002: That's already a prototype, that's something; this... this thing... it's a... at this point prototypes for you are still conversation triggers. Yeah, because you don't have ideas right now, I mean proper ideas also... because, uh, you're still trying like you should be more into the mindset of critical functions, critical experience prototype. I don't know if all of you, uh, remember that. So, it's important that you understand as soon as possible whether plastic is doable or not. (2022-02-02, SGM [S1 ↔ S2 prototyping 1], Pos. 79–81)

As the last sentence in the previous excerpt shows, interviews may play the most essential function in the instructional sequence; furthermore, participants rely on the knowledge and expertise of more advanced users to confirm and validate previous modelling options, and interviews are therefore an occasion for critical and creative encounters which are further detailed in this section. In the problem-solving process, a major disruption may emerge from

interactions with a culturally more advanced system and the participants in the activity system; this event is foreshadowed early in the process as participants meet in interviews with neighbor activity systems promoting similar technological. The idea of taking potential competitors as potential collaborators and organizing a meeting that may expand the division of labor during a critical encounter (Engeström et al., 1995) or a creative encounter (Miettinen, 2013) is reflected in the excerpt below:

P006: Also, because they work through their own artificial leaf and the person who we're going to interview is just really willing to help.

P002: Yeah, I don't know if they'd be interested in something like that?

F002: I think they would be, I think the scientists would be available for such a discussion. (2022-02-10, SGM [S1 ↔ S2 prototyping 2], Pos. 47–49)

#### ***4.9.2.1 Critical Encounter: Switching the Field of Application***

The excerpts exposed in this section pave the way for a major disruption understood as the possibility of a late switch in the field of application despite previous collective decisions in the field of application S1 ↔ S2. As the previous section illustrated the potential contributions linked to confrontation with more knowledgeable or more advanced—or culturally more advanced—forms of the activity, these encounters may acquire the potential to become *critical* or *creative* and trigger major changes in the activity systems. They may trigger shifts in stimuli, motives, auxiliary motives, or other elements that may involve qualitative development. This section charts this process.

##### ***4.9.2.1.1 Scientific Roadblock Resulting From a Tertiary Contradiction***

One unintended consequence of a low stake interaction in a knot is described below; in this case, the refutation of the viability of a tentative field of application is proven wrong by

scientific data exposed during an interview with a stakeholder. The contradictory information gets aggravated into a gridlock, which in turn triggers a major shift with regards the object of activity:

P001: So... so, his interview was particularly important to us because I think he made it very clear to us that it's not going to be viable or feasible to use the leaf or polyethylene. Um and that's, the main thing that we got so I don't know if everyone else got the same. Because he literally wrote a paper, last year, about converting CO<sub>2</sub> to ethylene and he was like "I literally studied this" and he's written a paper on it, and he said, our results where it's not... it doesn't produce enough yield. So that was the main problem, so the second problem that follows on from that, he was like there are very, very few technologies, that only produce ethylene. But our technology is one of the many that produce ethylene, along with other products, these other products need to have market value every single one and that market has to be big. That's what he said and I'm not sure about that I'm not sure we have a big market for all of our products except if we think of C004 and he was very interested in it for different reasons. So that's another insight. Um and it got me thinking whether we need to move away from that. (2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 106)

#### *4.9.2.1.2 Rethinking the Field of Application: Discontinuities in Building a Shared Object of Activity*

Resulting from this interview, tensions emerge caused by doubts regarding the viability of the plastic field of application:

P006: I am not a hundred percent sure if other plastics than polyethylene will actually be viable because carbon monoxide isn't widely used it is like such a small fraction and it's

not really a plastic that can that this recycled, very often, so I don't know about that.

(2022-03-04, SGM [S1 ↔ S2 prototyping 3], Pos. 109–112)

#### *4.9.2.1.3 Shifting the Object Towards Intermediate Steps of Development*

As an alternative to working with plastics and to provide a path towards a shared object, an intermediate path is suggested, focusing on more typical i.e., useful technological development through both enlarging the potential partner base and circumventing the inability to produce rational economic data by involving stakeholders with different skill sets to try and advance the technology closer to the market:

S002: Then, today, we will also discuss about the possibility to try to enlarge the kind of companies in which you can try to interview by also adding specific companies that are interested in... in building the plants, so they can be interested to acquire the technology, in order to build a plant for the CO<sub>2</sub> producer, eventually. I'm sure that they will also require numbers, for sure, but since they can be in the middle between what we develop here and the final end user, maybe they can... (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 73)

#### *4.9.2.2 Critical Creative Encounter: A Third Person Creative Encounter Experienced as a Springboard to the Conceptual Model of a New Activity System*

Although the conditions which allowed for this critical-creative encounter to happen have been discussed in previous sections, the following excerpt illustrates the expansive potential of this episode. Since this episode happened outside the scope of the data collection process, it is only featured in this section as retrospective accounts from a posteriori interviews.

#### 4.9.2.2.1 *Facilitators' Perspective*

From the point of view of facilitators, the joint presence and effort to allow for a common object to emerge was the defining feature of this encounter, and it was what later allowed for the emergence of the concept of co-design and co-configuration as a substitute object:

F002: From my perspective, it was honestly, one of the few, if not the only interview I shadowed and... So maybe that's also why, I felt it was so insightful, but also the students told me, it was different from the other interview because the other interview there were just some members of the team talking with a certain stakeholder. In the case of this C012 meeting, it was the company, at both scientists and most of the students altogether, so it was really more a co-design moment because the company was making questions about the technology, the scientists were answering real time the students were tracking down their questions and their answer... so there was really a different dynamic. (2022-07-04, facilitators interview, Pos. 52)

#### 4.9.2.2.2 *Student Perspective*

The feeling of mutual sharing of effort and energy over a common object is also recounted by students:

P006: I feel like there are two triggers for going for onboarding. First one was our first interview with C012, because over there, we saw that we were participating with the scientists and there were so many people from a company present as well. And during that interview like none of the students really talked because IIT was just explaining the technology and company was asking questions and just went back and forth, back, and forth, and after that, the day [inaudible] Where they're really interesting as a way of using this technology, one which we couldn't think of ourselves because we don't know the

technology as [well] as IIT does. And so that really shows how valuable a good onboarding process can be if you can co-design and collaborate together. (2022-07-05, students interview, Pos. 23)

The same episode is also related as being a trying moment, translating a deep break in the division of labor:

P004: We were... we couldn't really like... follow. For me it was devastating because I could not really follow and yes, I mean, even though they found this idea and the collaboration blablabla, it was really tough to take it.

P003: We were really under pressure. We were, I think that I can like talk personally, but I was... I was feeling, as if we were nothing in that meeting as if we were there just seeing the other people that were more technical talking to each other, but we were there, like... I don't know, maybe useless is not the right word, but it's strong but... That was kind of the feeling that I had but also, I think that the C012 interview was a really good example to validate the idea that came to our mind to ever like to facilitate the communication between the companies and, in this case IIT so it was both those experiences for me. (2022-07-05, students interview, Pos. 25–26)

Yet, this event was also perceived as being generative and associated to a leap forward in the process of acquiring some certainties with regards a tentative shared object as demonstrated in the two following excerpts:

P002: Oh yeah um the... for me like that was when we were doing that interview with C012. And you could see the... you know, a company member of your and the scientists like coming up with a solution for the technology that was like custom to C012 and to their systems. And, like, after that interview like it took us a few seconds, we were like



wait that was really cool. We want more of that to happen. If that can happen more, then this technology like we can see the potential of it actually getting onboarded by somebody. Um and so, then we like I remember having that was like at... in Bologna and I remember having like a really great meeting with F002 um where we were like ok so like how like, we know that that was really good, what can we do to like facilitate that, and so like, working through those steps, and I remember that whole like that whole day was like the most important day of our whole project, I would say. (2022-07-08, students interview, Pos. 37)

The same episode is further commented in another interview:

P001: Yeah so we were at... while you know while the C012 meeting was still happening between the scientists and C012 we were all mute and we took a backseat like I said, and we were also discussing what we were seeing in that... In the meeting, and we, and then we started saying let's change this makes more sense about the communication about the little things came about and P005 was like, but we have a presentation in two days and I'm like yeah, we have to redo all of this if we change it. It means we have to pull up like an all-day or an all-nighter really. And we then started again overwhelmed and then we went to the room and F002 kind of helped us she was just listening to us talk and talk and talk and she helped us frame she wrote some words that we were saying and then she helped us frame it and that's what I remember. (2022-07-12, students interview, Pos. 61)

#### *4.9.2.2.3 Implications for a Tentative Shared Object: Software Design*

Among the defining features from this critical encounter, the discrepancies appearing with regards communication seemed to be the ones having the most important implications to infer subsequent features and functions:

P001: So, we got knowledge from them, but I would also argue, we were witnessing in real time, the problem with onboarding slash innovation processes with C012. And C012 didn't work out and actually ended weirdly. And we saw that in real time they could not... that there was communication at many points that even both spoke Italian, but there was still a miscommunication because C012 or the client could not imagine and so... from witnessing it in real time and we decided, with these features which were some things worked out well, like the survey was inspired because C012 and asked us to answer a few questions about the technology and we were like oh great let's take that on and kind of flip it so that there's no miscommunication about the limitations, when the client from the get-go, you know from the first step. (2022-07-12, students interview, Pos. 95)

#### ***4.9.2.3 Critical Encounter: a Tentative Visit to the Showroom of a Big Company in Bologna Experienced as a Culturally More Advanced Form of the Central Activity***

##### ***4.9.2.3.1 Facilitators' Perspective***

If, on the one hand, the critical encounter was elaborated and built over various iterations, the visit to a big company's showroom in Bologna was fortuitous and served as the basis to an epiphany among participants:

F003: And from my side, I remember I wasn't there [...] and I remember that this was like let's say the "boom" moment [...] we went there, and we were like ok it is going to be useful, but at the end, we found out that C031 was... let's say a place of where the projects were showcased the... for the company's not project, sorry, technologies. And for the students who were super easy to understand what the technology was doing... we're doing... and let's say the... it was like an exposition of technologies and we were

trying to reflect on that and I remember that we were walking and I was like ok in what, in your opinion, what was C031's vision? And they were like probably shortening the distance between a company and a technology lab in a very pop way, let's say. And so, I remember that something was starting but we weren't actually aware of this, but there was like this intuition of "Ok, we are looking... we're looking for the best way to apply a technology, but at the end, there is something that is missing in the relationship between the company and the lab they are super far away and we need to find a way to shorten the distance." And I remember, we were talking about it, but still like it was just an intuition, and then they weren't... they weren't ready for it... for this, but I remember that was useful for them as well. And it was totally like random luck. (2022-07-04, facilitators interview, Pos. 38)

The visit and the embodied experience of interacting with artifacts dedicated to making tangible the use and sense of industrial technology to a larger public served to ground the experience and frame the object of activity. It should be noted that the further interaction and discussion with F003 were as instrumental in the elaboration and subsequent modification and change of object as the visit itself.

#### *4.9.2.3.2 Students' Perspective*

The embodied experience is further described by P003 as a defining feature of the experience:

P003:... as P004 said the visit to C031 was really... is an important point for our process, because the... and... also, because I think that we were there in person, and we experienced the... in person that kind of let's say lab that the company had. And it was basically what we were looking for, but we didn't know. So, like seeing that lab was

really something that like, I don't know, big idea that came to our, to our mind (2022-07-05, students interview, Pos. 26)

Furthermore, the following excerpt displays the overlapping—retroactively speaking—between the concepts of *visualization* and *onboarding*:

P005: I think. Then, when we had this idea we just said, we could, in the future, do something like C031, but it was just an example because they do this onboarding, let's say, for their clients. They have these rooms, where they show technologies like where people have touch points like here's the display and here you can change some values in real time, real life. So, this gave us an idea of how we could create this onboarding physically. (2022-07-12, students interview, Pos. 77)

#### **4.9.2.4 Object Modeling Through Knotworking**

All three critical and creative encounters recounted above play a significant role in the emergence of a tentative shared object. As the modelling process progresses, the principle of using interviews to channel tacit and implicit knowledge loses traction; as a result, the *rules* applied during interviews also evolve, an evolution illustrated in the following excerpt we chose to illustrate as one additional step towards integrating co-configuration to the process rather than extraction of expertise or emergence of insight:

F002: So, I was wondering if we... if it could be interesting, also, to give a slightly different direction to the interview with a company. From trying, I mean from trying to understand whether the technology it's interesting for them to try to understand, which are the needs, the constraints and the struggles related to implementing and developing a new technology in the plant. I know it's something that you're already tackling probably or quite surely. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 144)

The division of labor evolves further as the target audience gets refined and remodeled:

P001: I was thinking, maybe along the lines of what S002 said before and what you are suggesting now F002 and maybe we can... we can change our direction in the way that we kind of target research and development and innovation teams of those companies because those are the interviews that will always be the most interesting ones for me whether like what if what if this and maybe if we restructured the interview with those innovation teams, so that they're more of asking more to collaborate rather than by the technology or something maybe that would be useful. (2022-03-04, liaison meeting [S1 ↔ S2 prototyping 3], Pos. 148)

#### 4.9.2.4.1 *Knotworking as Co-Configuration Opportunity*

The evolution of the *rules* and *division of labor* from the evolution and refinement of interview methods allows for a new model to emerge through a series of defining encounters, as previous sections recount. A further step in the process is realized as an occurrence of *co-configuration*, and recognized as such; in this sense, it answers and responds to the problematic and conflicting situations during which the interview process may be disruptive or non-satisfactory among participants:

P002: Yeah, P005's question is hard, but we had a moment in the interview today like where like they were asking a lot of questions I didn't have the answer to, or like needed to calculate then come back but... they like together came up with this like solution like about the um, [inaudible] which was a co-design moment. (2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 32)

The following excerpt illustrates the release in tension and the looming influence this episode has over participants:

P001: But we but it wasn't only like we had problems with today's interview, but we also had a beautiful moment where we had the institution and the company co-design and that yeah.

P005: This one, I really wanted to mention this one that they co-designed, already and this inspired us to...

P001: Yeah.

F002: I think this thing has great potential.

P005: This is great, this is great storytelling. We now just need to put it into words.

(2022-03-16, SGM [S1 ↔ S2 concept formation], Pos. 182–186)

#### 4.9.2.4.2 *Critical Encounters as a Germ Cell*

The instance of germ cell as a tentative resolution of a double bind turns out to be a powerful event to participants. It also participates in the final foregoing of the initial field of application of plastics and marks a left turn in the modeling of the object, one step removed from the initial *service* and *business model* related to APT towards artifacts designed to promote co-configuration, or “co-design” i.e., on the *collaboration* process surrounding the modeling the object of an activity satisfying the needs of all parties involved:

P005: Let's focus on the plastic sector, right? We all agreed on focusing on the plastic sector. But then during the interview with C012, we realized that it's more important that we... that it's more important to focus on the collaboration between IIT and other companies to find a way to find answers to their questions, and that we can apply this in every sector. So, we decided to open up again to every sector, not only plastics. (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 17)

The insight produced is far-reaching, as it alters the rules, the instruments, the division of labor, and the actions undertaken by the subjects; the emergence of such an occurrence to reach beyond a single occurrence proves to have a direct impact on the subsequent direction taken by participants:

P001: The last interview was a moment of clarity for us, but we've noticed patterns in all the interviews and that they always ask the same questions, very detailed questions, and that... and then but this was the first interview that IIT was there, decided you guys were in and talking with them, right? And we were there from the background, and we were noticing that maybe it's not so helpful that we need to design something specific into a factory. Maybe what our role here is making companies feel like they can trust um the process. So, so here we said "create a system of reliability" when we don't have solid numbers. (2022-03-18 liaison meeting [S1 ↔ S2 concept formation], Pos. 24)

The importance of this single occurrence is further reflected upon in the following excerpt as an instance of alignment of complementary competences and forces:

F002: In the case of this C012 meeting, it was the company, at both scientists and most of the students altogether, so it was really more a co-design moment because the company was making questions about the technology, the scientists were answering real time the students were tracking down their questions and their answer... so there was really a different dynamic. (2022-07-04, facilitators interview, Pos. 52)

#### *4.9.2.4.3 From Germ Cell to Emergence of a Shared Object of Activity*

This occurrence may be identified as the emergence of a shared object of activity, as illustrated in the following excerpt:

F002: But from that moment onward, the purpose of the project became to create the tool and the condition to repeat this kind of... to let the scientists being able to reproduce this kind of experience with other companies. (2022-07-04, facilitators interview, Pos. 56)

Furthermore, the emergence of a germ cell as a shared object of activity may also be illustrated in the following quote:

F001: My only thought going into the black box of SUGAR is it was not magic it was therapy. Now, it was not magic it's the process.. like... there is something that seemed like magic happened here that actually yeah it's... It was... to get into the process and understand that ok their Aha moment came it came because there were a lot of steps that we were following in order to get this moment to come and all the people that they were interviewing and it was... (2022-07-04, facilitators interview, Pos. 78)

#### *4.9.2.4.4 Bidirectional Dynamics of Creative Shared Object Building*

This final excerpt may illustrate the dual instrumentalization of knots happening in an interdisciplinary hybrid educational activity: not only are participants instrumentalizing the community to gain insight, test, and extract expertise from practitioners of a given field, but creativity also happens to be the quality sought after by the participants to enroll in the program in the first place. The dual direction of this relation illustrates the dynamics involved in the shaping of a shared object:

F002: If we talk about the needs of the... of the Italian Institute of Technology and where you can help them so creativity, they were interested in your creativity, especially about exploring many different fields of applications, or supporting your background. I mean they were assuming that since you come from many different backgrounds, you could see something they couldn't see which was actually true because you brought some field of



application, they thought about already, but some others they never considered. (2022-01-19, SGM [Field of application], Pos. 78)

## 4.10 Results Summary

### 4.10.1 *Research Question 1: How does Transformational Agency by Double Stimulation Emerge in a Hybrid Educational Activity?*

In this section, we synthesize the results described in section 4.2 in response to research objective 1 and research question 1. We described the sequence as aiming at the creation of a *service* and a *business model* and we sought to understand the ways in which the object of activity had evolved over the sequence. We identified a running dilemma in the tentative framing of an object in the form of *novelty* vs. *usefulness*, and we identified an aggravated tension about the difficulty to align prototypes and interests of participants during interviews. The main conflicting motives appear as the difficulty to create reliability on a developing technology when confronting demanding interlocutors such as experts or scientists during interviews. The tentative auxiliary motives emerging from the sequence were shown to peak over the S1 ↔ S2 prototyping 1 phase, as described in Figure 31, while the emergence of a stimulus 2 followed an inverted dynamic, described in Figure 32, emerging in the S1 ↔ S2 prototyping 1 phase and progressively gaining traction over the three following S1 ↔ S2 phases exposed in sections 4.2 to 4.6.

