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Beyond the Dichotomy between the Socio-cognitive and Socio-emotional Spaces : The Pervasive Role of Emotions in Collaborative Problem-Solving

THÈSE

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Abstract

ENGLISH VERSION

The field of collaborative problem-solving has been gaining interest over the last decades. However, we are still far from getting a complete picture of its functioning. One of the reasons is undoubtedly its underlying complexity. Indeed, a comprehensive understanding of collaborative problem-solving requires paying attention to various phenomena that dynamically interact when people try to solve problems together.

The present thesis aimed at deepening the understanding of collaborative problem-solving at four main levels. The **first contribution** is an extensive review of the current state of research on various personal and interpersonal processes playing a role in collaborative problem-solving. To this end, we reviewed scientific contributions from different fields of research concerning the cognitive, motivational and relational aspects of collaboration. The **second contribution** is the construction of an integrative model that considers how these afore-mentioned dimensions interact during collaborative problem-solving at the personal and interpersonal levels. Moreover, the pervasive role of emotions as a source of information and regulation in each of these dimensions is also highlighted, challenging the classic dichotomy between socio-cognitive and socio-emotional spaces of collaboration classically presented in the literature. All in all, this model is intended to provide a theoretical framework for further research in this domain. The **third contribution** concerns the study of some ways in which emotional processes influence collaborative problem-solving. Four studies explored the impact of self-experienced emotions, explicit sharing of emotions and emotion regulation dispositions on collaborative exchanges and the perception of different aspects of the collaboration. Finally, as a **fourth contribution**, we build on the findings uncovered in this thesis and the literature to propose new promising avenues for future research in this domain.

FRENCH VERSION

La résolution collaborative de problème suscite un intérêt croissant ces dernières décennies. Cependant, nous sommes toujours loin d'avoir une vision complète de son fonctionnement. Une des raisons est sans doute sa grande complexité. En effet, une compréhension complète de ce domaine nécessite de prendre en considération une grande variété de phénomènes qui interagissent entre eux lorsqu'on résout des problèmes ensemble.

Cette thèse vise à approfondir la compréhension de la résolution collaborative de problème grâce à quatre principales contributions. La **première contribution** est un examen approfondi de la littérature en lien avec différents processus personnels and interpersonnels jouant un rôle dans la résolution collaborative de problème. A cette fin, nous avons examiné des contributions scientifiques de différents champs de recherche en rapport avec les aspects cognitifs, motivationnels et relationnels de la collaboration. La **deuxième contribution** est la construction d'un modèle considérant comment les différentes dimensions susmentionnées interagissent durant la résolution collaborative de problème aux niveaux personnels et interpersonnels. De plus, le rôle pervasif des émotions comme une source d'information et de régulation de ces différentes dimensions est mis en avant, remettant en question la dichotomie entre les espaces socio-cognitifs et socio-émotionnels classiquement présentée dans la littérature. En résumé, ce modèle vise à fournir un cadre théorique pour les futures recherches dans le domaine. La **troisième contribution** concerne l'étude de différentes manières selon lesquelles les émotions influencent la résolution collaborative de problème. Quatre études explorent l'impact des émotions ressenties, du partage explicite des émotions et de la disposition à réguler les émotions sur les échanges collaboratifs et la perception de différents aspects de la collaboration. Finalement, la **quatrième contribution** consiste, sur la base des résultats obtenus et de la littérature, à proposer de nouvelles pistes de recherche dans le domaine.

List of original publications

This thesis gave rise to the following scientific communications:

Journal papers

1. Molinari, G., Avry, S., & Chanel, G. (2017). Les émotions dans les situations de collaboration et d'apprentissage collaboratif médiatisées par ordinateur. Raisons éducatives, (1), 175-190.
2. Avry, S., & Molinari, G. (2018). Sharing emotions impacts computer-supported collaborative processes: effect of an emotion awareness tool. Travaux neuchâtelois de linguistique, (68), 85-96.
3. Avry, S., Chanel, G., Betrancourt, M., & Molinari, G. (2018). Effet des antécédents émotionnels de contrôle et de valeur sur la résolution de problème dans un jeu vidéo collaboratif. Revue des sciences et techniques de l'information et de la communication pour l'éducation et la formation, 25(1).
4. Avry, S., Chanel, G., Bétrancourt, M., & Molinari, G. (2020). Achievement appraisals, emotions and socio-cognitive processes: how they interplay in collaborative problem-solving?. Computers in Human Behavior, 106267.
5. Avry, S., Molinari, M., Betrancourt, M., & Chanel. (2020). Sharing emotions contributes to regulating collaborative intentions in group problem-solving. Frontiers in Psychology - Human Media interaction.
6. Avry, S. (2020). A three-level model of collaborative problem-solving. Manuscript submitted for publication.

Conference papers

1. Chanel, G., Avry, S., Molinari, G., Bétrancourt, M., & Pun, T. (2017). Multiple users' emotion recognition: Improving performance by joint modeling of affective reactions. In 2017 Seventh International Conference on Affective Computing and Intelligent Interaction (ACII) (pp. 92-97). IEEE.
2. Avry, S., Chanel, G., Betrancourt, M., Pun, T., & Molinari, G. (2017). Feedbacks de contrôle et de valeur dans un jeu vidéo de résolution collaborative de problèmes: effets sur les émotions et la qualité perçue de la collaboration. In 8ème Conférence sur les Environnements Informatiques pour l'Apprentissage Humain.
3. Molinari, G., & Avry, S. (2018). Flow in Computer-Supported Collaborative Problem-Solving. International Society of the Learning Sciences, Inc.[ISLS].

4. Avry, S., & Molinari, M. (2020). Explicit sharing of emotions improves the relationship of groups with lower dispositions to regulate emotions in collaborative problem-solving. Manuscript submitted in Society of the Learning Sciences, Inc.[ISLS].