We further identified the real conflict of stimuli as the cessation of the initial agreement on a field of application due to a critical encounter, described below in section 4.9.2.1, provoking an abrupt cessation of prototyping over the chosen field of application. The emergence of a tentative stimulus 2 is the result of two additional critical encounters further described in sections 4.9.2.2 and 4.9.2.3 above. To sum up, the sequence described in this section allows us to

characterize the emergence of TADS as the result of contradictions manifesting throughout the sequence and further detailed in section 4.8 resulting in aggravated tensions impairing the progression, while the conditions to the emergence of a convincing stimulus 2 come from the wider life channel, distinct from the intervention channel. TADS therefore emerge (a) from attempts at resolving conflicts while trying to model a shared object and emerge mainly from the *intervention channel*; (b) TADS emerge from the input of knots to the main activity system through the *wider life channel*. TADS therefore emerge in this case from the mutual effect of resolving conflicting motives and discontinuities from knots.

#### ***4.10.2 Research Question 2: How Does Transformational Agency by Double Stimulation Evolve Over Time in a Hybrid Educational Activity?***

The results presented in section 4.8 in response to research objective 1 and research question 2 aimed at bringing finer grain resolution over the main elements described in section 4.10.1, and in particular over the evolution of TADS over time. Section 4.8.1 allowed us to illustrate the distribution of DMC and the prevalence of *dilemmas* and *conflicts*; the overall dynamics showed a diminution of DMC over time, with the exception of a peak in *conflicts*, which we contend to be a consequence of critical encounters, illustrated in Figure 44.

Simultaneously, we identified in section 4.8.3 the dominating ELA in the sequence as *explicating new possibilities* and *resisting* while the overall evolution of ELA also diminishes over time, to the exception of *envisioning new models*, corresponding to the emergence of a stimulus 2, illustrated in Figure 32. Finally, section 4.8.5.1 allows us to identify three clusters of S1 ↔ S2 problem solving units, ELA and DMC, which we presented in Figure 39. The evolution of TADS over time is therefore characterized by shifts in the resolution of tensions and conflicting motives which are dominant in *cluster 1* as *dilemmas* and *explicating new possibilities* dominate (section

4.8.5.1.1), before shifting towards *conflicts* and *resistance* under the pressures exerted by critical encounters producing major shifts in the modeling of a shared object (section 4.8.5.1.2) and finally resolving in *double binds* and *critical conflicts*, leading participants to *envisioning new models*, *committing to concrete actions*, and *taking actions to transform the activity* (section 4.8.5.1.3). The trajectory, the *pathway*, described therefore displays an expansive trajectory as it allows for the modeling of a qualitatively different object to emerge.

#### **4.10.3 Research Question 3: What is the Role of Knots in the Emergence of TADS?**

In section 4.9, we presented results in response to research objective 2 and research question 3 regarding the role of knots in the emergence of TADS. The analysis presented uncovered the evolution over time of the role of knots to inform the processes involved in the main activity system; however, as the gradual impossibility to produce tangible artifacts and provide visualization opportunities for experts to react over working hypothesis, the role of knots gradually evolves from information provider to contact provider. Critical and creative encounters (section 4.9.2) deepen the role of knots and decenter both the activity and its object progressively over time to lend a more comprehensive and central role to interactions in interviews: in this sense, knots evolve towards co-configuration and get better integrated to the process. Finally, the concept of integration and involvement of communities and experts becomes the object of activity, through the concept of *onboarding* which we describe as *co-configuration*. Engeström (2013) suggests the following definition to co-configuration:

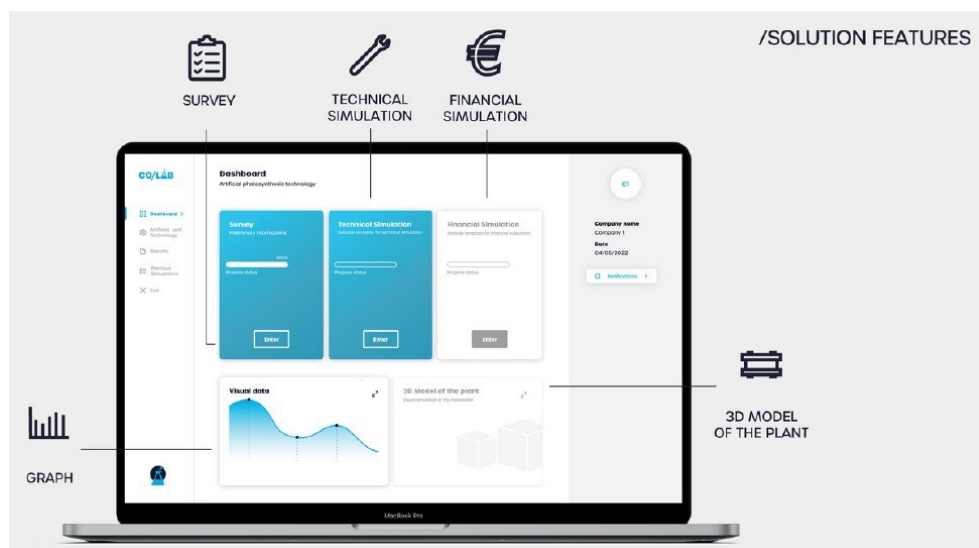
We may provisionally define co-configuration as an emerging historically new type of work that relies on (1) adaptive “customer intelligent” product-service combinations, (2) continuous relationships of mutual exchange between customers, producers, and the product-service combinations, (3) ongoing configuration and customization of the

product-service combination over lengthy periods of time, (4) active customer involvement and input into the configuration, (5) multiple collaborating producers that need to operate in networks within or between organizations, and (6) mutual learning from interactions between the parties involved in the configuration actions (p. 5).

According to this definition, the concept of co-configuration emerging spontaneously from interactions in knots in the shape of the concept of *onboarding* should allow for *adaptive product service combination*, insofar as participants come to the realization that due to the technology-readiness level of APT, it is not possible to produce reliable data potential clients may use to inform a learning activity involving the social-spatial dimension. The concept of *onboarding* also requires continuous and sustained interactions between participants in a collective, to become active members in *product-service combinations*, a process that may require extensive periods of time to expand from *knots* to stable interacting systems; in this research, we only focused on a micro-cycle of development, and we are therefore not addressing a full cycle of historical development. However, in the meaning progressively gained by the concept of onboarding over time, *active customer involvement* is actively sought as an important input to the process, especially *between organizations*, a process on both end of the interaction. As a result, we understand the concept of onboarding emerging in the process as the germ cell of knotworking aiming at co-configuration, later developed, and enriched as a digital artifact under the label *Colab*, illustrated below:

**Figure 43**

*Illustration of the Colab Artifact Illustrating the Onboarding Process*



## 5 Chapter 5: Discussion

The present research sought to document the emergence of TADS in a higher education setting in a hybrid collective composed of a stable core activity and peripheral participants in knots. We described hybrid activities as regulating through problem situations (S1) and resources used (S2) to break out of conflicting situations. Participants had to master collectively and expansively new types of activities *from below*, thus echoing e.g., Lotz-Sisitka and collaborators (n.d.) and *from above*, as discussed in this chapter. To gain mastery over new types of activity, participants had to reject a predetermined course of action and perform expansive *transitions* across expansive *dimensions* through potentially expansive pathways that may involve both *horizontal* and *vertical* development. We put agency at the forefront of hybrid educational activities in higher education and described the central system of activity as collectively *distributed* within and beyond the system rather than relying solely on an individual or collective agent. We asked the following question: “*How may collective will emerge and evolve in a higher education hybrid activity of creative problem finding through TADS in an expansive micro cycle of modeling of an object of activity aiming at the development of artificial photosynthesis technology?*”

This question was split into two research objectives, namely to document the emergence of agency and of a shared object of activity (research objective 1), addressed through two main questions: emergence (research question 1, addressed in section 4.2) and evolution over time (research question 2, section 4.2) of TADS, while research objective 2 questioned the role of knots in a hybrid educational activity. Research question 2 addressed the role of knots in the emergence of TADS, addressed in section 4.9. To answer this question, we sought to document and describe the emergence of agency through knotworking. This required to analyze the origin

of agentive actions and their evolution over time (Engeström, Nuttall, et al., 2022). The authors, however, warned about the nonlinear, inherent messiness of change in work and learning environment and its propensity to evade tidy analysis as it is ruled by iteration, reflexivity and tentativeness when dealing with everyday lives (p. 4).

To account for the extreme nonlinearity and unpredictability of the advent of change, we contended the prevalence of the community pole in activity where temporary coalitions may appear as a defining feature of double stimulation involving knotworking (Engeström, 2008) with a direct influence over the emergence of TADS. In this respect, agency was approached not as a quality individuals may possess, but rather as a process relying on participants (Engeström, Nuttall, et al., 2022). The analysis of data presented in chapter 4 allowed us to observe closer the expansive transitions which we discuss further in this chapter (Engeström, 2015; Engeström et al., 2014). We focus particularly on the transition from *systemic contradictions* to experienced *conflicts of motives*. To cover these topics, we described in sections 4.7.1 and 4.7.2 the main conflicting stimuli and conflicts of motives which we identified at macro level (see Table 4); we then proceeded to analyze the evolution of DMC over the problem solving unit at a macro level of analysis in section 4.8.1. In the first point of this discussion, we focus on primary contradictions that have emerged from the data analyzed and which were described in chapter 4 in an attempt to take a bird's-eye view and reflect on the contradictions manifesting in this activity; in our view, the implications of dealing with a developing technology related to climate change and the consequences of approaching it through a creative angle (i.e., a novelty-focused approach) have deep implications in a higher education setting which we intend to expose in section 5.1. In section 5.2, we then focus on the transition from *conflicts of motives* to *auxiliary stimuli* to characterize further the emergence of TADS across expansive *pathways*. Finally,

Engeström (2015; 2014) recommends the third transition to focus on *second stimulus* to *implementation of solutions*. However, we wish to remind our reader that the field of investigation covered in this research is restricted to a micro cycle of development corresponding to the modeling phase of an expansive cycle (described in section 3.2.2) which prevents us from addressing a complete cycle of historical transformation depicted by the theoretical complete cycle of expansive learning illustrated in Figure 9. However, we provide further elements regarding the role of knots in the emergence of a new concept-object (Foot, 2002) in a hybrid educational activity. The function of *interviews* as the main tool of knotworking was subsequently questioned in sections 4.9.2 and 4.9 as we sought to characterize both the role of knots in the emergence of TADS through critical and creative encounters. Our results show the influence knotworking had over the modeling of an object as we argue that the evolution of the function of interviews over the modeling phase served as a germ cell and supported the emergence of a stimulus 2 that directly addressed (a) conflicting motives across the process reported in the data in chapter 4, and (b) occurred through a rupture in the process which triggered an instance of ascending from the abstract to the concrete and allowed participants to anchor the process through a *model*. Following Engeström (2020a), we characterize a germ cell emerging from collaborative concept formation as (a) the simplest initial unit of a complex whole, (b) as carrying its foundational contradictions and the potential to overcome it, (c) as being commonplace, i.e., usually available to the participants during the activity (d) representing multiple potential applications and (e) being actionable.

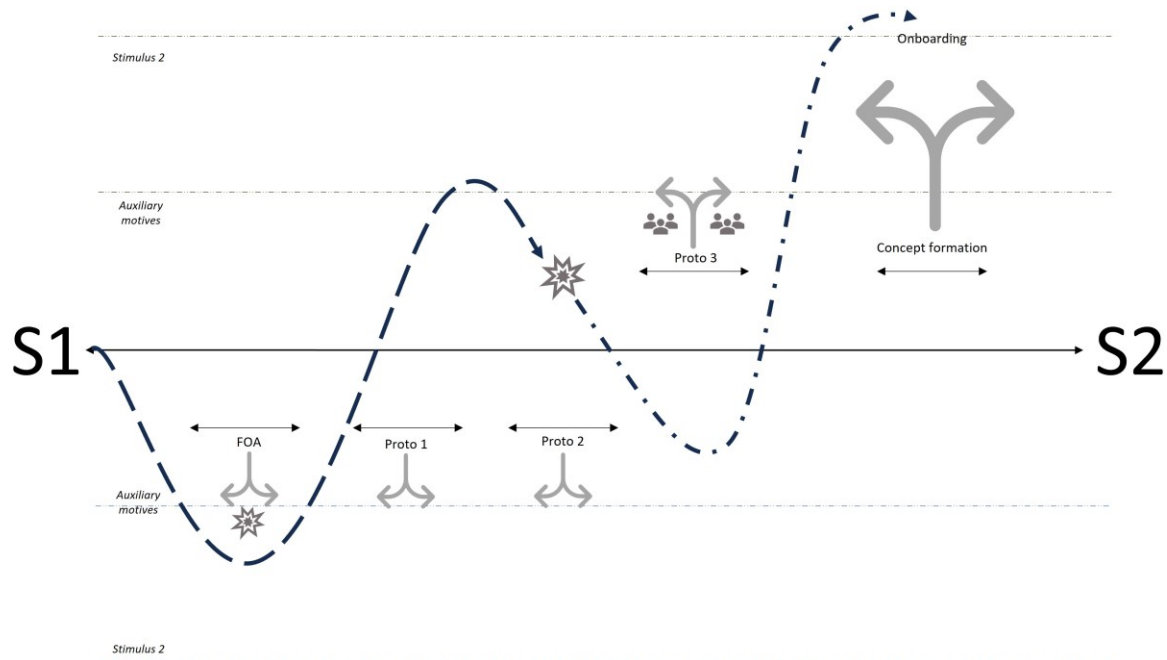
We therefore attempt to link and build on the results exposed in chapter 4 according to the following topics: (a) primary contradictions specific to the case (section 5.1), (b) the nature of expansive movements in expansive pathways and the importance of the vertical axis which is






not usually accounted for in depictions of double stimulation of concept formation in the wild (Engeström, 2020b; Hopwood & Gottschalk, 2017) and which are discussed in sections 5.2 and 5.2.4. (c) We then describe further the distribution across time and space and inquire into the learning processes evidenced. (d) We close the discussion by evidencing *onboarding* as the result of vertical development emerging from interactions in knots (section 5.3). We further identify the *germ cell* that enables participants to break away from the dominating conflicting motives through knots, while we intend to establish a potential contribution to collective concept formation. Mainly, this section investigates the associations of EMA and DMC as modes of inquiry into the nature of the problem-solving process occurring across a *horizontal* and a *vertical* dimension of development (Olsen et al., 2019). To proceed with this line of argument, we first present a timeline of the process to illustrate the oscillation between channels, and the progression over time displayed in Figure 44 which displays the multiple iterations of double stimulation during the process of emergence of TADS; the oscillations it produces between *intervention* and *wider life* channels (i.e., knots) (Engeström, Nuttall, et al., 2022; Sannino, 2015b) is represented below:

**Figure 44**

*Multiple Iterations of Double Stimulation in Co-Creative Problem-Solving Activity*



*Note.* The legend of the symbols in the above figure is as follows:

-  Directional Discontinuities
-  Double Stimulation Instances ( $S1 \leftrightarrow S2$ )
-  Critical Encounters

$S1 \leftrightarrow S2$  units below the main  $S1 \leftrightarrow S2$  pathway are concerned with *intervention* channel, while the subunits positioned over the middle line are concerned with *wider life*, i.e., with knots.

The following discussion is set to expand upon previous results and is structured according to three phases that we deemed essential to further report on the emergence and evolution over time of TADS. The following structure is inspired by the timeline above in

Figure 44: we first discuss the implications of stimulus 1 in relation to primary contradictions in section 5.1 as we proceed to identify three primary contradictions which we identify as overarching forces shaping the emergence of a shared object, in this case *preserving cultural forms vs. transforming culture, novelty vs. usefulness* and *preserving vs. developing*. Having stressed the importance of resolving conflicts of motives to trigger expansive movements, we then discuss in section 5.2 the relation from expansive resolution of conflicting motives to expansive learning through expansive dimensions and expansive pathways. Finally, in section 5.3 we seek to characterize more precisely the relation and expansive movements in relation to DMC and ELA.

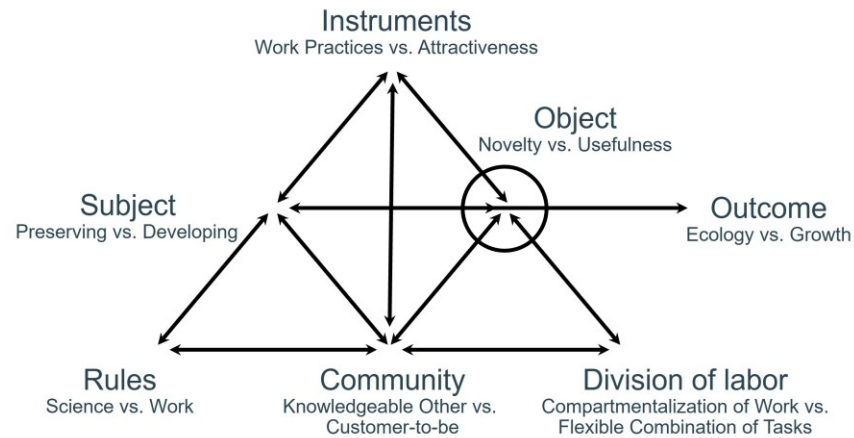
### **5.1 Primary Contradictions in the Co-Creative Building of a Shared Object of Activity**

In our view, one of the defining features of the case studied in this research project is its unique blend of the three lineages identified by Engeström (2015, p. 73) of *school going, work* and *science* which provides a unique combination of primary contradictions at the poles of the activity system, subsequently emerging in interactions in the knots involved. Our results have allowed us to identify a set of primary contradictions relating to the object of activity, which may display a use value vs. exchange value contradiction; we consider these contradictions to be overarching in the activity system and we have selected them according to their objective nature: they are objectively stated and recognized in the activity system, contrary to *rules*, for instance, which do not get mentioned in the transcripts. The identification of contradictions is the first step in a potentially expansive cycle (Engeström & Sannino, 2013) and although they are never directly accessible to the researcher, they may paralyze an ongoing transformative process (Virkkunen, 2013). Due to the focus in this dissertation on higher education and on a micro cycle of object development (section 3.2.2), we chose to dedicate the following sections to the primary

contradictions of higher education, creative work and consequential issues such as global warming. The section concludes on primary contradictions identified on sustainable development which we interpret as concerned mainly with the *outcome*. Figure 45 below illustrates the main primary contradictions identified during the process, understood as a dialectical unity of opposites relating to each other within the historical evolving structure of activity; as a result, the following section displays some of the tensions emerging regarding the object:

**Figure 45**

*Primary Contradictions in Co-Creative Hybrid Educational Problem-Solving Activity Adapted From Engeström (2015) and Miettinen (2009)*



As we intended to address contradictions and tensions in this research, we further report below the main explicit objective contradictions that we understand to be constitutive of the hybrid educational activity aiming at creativity and dedicated to climate change which we aimed to describe. Each of the primary contradictions depicted below brings about further dilemmas which emerged from analysis of the data (e.g., section 4.8.1), and we report them below as we interpret them to be closely interconnected and constitutive of the specificity of the case.