Posters

1. Avry, S., Molinari, G., Chanel, G., Betrancourt, M., & Pun, T. (2015). The display (or masking) of emotions during computer-mediated interaction: A relationship with reappraisal.In International Society for Research on Emotion
2. Avry, S., Molinari, G., Chanel, G., Pun, T., & Betrancourt, M. (2017). An Emotion Awareness Tool for the Sharing of Emotions: What Impact on Computer-Supported Collaborative Processes?. In 12th International conference on computer-supported collaborative learning.
3. Avry, S., Chanel, G., Molinari, G., & Betrancourt, M. (2019). Emotions and Collaborative Processes in Dyadic Problem Solving. In International Society for Research on Emotion
4. Avry, S., Molinari, G., Chanel, G., & Betrancourt, M. (2020). The role of emotional competencies in the relational aspects of collaborative problem-solving. In Consortium of European Research on Emotion

Contents

Chapter 1

INTRODUCTION

Since the last decades, the labor market has been facing an increasing need for jobs dealing with new complex scientific, environmental, technological and societal issues that require non-routine skills such as collaborative problem-solving (World Economic Forum, 2015). However, in the 2015 international assessment of collaborative problem-solving conducted as part of the Programme for International Student Assessment (PISA), less than 30% of students succeeded at solving the lowest complexity test and less than 10% scored at the highest level. Besides, employers report a clear gap between their needs in terms of collaborative problem-solving skills and the current graduates' competencies and perception of competencies in this domain (Fiore et al., 2018).

If different reasons can be proposed to explain why people have difficulties to solve problems together (e.g., lack of accurate knowledge about what is collaboration, lack of functional collaborative routines), we think that collaborative problem-solving primarily suffers from a lack of understanding of its complex nature by the scientific community itself. Therefore, it is especially challenging for educators to scaffold the students' acquisition of efficient collaborative problem-solving skills. A research effort is thus highly desirable to deepen the theoretical understanding of collaborative problem-solving.

Nearly twenty years ago, a pioneering article from Barron (2003) highlighted, for example, that purely cognitive variables could not plainly explain how groups succeed at solving problems together. If cognitive abilities play undoubtedly a fundamental role in problem-solving outcomes, it is not a sufficient condition. People often fail to be successful at collaborating for various reasons that do not depend only on their cognitive abilities to deal with the problem in question such as motivational or relational issues.

Therefore, the necessity to open the study of collaborative problem-solving to other kinds of group processes has become blatant. Until now, collaborative problem-solving has mostly been understood as an activity implying the management of two spaces of interaction, one dedicated to the socio-cognitive processes, the other dedicated to the socio-emotional and social processes (Kirschner & Van Bruggen, 2004).

Number of studies have since explored these socio-emotional and social aspects, which cover numbers of processes not dedicated to specifically solving the task such as affective/emotional (e.g., Andriessen et al., 2011; Baker et al., 2013), motivational (e.g., Järvelä and Järvenoja, 2011) or relational (e.g., Isohätälä et al., 2019) processes.

If the cognitive/problem-related space of collaboration has been described in some detail (see for example the comprehensive model of Decuyper et al., 2010), the social space of collaboration encompasses numbers of intertwined motivational and relational aspects, sometimes conceptually unrelated to each other, that makes them more challenging to investigate.

Therefore, one part of the work described in this thesis concerns an attempt to go one step further in the theoretical description of the different processes that play a role in collaborative problem-solving. This work has required to conduct an in-depth investigation of the literature about various and somewhat unrelated fields of research that account for specific aspects of collaborative problem-solving. In **chapter 2**, we describe the different personal and interpersonal processes that intervene in collaborative problem-solving. Our overview of the literature covered the cognitive, motivational and relational processes in group interaction, collaborative learning and computer-supported collaborative learning and work, and collaborative problem-solving. Moreover, we built on these various research contributions to go further than the commonly described *double space of collaboration* and propose the first version of a new cognitive and interactional model of collaborative problem-solving, the three-level model of collaboration.

A second part focuses on emotional processes and their role in collaborative problem-solving. In our view, emotional processes are too often assimilated to the relational aspects of the collaboration. This is even more pregnant when non-problem-related aspects of collaboration are referred to as the socio-emotional space of collaboration. Contrary to this idea, we highlight in **chapter 3** the role of emotions in collaborative problem-solving and how it can affect not only the relational but also the cognitive and the motivational dimensions of the collaboration.

In **chapter 4**, the main objectives of the thesis research are explained, with the idea to provide empirical evidence of the role of emotional processes in collaborative problem-solving. Four studies have been described in which different emotional processes (subjective feelings, explicit sharing of emotions and interpersonal emotion regulation dispositions) have been studied in relation to the cognitive, motivational and relational dimensions of collaborative problem-solving. In the different studies presented in this thesis, computer-supported collaborative environments have been used. These environments made it possible to gain better experimental control on the variables studied. This choice also echoes the crucial role of computer tools to scaffold non-routine interpersonal skills, as pointed by the World Economic

Forum (2015). For these reasons, we decided to involve our participants in different realistic computer-supported collaborative environments to be in tune with the increasing role of computer tools in collaboration.

In **chapter 5**, we studied the impact of self-experienced emotions, and especially a specific kind of self-experienced emotion called achievement emotions, on the perception of socio-cognitive processes of collaboration. In **chapter 6**, we studied the impact of explicit emotion sharing on socio-cognitive and socio-relational communicative exchanges. In **chapter 7**, we studied the interaction between explicit sharing of emotions and interpersonal emotion regulation dispositions on socio-relational perception.

Finally, in **chapter 8**, we propose a summary of the main contributions of this thesis and give promising avenues for future research in this domain.

Chapter 2

MULTI-DIMENSIONAL DESCRIPTION OF COLLABORATIVE PROBLEM-SOLVING

This chapter presents a literature review in the domain of personal and interpersonal problem-solving and learning and integrate them into a cognitive and interactional model of collaborative problem-solving (Figure 2.4). In line with this model, the theoretical contributions reviewed are divided in a first section dedicated to cognitive and motivational processes at the personal level and a second section covering cognitive, motivational and relational processes at the interpersonal level.

2.1 General definitions

2.1.1 What is a problem?

Problems are omnipresent throughout daily life, and problem-solving is, therefore, an everyday activity. Getting into a given place in an unknown city or sending a rocket into space both imply problem-solving, at different levels of complexity. When a discrepancy arises between a current condition and the imagined state that we desire, we encounter a problem (Robertson, 2016, p. 2). More specifically, a problem is "a situation in which one's current state differs from some goal state, and in which there is some uncertainty as to whether or how the goal can be achieved, within any relevant constraints, such as time" (DeYoung et al., 2008, p. 278). A problem has different features that we briefly discuss here (for more detail, see Robertson, 2016, pp. 20-24). First, a problem can be knowledge-lean or knowledge-rich. A knowledge-lean problem does not require much prior knowledge from solvers other than general knowledge. A knowledge-rich problem, however, generally implies more specific knowledge about a particular domain (e.g., thermodynamics). Second, a problem can be semantically-lean or semantically-rich, depending on how

it requires the solvers' experience of the problem. For example, cricket may seem particularly puzzling for a rookie but completely meaningful for an avid fan. Finally, a problem can be well or ill-defined, depending on how well the problem components are specified. For example, a problem is well-defined when its initial and goal states, as well as the available operations available to solve it, are clearly stated (e.g., a recipe) (Gilhooly, 2012, p. 3; Robertson, 2016, p. 20). In other words, a well-defined problem has a precise problem formulation. In this way, its resolution is straightforward as long as the problem solver has the relevant knowledge and skills. However, in everyday life, problems tend to be ill-defined, i.e., uncertainty exists regarding how to reach the solution. In this case, the problem formulation is unclear. For example, the problem of how to find a life partner is ill-defined because even if the goal state appears bright, the path to the solution is somewhat fuzzy. Hence, the challenge in solving an ill-defined problem is often to clarify the problem, i.e., to transform it into a well-defined problem. Since the 1970s, the complex problem-solving field has emerged, following a shift of emphasis from the early study of well-defined and straightforward problems to more complex, dynamic, ill-defined, and realistic problems (Fischer et al., 2011).

2.1.2 What is problem-solving?

Problem-solving is one of the various learning activities (Wasserman & Davis). It refers to a form of information processing, consisting of manipulating symbols and meanings to solve problems. It has a number of formal definitions (Frensch & Funke, 2014). The most restrictive and amusing one might come from Wheatley (1984), who states that problem-solving is nothing more than "what you do when you don't know what to do." Heppner and Krauskopf (as cited in Frensch & Funke, 2014, p. 375) provide a more functional definition in that "problem-solving is defined as a goal-directed sequence of cognitive and affective operations as well as behavioral responses for the purpose of adapting to internal or external demands or challenges." Problem-solving is often a complex process as it involves errors, false starts, and sometimes failures. It includes different phases in a cyclical and iterative process (Carlson & Bloom, 2005). In order to solve a problem, the problem solver must go through several stages more or less linearly such as (1) identifying the problem, (2) defining the problem, (3) developing a solution strategy, (4) organizing the required knowledge, (5) allocating resources for solving the problem, (6) monitoring the progress, and (7) evaluating the solution (Pretz et al., 2003; see also Polya, 2004).

As we will see further and contrary to the layman's idea, problem-solving not only involves basic skills (i.e., cognitive components; Sternberg et al., 1985) but also what Mayer (1998) calls metaskills and will. According to this author, if basic cognitive skills are necessary, there are not, however, a sufficient condition to successfully solving complex problems. Basic skills also need to be orchestrated and controlled (metacognitive factors) for problem-solving to be successful. Furthermore, will (i.e.,

motivational factors) also comes into play as individual interest, self-efficacy, and attribution (i.e., the ascription of the cause of success and failure) influence persistence on the task. Following sections will describe in more detail the different processes involved in problem-solving at the personal level.

2.1.3 What is collaborative problem-solving?

Collaboration is an essential tool in our modern organizations, where no single individual is often capable of accomplishing complex projects alone (Dechant et al., 1993). Not surprisingly, the need for collaboration is increasing all around the world, as more and more employees work in teams to solve non-routine problems (Fiore et al., 2017). An important question that arises when we are moving from single-handed to joint problem-solving is the nature of the changes taking place. Research strongly suggests that collaboration goes far beyond a simple pooling of knowledge and skills, promoting intersection and amplification that produce emergent characteristics (Kozlowski & Bell, 2007).

When we think about people solving problems together, two terms generally come to mind: collaboration and cooperation. If these two terms have a relative corresponding general definition in colloquial speech and have more similarities than differences (Kreijns et al., 2003), some authors in the scientific literature make, however, a clear difference between them. Interestingly, the meaning of cooperation from one author sometimes meets that of collaboration from another. For example, McInnerney and Roberts (2009, p. 205) describe the adjective cooperative as "to work or act together as one to achieve a common goal, while tending to de-emphasize the input or particular individuals". Conversely, Dillenbourg (1999) highlights the fact that collaborative problem-solving relates to a situation where people do work together and shares a common goal. In this thesis, we will refer to the general definition given in Borge and White (2016, p. 324), who define collaboration as a "synchronous activity that occurs as individuals engage in collective thought processes to synthesize and negotiate collective information in order to create shared meaning, make joint decisions, and create new knowledge". As regards to collaborative problem-solving, the Programme for International Student Assessment (PISA) defines it as the "capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills, and efforts to reach that solution." (Fiore et al., 2017, p. 6). According to Dillenbourg (1999), a situation is collaborative when it meets several criteria. First, a collaborative setting assumes **symmetry of actions**, i.e., partners have access to the same repertoire of available actions (see Dillenbourg and Baker, 1996), **symmetrical knowledge between partners**, i.e., both can usefully bring their expertise to solve the task. The pursuit of a **shared goal** also characterizes a collaborative situation. As mentioned in Dillenbourg (1999), partners may not have the same personal expectations in pursuing a predefined goal. Hence,

the shared goal sometimes needs to be negotiated among partners. Third, the collaboration reflects a **spontaneous division of roles** throughout the task, which are flexible and interchangeable (i.e., horizontal division of labor). On the contrary, cooperation implies a division of labor, in the sense that partners split the work into fixed and independent sub-tasks and then assemble their work into a final output (i.e., vertical division of labor). In this thesis, we will generally use the term collaboration as defined in Dillenbourg (1999).

During the last decades, advances in information and communication technologies have profoundly impacted the study of collaborative learning. Two fields of research, namely Computer-Supported Collaborative Work (CSCW) and Computer-Supported Collaborative Learning (CSCL), have emerged focusing on collaborative work and learning and the use of technologies to scaffold them. CSCW addresses the role of technologies to support group work (Grudin, 1994). In contrast, CSCL focuses on how technologies can be used to improve group learning by, for example, using representational tools to stimulate mutual awareness of knowledge/feelings or scripts to structure group members' interaction (Suthers, 2012). Both CSCW and CSCL draw on various fields of research dealing with some aspects of the complex system that is collaboration, such as education, educational psychology, cognitive psychology, social psychology, organizational psychology, sociology, affective sciences. These two fields of research involve research on the generic functioning of collaborative learning/work (CL/CW), research on computer-supported tools for collaboration (CS) and research on the psychological, social, and organizational effects of tools that support collaborative learning/work (CSCL/CSCW) (Sangin, 2009). As part of this thesis, although the collaborative tasks we designed involve the use of computer environments, our focus is not on the role of technologies in collaborative problem-solving per se but rather on the generic individual and collaborative processes taking place both in face-to-face and computer-supported settings. Therefore, we will refer to various research in both the CSCW and CSCL fields, focusing mainly on the CL/CW parts.