### ***5.1.1 Preserving Cultural Forms vs. Transforming and Creating Culture in Higher Education***

According to Yamazumi (2021), the value of learning in school may appear as constrained by the primary contradiction of mastering one's own relation to society, on the one hand, and getting grades and following school regulations and norms to optimize one's value on the labor market, on the other hand. Engeström (1991) advocated for the de-encapsulation of instruction to overcome the primary contradictions of school going, a point also reported by

Jóhannsdóttir (2018) or Nilsson and Wihlborg (2011). In this respect, we may describe transformative agency as the ability and power to create one's own collaborative interventions.

In the case of higher education, the value of learning is mediated by general instruments such as fragmented curricula, stepwise lesson plans and standardized tests. However, when introducing shared object-oriented actions, instructional guidance may force motives into the system that are not those of the participants, which may cause inner contradictions to manifest (Engeström, 2015, p. 146) and may therefore provide opportunities for a learning activity to occur. To reiterate the point stressed in section 2.1.4, learning at activity level is the product of a theoretical reconstruction of the object resulting from analyzes and connections between discrete elements with their systemic activity contexts. These elements are then converted into contradictions demanding creative solutions which may expand and generalize into a qualitatively new activity structure. In further stages, instruments of learning activity are *models* that objectify the essential relations of the object, and the construction of models is accomplished via a methodology. This process is essential to the line of thinking developed in this research: *learning activity is expansive movement* from models to the methodology of making models (Engeström, 2015, p. 99). As stated in section 1.2.3, although typical learning activities may rely on behavioral approaches relying on establishing links between professional and didactic competences assessed through performance-oriented assessment methods, *learning activities* from a CHAT perspective may offer an integrated way to create general means of producing knowledge that takes into account the collective and integrated type of active knowledge that is enmeshed and emerging in concrete practice.

The tentative resolution of conflicting motives from the perspective of higher education may offer a powerful framework to collective creative problem solving. In this respect, a hybrid

educational activity may represent an opportunity for a learning activity in which expansive cycles may take place through collective creative problem solving. This process may display a shift from transmitting and preserving cultural *forms* to transforming and creating *culture* (Yamazumi, 2013); as a result, it may represent an opportunity to engage creatively in collective future-making.

Hybrid educational activities of problem solving across higher education and work may be defined as (a) offering students the position of subjects in educational practice and (b) engage students and facilitators in a common object which transcends the value of formal instruction (Nilsson & Wihlborg, 2011) e.g., passing the exam (*exchange* value) as opposed to gaining valuable knowledge and experience (*use* value). The engagement with a shared object of activity may depend on contradictions manifesting in the activity, and whether these contradictions are explicit to the collective. Following this line of argument, hybrid educational activities may offer a way to reframe *use value* in higher education, as participants are trusted to create use value through the modeling of a new object.

Engagement in deeper organizational and collective social environment may provide a potent incentive to creativity (Vygotsky, 2014; Yamazumi, 2021) e.g., community revitalization, cultural production or citizenship activation. As a result, learning, agency, and collective creativity may appear intertwined and emerge as collective, future-making, and transformative processes requiring both agency and collective creativity. However, despite the potential benefits of providing opportunities for higher education students to engage in shared activities with communities and organizations (Yamazumi, 2021), manifestations of inner contradictions are conditions to the process of its solution through a dynamic transition to creative human activities. This process could be dampened when the exchange value of school going (e.g., getting good

grades) prevails over use value (e.g., gaining valuable knowledge and competences, making a difference to the community). We were able to identify 1064 instances of primary contradictions in the data, and we chose to further illustrate this point from excerpts of interviews with students below which we believe to display the ambivalence and ambiguity caused by the tension between use value and exchange value in higher education. The first excerpt stresses the use value (quality of experience, investment in terms of professional competences) in the first part of the excerpt, while the end of the excerpt reasserts the importance of grades nonetheless (i.e., exchange value):

P002: I am actively trying to not focus too hard on grades, to really just focus on the... like... critiques that I got and the responses that I get and how much I feel like I'm growing and what I'm able to build for my portfolio that is like... that's the most important thing for me is, can I come up with something that is a cool upgrade to my portfolio, inspired conversations... but I will not lie that if I get a bad grade I'm going to be sad about it, so I still really want to get a good grade. (2022-02-24 interview, Pos. 61)

The second excerpt, on the other hand, also draws on the contradictions between use value and exchange value and of the inability for grades (exchange value) to account for the nature of the experience of being part of a hybrid learning activity:

P006: Me, I hate to admit it, but I love getting a good grade. But I don't think for this project it is going to be that representative of what we've actually done for our... [...] so I'm not too sure about how accurate grades are going to be so... I am... I know that, whatever our grades are going to be... it's not going to be a great reflection of the work that we actually did so during this project, the... like... it doesn't say that much to me. (2022-02-24 interview, Pos. 71)



From analysis of the data in this research, we believe two sets of primary contradictions to be particularly prevalent and to be articulated to higher education, which we describe in the two following sections.

### 5.1.2 *Novelty vs. Usefulness*

The argument developed in this section frames the activity in contradictory dilemmatic tension which we chose to describe as the dilemma of creativity i.e., *novelty* vs. *usefulness* after the standard definition of Runco and Jaeger (2012): on the one hand, the collective recognizes the possibility of transformation of the object of activity while, on the other hand, the collective also recognizes the need to maintain its acceptability, its *usefulness* towards a field or a domain. We therefore suggest to characterize this primary contradiction dealing with the object pole as a *creative dilemma* whereby participants are split between *novelty* and *usefulness*; this dilemma extends the notion of primary contradictions suggested by Engeström (2015) or Miettinen (2009) while still preserving the definition of dialectical unities of *use* vs. *exchange* value. The relevance of this dilemma is involved in the modeling of a shared object and interrogates the openness and uncertainty attached to the process; in this respect, it directly addresses the problem area by defining its width and depth. As an illustration, we suggest the following excerpt, whereby a researcher experiences a conflict of motives between novelty (choosing a new field of application, i.e., *plastics*) or remaining consistent with previous information (maintaining a previously established field of application i.e., *cement*):

S002: I'm a little bit... how to say, "torn in two." For sure in... yes, what you said is interesting, is intriguing. I maybe I will also vote for the cement application, I don't know. I'm torn in two. For sure that will be something different, and new for us to try to

move in the... in the plastic scenario. I don't know, I will say 50/50 among the two. For different reasons. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 92)

Despite the risks involved, participants chose to favor novelty at the onset of data collection. Among the available options, the option to value *creativity*—understood in this case as novelty-generating through divergent thinking and ideation strategies—against *usefulness* in modeling a shared object of activity as illustrated in the following excerpt:

S001: But maybe this is the project in which the fancy takes place in the most interesting ways, so why not considering different scenarios that what we share me and S002 may be completely different if you feel that the stakeholders are very interested in and also because you feel that this can be successful, we have not that the answers for all, we just have feelings on based on our work so and you have had another point of view, so what we told is what we feel could be more successful or more interesting in thinking in an application that means that the company will invest and pay money to have a technology but apart what we told that if you feel that the waste or the other selection can be more successful, I think that this is a good project to try. (2022-01-21 IIT [S1 ↔ S2 field of application], Pos. 99)

### 5.1.3 *Preserving vs. Developing*

This research is focused on engaging with hybrid educational activity involving the *benign object* of APT in higher education. In a sense, this benign object (Engeström, 2009) may be understood as a *proxy* to the runaway object of global warming. The challenge addressed by the activity is the design of a service and corresponding business model based on APT, which we further consider as embodying the original contradiction of use value vs. exchange value of sustainable development as suggested by Hickel (2019; 2020). These authors have suggested that

the SDG 2030 display a fundamental contradiction as *environmental preservation* is nullified by the objective to *maintain global economic growth*: the latter prevents reduction in resource use while also preventing reductions in Co2 emissions. We therefore extract and rephrase the contradiction described by Hickel (2019) as *ecology vs. growth* as the main contradiction manifesting at the object pole in the problem-solving activity system. We contend that this primary contradiction is fundamental at a systemic level: it conditions the main obstacles encountered by participants to model a shared object of activity, while also influencing other poles. It could be contended that these opposites form an original hypothesis of use value vs. exchange value as they stretch both activity systems and knots beyond the purely materialist dimension of capitalistic systems to include natural, biological and ecosystemic dimensions. We argue that the capitalization of ecosystems is at the heart of an extended hypothesis of use value and exchange value: instead of the total societal production and specific productions clashing against one another, the total activity system in this case is the biosphere and the specific productions is APT designed as a bridging artifact between human activities and global warming. Participants in the activity sensed this potential, and as an illustration we recall a quote from section 4.8.1:

P006: Oh yeah, yeah. It's kind of switched around at some point. In the beginning, at least for me, I was like "Ok, what can this technology do for to combat climate change?" I was really looking into the ecological aspects, but later it shifted more into, as you know, how can companies use this technology? So, the climate benefits became more of a secondary thing, and it was more about finding an outlet for the technology and how can we get to this point, so... that's switched around a little bit my ice during the process but

also if we find an outlet that is going to make a difference, so I still feel like these two parts are connected in a way. (2022-07-05, students interview, Pos. 10)

The analysis of systemic contradictions in this section allows us to identify dominating primary contradictions that are particularly relevant in co-creative problem solving i.e., *novelty* vs. *usefulness* and *preserving* vs. *growth* in a hybrid setting across higher education and work. The internal conflicts experienced by participants translate into pressure on the various systems' components, providing participants with the opportunity to grow as they adapt the system to changing conditions using cultural tools. New activities seek to overcome the contradiction between use and exchange value, hence fostering the development of new use value. In this case, we identify the primary contradictions of novelty vs. usefulness and preserving vs. growth as the two main forces shaping the potentially shared object whereby participants gain the ability to switch the use value of learning. These contradictions therefore act as potent developmental forces as conflicting motives are forced into a system that is not solely experienced by participants but is also relevant at societal level, which in turn causes new contradictions and further conflicting motives to emerge at various poles of the system (Engeström, 2015, p. 146). Furthermore, these contradictions appear in the first two sessions of data collection (further detailed in section 4.2) in the process and may be described to cause paralysis and doubts for most of its duration (Kornelaki & Plakitsi, 2022), a point we further discuss in section 5.2.4. Having established hybrid educational activities as offering a potential to produce conflicting motives that may emerge from the very system of higher education or to adopt conflicting motives from neighbor systems or knots, we further question and discuss expansive dimensions and their relation to conflicting motives in the following section.

## 5.2 Conflicting Motives and Expansive Transitions

### 5.2.1 *Expansive Transitions*

In this section we seek to establish expansive resolution of conflicting motives as a potential way to alter use value vs. exchange value in hybrid educational activity, and we seek to characterize expansion happening under the primary contradictions described in section 5.1.

With this purpose in mind, we suggest a cross analysis of expansive *transitions* (described in section 2.1.3.1.1) and expansive *dimensions*. As exposed by Engeström and contributors (2015; 2014) and subsequently put in practice by Ivaldi and Scaratti (2020), expansive transitions occur (a) from systemic contradictions to conflicting motives, (b) from conflicting motives to auxiliary motives and (c) implementation of a stimulus 2. On the other hand, the four expansive dimensions have been identified according to Engeström and Sannino (2010, p. 8) as (a) *social-spatial* (“Who else should be included?”), (b) *anticipatory-temporal* (“What previous and forthcoming steps should be considered?”), (c) *moral-ideological* (“Who is responsible and who decides?”) and (d) *systemic-developmental* (“How does this shape the future of the activity?”). Expansion may occur according to these dimensions. In the following section, we will first look at (a) expansive *transitions* and (b) at expansive *dimensions*. We present expansive transitions and dimensions in Table 13 below:

**Table 13***Expansive Dimensions and Transitions After Engeström and Contributors (2015; 2014)*

Expansive dimensions/transitions	Social-spatial	Anticipatory-temporal	Moral-ideological	Systemic developmental
1. From <i>systemic contradictions</i> to <i>conflicts of motives</i> (S1 ↔ S2 field of application)	High-level representatives in plastic industry	Participant recruitment hardships Funding Data generation	Voting overtaken by the most influent/stakeholder	NOVELTY vs. Usefulness
2. From <i>conflicts of motives</i> to <i>auxiliary motives</i> (S1 ↔ S2 prototypes, 1, 2, 3)	High-level representatives in plastic industry Engineering company (further optimization) Realistic potential partners	Instrumentalize the community for insight (validating evidence) “Reverse instrumentalize” the community for a point of acceptance (participate in the process of building it)	Plastic invalidated by exterior participant	Novelty vs. USEFULNESS Swap the object of activity from one domain with the object of activity of another domain
3. S2, implementation and effects (S1 ↔ S2 concept formation)	All domains	The role of stakeholders becomes the very object of activity	Co-configuration implies a shared decision process with potential clients	Rules Division of labor New instrument

*Note.* The capitalization of letters in the *novelty* vs. *usefulness* dilemma indicates the priority given to which term regarding the corresponding S1 ↔ S2 unit.

### 5.2.2 *Expansive Dimensions*

When looking at each separate transition and dimension in Table 13 and section 5.2.1, we may observe the *social-spatial* (“Who else should be included?”) gradually widens over S1 ↔ S2 pathways occurring over the process. The field of application of APT and the potential object both widen through involvement of different types of stakeholders representing different sets of skills, and it also deepens, as the initial framing of the community gradually enlarges to encompass any field of application as participants elaborate a model (expanded in section 5.3.3). In this sense, the widening of participants eligible to take part in knots happens alongside a widening of the field of application, under the pressure exerted through a critical encounter (described in section 4.9.2.1.1). As a result, the *social-spatial* dimension evidences an instance of learning that triggers a transition from *individual actions* to *new collective activities* i.e., from the individual to the social..

Similarly, observing the evolution of the *anticipatory-temporal* dimension (“What previous and forthcoming steps should be taken?”), we observe the initially peripheral importance of knots as the main decisions and actions initially emerge from the *intervention* channel and its growing centrality as it overtakes most other concerns dealt with in the problem-solving activity. Simultaneously, knots require efforts to recruit participants and to adapt *rules* and *division of labor accordingly*.

On a different level still, the *moral-ideological* dimension (“Who is responsible and who decides?”) also illustrates major qualitative shifts: although the decision process is largely overtaken in S1 ↔ S2 field of application (described in section 4.2), the prototyping S1 ↔ S2 phases of the process (including S1 ↔ S2 prototyping 1, 2 and 3) evidence different roles applied to knots by *instrumentalizing* the interactions (providing validating evidence to some

current hypothesis for a shared object on behalf of participants) and *de-instrumentalizing* the interactions by allowing participants in knots to occupy the role of co-creator in the process. The idea is therefore adopted *as the object of activity* which we define as co-configuration after Engeström (2013) in section 5.3 below.

Finally, although the *systemic developmental* dimension (“How does this shape the future of the activity?”) is mostly concerned with the dilemma of *novelty* vs. *usefulness*, the most salient feature of this dimension is the progressive reversal of the pair over the process. This reversal impacts the *rules* among participants, the *division of labor*, and the *instruments*, which we interpret as a sign that the tentative shared object has expanded.

In summary, we wish to conclude the discussion on expansive *dimensions* and *transitions* by recognizing the importance of knots and their evolution over the *social-spatial* and *anticipatory-temporal* dimensions while we interpret the *moral-ideological* to evidence the discontinuity emerging over the process; simultaneously, the *systemic-developmental* dimensions make systemic contradictions appear clearer over the modeling process leading to a qualitatively different shared object. This contrasting analysis and this perspective allow us to contend a switch in use value of the object, in response to the point risen in section 5.1.1, and therefore to characterize further the expansive resolution of conflicting motives as a source of qualitative change at systemic level. We may therefore contend further and validate the hypothesis according to which a creative expansion leading to a shift in use value based on the resolution of conflicting motives during the process.

The evolution of the occurrence of knots over time (depicted in section 4.9 and Figure 40), while growing over the course of the process, culminates as it then becomes the very object of activity, a point we further discuss in section 5.3.3. Knotworking therefore plays a dual



function: (a) it generates a system of object-oriented and instrument-mediated collective learning activity modeled after interactions in knots and their evolution (detailed in section 5.3) by exerting tension at the community and at the instrument and tools pole of the activity system and (b) the object-oriented and instrument-mediated collective learning activity (detailed in section 4.9) shapes the emergence of a stimulus 2 and a new object (detailed in section 5.3).

### **5.2.3 *Expansive Learning***

Yamazumi's characterization of expansive learning (2021) owes much to the classic vision elaborated by Engeström (2015); we would like to present the latter in Table 14 to further address the emergence of a new type of learning, and the way it creates instruments for the expansive development of new activities. We have charted the learning according to our analyses in Table 14 below:

**Table 14***Learning and Location of Expansive Learning After Engeström (2015)*

Learning	Activity system as a unit of analysis	Multivoicedness	Historicity	Contradictions	Expansive cycles
Who are learning?	Interconnected activity systems UCA/UniBO /IIT	Researchers Professionals Students Facilitators			
Why do they learn?	Building of a shared object of activity		Historically emerging pressures: new tech available responding to a societal need, need to bring it to users	Contradictions between new object and available tools and rules in activity systems	
What do they learn?	New pattern of activity: based on onboarding, i.e., the involvement of participants in activity systems under a different division of labor towards third parties		Coexistence of old and new concepts: technology readiness and market research vs. co-construction of needs between stakeholders and researchers	Old and new concepts: tech readiness vs. onboarding of users into the process	Expansion of the object from auditing of clients and opportunity measurements to researcher/professional student network

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How do they learn?	Instrumentalization of community Knotworking	Dialogue and debate between positions and voices focused on needs	Contradictions converted from need state to double bind to resistance to realignment	Learning questions to analysis, modeling, examining
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We would like to characterize the new type of learning focusing on *what is learned* and *how it is learned in the activity*. We contend that a new pattern of activity is the main source of learning. It implies the coexistence of old and new concepts stemming from the instructional sequence (channel intervention), and new ones emerging both from the experience of the instructional sequence and from the evolution of interactions in knots. This two-fold influence allows participants to address the aggravated conflict of making a developing technology *reliable* i.e., trustworthy to third party potential users. This resolution occurs through the emergence of a relevant process stemming from interactions in knots: we contend that the outcome of the modeling phase displays a switch in use value as far as the object is concerned. This suggests the prevalence of the merging of concurrent goals into a shared object, visible in Table 14 above, considering *how things are learned*. Knotworking, through multivoicedness, allows for contact between positions and needs that are concurrent, revealing further contradictions leading to resistance, aggravated conflicts, and progressive emergence of associated types of DMC and ELA, which are further discussed below in section 5.2.4.