2.2 Personal aspects of problem-solving

This section describes various scientific contributions related to the cognitive, metacognitive, motivational and meta-motivational processes occurring at the personal level during collaborative problem-solving.

2.2.1 Cognitive processes

Cognitive processing refers to different abilities of mental functioning, such as memorizing and remembering, inhibiting, focusing attention, or reasoning (Robinson, 2012). Problem-solving relies on some of these cognitive abilities to solve problems

efficiently (Robertson, 2016, p. 21). These cognitive processes have built-in limitations in terms of capacity. First, working memory is a critical component of cognition as it is involved in a wide variety of online processing, including language, imagery, creativity, among other things. Its role in analytic problem-solving is well demonstrated (Fleck, 2008). The limited capacity of working memory compels how much information we can keep in mind, which hinders the use of problem-solving strategies requiring to keep countless information in mind (Gilhooly, 2012, p. 7). Our ability to properly encode information in the environment is also flawed, so that much information may be improperly coded or lost. Besides, the information we manage to store suffers from distortion, due to environment interferences and prior expectations. As a result, not only is the information coming back to mind sparse but often inaccurate. Last but not least, we hardly keep a constant level of attention over time, making our performance somewhat unstable (Robertson, 2016, p. 32). Consequently, all these limitations tend to compel the way we solve problems. Because of the non-exhaustiveness of the lower-level cognitive processes outlined above, humans need to reduce the available information. This is achieved by various higher-level processes. Examples include processes like analysis (i.e., breaking down a complex problem into few manageable elements) or synthesis (i.e., putting together various elements to arrange them into something useful).

Problem-solving is bound to the three commonly described general types of reasoning, namely inductive, abductive and deductive reasoning. **Inductive reasoning** refers to the capacity to generalize from specific facts or observations. In problem-solving, inductive reasoning consists of using existing knowledge to make predictions about novel cases (Hayes et al., 2010). Induction can be liberal (generalization for single instances) or enumerative (generalization from a sample to a population). According to Sternberg et al. (2011, p. 520), inductive reasoning plays two significant roles. First, it helps people to extract meaning from their environment through the establishment of general rules. Second, it helps to hypothesize the future in reducing the uncertainty of events. However, as induction always consists of generalizing based on limited observations, it could be a source of overgeneralization and leads to false inferences. Therefore, we can never reach a definitive conclusion. For this reason, people generally tend to adopt conservative inductive reasoning in problem-solving, i.e., they are cautious about how much they are willing to generalize (Robertson, 2016, p. 128). As a result, people generally tend to adopt **abductive reasoning**, i.e., from a given a set of observations, they conceive the likeliest possible explanation for it (Douven, 2017). Conversely, **deductive reasoning** consists of starting from a general statement to draw a reasoned conclusion (Sternberg et al., 2011, p. 507). An example of deductive reasoning is conditional reasoning, based on a "if p then q. p, therefore q" proposition (e.g., *if Myriam goes to the University of Geneva, then she is a student*. She goes to the University of Geneva. Therefore, she is a student). Similarly to inductive reasoning, deductive reasoning may lead to wrong conclusions. Deductive validity is indeed not equivalent to truth but depends on the

truthfulness of the premises. For example, in our example, although our deduction is logically valid, it is not necessarily true because the premise *If Myriam goes to the University of Geneva, then she is a student* is not true. Indeed, she could be a professor.

Problem-solving mobilizes two well-known types of thinking that are based on the aforementioned inductive, abductive and deductive reasoning, namely divergent (also referred to as lateral) and convergent thinking (also referred to as vertical) thinking. **Divergent thinking** represents the generation of many new possible solutions to a specific problem in a short period of time (Razumnikova, 2012). It is classically associated with four types of cognitive processes, namely fluency (i.e., ability to produce rapidly a large number of ideas), flexibility (i.e., the ability to generate multiple problem solutions), originality (i.e., the ability to generate genuine ideas) and elaboration (i.e., the ability to detail a problem solution) (Guilford, 1967; Razumnikova, 2012). Although divergent thinking appears to be an essential component of creativity in problem-solving, it cannot be completely reduced to it. Especially, along with divergent thinking, creative efficiency also demand the ability to figure out rapidly a solution by applying established rules and logical reasoning, called convergent thinking (Acar & Runco, 2012). While divergent thinking deals with the creation of new ideas in an associative way (DeYoung et al., 2008), **convergent thinking** is oriented toward the search of a single best solution to the problem (Cropley, 2006). Hence, these two types of thinking are complementary and usually co-occur in problem-solving, especially in ill-defined problems, where the path to the solution may be unclear. For example, while building an initial representation of a problem involves logical analysis and reasoning, the inefficiency of a possible solution often compels problem solvers to abandon their previous idea and discover new outlooks.

As we just mentioned, the ability to represent a problem (also called mental formulation; DeYoung et al., 2008) is an essential component of problem-solving. Newell, Simon, et al. (1972) refer to this representation as a problem space, i.e., an internal representation of the problem. The problem space represents all the possible actions that can be applied to the resolution of the problem, given the constraints that apply to the pursued solution (Sternberg et al., 2011, p. 535) or the available operators and procedures allowing to change the current state into the goal state (DeYoung et al., 2008; Newell, Simon, et al., 1972). Various kinds of information contribute to the formation of the problem space. According to Robertson (2016), the task environment, i.e., the specified initial state and goal as well as the possible operators and constraints, is the primary source of information. Another source of information comes from the problem solver's own inferences, especially when the task environment is not clearly stated. However, the counterpart of this extra-information can be its lack of accuracy with the problem, leading to some misunderstanding. The previous experience with the problem (or an analog one) also represents a source of information. This stored knowledge can give an edge for solving the problem, as

it allows the solver to recognize a similar structure and recall comparable solving procedures. Finally, problem solver can also use external memory, i.e., information about the current state of the problem that we back up externally (e.g., on a paper) in order to not overload the working memory. All this information contributes to setting up the problem solver's problem space. As the state space of a problem (i.e., the set of all the possible actions in the problem) may be much broader than the solver's capacity to represent it, problem solver cannot be aware of all the existing possibilities. Therefore, they have to find ways of accurately limiting their search space (Robertson, 2016). To this end, the use of reduction strategies is needed (Fischer et al., 2011). Achieving such a reduction requires to transform the whole complex problem in smaller and more comprehensible parts, merging bunches of elements into useful products, and refining the field of possible solutions. Once the problem space is adequately represented, solvers can choose the strategies and knowledge they will need to solve the problem (Dörner, as cited in Fischer et al., 2011).