To conclude this section, we interrogate the constitutive elements of expansive learning in the context of hybrid educational activity after Yamazumi (2021, pp. 59–62). We contend the analysis of data has allowed us to identify (a) a *historically new type of learning*, as a pattern of activity relying for its emergence on both the instructional sequence supporting the process and new concepts gathered from interactions in knots (b) emerging as *a system of object-oriented and*

*instrument-mediated collective learning activity*, occurring over multiple interactions in knots where interview processes are refined and adapt as instruments in the system (c) as an *activity-producing activity*, through the emergence of a concept-object systematizing the knotworking process (onboarding), qualitatively different from the initial stimulus 1 (d) as learning based on *dialectical change and development of human activities driven by their inner contradictions*, which we exemplified in section 5.1; (e) as learning causing a transition from *individual actions to new collective activities*, characterized by the widening of potential participants coupled to a widening of the field of application which expands the social-spatial dimension to foster new collective activities. We further contend this widening resulted in the emergence of a generic model. Finally, Yamazumi identifies expansive learning (f) as learning aimed at the expansive development and *mastery of new activities* through the creation of instruments. In this sense, we contend *co-configuration* as emerging from a vertical path of development aiming at the mastery of collective relation to society, inspired and modeled after knots. The pathways used to produce the expansive learning described above are further detailed and characterized in the following section where we discuss the DMC and ELA reported in section 4.8. We develop further the clusters identified in section 4.8.5.1 in the following section.

#### **5.2.4 Expansive Pathways: Two “Pushes” and one “Pull”**

The evolution in DMC and ELA identified in previous sections allowed us to identify a series of major changes occurring over *S1 ↔ S2 prototyping 3* and *S1 ↔ S2 onboarding*. These changes resulted from the joint effect of three critical encounters which resulted in major shifts in activity, described in section 4.9.2. Sannino and Engeström (2017) have suggested a strong connection between DMC and ELA; we intend to refine further the results presented in the previous section and interpret the results according to two distinct phases: the first sequence (S1

↔ S2 field of application, S1 ↔ S2 prototyping 1, S1 ↔ S2 prototyping 2 S1 ↔ S2 prototyping 3) is dominated by conflicting motives expressed as *dilemmas* exerting a *push* phenomenon on the activity that the participants respond to by *explicating new possibilities*. We interpret this as a *push* phenomenon due to the high prevalence of *dilemmas* and *conflicts* during which conflicts of motives translate into ambiguity and uncertainty over the object of the activity. Additionally, the number of auxiliary motives remains high under the joint pressure of a wide problem space and lack of a defined object as evidenced in Figure 31. As a result, participants envision a wide number of possibilities through divergence, imagination, and future orientation.

A second phase (S1 ↔ S2 prototyping 3 and S1 ↔ S2 onboarding) sees the emergence of stronger auxiliary motives and stimulus 2 under major pressures exerted by critical encounters in knots. We identify it as *future-oriented* and ruled by a *pull* phenomenon as the second stimulus creates a perspective aimed at mastering and overcoming problematic situations. In our view, the *pull* exerted is made possible by a restrained problem space, characterized by lower manifestations of discursive manifestations of contradictions (Figure 33) and the simultaneous emerging rise of learning actions specific to *committing to concrete actions to change the object* and *envisioning new models* (Figure 46). As described in section 4.8.5.1, our results suggest three potentially expansive pathways which we describe as associations of DMC, ELA and S1 ↔ S2 pathways at intermediate levels. We recall the results from section 4.8.5.1 here: (a) *dilemma* and *explicating new possibilities*, (b) *conflicts* and *resisting*, (c) *critical conflicts*, *double binds* associated to *envisioning new models* and *committing to concrete actions*. In our case, pathway 1 may be associated to S1 ↔ S2 field of application and prototyping 1, while pathway 2 involves S1 ↔ S2 prototyping 2 and 3. The third pathway may be associated to S1 ↔ S2 concept formation. The DMC, ELA, and conflicts of motives associated to each sequence are described

in Table 15 below. We also contrast the data with expansive transitions described by Engeström and Sannino (2010):

**Table 15**

*Conflicting Motives Across S1 ↔ S2 Units and Related Expansive Transitions and Conflicting Motives*

S1 ↔ S2	S1 ↔ S2 FOA	S1 ↔ S2 Prototyping 1	S1 ↔ S2 Prototyping 2	S1 ↔ S2 Prototyping 3	S1 ↔ S2 Concept
	“Push 1”		“Push 2”		“Pull”
Type					
Conflicting motives	Learning ambitions vs. performance	Centricity vs. systemicity	Developing an intangible object	Having a field of application vs. not having a field of application	Reliability vs. developing technology
	Risk vs. reward		Lack of numbers and figures	Reaching a satisfactory result vs. not reaching a result	
DMC	Dilemma		Conflicts		Critical Conflicts
ELA	Explicating new possibilities		Resisting		Double Binds Envisioning New Models
					Committing to Concrete Actions
Expansive directions	Social-spatial		Anticipatory-temporal		Systemic-developmental
	Anticipatory-temporal		Moral-ideological		
	Moral-ideological				

In our data, *push 1* is associated to three types of conflicting motives altogether: one is concerned with the object of the activity from different perspectives: a student perspective,

setting learning ambitions vs. performance of the outcome of the process; the second conflict of motives is between the position in the context of APT i.e., as the *object* or as a *tool*. Finally, the last conflict of motives identified also regarded the object of activity which we identify as a manifestation of the *novelty* vs. *usefulness* primary contradictions described at section 5.1.2. In this phase, the conflict of motives is experienced as a *risk* vs. *possible reward* attached to finding a field of application convenient and compelling to all participants. We identify this phase as a primarily divergent phase during which primary contradictions are questioned and debated in polylogs and may serve as generative devices which afford participants with material to trade off, generate, and explicate new possibilities from the debated tentative configurations in activity.

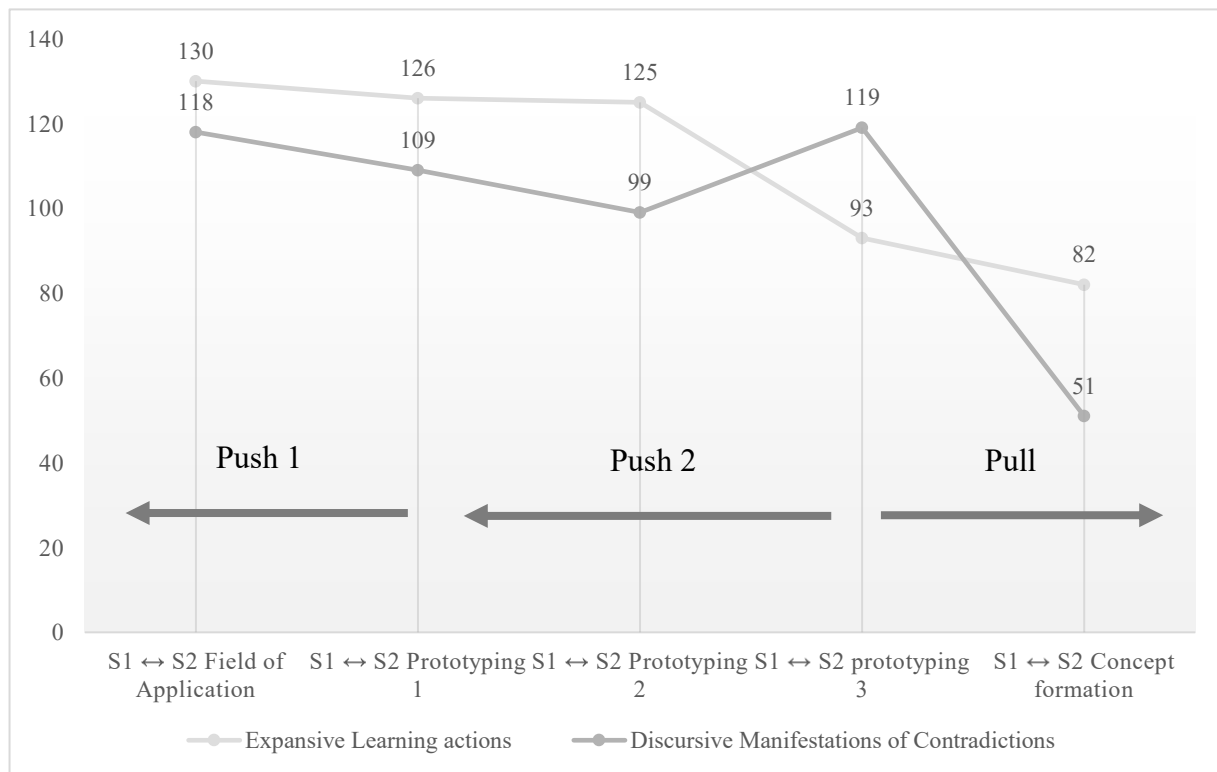
The *push 2* phase, on the other hand, is dominated by *conflicts* and by *resisting* in the face of contradicting motives directly related to the main double bind faced in the activity: the intangibility of the object causing discrepancies in interviews caused by the lack of data to either stimulate or prototype relevant artifacts to use in knots interaction. This sequence is also characterized by a critical encounter that drives the collective to switch *field of application*; this major discontinuity forced participants to ascend from the abstract to the concrete, by devising a generic solution, a model.

Finally, the *pull* phase is characterized by *critical conflicts* and directly addresses the *double bind* of *creating reliability with an intangible developing technology*. Interestingly, this sequence is characterized by *envisioning new models* and *committing to concrete actions* to affect the object of activity derived from the concept of *onboarding*, which serves as an auxiliary motive. We summed up the three phases in Figure 39 and integrated DMC and ELA in Figure 46 below:



**Figure 46**

*Distribution of Clusters of DMC, ELA and S1 ↔ S2 units*



Furthering the effort to identify conflicting motives and expansive transitions allowed us to identify each of these transitions as reported in Figure 38 above. The transitions may be conceived as overlapping; as a result, we identify the first sequence running over S1 ↔ S2 field of application and S1 ↔ S2 prototyping 1 as revolving around setting ambitions across non-shared objects of activity involving groups of individual subjects rather than collective subject *per se*. The dimensions concerned at this stage may be described as primarily *moral-ideological* involving negotiations about responsibility to perform the choices to get the collective closer to a shared object across a variety of interests represented. We identify two further overlapping dimensions, typical from a knotworking situation in which interviews are performed, i.e., attempting to respond to the recurring question of “Who else should be included?.” The *social-*

*spatial* dimension is particularly prevalent given the conflicting motives involved in the activity at this stage. A third dimension may further be identified as *anticipatory-temporal* and regards the design of the process undertaken by participants to overcome conflicting motives in this sequence, i.e., the subsequent steps to be taken in the process.

By contrast, the second sequence (S1 ↔ S2 prototyping 2 and 3) may be characterized as occurring across two developmental transitions: *anticipatory-temporal* (“What previous and forthcoming steps should be considered?”) as it relates to tensions emerging from the difficulties related to developing an intangible object for which no data previously exists. As a result, participants are constrained to give up the field of application they have been working on, triggering further conflicting motives i.e., the prospect of producing a satisfactory outcome to the project. These motives trigger a discontinuity in the activity from information emerging in a knot. Nonetheless, the *moral-ideological* dimension is still prevalent over this phase, as the main discontinuities addressed are suggested to participants through interactions in knots, which reveals a progressively and increasingly distributed process of decision in space and time. The response to the question: “*Who is responsible and who decides?*” is harder to answer for participants as the process progresses, which hints at a major reshuffling of the division of labor in the system as credibility and decision power are redistributed across subjects.

Finally, the third phase we identified (S1 ↔ S2 concept formation) is more directly concerned with addressing the double bind of creating reliability on a developing technology and eventually a tentative model addressing how this double bind emerges. The ascension from the abstract to the concrete that ensues, and the subsequent progressive modeling of a shared object is in our view concerned with the *moral-ideological* dimension of determining who should be involved in the process, while at the same time fostering a major qualitative change in the object

considered. It therefore addresses *systemic-developmental* expansion e.g., considering the future development and future-oriented projection regarding both object and system of activity.

Barma and contributors (2023) showed over a longitudinal investigation that the expansion of teachers' activity could take the form of three categories of conflicting motives that were used through dialectical analysis relying on DMC and ELA. Namely, the authors identified three categories of conflicting motives involving (a) the importance of critical contexts involving *questioning* and *resisting change*, (b) productive discovery episodes leading to *modeling of new objects* of activity, and (c) social contexts consequential to practice and to the community of practices involved implying broader expansion of the activity. From the perspective of this research, the three categories exposed above echo categories in section 4.8.5.1. To put the results in perspective, we suggest Table 15 to visualize the evolution of conflicting motives over the macro  $S1 \leftrightarrow S2$  pathway. First we explain the role of each conflicting motive in the pathway in which it occurs, then we intend to contrast them with the clusters identified in our data. Finally, we intend to question whether the phases identified may be compared to the ones identified by Barma and contributors (2023). The detailed description of each  $S1 \leftrightarrow S2$  unit in this PhD study may be consulted in sections 4.2 to 4.6.

Following Barma and contributors (2023), we interpret the first set of conflicting motives as inherited from historically accumulated tensions, and the second set as a reaction to a shifting context due to the introduction of a different set of norms resulting in a productive episode. The latter may involve creative divergent sub episodes as a reaction to the previous phase which bleeds over to the third phase as practice gets impacted, undoubtedly reaching historical change. However, the results from Barma and her collaborators may hint at a sequence of questioning and resisting change due to a critical context, which may be put on the same plane in our results

as occurring over the second phase during which critical encounters trigger discontinuity. In the study of Barma and collaborators, the second phase is characterized by a *divergent phase* which may hint at productive discovery and therefore at the modeling of a new object, which in our case is akin to the beginning of the sequence while the last conflicting motives may be compared to implementing a new object of activity, and pushing it towards historical transformation of the system, which is beyond the scope of the data collected in this research.

However, the perspective provided by this PhD study informs both cases by evidencing a succession of *regressive* and *expansive* phases. Expansion leads to resistance which in turn leads to a new model characterized by successive rounds of progressive expansion. Although the succession of the sequences may not overlap, the rotation of potentially regressive and potentially expansive phases may be a common feature in both cases, with an important influence of the context as in our data they emerge from interactions occurring in knots. To Barma and colleagues (2015), expansive resolution of conflicting motives (p. 9) refers to the expansion of conflicting motives leading to further conflicts of motives in expanding development cycles analyzed through double stimulation which seek to resolve tensions producing subsequent struggles, obstacles, tensions and clashes.

The inclusion of developmental transitions from Engeström and Sannino (2010) in section 5.2 allows us to determine further and characterize expansive pathways as tentative resolution of conflicting motives (Barma et al., 2015) along expansive dimensions that evolve over time, and contextual encounters according to the phase and transformation trajectory undergone by the object. In our view, the dimensions get refined over time, as the process is “trimmed” and focuses more efficiently and energetically as time goes by. The following section further questions the process and seeks to add resolution to the process of *problem finding*.

A study from McComb (2014) may provide further contrast in this discussion: according to the authors, a divergence effort is to be expected in initial phases of problem construction, which is consistent with the push 1 phase described above, and its high quantity of related auxiliary motives contemplated by participants. However, the study of McComb and collaborators indicates that the highest-performing teams *quickly converge* while low-performing teams had difficulty converging on a shared object of activity. Furthermore, high-performing teams incorporated new elements and improved their designs, while delayed convergence was associated with a decline in performance. These results therefore suggest a threshold of divergence above or below which overall quality of designs may be affected.

In other words, we contend that *energy* is required to move a collective to control and mediate its volitional processes over highly ambiguous, open-ended, and ill-defined issues such as the benign object of APT. These efforts are costly in the early phases of the process and may result from the joint effect of intra-collective dynamics and material circumstances used to break away from problematic situations by resolving conflicting motives. Therefore, conflicting motives may be more conducive to the emergence of a new object when the problem space allows the energy to be focused efficiently i.e., when it is *narrower*, illustrating the argument of Sannino according to whom *problem defining* may be characterized as a critical step in expansive cycles (Sannino, 2023).

### **5.3 The Pull Towards S2: Object Modeling in Practice**

We have defined in section 2.1.3.3 an emerging second stimulus as satisfying four characteristics: (a) *intentionality*, (b) *progressive sense making*, (c) *anchoring* device bringing stability to the activity over time (d) addressing aggravated *contradictions* (Engeström, 2011). We define the emerging concept of *onboarding* as an initial tentative formulation coming from a

critical encounter in a knot, and we further contend that it results in participants coming up with a *model*, which we further detail in section 5.3.3 below. This model emerges as a generic solution that embeds characteristics and functions previously identified and accumulated. In hindsight, we were able to identify the model as a rapidly emerging occurrence. We identify it as an instance of will formation and therefore we qualify it as a conscious decision offered, debated, and agreed upon across the integrality of participants.

We have described the stimulus 2 in our data as emerging from the concept of *onboarding*. We analyze this emergence as reflecting the evolving role of the *community* over interactions in knots. It emerges as a *hybrid* (Engeström, Rantavuori, et al., 2022a) concept emerging across worlds which further gets refined and layered with further meaning. We identify this progressive complexification and layering dynamic after Olsen (2019) as primarily *vertical* i.e., emerging from interactions with experts and more advanced systems, and subsequently refined through *horizontal* regulation i.e., negotiated with peers within the central activity system. Although we interpret the object as *emerging from* this vertical expansion process, its final iteration appears as a hybrid mashup of the concepts of onboarding, simulations, visualization tools, and websites, dubbed *Colab* by participants. In our view, *Colab* resulted both from a *horizontal* and a *vertical* regulation process. In this next section, we discuss the vertical character of emergence and the horizontal nature of refining and negotiation involved and which coincides with shifts in DMC and ELA.

Analysis in previous sections suggested in Figure 46 and Figure 39 displayed the correspondence and shift both from problem definition to problem solving and envisioning new models. These shifts are attributed to the stabilizing force of the object for the collective who then invests its time and energy in a *pull* effort towards potential futures. Foot (2002) also

reported the difficulties associated to the pursuit of an object of activity and concluded her study suggesting identifying an object through what is *energizing* it (p. 148). In this case, we interpret this energizing as addressing the motives of the activity which manifest as *object-concepts*. We further associate it to the *push* effect identified by Sannino and Engeström (2017), as different types of energy emerging and channeled in the activity.

Finally, the analysis suggested in previous sections illustrates the emergence of a stimulus 2 in response to aggravated conflicts and contradictions experienced as *dilemmas* and *double binds* (section 4.7.5). These dilemmas and subsequent double binds aggravate through interactions in knots. In our view, the emergence of a stimulus 2 with enough attraction corresponds to a clear expression of agency as it breaks away from the initial formulation of the process (described in section 3.2.2). Relying on TADS, we identify the emergence of agency as depending on the gradual refining of problem space which implies the growing experience of participants and encourages a constant refining of auxiliary motives over time. In this sense, the emergence of a stimulus 2 (Figure 32) corresponds to (a) the simultaneous decreasing over time of DMC and of ELA (Figure 33, Figure 35)—with the exception of a final rise in *taking actions to change the activity*—and (b) the number of auxiliary motives produced. We do not attribute this effect to the progressive diminution of artifacts used and commented above (Figure 31) but rather to the cumulation of epistemic actions over time, accumulating energy which may reenter the system through a growing “buffer” of potential ideas and artifacts stored over divergent phases of the process. This buffer stores tentative artifacts, concepts, and concept-object over time, until some of its contents may be redirected to bridge the execution gap. The adoption of such a critical artifact then triggers a *conditioned response* described by Sannino (2015b) in the second apparatus of decision-making (Figure 7). The triggering of such a conditioned response

requires energy, time, patience, and persistence on behalf of the collective prior to its activation. Once activated, it may then resort to an operative mode of action-rather than actions or activity motivated by motives: the path gets reinforced and enacted through the pull force of an emerging shared object. In this respect, problem finding i.e., object modeling may indeed result from the matching of a need and object (Miettinen, 2013), and agency may result from the alignment of both. The following section interrogates and contrasts the interconnection of TADS and knots.

### 5.3.1 *Secondary Contradictions at the Community Pole*

We described knotworking with respect to activity systems after Yamazumi (2021) and Engeström (2008) in Figure 11, which displayed the centrality of the *community* pole which we have described as subjected to constant negotiation and change over time (described in section 4.9). We further identify secondary contradictions whereby two elements of a system are und tension. We adopt the perspective according to which *rules* and *community* should be taken into account according to their mediating effect on *object*, *subject* and *instruments* (Grimalt-Álvaro & Ametller, 2021). Ivaldi and Scaratti (2020) report on the role of the *community* pole outside of a knotworking scenario. They report tensions between subject and end users involving a top-down approach versus the need to reconfigure peer-to-peer interaction. They interpret the nature of the changes observed as rooted in exchange value (organizational change) vs. use value (emergent needs in the territory). We consider this case to be relevant to our study, as in this research the modeling of a new object involves subsequent tensions and adaptation occurring in the activity system. In our case, the gradual evolution of the *rules*, *community* and *division of labor* have been illustrated in detail in section 4.9. The *instruments* used in the process show the prevalence of interviews submitted to qualitative shifts over time. As the main information gathering tool available to participants, they are central to inform both process and subject about potential



subsequent courses of action: we contend progressively resolved contradictions at the *instruments* pole directly inform the *community* pole due to the participative nature of the interviews occurring in knots, changing both the nature of these interactions and commanding the progressive tentative reorganization of the central activity system, modeled after knots: we further contend in section 5.3.3 that interactions in knots are *instrumentalized* and serve as the model of a germ cell and therefore acts as a regulation device to overcome the primary contradictions through mastering one's relation to society; expansion in this case, as a regulation process, therefore involves *horizontal* and *vertical* dimensions.

### **5.3.2 TADS and Its Evolution Across Knots**

We have contended that interactions in knots are potentially generative in exerting the *pull* force described above. From this perspective, previous sections (4.9.2) identified three encounters as instrumental in the evolution of the roles played by the community in knots. We have argued after Hopwood and Gottschalk (2017) that knots may serve a similar purpose in a hybrid educational activity as channels appear as constitutive elements of double stimulation processes in ecological settings i.e., *in the wild*. Knots may be constitutive of the potential for agents to shape and master their relationships to the environment in challenging situations. Bringing professional and higher education cultures into direct critical and potentially creative encounters may have the same effect and appear as defining elements of expansion in hybrid educational activities. We have further identified after Nawab and collaborators (2021) potentially expansive disturbances in educational settings as caused by the *multiplicity* of stakeholders involved, the participation of *external* participants, the intervention of an *external* source and the involvement of *novices* as major sources of contradictions within an activity. All four characteristics apply in this PhD study to knotworking.

Warmington and colleagues (2004) further point to the lack of conceptualization of work-related learning characterized by knotworking and wonder whether professionals could be trained to knotwork, a perspective that could be addressed through promoting the overcoming of contradictions and conflicts, allowing participants to overcome classic notions of partnerships, teams and networks. According to the authors, knotworking may involve a redefinition of roles, which we identified in our data as expansion at the *division of labor*, *community* and *rules* poles of activity systems promoting hybrid professional types and co-configuration.

When considering the emergence of a new object of activity, our data suggested important qualitative shifts at the *community* pole of activity in which people may be acting as instruments mediating the activity from interactions in knots (section 4.9.2). Besides, interactions with organizations across fields and domains may raise further contradictions in an activity system such as tertiary contradictions, which are activity-producing contradictions (Engeström, 2015) with the ability to generate creative energy in groups exposed to culturally more advanced activity systems. Morselli and Sannino (2021) establish a direct connection between the idea of critical encounter (Engeström et al., 1995) and the significance of contradictions in DMC (Engeström & Sannino, 2011) as a potential locus for the emergence of an object under the constraints of a conflict of motive rooted in historically accumulated systemic contradictions (p. 50). However, as we have discussed the *dimensions* of expansion and identified the ruptures brought by vertical collaboration and elaboration processes brought by horizontal ones, our data has allowed us to identify further expansion processes beyond pure instrumentalization of the community pole of activity, which we discuss below.

In this section, we further discuss the emergence of stimulus 2 resulting from *ascending from the abstract to the concrete* (Davydov, 1990) and the importance and relevance of knots in

the expansion process. Sannino and Engeström (2017) stress the importance of both conflicts of motives and second stimulus as preconditions for ascending from the abstract to the concrete originating from a spontaneous episode, abstracted into a *model* (Davydov, 1990). Engeström (2015) further envisions this method as the gradual process of inferring the essence of an object and the subsequent reproduction of its development through tentative resolution of its inner contradictions. It is an important instrument of the expansion process which materializes in this case in the global shift from stimulus 1 (*“Creating a service and corresponding economic model”*) to a stimulus 2 (*“Onboarding potential partners to co-configure solutions adapted to their needs”*). This shift is heavily influenced by critical encounters experienced in knots and seems to mirror accumulated experience and tensions emerging from the interaction between two or more interacting activity systems. These interactions involve debate, negotiation of various viewpoints and voices and they may result in a hybrid educational activity (Yamazumi, 2021, p. 34). This process may lead to the development of *hybrid educational innovation*, defined as “a process aiming at creating advanced networks of learning based on the collaboration among a variety of participants both inside and outside a school, gradually transcending the school’s institutional boundaries” (Yamazumi, 2013, p. 61). The goal of this technique is to encourage cycles of expansive learning that will nurture creativity.

Engeström and contributors (2015) describe *critical encounters* as “an event in which two or more relevant actors come together to deal with a problem with a potential shared object of activity” (p. 49) and the authors also equate this potentially shared object with a corresponding *conflict of motive*. As such, critical encounters represent opportunities for learning i.e., formation of transformative agency and emergent concepts. It therefore results that conflicts of motives may fulfill a double function: (a) trigger learning and (b) stimulate creative agency. The authors

further state that they stimulate a *conceptualization effort*, understood as the articulation of an idea or characteristic that has integrative potential for setting a direction to a solution to the perceived *conflict of motive*. Hopwood and Gottschalk (2020) further associate double stimulation as closely related to the necessity of volitional action brought to resolve situations in which a conflict of motives is experienced. However, our data suggests conceptualization efforts and critical encounters as separate occurrences over time; critical encounters may engender tertiary contradictions, and they appear as ruptures between motives and objects. Such ruptures involve at least another activity system to interact with the central activity. Contradictions in this case, when encountered, give rise to new qualitative stages and forms of activities or invisible breakthroughs (Engeström, 2015, p. 73). However, our results show the role of tertiary contradictions occurring during critical encounters as ruptures from the activity model that carry them, and which act as germ cells of more culturally advanced activity systems. As such, tertiary contradictions may emerge from confrontation and analogies operated with culturally more advanced systems.

According to Engeström and colleagues (2007), learning in distributed networks involving multiple activity systems is challenging: it may not only require to consider activities as generative but the expansive learning process may also appear as discontinuous and interrupted over periods of time, albeit during a micro-cycle. These disruptions may vary in length and intensity due to gaps in knowledge or agreement among participants triggering further conflicts, e.g., in  $S1 \leftrightarrow S2$  concept formation in the data presented in this research (section 4.6).

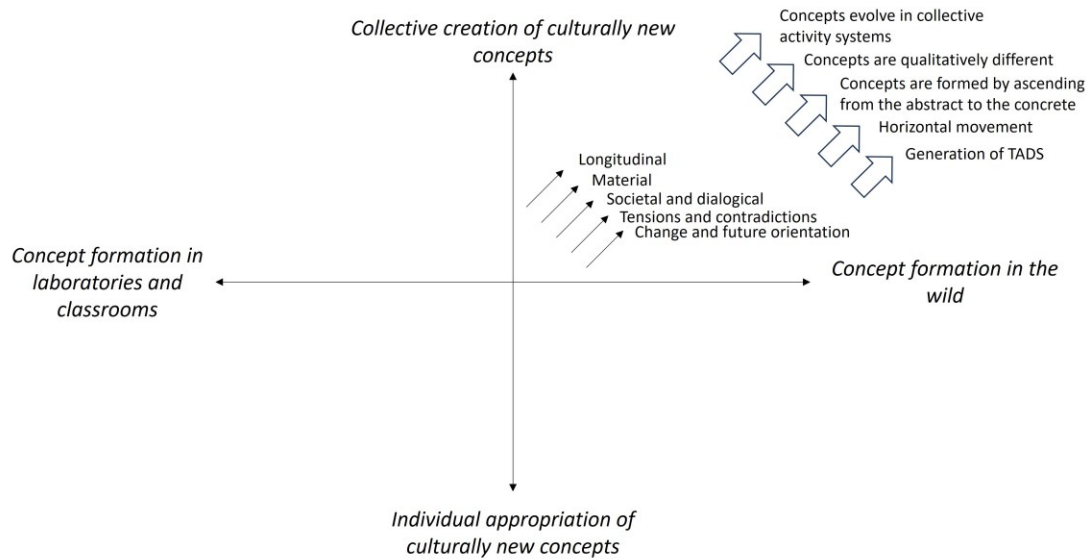
Engeström and collaborators (2007) further specify the difference between *mundane* and *directional* discontinuities as *breaks* in the developmental process. *Directional discontinuities* result from the cessation of a collective learning effort and trigger an alternative pathway. This

cessation leads to dropping the current expansive learning process. *Mundane* discontinuities, on the other hand, are ones that appear from the fragmentation and diffusion of learning efforts due to e.g., inadaptability of instruments used and results in the gradual cessation of actions. While this echoes the argument of Blunden (2023) about incoherent activities, and the potential shortcomings regarding the loss or inability to model and share an object, cessation of a pathway, on the other hand, requires *bridging actions* to enable the following cycle of learning actions to build on the outcomes of the preceding cycle. Our data shows *directional discontinuities* emerging from critical and creative encounters which are discussed in the following section.

Engeström (2020b), in this respect, expanded the analysis offered here in the sense that he envisioned the need stated in previous sections to address *concept formation* across productive activities including education. He suggested accounting for concepts as complex instrumentalities, social relationships, and patterns of learning within the activity system. We illustrate the premises in Figure 47:

**Figure 47**

*Concept Formation in the Wild Adapted From Engeström (2020)*



### 5.3.3 Knotworking as the Germ Cell of Onboarding

Foot (2002) reported in her research the emergence of an *object-concept*, shaped by phases of “chronological sequencing” (p. 148) which we have identified in this PhD study as S1 ↔ S2 units of analysis. Foot describes the layering of the object concept through hybridization in epistemic community building as an additional layer to the object-concept. We therefore interpret this instance as an occurrence of an object modeled from interactions in knots. Knotworking may intensify and accelerate early phases of a design process by creating mutual understanding of needs in a collective, a process that should require development of tools and processes (Kerosuo, 2018). The concept of *critical encounters* (Engeström et al., 1995) with a potential to expand in *creative encounters* (Miettinen, 2013) may fruitfully account for the creative nature of object-oriented analogical reasoning in which boundary-crossing objects may transfer ideas, concepts, and instruments from unrelated domains into inquiry, i.e., as the emerging object resulting from encounters during which the complementarity of competences

displayed may serve as a trigger for agentive actions and may allow participants to operate analogical transfer at object level rather than in actions or operations in an activity. This lead is accurately supporting our analysis of the emergence of a stimulus 2 originating from such a process. It also supports our interpretation of both a *critical* and a *creative* encounter over very limited time spans as carrying the germ cells of future-oriented models resolving conflicting motives. In this respect, the knot may itself be understood as a tentative model, a prospect that should be further supported by subsequent studies. However, when comparing results from Kerosuo (2018), one specificity in our case stems from the extremely short-lived nature of the knots emerging in our data. Indeed, these encounters were most often single occurrences rarely over an hour in duration. In Kerosuo's study, however, the knot is two days' length. Furthermore, Sannino and Engeström (2017) also reported a case in which the knot was used as an auxiliary motive to help a collective break from a paralyzing situation involving societal change in a change laboratory; in this sense, this PhD study complements their results by showing a similar process *in the wild* and simultaneously showing the far-reaching influence of knotworking in the process.

Engeström (2013) signals the necessity of creating *bridges* between alternatives over the course of discontinuous cycles of expansive learning. Bridges require the articulation of contradictions and of an object to be modeled *historically*. We argue that critical and creative encounters may participate in fulfilling this function as *they cause* a breakdown of scientific validity of a tentative object of activity. The cessation of the *plastics* field of activity forces participants to *ascend from the abstract to the concrete* and create a model with generic value and function to the activity. However, a possibly distinctive feature in our case is that *bridging*

*actions* are performed through critical encounters and tertiary contradictions, an instance we were not able to identify elsewhere in the literature, as exposed in the coverage in section 2.1.1.

Notwithstanding, expansive learning in hybrid educational activities may be seen as a historically new type of learning (Yamazumi, 2021). Expansive learning in knotworking aims at constructing a new object and concept for collective activity and implementing the new object in practice. However, such advanced levels of development are beyond the scope of this dissertation, as detailed in section 3.2.2. This includes practices, goals and understanding of why participants do things the way they do. Expansive learning therefore involves an agentic layer (Engeström, 2008, p. 62) stemming from a vertical dimension of expansion and a directional discontinuity in the process.

Yang and contributors (2022) have reported the importance of analogical reasoning in real-world problem solving, i.e., knowledge-rich contexts. Engeström (2015) identified analogies as an instrument of expansion. However, in this case, the contradictions emerging from exposition to a more advanced model of activity show that vertical, and *generative*, are perceived as properties of a target system inferred from and brought into the main activity system (Clement, 2008). In the case reported in this research, we contend that the main qualitative changes, namely the main breakthrough occurring is twofold: (a) it hints at analogical object modeling, as the whole model of a single meeting is abstracted and inserted onto the source model of activity, and (b) it is further reinforced by the embodied visit to a company showroom which gets layered as a secondary feature of the main object of activity as complexification of the object (Cakir et al., 2022). In this respect, we identified analogical reasoning as a main instrument in object modeling to insert an object-concept into a new system of concepts, therefore bringing novelty and resolving conflicting motives. Simultaneously, our data



exemplifies the use of models in expansion processes, and we contend that the connection between analogical reasoning in concept formation in the wild may be a further valid point of inquiry. Further, though associations operated through analogies may appear fortuitous and hard to predict, it appears relevant to observe that in spite of the seemingly randomness, it is possible to establish that both solutions (source and targets) in both contexts appear to address comparable motives as a precondition of analogical mapping to ascending from the abstract to the concrete. This is another valuable research avenue in our view: the potential relation from motives to ascending from the abstract to the concrete through matching motives.

In this instance, the emergence of stimulus 2 resulting from analogical reasoning operations is *an activity producing activity* resulting from tertiary contradictions and triggering a critical and creative encounter. In this sense, it participates in generating expansive learning through object-oriented collective activity over evolving instruments. The process of modeling of an activity system may be further described as learning propelled *by dialectical changes* under the pressure of primary contradictions identified through their discursive manifestations. Dialectical changes further triggered development regarding the *division of labor, subject, and community*. Individual subjects in this respect evolve into a *collective subject* as conflicting motives are addressed and resolved, and new activities are envisioned. Learning creates *new instruments* from expansive development and allows collectives to master their new activities, and their relation to society through an expansion of the role of the community as temporary coalitions embedded in knots towards the expansion of instruments in the activity. Community may therefore be said to be instrumentalized through knots, a perspective that explains the reason its functions evolved over time towards one we defined as *co-configuration*, which we identify as the germ cell of *onboarding*.