A critical question in problem-solving research is to understand how solvers choose strategies and under which conditions. Solvers' experience appears to play a crucial role in this domain, constraining the set of possible applicable strategies and eliciting the best suited to a given problem. According to the type of problem at stake and the previous experience of it, solvers must choose an appropriate method. These methods are classified into two main types, strong and weak. In **strong methods**, solver relies mainly on their domain-knowledge, i.e., the knowledge that applies to a specific field. Strong methods are previously known for a given type of problem so that they can guarantee the solver to get a straightforward solution in following the appropriate algorithm, i.e., a recipe of specific instructions. For example, as extensive knowledge about a domain promotes a more efficient representation of the problem, experts generally remove more effectively irrelevant details to get a more accurate representation of the problem and apply more effective strategies (Chi et al., 1981). However, if domain knowledge help solvers, it could also prevent them from incorporating new strategies or modifying core older ones. Therefore, solvers' mental sets (i.e., a frame of mind involving an existing model for representing a problem) may lead them to fixate on wrong strong strategies (Sternberg et al., 2011). For example, Coughlin and Patel (1987) found that qualified physicians have more difficulties than medical students to make their diagnosis when the typical clinical case structure is disrupted. When such domain knowledge leads solvers to a dead end, they must reconsider their problem space, i.e., make change in their problem space representation. The second type of method is called weak. Unlike strong methods, **weak methods** are general strategies used when no appropriate strategy is available. The feedback resulting from this first approach to the problem is monitored and contributes to refining further the problem space (Robertson, 2016). Heuristics are a kind of weak methods. Unlike computers, humans cannot compute quickly numerous possible combinations to find a solution. However, they can store in long-term memory turnkey solutions that can be applied to a variety of

problems in order not to overload working memory (Sternberg et al., 2011, p. 449). Heuristics exempt the solver to fall back in a blind trial and error process. They help to narrow the range of possibilities toward a possible solution. However, contrary to algorithms, they cannot guarantee to get a solution (Robertson, 2016, p. 42). For example, the heuristic of means-ends consists of trying to decrease the distance between the current state and the desired one by breaking a problem down in its goal-sub-goals structure. It is the case, for example, when we try to get some distant destination (goal). The first thought that comes to mind is to go there by plane. At the airport (subgoal), the distance between our current and final destination is indeed reduced. However, the airport is not just outside the hotel. Therefore, we have to consider another mode of transport, allowing us to reduce the remaining distance again. If the subway is available, it can help us to lower the remaining distance again, taking us to the closest station (subgoal) to the hotel. Finally, we still have to walk a few hundred meters to get our final destination. As a clear path to the solution is not always as clear as in this example, the problem space needs to be continuously updated and reformulated through generation, gathering, and integration of new information all along problem-solving (Fischer et al., 2011). New methods also need to be explored in case of aborted attempts to the solution path. This often requires reconsidering the problem into new meaningful ways.

In summary, collaborative problem-solving requires problem solvers to mobilize lower-level (i.e., memorizing and remembering, inhibiting, focusing attention) as well as higher-level cognitive processes (analysis, synthesis, reasoning). Reasoning encompasses three main types of reasoning, namely inductive, abductive, and deductive reasoning. These reasoning types are involved in divergent and convergent thinking, which co-occur in problem-solving, especially in ill-defined problems. During the problem-solving task, individuals build a problem space, i.e., an internal representation of the problem, including the constraints, available procedures, and actions to be taken to solve the problem. As the number of possible actions may be vast, individuals use reduction strategies to circumscribe the field of possibilities, using strong (previously learned strategies specific to a given problem) or weak methods (generic problem-solving strategies).

2.2.2 Meta-cognitive processes

The various cognitive processes discussed above often require extra knowledge and skills to use, coordinate, and monitor them efficiently (Mayer, 1998). The awareness about these aspects has led to the emergence of one of the most important area of research in educational psychology called self-regulated learning. This field

of research is interested in the thoughts, feelings, and actions that teammates self-generate and that are systematically oriented toward the attainment of their own goals (Zimmerman, 1989).

Metacognitive processes can be defined as the knowledge of cognitive processing (Davidson et al., 1994) and metacognitive skills (Veenman et al., 2004). It refers specifically to higher-order thinking directed to the appraisal, monitoring, and control of the cognitive processes involved in problem-solving (Livingston, 2003). Finding a clear dividing line between cognitive and metacognitive is not straightforward as cognitive and metacognitive processes may closely intertwine. For example, the same strategy may be both cognitive (self-explaining content to obtain knowledge) or metacognitive (self-explaining content to check comprehension). However, according to Livingston (2003), a simple criterion that could allow for disentangling cognitive from metacognitive strategies is that cognitive strategies help individuals to complete the goal while metacognitive strategies ensure that the goal is being achieved. From another perspective, metacognitive processes have a goal of rectification. In this way, metacognition can be roughly seen as a representation of cognition built on incoming information from a monitoring function, informing a control function that gets strategies underway when cognition fails (Efklides, 2011; Winne, 2011).