Lotz-Sisitka and colleagues (2015) define *germ cell activity as an activity* embodying a response to a contradiction by combining critical, social and historical-material processes with values, dispositions, cognition, individual and collective agency to foster expansion, change and transformation (p. 77). The authors point to *socio-cultural expansive environmental learning studies* as potentially conducive to the emergence of new expressions of agency occurring in niches at local level, a level that may be conducive to social change and transformation. However, transitions represent major challenges that need to be addressed through pedagogies that value disruptive competences such as *transformative learning*. The authors contend that to address those issues requires to expand the learning modes available to engage the wicked problem, societal challenge, or runaway object of climate change, which may require an integration of sustainability-oriented higher education research teaching and learning for the emergence of agency in transformative praxis contexts. We believe the current case to be an instance of such teaching for agency in transformative praxis context, and a tentative pattern is illustrated in Figure 48 below:

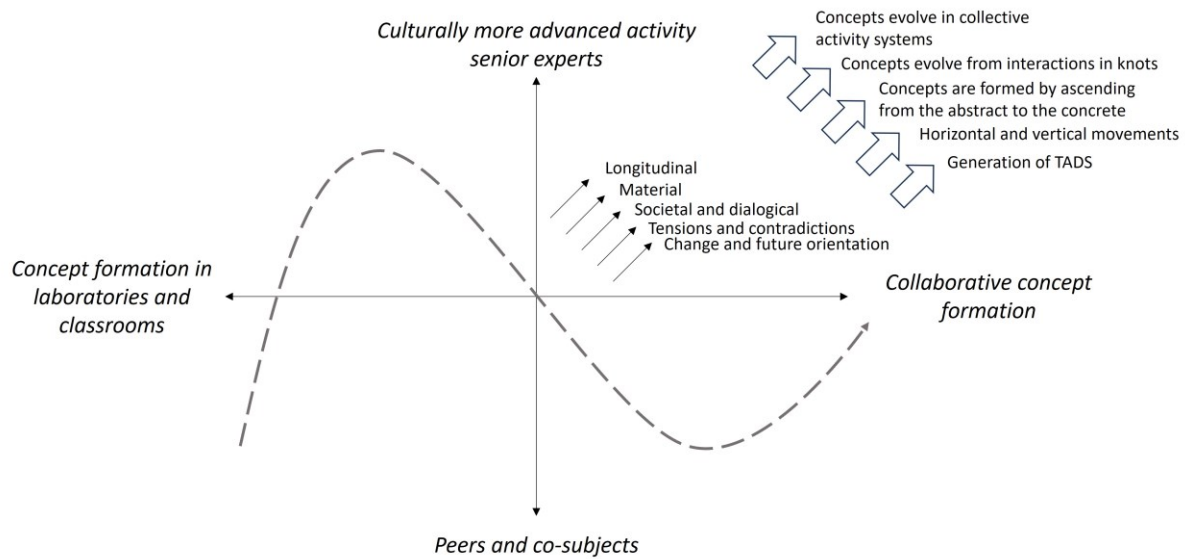
**Figure 48***Oscillating Pattern of Collective Concept Formation in the Wild Through Knotworking*

Figure 48 attempts to present a generic pathway after Figure 44 presented in introduction of this chapter. It incorporates the oscillation patterns observed by Sannino (2016; 2015) and Hopwood and Gottschalk (2017) and suggests to incorporate a vertical axis of development, as evidenced by knotworking, aiming at concept formation described by Virkkunen (2013) and Engeström (2020b) while adding a vertical axis of development.

## 6 Chapter 6: Conclusion

This section aims at taking perspective on results and discussion and exposing the main scientific and practical contributions of the current research project. The main results and orientation are connecting the notions of *collective concept formation* (Virkkunen, 2013) and *expansive learning in the wild* (Engeström, 2020b) as its main scientific contribution. We further approximate the notions of hybrid collective concept formation to the fourth generation of activity theory. We then proceed to identify practical contributions; from our perspective, and due to the time spent on the field, we view the use of contradictions as fruitful additions to creative problem-solving activities in educational contexts. We close the chapter with an exposition of limitations of the research and potential subsequent studies.

### 6.1 Scientific Contributions

#### 6.1.1 *Collective Concept Formation in the Wild*

This research allowed us to contrast previous findings (Barma et al., 2023; Engeström, 2020b; Engeström et al., 2015; Hopwood & Gottschalk, 2017) and suggest the role of knots in temporary coalitions occurring in non-formative interventions as producing a tentative germ cell to the new activity, through a process we described as an occurrence of analogical reasoning used to frame artifacts within new systems of concepts. As a result, this research contributes knowledge to hybrid activities, and suggests an original framework to studies of problem solving and creativity from a sociocultural perspective. Further, teams engaged in creative problem solving spent the great majority of their time engaged in problem construction behaviors (53.56% of data) compared to idea generation (28.03%), or idea evaluation (18.56%) (Leone et al., 2023). In this respect, regulation may occur in a variety of ways, including vertical expansive movement and directional discontinuities which are further accommodated through horizontal

negotiations; in this respect, we further identify analogical reasoning as an instrument of collective regulation which allows the collective to reframe and recombine the new object-concept into a new system of concepts to mitigate tensions. We further argue for knotworking as a potentially fundamental element of double stimulation in ecological settings. Although the literature describes and expects mostly horizontal development to occur either in formative interventions through dialogical, synchronous, distributed, collaborative and self-organized development of knowledge (Engeström, 2020b; Virkkunen, 2013, p. 123) as illustrated by Figure 3 and Figure 47 when participants belong at least temporarily to the same activity system and at least partially share an object or motive. However our results and analysis are in line with Hopwood and Gottschalk (2017) where double stimulation in the wild may appear rather dispersed, fragmented, recursive, multithreaded and nonlinear. In the process, stimuli may be reconfigured relative to other stimuli brought to the main system through knots to bridge past and present (Hopwood & Gottschalk, 2017, p. 35), further displaying the function of secondary stimuli in relation to volitional action and conflicts of motives; in this respect, this research lent less importance to artifacts and stimulus 2 and therefore stressed less the potential of mediation usually used in other studies. The array of disturbances described by Nawab and contributors (2021) allowed to link knots as sources of vertical development, understood as necessary features of double stimulation in the wild, and which may point to subsequent studies aiming in the same direction. This dissertation therefore also contributes to understanding the functions of knotworking e.g. (Kerosuo, 2018) while bringing greater resolution on double stimulation. Furthermore, as far as development of the object, systemic contradictions may generate complex, adaptative and multilayered problems in activity systems where contradictions may be generative (Cakir et al., 2022, p. 2). Spinuzzi (2011) called for more studies to limit and define better the

object of activity, both theoretically and methodologically through the emergence of expansive learning, and to explore alternate frameworks to limit the object. We contend that this research aimed and contributed to the debate by suggesting the relevance of knots and vertical modes of expansion.

### ***6.1.2 Expansive Learning in the Wild***

This research set out to investigate the emergence and evolution over time of TADS as a collective regulation device over the modeling of an object of activity, which we characterized as a problem identification activity. Our analysis of S1 ↔ S2 pathways of ill-defined open-ended problem finding of the benign object of APT led to the emergence of a stimulus 2 and subsequent new object of activity resulting from major discontinuities resulting from critical and creative encounters occurring in temporary coalitions through knotworking. The case studied allowed for the description of expansive learning emerging from the transformation of the object of activity, as distributed and discontinuous movements occurring over a micro-cycle of learning actions; we were able to identify three main movements, each characterized by particular combinations of ELA and DMC and which we have characterized as two consecutive *push* from conflicting motives towards a *pull* aiming at a the emergence of a stimulus 2.

Regulation and the use of the post-Vygotskian model of TADS based on double stimulation allowed us to identify some regulation processes in complex co-creative problem solving in a hybrid educational context. By paying attention to the material dimension and using an S1 ↔ S2 unit of analysis, we were able to link the emergence of TADS to both vertical and horizontal regulation processes characterized by an integrative process composed of three phases. As a result, we were able to identify regulation happening as a socially shared process of construction of shared cognition aimed at the mastery of one's relationship to society. In this

respect, we were able to show that the activity produced expansive learning through overcoming of contradictions which we identified at three distinct levels (primary, secondary, tertiary). According to Engeström (2016, p. 47), “contradictions become an actual driving force of expansive learning when they are dealt with in such a way that an emerging new object is identified and turned into a motive” therefore echoing the cascading resolution of conflicting motives identified by Barma and colleagues (2015, 2023). On the other hand, transformative agency may be considered a quality of expansive learning in CHAT studies (Kerosuo, 2017), as discussed in the previous chapter. We further characterized *problem solving* as a *problem finding* activity involving both horizontal and vertical dimensions as an integral part of the building of a shared object of activity by giving a shared frame of activity and making meaning and sense. In this respect, problem finding generates expansion across dimensions, and favors *learning*.

The results of this research allowed us to identify (a) a *historically new type of learning*, a process of merging concepts both from the intervention channel and from interactions in knots. This led to reframe the object of activity as (b) a *system of object-oriented and instrument-mediated collective learning activity*, evolving and refined over multiple interactions in knots evolving over time through adaptation of instruments. This system was characterized (c) as an *activity-producing activity*, through the emergence of a concept-object systematizing the knotworking process as an instance of co-configuration. We also evidenced the importance and role of different types of contradictions occurring over the learning process (d) as learning based on *dialectical change and development of human activities driven by their inner contradictions*. The learning activity occurring (e) caused a transition from *the individual to the social* which we characterized as the widening of participants simultaneously to the widening of the field of application to expand the social-spatial dimension to foster new collective activities. We further

contend this widening resulted in the emergence of a generic model. Finally, we identified expansive learning in a hybrid learning activity (f) as learning that creates instruments for the expansive development and *mastery of new activities*. In this sense, we contend *co-configuration* as emerging from a vertical path of development aiming at the mastery of *collective relation to society*, emerging from and modeled after knots. The *pathways* used to produce the expansive learning displayed oscillation between channels (intervention and wider life, which we identified as knots) and aiming at collective concept formation. We further identify scientific and practical contributions in the following sections.

### **6.1.3 Hybrid Collective Concept Formation and the Fourth Generation of Activity Theory**

Rajala and contributors (2023) have stressed the neutrality of the learning sciences as a scientific community and a research object to engage with critical pedagogies in the age of the Anthropocene, marked by overconsumption and the indelible mark of human activities on climate and environment, which may in turn influence future human activity. The authors argue for student's involvement in transformative activity regarding issues such as climate change, and this research is in sympathy with this stance. In some sense, however, the prefigurative enactment of visions and futures in the present resonates with the creative act of the expansive resolution of conflicting motives within a specific framework, be it a purely utilitarian one, as the act of imagination typical of divergent thinking relates to tentative utopian visions; in this respect, Hadjichambis and collaborators (2023) contemplate the potential transformation of citizens into change agents for environmental issues through participation, pedagogy, and education for environmental citizenship. However, we remain in sympathy with the view of e.g., Schmelzer and Nowshin (2023) who contend the interdependence of both hemispheres in promoting degrowth from a global perspective; as a result, degrowth and ecological reparation



policies should emerge from the connection and integration of opposite perspectives. In an age of super complexity (Barnett, 2000), academic knowledge remains as elusive as ever to prepare for an uncertain future in which generic competences may lead to a dead end, implying an ontological transition towards human qualities and dispositions (Barnett, 2012). One potential way to address the conundrum of educating for an uncertain future may be addressed by developing global citizenship (Calvera-Isabal et al., 2023; Granados-Sánchez, 2023; Hadjichambis et al., 2020, 2023).

Coalitions need to be built between societal actors to generate learning activities that may be sustained across different spheres of activity (Engeström, 2020a); in this respect, expansive learning and hybrid learning activities may represent promising avenues to move forward beyond educational institutions and expand their relations to society at large. Sannino (2022) stresses that studies of expansive learning and transformative agency have remained circumscribed to organizational contexts and boundary-crossing settings, which we see this research contributing to. However, when addressing heterogeneous global runaway objects such as equity, social justice or climate change, these conceptual resources may fail to address the unfathomable complexity of these ambitions, however consequential or fateful the outcomes in practice. Gradually evolving learning necessities may foster new challenges on educational research; simultaneously, educational research may bring new insight to societal demands. In this sense, *hybrid educational innovations* (Yamazumi, 2021) may offer a way forward, favoring learning happening at various levels of a system. However, learning required by global citizenship may produce too many constraints for hybrid educational activities to foster true *innovations* at the border of higher education and society.

Engeström and Sannino (2021) further root a tentative agenda on participatory governance and co-creation to trace collective processes of emergence of learning and agency, and further call for a fourth generation of activity theory research relying on a unit of analysis based on multi-sectoral service integration and production across multiple levels, described as coalescing heterogeneous work activities (p. 5) and involving multiple learning cycles across hierarchical levels in society. The types of learning involved in such systems are a priority for educational research to contribute to the societal efforts required to combat climate change and foster social equity. From our perspective, the strength of expansive learning patterns engendered may increasingly rely on interwoven formative and non-formative expansive learning efforts impacting both individual competences and reorganization of human activity. In this respect, the modest contribution brought by this research regarding the regulation of collective will in uncertain and ambiguous activities may contribute to the analysis of such hybrid expansive induced across social levels, which higher education may foster. From our perspective, expansive learning should be sustained both by research teams and encouraged in everyday activities in education. However, no clear lines of guidance have been identified to engage into such global development (Agbedahin & Lotz-Sisitka, 2019), a problem which also permeates educational contexts (Hadjichambis et al., 2020, p. 2).

We contend that the merging of opposing perspectives and relations between indigenous voices could be put to work to expand the notion of knot in a higher education setting and address sustainable, developmental issues to create new exchange value. In this hypothetical scenario, fourth generation CHAT settings may appear as ways to promote learning efforts across levels, switching gear in hybrid educational activity format from multivoicedness to “hypervoicedness,” from object-orientedness to “runaway-objectedness,” specifically. Climate

change is becoming a major issue for the foreseeable future which will require to answer both to the calls of Agbedahin and Lotz-Sisitka (2019) or Hadjichambis and collaborators (2020) to promote instructional methods that promote change at individual level while being consistent with a fourth generation framework in which multiple cycles of expansive learning coalesce to foster deeply rooted and transformation across *levels of a system*.

Such scenarios involve simultaneous levels of development and a consequent number of participants. It is therefore unlikely that expansive learning could be promoted and analyzed through any one type of inquiry, and we therefore contend that complementary approaches might be mutually reinforcing the interconnectedness necessary to assume the many challenges raised. *Utopias* and *instrumentalities* thus created could bring together activists across social and educational spheres. However, the case reported in this PhD study suggests confronting perspectives to be potentially fruitful in enacting utopias. If we follow Wright (2016, 2020) and recognize such *real utopias* or *enacted utopias* (Sannino, 2020) as emerging across the world of practice and research, we may subsequently use them to infer political agendas to mediate capitalism through regulating devices, on the one hand, and as sources of alternative models of institutions and means of organizing production and distribution of goods and services, on the other hand. Pushing this process further provides us with a bridging device, a germ cell that may be followed as an object to provide expansion or transformation opportunities in multi-coalescing systems. In the case reported in this dissertation, resolving to operate major qualitative change on the object of activity and switching its use value from mere creation of a service to co-configuration is an encouraging sign of the potential of hybrid educational activities as initiators of transformations to be further pursued in different levels or scales of a system. As such, we contend fourth generation potentially expanding activities are necessary to consider in

the grand scheme of the Anthropocene; higher education must take its place and take its responsibilities as the essential agent that it is in tackling climate change and to foster sustainable options, which may be further promoted through temporary coalitions and learning simultaneously on multiple levels. Ironically, eco-anxiety may emerge as the product of expectations, motivation and hopes (Pihkala, 2020) and may therefore provide enough ambiguity to produce conflicting motives in participants. Paradoxically, then, eco-anxiety as a global phenomenon may provide incentive and ground for the emergence of TADS, either through formative interventions, or through hybrid education activities. In other words, we subscribe to Engeström's point of view that schools cannot be separated from contradictions and challenges occurring in society as they represent a pool of social and societal renewal (2020a).

Simultaneously, we follow the author in that concept formation in the wild as a phenomenon requires educational researchers to step out of the classroom, i.e., to be *wilder*. In recent years, creativity researchers such as Sternberg (2021) have addressed the need to develop transformational creativity approaches in order to address not only sustainable development objectives but also armed conflicts. Service learning has been pointed out by Desmet and Roberts (2022) as a way to support transformational creativity. Emerging research communities, such as the Possibility Studies Network<sup>13</sup>, are additionally tackling these challenges from an interdisciplinary standpoint.

## **6.2 Practical Contribution: Contradictions as Teaching Tools**

Contradictions may be powerful devices for facilitators and teaching staff to facilitate complex open-ended activities involving knotworking. Promoting open instructional strategies in

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<sup>13</sup> <https://www.possibilitystudies.net/>

which participants are required to build a shared object and encouraged to co-creatively amend the use value of their activity may be identified as a promising avenue. Training teaching staff to recognize contradictions as they emerge in such situations, along with a functional understanding of the mechanisms of double stimulation may also provide such activities with a sound conceptual background to deal with their potentially transgressive nature, which may also turn out to be disruptive in higher education contexts. Despite inherent difficulties to do so, training in activity theory may represent a fruitful way forward as it puts higher education and society at the same level. As a result, work, education, civil society, and politics may more easily contemplate maintaining a fruitful polylog which may lead to satisfactorily addressing contemporary issues across sectors and hierarchical levels. Nawab and colleagues (2021) further recognize the potential to educate teachers and staff about the prevalence of contradictions in continuous development and lifelong learning and suggest rooting it in situative perspectives of learning and self-directed experiential learning. Curricula for teacher education, leadership training and school improvement programs may benefit from bringing contradictions forward and suggest leads to turn contradictions into learning opportunities. The counterpart of this is the risk of undergoing unnoticed contradictions and therefore wasting learning opportunities.

### **6.3 Limitations and Subsequent Studies**

Limitations of our research stem from methodological, theoretical, and practical issues. From a methodological perspective, interactions in knots were left out of the data due to nondisclosure agreements and to preserve the process of interviews, and therefore the integrity of the instructional sequence. Furthermore, the size of the sample does not allow to make generalizations, and therefore tones down the external validity of a single case study in which the specificity of the case may not lend much external validity to our PhD study beyond congruence

or incongruence with other similar or dissimilar cases reported elsewhere in the literature. In this respect, issues of climate change and technological transfer may not be transferable to other cases. Furthermore, the program studied is subject to variability, due to the fluctuations and variety of topics studied, to participants (i.e., students, facilitators, and liaison). Finally, the data was collected under specific sanitary measures which had an impact on the way the program was run across the higher education institutions that hosted the program.

The TADS model brings contrast and definition to other studies; however, we admit to the narrowness and specificity of the scope brought to the topic which may represent a hindrance to other cases. Further analysis of the data could be undertaken by taking a different stance on its analysis, i.e., relational agency (Edwards, 2010) and its focus on the progressive building of common knowledge to contrast the results and the analysis undertaken in this dissertation. Furthermore, by choosing to focus on collective processes of regulation, we did not account for the nature and specificity of each category of participants (student, facilitator, researcher). Identifying the specificities and questioning whether more subtle types of agencies emerged in the process may represent a fruitful research avenue.

Although we accounted for a relative lack of focus on an artifact used, which we interpreted as a specificity of the case and the related double bind of the intangibility of the object, further analysis could include a more precise analysis of artifacts and the functions that were retained across the process, and their influence on the final stimulus 2.

As stated in early sections of this research, double stimulation is understood as a volitional and regulation device; though definitions were established in the first section of this research, given the time and resource costs involved in conducting qualitative research, also addressing the limits of this research paradigm, Computer Supported Collaborative Learning,

possibly coupled to Artificial Intelligence solutions may be a promising way to address some of its limitations and possibly to apply some of its findings more widely in classroom environments; in this respect, speech to text applications may be significant to map DMC as a first building block of analysis and help teachers or facilitators working across different groups simultaneously to track the evolution of the co-regulation process occurring; in this respect, it could be a valuable resource for teaching and learning on a variety of topics, beyond societal challenges of hybrid and complex environments.