Metacognition encompasses metacognitive knowledge and metacognitive skills. **Metacognitive knowledge** relates to stored facts about mental activities. **Metacognitive knowledge about persons** is the general knowledge about the functioning of self and others in problem-solving. For example, Ph.D. students may be aware that background music with lyrics has a disturbing effect on attention. However, Ph.D. students may also think that listening to their favorite song boost their own productivity. Second, **metacognitive knowledge about tasks** refers to knowledge about the nature of the task and how it is cognitively demanding. For example, Ph.D. students may know that writing a thesis dissertation is more demanding than writing a blog post. Third, **metacognitive knowledge about strategies** refers to the knowledge of both cognitive and metacognitive strategies and their proper use. For example, Ph.D. students may consider that they should take notes when reading a scientific article in order to enhance memorization. Metacognitive knowledge does not automatically lead to effective task behavior (Veenman et al., 2004). **Metacognitive skills** or **skillfulness** refers to procedural knowledge or strategies dedicated to the actual regulation and control of activities and outcomes (Veenman et al., 2004). These stages of metalevel executive processes are also called metacomponents and guide problem-solving (Sternberg et al., 1985). It includes strategies like problem analysis, planning, monitoring, checking, and recapitulation. These strategies are defined as sequential processes that help to check if problem-solving goals have been adequately performed (Livingston, 2003). For example, self-explanation, i.e., the fact that we explain the meaning of information to oneself, is a part of the metacognitive

strategies as it helps to update one's own understanding.

Several models of self-regulated learning have been developed to date (see Panadero, 2017 for a comprehensive review). In a nutshell, models tend to describe the regulation of learning as three main stages (preparatory, performance, and appraisal) in which several subprocesses occur. Three main areas of emphasis can also be found through most of the models, namely metacognition (e.g., metacognitive knowledge and skills), motivation (e.g., goal-directed behavior), and emotions (e.g., affective reactions). In this section, we will present a model with an important cognitive anchorage, namely the Winne and Hadwin's model (Winne & Hadwin, 1998).

2.2.2.1 Winne and Hadwin's model

Winne and Hadwin's model (Figure 2.1) mainly outlines the meta-cognitive processing that occurs during learning. It also appears to be particularly suited to problem-solving as it describes the learning activity as repeated sequence of different operations resulting in performance and evaluations of performance.

For Winne (2011), self-regulation of cognition is consubstantial to learning. Two crucial reasons cause people to self-regulate the content and operation they select. First, working memory has a limited capacity and can be overloaded. Second, due to complex or time-limited tasks, learners often undergo a lack of information or knowledge. In this model, learning encompasses four phases, namely task definition, goal setting and planning, studying tactics and strategies (or engagement), and adaptations to metacognition (or large-scale adaptation). In the task definition phase, learners create a model of the task. In the goal setting and planning phase, learners define goals accordingly to their model and a plan to achieve them, such as the learning strategies. In the studying tactics and strategies phase, they implement the actions needed to reach the goals. The actual implementation of strategies generates information that updates learners' knowledge and beliefs. Finally, in the last phase, the products created and their evaluation allows learners to monitor and adapt learning if progress deviates from the goals standards, i.e., qualities or properties of an ideal product (Winne, 2004), and make long-term changes in their motivations, beliefs, and strategies for the future (Panadero, 2017).

In this model, a set of processes designated by the acronym COPES (**Conditions**, **Operations**, **Products**, **Evaluations**, **Standards**) represents the core component of learning. Contrary to other models, the set of COPES processes intervene within each phase above mentioned.

- **Conditions** refer to the resources available to a person (cognitive conditions) and the constraints inherent to the task or environment (task conditions). Cognitive conditions represent the set of learners' (meta)cognitive knowledge (e.g., domain knowledge, knowledge of study tactics and strategies), attitudes, and dispositions coming from past learning experiences and personality. Tasks

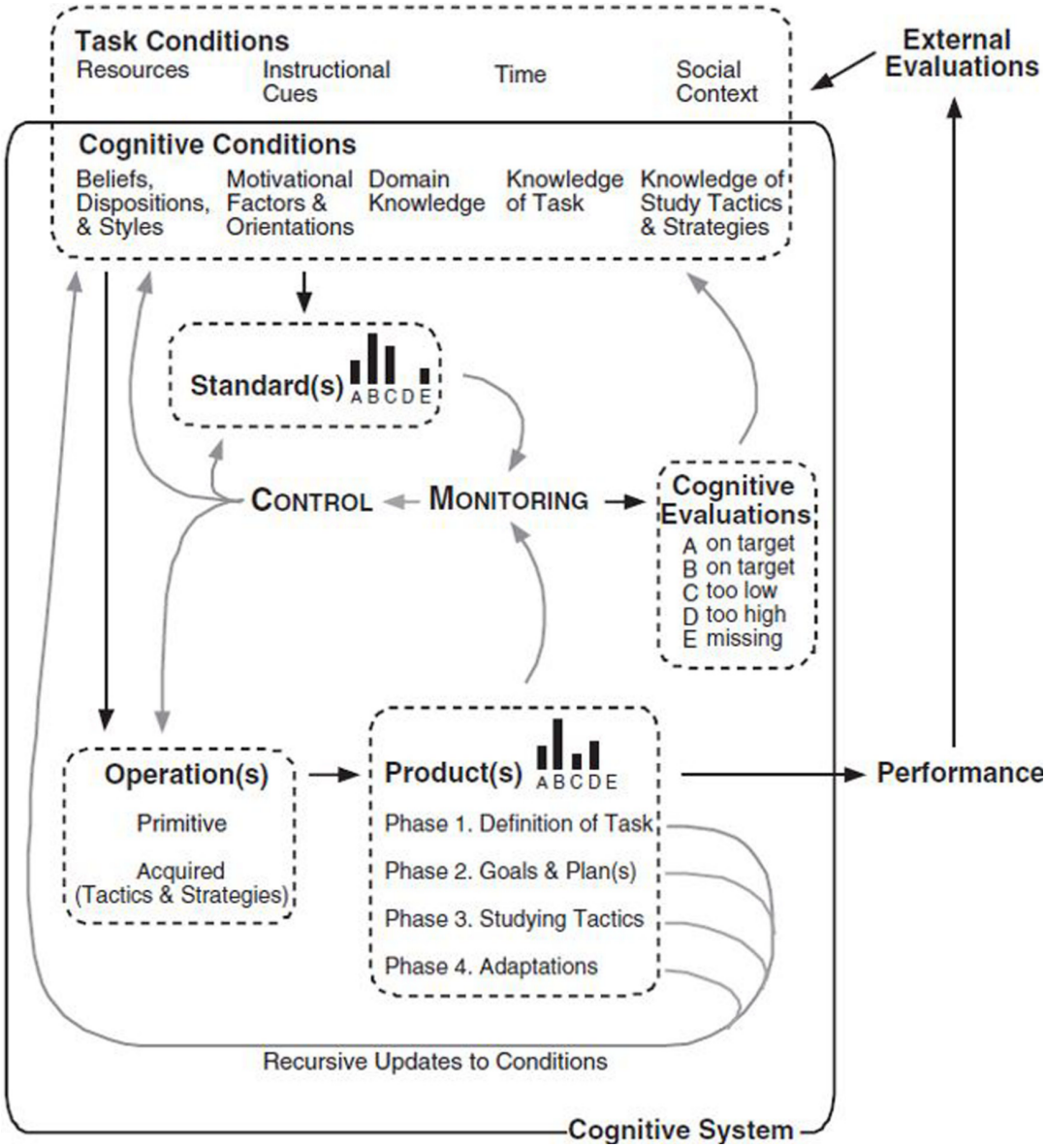

FIGURE 2.1: Winne and Hadwin's model. Retrieved from Winne and Hadwin (1998)

conditions represent external resources, such as instructional clues or time. The conditions phase is involved in the creation of standards and the use of operations used by the learner.

- **Operations** represent all the cognitive processes, tactics, and strategies used by the learner to manipulate information. It encompasses five primitive cognitive operations (i.e., for which it is not helpful to disassemble them into smaller parts) designated by the acronym SMART (**Searching**, **Monitoring**, **Assembling**, **Rehearsing**, **Translating**). **Searching** corresponds to retrieve knowledge in memory, i.e., previous information or knowledge. **Monitoring** is a generic operation that compares a set of features with standards (i.e., qualities or properties of the ideal product). It creates an index of the matches between them, allowing learners to determine if the objectives are met or if additional

work still has to be done (Winne, 2004; Winne, 2011). If the fit between products and standards is not acceptable, control processes take place to refine the product according to the standards (Greene & Azevedo, 2007). **Assembling** involves the creation of links between two items of knowledge and produces a knowledge structure of different forms (e.g., A explains B, A precedes B, g is included in G, etc.). For example, the fall of the government is explained by the vote of no confidence (Winne, 2011). **Rehearsing** consists of keeping attention on the information at stake so that it could be re-inspected or processed later. Finally, **translating** refers to the process of reformating information or knowledge in another representation.

- **Products** refer to the new information created as a result of operations (formation of new knowledge). Successive products may have to be produced to complete a task. Products may either be kept in mind or be stored externally.
- **Evaluations** are the phase where products are monitored so as the learner's feedback corresponding to the fit between standards and products is characterized.
- Finally, in the **Standards** phase, the criteria against which products are created are monitored (Panadero, 2017).

An essential aspect of this model is the fact that monitoring and control pervade all the learning phases. First, monitoring takes place at two levels. At its basic level (Monitoring), it means, for example, checking if the product of a problem is right. However, at a second level (Evaluations), monitoring entails checking how right the product is. In other terms, how is it possible to refine it. As illustrated in Winne (2011), a student asked to answer the following question "What caused the fall of the Roman empire?" will monitor if a response can be found in memory and if what he found matches the standards of a potential right answer (Monitoring). However, subsequent monitoring (Evaluations) may take place if the student asks themself how they will answer the teacher's question. For example, whether the answer needs to be more or less complete or concise. Second, metacognitive control intervenes when monitoring reveals a difference between standards and products. Tactics and strategies are then chosen to reduce the differences. For example, if a student does not understand the meaning of a word and that meaning is needed to continue learning or problem-solving, he can implement strategies such as looking up in the dictionary. According to Winne (2011), a student has three basic choices to tackle cognitive challenges through meta-cognitive control. The first one is changing the environment, externally or internally (e.g., give oneself more time or interpret errors as opportunities to improve). The second form of metacognitive control involves selecting the content (e.g., focus only a part instead of all content to study). Finally, the third one concerns the selection of operations for processing information and knowledge (e.g., select keywords to summarize the content).

If the Winne and Hadwin's model describes the cognitive aspects of self-regulation thoroughly, motivation and affective aspects of self-regulation remain mostly underdeveloped. As outlined in Safari and Meskini (2016), the association of metacognitive knowledge and skills may not always provide positive effects on problem-solving. Incorrect inferences about poor cognitive abilities (metacognitive knowledge about persons) can emerge following a failure to cope with a difficult problem (metacognitive skills). Therefore, motivational aspects such as self-beliefs or persistence also play a crucial role in problem-solving efficiency and need more significant consideration. From this perspective, problem-solving efficiency also involves considering how problem-solvers also deal with these motivational challenges.

In summary, collaborative problem-solving requires not only cognitive processes but meta-cognitive processes to monitor and control them to ensure goal achievement. Meta-cognitive processes encompass general knowledge (about oneself and others, the task and problem-solving strategies) and skills dedicated to regulating problem-solving activities and outcomes. Winne and Hadwin's model (Hadwin et al., 2011) proposes a comprehensive description of how cognitive and meta-cognitive processes build learning activities.

2.2.3 Motivational processes

Alongside cognition and affection, motivation is one of the three classically described components of mind. Motivation is a fundamental condition for problem-solving because it promotes engagement, which is a necessary condition to become proficient in whatever effortful activity (Fortus, 2015). Motivation concerns "the process responsible for the initiation, intensity, and persistence of behavior. Motives are causes that produce certain effects or actions (including inaction)" (Usher & Morris, 2012, p. 36). In the academic context, achievement motivation concerns the learner's striving to be competent in effortful activities (Low & Jin, 2012). Three different kinds of motivation constructs appear fundamental in academic functioning and success, namely self-beliefs and attitudes, achievement goals and values, and attributions about success and failure (Usher & Morris, 2012). In the following sections, we will describe several theories regarding these motivational constructs to highlight the different ways by which collaborative problem-solving can be affected by personal motivation.