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## Appendices

### Appendix 1: Participants Characteristics

#### *Students: Characteristics*

The sample comprises six students working remotely in hybrid format varying across age, gender, university (Université Côte d’Azur/Università di Bologna), nationality, academic profiles, and previous experience of co-creative activities. The students participating in the program were between twenty-four and twenty-eight years of age during data collection. Their undergraduate profiles were physics, engineering, pharmacology and physiology, industrial product design, international and diplomatic affairs, architecture. Four out of the six participants reported having experience in collective creative work and being satisfied with their previous experience on the subject.

#### *Facilitators: Characteristics*

Three facilitators intervened in the program, varying across age, professional experience, university of origin (Université Côte d’Azur/Università di Bologna), nationality. Professional experience varied from open innovation to knowledge transfer and facilitation experience varied between three and eight years.

#### *Liaison: Characteristics*

The liaison team was composed of four people working as researchers in a research institute varying across the following criteria age, gender, professional experience, and position in the organization. The variety of participants allows for a plurality of points of view expressed within the group. It therefore serves the purposes of multi-voiced dialogue in which participants feel their contributions are welcome and appreciated. This *multivoicedness* is one of the five defining features of activity systems described in previous sections and are considered a

necessary feature of any activity system (Engeström, 2015). The characteristics of participants are summed up in Table 16 below:

**Table 16***Characteristics of Participants to the Research*

Organization	Role	Male	Female	Total
UCA	Student	1	2	3
	Facilitator	0	1	1
UniBo	Student	1	2	3
	Facilitator	0	2	2
IIT	Researcher	1	1	2
	Knowledge transfer officer	1	1	2
Total		4	9	13



## **Appendix 2: Composition of Meetings and Timeline of Recordings of Data**

### ***Video Recording of Working Sessions***

The primary source of data was afforded by the continuous recording of working sessions described in section 3.2.4. To comply with sanitary requirements relating to COVID-19 restrictions, all meetings were recorded. This format was rife with the opportunity to investigate DMC across interacting activity systems between team members, facilitators, and liaison. The types of meetings are described in the sections below.

### ***Small Group Meetings***

SGM are formal teamwork sessions organized and facilitated by each team's facilitators. In these meetings, participants share and build research, advancement and understanding of the technology, and they also work out questions and challenges regarding the general progression of the project with regards the technology, the context, and the challenge itself. Systematic progress is carefully tracked and discussed, as well as any conflict, roadblock, doubt, or observation. All group members are expected to join according to their availability and conflicts with other courses. The recurrence of SGM is one-hour online meeting every week.

### ***Liaison Meeting***

The Liaison Meetings (IIT meetings) are meetings in which students, facilitators and *liaison team* formed of two to four people from the client organization meet to discuss progress and current stakes in the progress of the project. These meetings allow liaison to provide guidance, feedback, and information about the background context of the project. It is also an opportunity for the students and coaches to share progress and regulate potential issues. These meetings were initially planned to occur every two weeks over the duration of the program, with increased frequency at critical turning points in the process. Two members of IIT were regular

attendants, with potential participation of knowledge transfer offices colleagues up to four participants.

### ***Large Group Meetings***

LGM are conceived as workshops primarily designed to expose concepts and tools to be used in activities. These meetings are integrally organized online and are shared among all the groups (n=18) taking part in the academic program during the 2021–2022 academic year; as such, they allow for intergroup progress checkups, and intergroup feedback on advancement. The recurrence of LGM is bimonthly and they were systematically attended by the researchers to inform the nature of tasks that were required of participants who would inform minutes and tasks in Small Groups Meetings (SGM) and Liaison Meetings between the participants and the stakeholders from the Istituto Italiano di Tecnologia (IIT meetings). Finally, two face-to-face working weeks were held in presence during the month of March 2022, as described above. These opportunities were also harnessed to gather data-rich in-presence work being done and shared by students.

### ***Temporary Clients/User's Interviews***

As described by Koppenhagen (2021) in above sections, an important part of the work students do is related to the organization and management of meetings with potential clients in knots to gather feedback and check whether the progress and evolution of the prototypes are matching the reality of the fields. Due to the confidential nature of information exchanged during client interviews, these meetings were not open to the researchers.

***Timeline of Meetings***

The data collected lasted over the period spanning from the 17<sup>th</sup> of January 2022 to the 18<sup>th</sup> of April 2022, i.e., 13 weeks in duration. The repartition of meetings and their types are illustrated in Table 17 below:



*Timeline of Recordings***Table 18***Timeline of the Recording and Duration of SGMs*

Week	Duration (hours:minutes:seconds)
1	01:16:01
2	00:54:37
3	00:36:24
4	01:23:22
5	01:04:16
6	00:57:37
7	00:36:01
9	00:37:56
11	01:20:21

The total of SGMs recording in the data collected is 8:46:35.

**Table 19***Timeline of the Recording and Duration of Liaison Meetings*

Week	Duration (hours:minutes:seconds)
1	01:18:49
3	01:29:33
5	01:13:32
7	01:19:02
9	01:30:41
11	00:30:52

The total of liaison meetings in the data collected is 7:22:29.

The total of both types of meetings amounts to 16:09:04.

## ***Interviews***

### ***Initial Semi-Directed Interview Formal Focus Groups Interviews***

Shortly after the inception of the data collection period, a focus group was planned with students; a semi-directed interview is a focus group that rely on the interactions among participants to generate data (Hatch, 2002); this document was aimed at reflection on the first phase of the program dedicated to the identification of needs in the project, and on the experience of participants during the previous phases of work. Interviewing took advantage of the collective to produce data and insights that would be less accessible without the group interaction (Hatch, 2002). The researchers were not allowed to collect data during the observation phase. This interview served to establish an initial mapping of the tensions and contradictions experienced by the participants at the inception of data collection, allowing for contrast of analysis results and triangulation of data.

### ***Stimulated Recall Interviews***

Stimulated Recall Interviews are an introspective method aiming at reflection on mental processes, investigating knowledge types, knowledge structures, cognitive processes and learner strategies (Gass & Mackey, 2013). Within the recall support shared by Gass and Mackey (2013), the sessions focus on the relationship to specific actions undertaken within the group, with the potential to showcase agentic qualities; in particular, landmarks, achievements, breakthroughs (Engeström, 2015, p. 73).

While it had been initially agreed upon with facilitators that SRI would be conducted on a weekly or bi-weekly basis, this frequency turned out to be inappropriate to the commitment in time and energy from participants on all sides. Besides, due to the unpredictable nature of the creative problem-solving process, it was not viable to articulate those interviews around

breakthroughs without having the ability to predict ahead of time when they would be occurring. SRI were initially planned to be integrated into the weekly meeting schedule of the team, with a maximum duration of 20 minutes, which turned out to be impractical. As a result, two SRI were organized across the data collection period and organized around key pivotal steps in the procedure. Borrowing from Miettinen (2013), significant progression about needs and definition of a shared object were favored in the choice of the themes to be treated; besides, the experiencing of contradictions, both at systemic level and at activity levels were also favored. Finally, significant concepts or artifacts emerging from transcripts were added as significant elements potentially producing insight.



### ***Timeline of Collection***

**Table 20**

*Timeline of the Collection of Secondary Data*

Week	Type of interview
4	Interview
6	Stimulated recall interview
11	Stimulated recall interview

### ***“Feedback” Global Interview***

At the end of the program, an additional interview was organized by the participants to reflect on the program and its outcomes. Due to the encompassing nature of the meeting, it was also included in the corpus of data as it allowed the participants to reflect on the process and therefore manifest important data about contradictions, motives, and the formation of collective will.

### ***End of Cycle Interviews***

A series of five additional interviews were used in the corpus of data in this research. Semi-directed interviews were conducted with the facilitators of the program, and a series of three interviews were conducted among students since no single time slot was convenient; as a result, student final interviews were conducted over three separate interviews. A feedback interview was organized by the facilitators as a global feedback session for facilitators, liaison, and students, which was also used as an opportunity to gather feedback from the liaison team, as no additional interview was managed to be organized. The interviews and the corresponding data are described in Table 21 below:

**Table 21***Timeline of the Recording and Duration of Final Interviews*

Date	Type	Duration (hours:minutes:seconds)
2022/07/04	Facilitator's interview	00:55:21
2022/07/05	Student interview 1	00:43:19
2022/07/11/	Liaison feedback meeting	00:54:34
2022/07/12	Student interview 2	00:49:19
2022/07/18	Student interview 3	00:35:41

The total duration of the end of cycle interviews in the data collected is 3:58:14.

The final total duration of video recordings in the data corpus of this research is 20:07:18.

### **Appendix 3: Data Selection Process and Criteria**

#### ***Data selection process***

Merriam and Tisdell (2015) argue that to ensure maximum precision researchers should create criteria relevant to identify the ways they engage in data collection and gain access to participants' experience. Many interactions were involved in the process of emergence of a shared object along the course of the project. Design thinking, the global method applied is consistent with alignment of user needs and products; besides, CHAT stresses the importance of needs in the determination of a common object as a hypothesis for resolving contradictions (Miettinen, 2013). Below we recall the main phases of the SUGAR/ME310 program.

Problem solving was privileged in the selection and treatment of the data; the pilot study made the main researcher aware that the diverse types of meetings occurring in the SUGAR/ME310 program allowed for diverse types of activities and interactions and produced high volumes of rich data that could have been systematically captured. It also showed that distinct types of activities and interactions could occur in any given type of activity which made the process of identifying the adequate sequences of events to the progression of the research tricky.

Once the data collection started, it was observed throughout the "ideation" sequence which took place throughout the winter quarter that the group had "inherited" unresolved sequences from the need finding sequence. The pursuit of a need and the quest for a common object of activity lasted most of the project and was extended across all the work sequences. As a result, once the analysis of the corpus started, interpersonal interactions were systematically edited out of the corpus; all activities related to the definition of a common object were systematically included. The term of the data collection was identified as the emergence of a

shared object of activity, a common vision and a commitment to the realization of a product or service (Miettinen, 2013). Due to the nature of the different meetings the participants, the following inclusion criteria were defined:

- Focused on decision-making
- Deals with contradictions to the activity system
- Deals with the construction of a shared object
- Involves S1, S2 or both S1 and S2
- Involves complex tools as S2

The purpose and objective of this selection process is to restrain the data and increase its relevance as far as providing enlightening information about group negotiation, management of contradiction, conflicts of motives and subsequent concept formation. The following exclusion criteria were applied to help reduce and make the corpus more relevant:

- Deals with the planning or the carrying out of operations
- Time and logistics of the group, including meetings set up between group members or with potential partners or clients
- Life and mood of the group
- Travels and coordination among participants
- Exposition of pedagogical content relative to the practice of the facilitators

Based on this last criterion, LGM were systematically excluded from the data set.

As reported to the Committee on Ethics for Non-interventionist Research at Université Côte d'Azur, any recording, either video or audio or any trace in written form displaying the following attributes have been systematically *excluded* from the corpus:

- Comments involving personal life situations

- Interpersonal conflicts, conflicts, or personal attacks between participants
- Signs of interpersonal relationship of an intimate nature between participants
- Discourteous commentaries regarding participants who may or may not have been present at the time of interaction
- Judgments or commentaries regarding the facilitators of the group
- Judgments, commentaries regarding the origins, political preferences, social, sexual, or religious preferences
- Discourteous comments regarding one of the partner institutions or regarding the methodologies used (methodologies, selection criteria, assessment of projects)

## **Appendix 4: Authorization to Participate and Informed Consent (adult participant)**

### **Research title**

Study of co-creativity in interdisciplinary real-world problem solving in higher education

### **Main Researchers**

Guillaume Isaac, INSPE of Nice, Laboratoire d'Innovation et Numérique pour l'Éducation (LINE), Université Côte d'Azur under the supervision of Prof. Margarida Romero (Université Côte d'Azur) and Prof. Sylvie Barma (Université Laval, Québec).

### **Objectives**

The project aims to analyze collective processes in co-creative real-world problem-solving activities in higher education in the context of the SUGAR minor program. The analysis of problem-solving activities are problem-solving strategies and group dynamics, not grades.

This PhD study does not have any influence on the grades obtained by participants.

### **Surveys**

The data collected through surveys will be collected online. Surveys are designed to last 15 to 20 minutes.

### **Video recordings**

Zoom video working sessions will be recorded for posterior analysis of problem-solving situations and sequences of events.

### **Interviews**

Interviews will be conducted at the beginning and at the end of the spring semester (semester 2) and during the semester on a weekly to a bi-weekly basis. The frequency of interviews may vary depending on global progression.

## **Research Progression**

We will closely follow and record working sessions during the spring semester (semester 2) of the 2021–2022 academic year. During this period, all Zoom workshop sessions will be recorded for the purpose of the research. Two questionnaires will be applied. The first questionnaire is designed to assess incentives to take part in the SUGAR program, while the final questionnaire will seek to provide information on your experience as a participant. The interviews are designed to bring important breakthroughs and creative episodes to the attention of the participants to understand the processes at play and the meaning of these experiences.

## **Planning**

Initial questionnaire (15 minutes)—February 2022 at participants' convenience

Initial interview (30 minutes)—February 2022 on a common date to be determined

Stimulated recall interviews at the beginning of every workshop (10 to 20 minutes)—  
every two weeks

Final interviews (30 minutes)—June 2022 on a common date yet to be determined

## **Confidentiality and data management**

Videos of meetings and workshops are recorded for internal use. These videos will not be broadcast on any public support and will only be used to identify co-creative real-world problem-solving activities. The video transcripts and the surveys will be recorded under a participant number code (format pNNN). This anonymous participant code allows participants to exercise their right of withdrawal should they choose to. While the transcriptions of video interviews and in-person interviews will be stored and kept at INSPE Liégeard (43, Avenue Stephen Liégeard 06106 Nice) for a standard legal duration of 15 years, the video recordings themselves will be destroyed by the end of the research project.

### **Right of Withdrawal**

Participants may withdraw at any time without condition. Should you withdraw, no prejudice will be involved, either for the study or as far as your involvement with the SUGAR program. You may also choose to withdraw beyond the term of the PhD study. The procedure for the participant consists in signaling their participant number (pNNN) either to the research team, the facilitator, or the LINE (Laboratoire d'Innovation et Numérique en Éducation) director (contacts provided below). In case of withdrawal, all participant data will be destroyed. No risk for participants has been identified in the design of the research beyond the fact of hearing and watching one's own action and reflecting on the progression of problem-solving activity; should you feel uncomfortable at any point in the process for any reason, please be so kind as to report it to the researchers or facilitators; a remediation procedure can be undertaken if necessary.

### **Acknowledgements**

We would like to thank you for your collaboration in this PhD study, which will enable us to make progress in the identification of problem-solving strategies in higher education. This will benefit academia, scientific education research and other students and facilitators such as yourself. For real: thank you (you are awesome—in more ways than one).

### **Additional information:**

Should you have any additional questions about this PhD study, you may contact any or all of the following contacts:

- Guillaume Isaac [guillaume.isaac@univ-cotedazur.fr](mailto:guillaume.isaac@univ-cotedazur.fr) (on-field researcher)
- Professor Margarida Romero, [margarida.romero@univ-cotedazur.fr](mailto:margarida.romero@univ-cotedazur.fr) (scientific supervisor)
- Professor Sylvie Barma, [sylvie.barma@fse.ulaval.ca](mailto:sylvie.barma@fse.ulaval.ca) (scientific supervisor)



- Professor Eric Guerci [eric.guerci@univ-cotedazur.fr](mailto:eric.guerci@univ-cotedazur.fr) (supervisor of the SUGAR minor program)

## Appendix 5: Initial Questionnaire and Consent

1. Authorization to participate and informed consent:

“I have read, and I understand the above information and I voluntarily agree to participate in this research. The experimenter was able to answer all my questions about the study.”

“I do not agree to participate in this research.”

\*Last Name, First Name:

2. \*Gender: F-female, M-male, O-other, U-unspecified

3. \*Age:

4. \*Prior undergraduate studies:

5. \*If relevant, prior master studies:

6. Professional project: [optional question]

7. What is your dream job? [optional question]

8. \*Previous experiences with design thinking/with co-creative activities/project-based learning: yes/no

- a. If yes, please specify the type of experience:

- b. If yes, rate the experience: Likert scale (5 options)

- c. If relevant, please describe previous experiences:

9. \*Main motivation/incentive for following the SUGAR minor:

10. \*Do you feel that the complementarity of skills within your team was adapted to the project you were presented with?

11. \*If given the choice, would you rather work on another project?

12. How many hours a week of personal work on average do you dedicate to SUGAR?

## **Appendix 6: Initial Focus Group (2022/02/24)**

### **Introduction**

Focus groups are sets of individuals with similar characteristics and/or having shared experiences (Hatch, 2002). The goal is to create a conversation that allows participants to explore a topic in depth. The topic is your work during semester 1; “Phase 1” of the process was about “need finding” and lasted from October to December 2021. It comprised the following phases:

1. Desk research
2. Stakeholder map
3. Interviews (first series)
4. Observations
5. Fall presentation, presenting three design opportunities and a report

Looking back on it now, how do you feel about it?

### **Conflicts of motives and agency**

1. Since the first sequence was called “need finding,” how well do you feel you have pinpointed the need? How has it evolved if at all? How does that make you feel?
2. How close do you think you are to reaching a common vision of a new product between you and IIT (Miettinen, 2013, p. 159)?
3. Is there any topic at all that you think you have changed your minds about since the beginning of semester 1—regarding what you do here in SUGAR, regarding teamwork, problem-solving, sustainable development, technology and industry, scientific research, or anything else really?
4. Do you feel you have suggested/offered different ways of working? Do you think you should? Do you think it is useful to “bend the rules”?

### **Epistemic objects**

So, at the end of semester 1, you had three main design opportunities. Can you remind me what these were and how they came about? Was it satisfactory to you?

1. Tell me about the prototypes: you have produced prototypes during the first semester, how did that go? Do you feel they are different from the ones you are producing now?
2. How do you feel you have changed the way you think about certain topics related to this project?
3. Regarding the prototypes/concepts you have produced: would you say that they have informed or changed the way you think or do certain things? If yes, how would you characterize this influence?
4. Do you feel that the prototypes you do now still display some qualities now that were already present in the prototypes during semester 1?
5. Do you feel you are close to finding “the one” prototype? Do you think there can be one?

### **“Game”**

Contradictions (Engeström, 2015)

I will suggest a few prompts in the form of oppositions, tell me how you feel that resonated with your work through the first semester; did you think about it? Was it something you had in mind? Do you still think about it?

1. “Developing a commercial product vs. promoting renewable energies.”
2. “A new technology might solve some energy problem while also producing new wastes.”

3. “Acting out of conviction for ecological transition vs. producing greenwashing/business opportunities.”

4. “Clashes of the old business model vs. new opportunities afforded by the new one.”

5. Cryptocurrencies vs. old carbon industry.

What have the main challenges been?

Have you identified trends, or running ideas that have been recurring over and over?

Have you noticed that some of these “show up” repeatedly?

### **Complementary questions:**

1. Usually, how do you share/split the workload among yourselves?

2. What have the main challenges been according to you?

3. What were the main takeaways: how do you feel the work done in semester 1 is having an impact on the work you are doing now?

4. How important is the grade at the end of the process?

5. How much fun are you having?

6. Is there any question you would like to ask me about either this interview or the research or anything else, really?

### **Personal notes**

## **Appendix 7: Stimulated Recall Interview Outline: Students (2022/03/31)**

### ***Scope of the interview***

Introspective method to reflect on mental processes, investigating knowledge types, knowledge structures, cognitive processes, and learner strategies. This method here is used within a qualitative ethnomethodological research framework on co-creative real-world problem solving. Within the recall support method (Gass & Mackey, 2013), the present session focuses on the relationship to specific actions undertaken within the group, which display agentic qualities.

### ***Procedure***

Three topics are prepared, hoping to have time to treat two and get an opportunity to adjust in real time.

The global procedure suggested by (Dempsey, 2010) is the following one and is described below for each rubric. A tentative three (3) rubrics are suggested.

1. Create a rubric describing activities
2. Develop questions about processes developed
3. Record participants' activities/responses

### **Rubric 1: arguing over size and scale**

#### ***Description***

Since the beginning of data collection, participants have been iterating prototypes and testing them on potential stakeholders and future partners. However, the difficulty to visualize data and produce tangible artifacts is manifests in working sessions and appears as a hindrance to produce a convincing artifact. One representative episode was a working session between

researchers, facilitators, and students, used as a stimulus to uncover conflicting motives and tensions in the activity.

***Stimulus***

The following screenshot was used as a stimulus:

**Figure 49**

*Screenshot of Video Excerpt Shown as Stimulus*



### ***Questions***

1. Can you explain to me what is happening in this extract? What is the discussion about?
2. What issue is being debated in particular?
3. What was the main motivation to start this conversation?  
What impact did it have on the work?

### **Rubric 2: Artifacts produced**

#### ***Description***

As a result of the uncertainty caused by lack of available data, a variety of artifacts are produced as auxiliary motives. However, none of them gain enough traction to anchor the process.

#### ***Stimulus***



No stimulus was used in this sequence.

### ***Questions***

1. How did the idea of the simulation come about?
2. How do you explain it?
3. Has it brought any development that has changed either your views or your actions?
4. How do you feel it affected your progress—either positively or negatively?

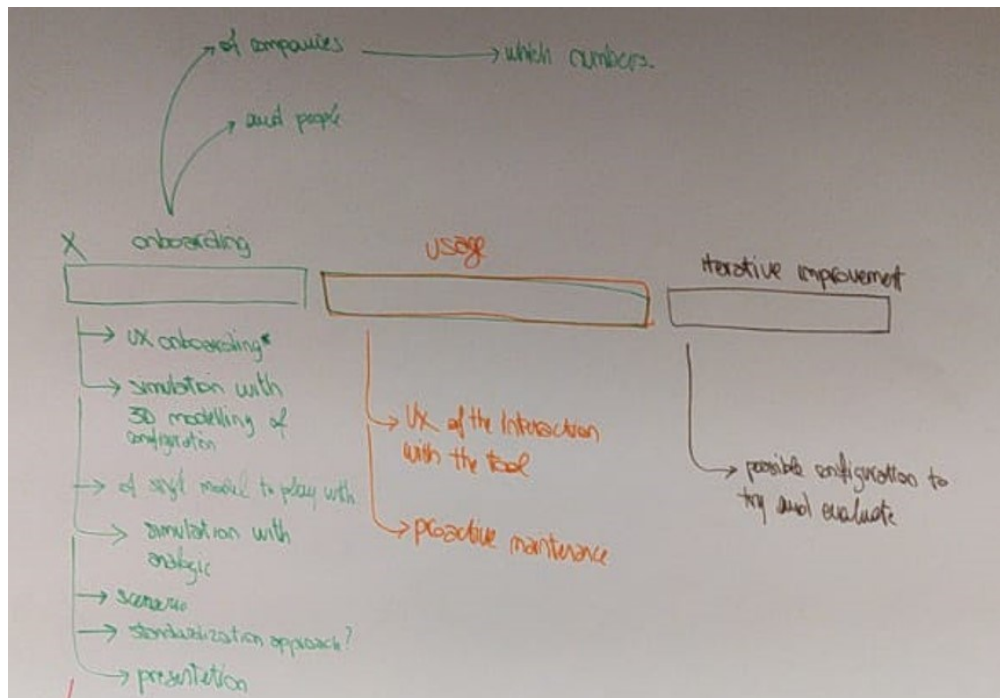
Hindsight observation from the researcher—completed afterwards

### **Rubric 3: onboarding**

In down times, one participant mentioned the fact that it had been a long time since the group had performed a “vibe checker.” This tool/artifact is unknown from the facilitators of the group and is therefore a potential self-directed initiative undertaken by the participants. As such, and resulting from the difficulties described above, it was decided to investigate further the nature and function of this device.

### ***Stimulus***

The following figure was used as stimulus:

**Figure 50***Early Schemes of Onboarding Concept***Questions**

1. Can you explain what this scheme is about?
2. Can you briefly explain it?
3. How does it inform the direction you are taking now?
4. How is your progress with it?

**Hindsight observation from the researcher—to be completed afterwards**

## Appendix 8: Stimulated Recall Interview: Facilitators (2022/07/04)

### Rubric 1: convergence meeting

#### *Description*

Since the beginning of January 2022, much effort has been dedicated to the convergence of the field of application of the technology being studied by the group. Namely, participants have been struggling on two accounts:

1. Converging on the final “object” of their process with three main candidates (maritime transportation/fume treatment and chimneys/plastic production and treatment) exposed to the clients and the whole group during a December presentation.
2. Adapting and regulating their processes to reduce stress and get the feeling of setting in the “right” direction to increase productivity and reduce uncertainty about the end product of the process. The transcripts display students and stakeholders’ feelings and contradictions about it, but not the facilitators, which is the reason.

#### *Stimulus*

Two quotes were used, extracted from two working sessions from the beginning of 2022.

- 2022/01/19—P005: *“Because we are, yeah, I don’t know, trying to focus on all these different applications, so we cannot really work as a team in a way, so if we could focus on one thing, I think we could bundle our energies which would help us and also like this, yeah, in LGMs F004 tells us: ‘Find your prototype and test it,’ but for us it’s not so easy to, ok, contact the company and say ‘Ok let’s test our prototype’ [...] yeah, it’s more difficult, in my opinion.”*
- 2022/01/21—S002: *“I’m a little bit... how to say... torn in two. For sure in yes, what you said is interesting, it’s intriguing. I maybe I will also vote for the cement*

*application, I don't know. I'm torn in two. For sure that will be something different, and new for us to try to move in the plastic scenario. I don't know, I will say 50/50 among the two, for different reasons."*

### ***Questions***

1. Both quotes display a fair number of tensions and conflicts, dilemmas and so on... do you remember how that applied to you as facilitators? Do you remember facing dilemmas yourself?
2. How did you resolve the situation?
3. Did you feel this was beneficial for the progress of the group?

### **Rubric 2: calling into question the relevance of the feedback in LGM**

#### ***Description***

Consequently, over the two last SGM, increasing tension has been observed regarding the rules (following closely the design thinking method/steps the other groups have been following and focusing on a tangible product that might be a prototype to get feedback on and enrich vs. the systemic vision imposed by the abstract/intangible nature). As a result, the participants have expressed the disconnection experienced between the nature of the feedback gathered during LGM.

#### ***Stimulus***

Direct quote from the transcript of the 02/02/2022 displayed on screen to trigger reactions. The transcript is the following:

*"What they [other teams] have is a lab prototype, and what we are building is something that works in the real world. We are skipping, like the scientists said, three levels of research and*

*development, which is fine because it is good for the future and it's good for us. But that's what makes it so hard. And then you understand these restrictions we have, and we're presenting towards the LGM, but the feedback we get is something that will not help us, you know, because we are not at the level of other teams, we don't have the same priorities or path. So, at least for me, when I am in a large group meeting, I love the feedback you're giving me, but I can't do anything about it. And that's what is frustrating for me, at the prototyping level."*

### ***Questions***

5. Did you feel this observation was relevant?
6. How do you explain it?
7. Has it brought any development that has changed either your views or your actions?
8. How do you feel it affected your progress—either positively or negatively?

Hindsight observation from the researcher—completed afterwards

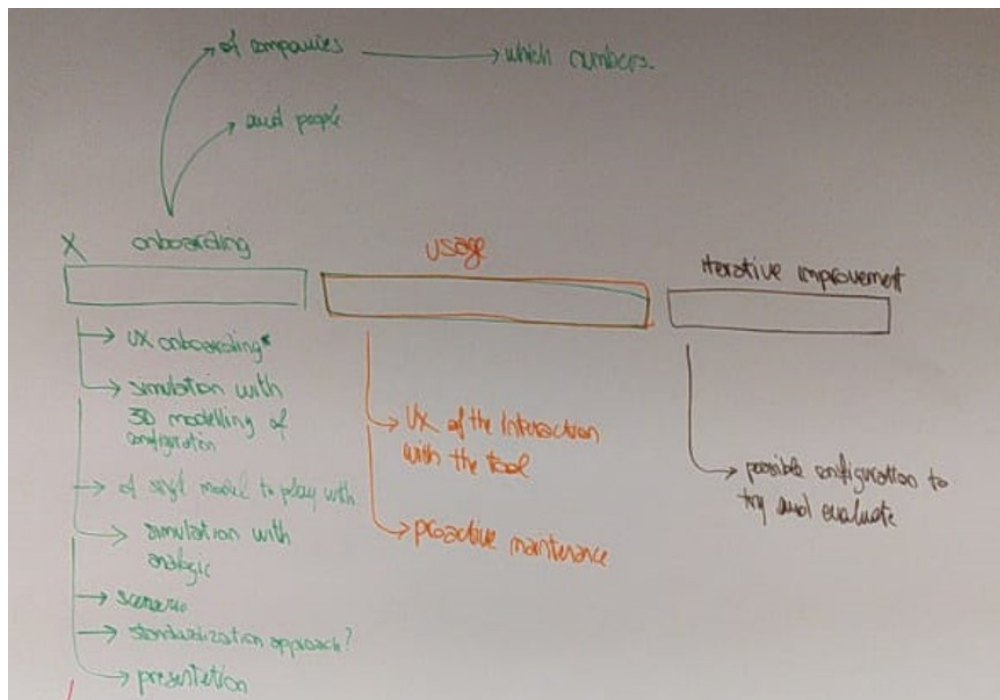
### **Rubric 3: onboarding**

#### ***Description***

In down time, one participant mentioned the fact that it had been a long time since the group had performed a “vibe checker.” This tool/artifact is unknown from the facilitators of the group and is therefore a potential self-directed initiative undertaken by the participants. As such, and resulting from the difficulties described above, it was decided to investigate further the nature and function of this device.

#### ***Stimulus***

The following figure was used as stimulus:

**Figure 51***Early Schemes of Onboarding Concept*

**Figure 52**

*Onboarding Steps Described on the Final Report of the Project*



### ***Questions***

5. Can you explain how the notion of *onboarding* came about?
6. Can you briefly explain it?
7. What function/conflict did it resolve for you?
8. In hindsight, how satisfied are you with it? Do you think the stakeholders were satisfied with it?

**Appendix 9: Stimulated Recall Interview Students (2022/07/05, 2022/07/08, 2022/07/12)****Rubric 1: tensions and contradictions*****Description***

This interview is dedicated to the facilitators of the program to collect their thoughts in hindsight on the process according to what was identified as the main episodes.

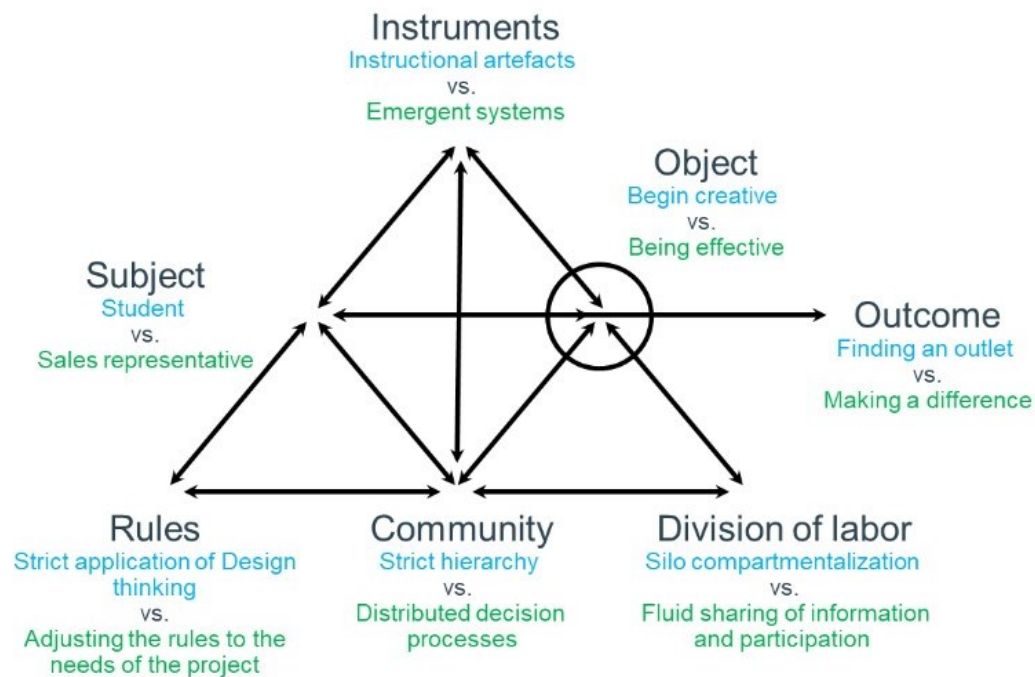
***Stimulus***

The following figure was used as stimulus:



**Figure 53**

*Primary Contradictions of Co-creative Problem Solving*



### **Questions**

Is there something among those contradictions that make sense to you or that has a particular impact or relevance or importance for you over the process?

### **Rubric 2: Large Group Meetings**

#### **Description**

Consequently, over the two last SGM, increasing tension has been observed regarding the rules (following closely the design thinking method/steps the other groups have been following and focusing on a tangible product that might be a prototype to get feedback on and enrich vs. the systemic vision imposed by the abstract/intangible nature). As a result, the participants have expressed the disconnection experienced between the nature of the feedback gathered during LGM and the object of the work sequences.

***Stimulus***

Direct quote from the transcript of the 02/02/2022 displayed on screen to trigger reactions. The transcript is the following:

*“What they [other teams] have is a lab prototype, and what we are building is something that works in the real world. We are skipping, like the scientists said, three levels of research and development, which is fine because it is good for the future and it’s good for us. But that’s what makes it so hard. And then you understand these restrictions we have, and we’re presenting towards the LGM, but the feedback we get is something that will not help us, you know, because we are not at the level of other teams, we don’t have the same priorities or path. So, at least for me, when I am in a large group meeting, I love the feedback you’re giving me, but I can’t do anything about it. And that’s what is frustrating for me, at the prototyping level.”*

***Questions***

9. Did you feel this observation was relevant?
10. How do you explain it?
11. Has it brought any development that has changed either your views or your actions?
12. How do you feel it affected your progress—either positively or negatively?

Hindsight observation from the researcher—completed afterwards.

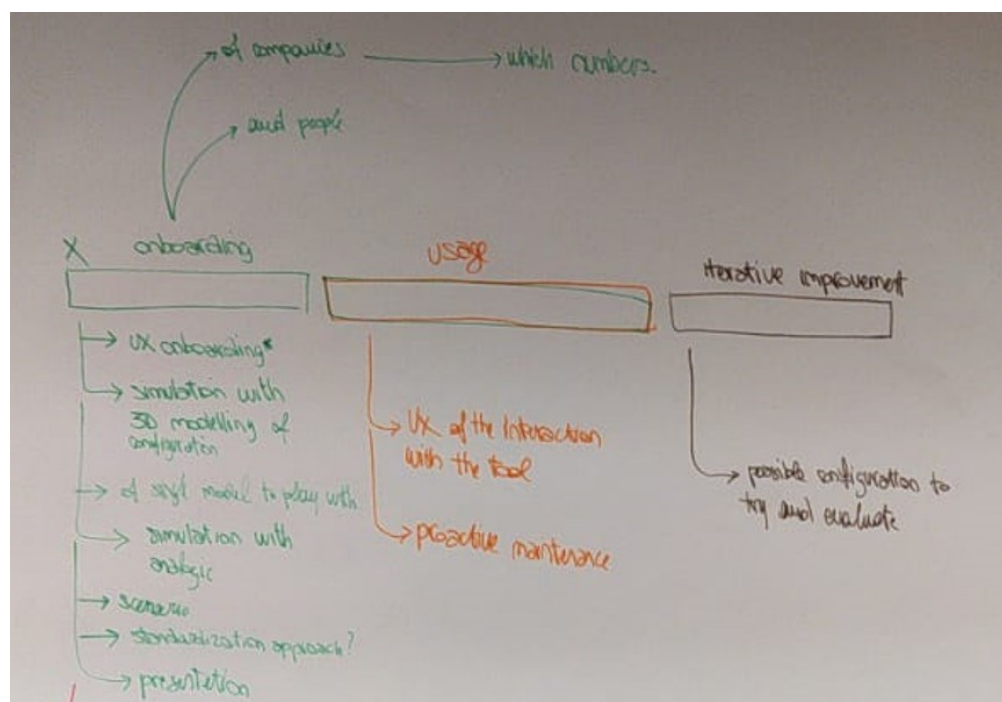
**Rubric 3: onboarding*****Description***

As a final product, the group has settled on the concept of onboarding as a tentative auxiliary motive, which they further used to design an application as a hub of functionalities for onboarding. This rubric is dedicated to the emergence of auxiliary motives and stimulus 2 and

questions the motives involved and the solidification into an artifact that addresses the contradiction experimented by the participants.

***Stimulus***

The following figure was used as stimulus:

**Figure 54***Early Schemes of Onboarding Concept*

**Figure 55**

*Onboarding Steps Described on the Final Report of the Project*



**Figure 56**

*Colab Presentation From the Final Report of the Project*



**Figure 57***Features of the Colab Solution***Questions**

9. Can you explain how the notion of *onboarding* came about?
10. Can you briefly explain it?
11. What function/conflict did it resolve for you?
12. In hindsight, how satisfied are you with it? Do you think the stakeholders were satisfied with it?