2.2.3.1 Self-beliefs and attitudes

Self-beliefs The notion of **self-beliefs** broadly refers to the beliefs people hold about their attributes and abilities as persons" (Valentine et al., 2004, p. 112). This term is actually a portmanteau word and encompasses several concepts related to

individuals' beliefs. Findings demonstrate that self-beliefs addressing the academic domain have a more significant influence on academic achievement than more general self-beliefs about oneself. A first type of self-belief is the notion of **self-concept**. It is defined as the individual's descriptive knowledge about themself regarding skills, abilities, attractiveness, socio-acceptability, etc. (Bong & Skaalvik, 2003; Byrne, 1984; Mcinerney, 2012). A second type is **self-esteem**, which refers to how an individual evaluates themself (Ruholt et al., 2015). Finally, **self-efficacy** refers to individuals' convictions that they can successfully perform a task (Bong & Skaalvik, 2003; Zimmerman, 2000). These three constructs slightly differ and are highly correlated (Usher & Morris, 2012; Valentine et al., 2004). However, some differences can be found between self-esteem and self-concept. For example, people can have different levels of self-esteem depending on the self-concept domain to which it refers (e.g., "I'm a bad writer" or "I'm good in mental arithmetic"). Besides, self-efficacy and self-esteem can also slightly differ in the sense that self-efficacy relates more to the capacity to perform a given task, no matter the self-esteem in the field in question. Furthermore, self-efficacy is also more closely related to goals than self-concept and self-esteem.

Regarding goal-directed activities, these three constructs have been related to achievement, self-regulation, persistence, and effort (Usher & Morris, 2012). For example, the accuracy of academic self-beliefs impacts academic achievement as students with realistic and well-informed beliefs appear more productive, persistent and effortful. Conversely, false academic self-beliefs may dampen confidence and lead to false attributions such as a lack of academic abilities (Seel, 2011). More specifically, students with positive self-concept tend to act according to this belief. In this way, they are more likely to exhibit achievement-related behaviors (e.g., studying hard for test grades or doing homework consistently), which leads to better academic outcomes (Valentine et al., 2004). Academic self-esteem is also related to one's global sense of worth as a student. Students with positive self-esteem are more eager to preserve this feeling in striving for high academic outcomes. Positive self-esteem also allows better coping with failure as well as better persistence that facilitate academic achievement. Conversely, students with negative academic self-esteem would be more likely to exhibit behaviors allowing them to avoid situations that could confirm poor abilities (e.g., procrastination). However, these behaviors may have a deleterious effect on academic achievement and reinforce negative self-esteem (Valentine et al., 2004). Students with positive academic self-efficacy would be more likely to exert more effort and show more persistence (Low & Jin, 2012; Mcinerney, 2012). They would also exhibit approach-behaviors regarding the tasks for which they have positive self-efficacy. In this way, they would have more opportunities to practice and receive feedback. Positive self-efficacy is also related to the use of more self-regulatory strategies and predict better performance (Low & Jin, 2012; Valentine et al., 2004).

Attitudes Although attitudes and beliefs are sometimes used interchangeably, the notion of **attitude** or mental attitude rather refers to a relatively enduring general evaluation that derives from specific beliefs (Scherer, 2005). Attitudes also predispose people to form relatively stable positive or negative judgment toward an object (e.g., an academic activity) and act accordingly (Seel, 2011). Similarly to positive self-beliefs, positive attitudes toward learning would improve academic achievement. Positive relationships have also been uncovered between academic attitudes and interest in learning, degree of participation, eagerness to acquire new information and skills to solve problems, and emotional engagement. Positive attitudes would also influence outcomes and predict better academic outcomes (Frasson & Heraz, 2012; Kara, 2009).

2.2.3.2 Achievement goals and values

Task goals are the purpose of an activity that structure cognition and affect according to this purpose. Achievement goals are a kind of personal goals that reflect the purpose of individuals' achievement behaviors (e.g., because I want to understand the subject or because I want to demonstrate that I am better than others) (Niemczyk, 2012; Scherer, 2005; Wolters & Taylor, 2012). Besides, values represent incentives that foster task accomplishment (e.g., because it is interesting per se or because it will bring me further reward) (Eccles & Wigfield, 2002).

Achievement goal theory Achievement goal theory (Pintrich, 2000) describes different types of goal orientations that influence motivation and behaviors in learners. Two major academic goals have been described in the literature, namely mastery goals and performance goals. **Mastery goals** rely on the belief that ability is improvable and that effort leads to success (Bong, 2012). In this case, learners favor the intrinsic value of learning, i.e., they focus on improving their level of competence and developing new skills for personal reasons (i.e., the desire to understand the subject matter). In this case, the learner's success is not assessed relative to the others' performances. Instead, success is about feeling a sense of mastery in completing the task (Mcinerney, 2012). Failure is mainly seen as a normal learning process, a condition for improvement, rather than a consequence of low ability (Bong, 2012). **Performance goals** rely on the belief that ability is fixed and primarily depends on inherent qualities (Bong, 2012). In this case, learners favor the extrinsic value of learning, i.e., they focus on doing better than others and surpassing established standards. If success indicates superiority over others, failure is mainly seen as evidence of low ability and may damage self-worth (Mcinerney, 2012).

These two main goals have been later divided into a 2 x 2 framework that distinguishes mastery vs. performance on one axis and approach vs. avoidance on the other. **Mastery-approach goals** are substantially similar to the mastery goals described above (Bong, 2012; Low & Jin, 2012; Mcinerney, 2012). **Mastery-avoidance**

goals refer to the avoidance of situations that highlight difficulties in understanding, learning or mastering a given task (e.g., refraining from understanding a notion that seems too complicated). It is grounded on personal standards (Van Kleef, 2009). Perfectionists, elderly people or former high-level performers would be more susceptible to behave this way (Bong, 2012). **Performance-approach goals** refer to the willingness to perform tasks where it is possible to outperformed others so as to validate one's superior competencies. Conversely, learners with **performance-avoidance goals** orientation perform tasks so as not to appear incompetent in the eyes of others. They generally avoid risky tasks and use self-defeating strategies (e.g., I'm not well today) to explain their failure (Bong, 2012; Mcinerney, 2012).

Researchers have also focused on the factors that may influence achievement goal orientations. Such factors generally fall into two major categories, namely student-related factors and contextual factors. **Student-related factors** deal with students' disposition or personality, while **contextual factors** are about instructional practices or group climate (Wolters & Taylor, 2012). Concerning student-related factors, performance-avoidance orientation has been related to the fear of failure, while the need for achievement rather drives mastery-approach goal orientation. Performance-approach orientation may be induced by either fear of failure and the need for achievement. Motives concerning mastery-avoidance are less clear (Feltman & Elliot, 2012; Wolters & Taylor, 2012). Other factors have also been reported to influence achievement goals orientations such as implicit theories about ability. For example, students who believe that ability is unchangeable (entity theory) would preferentially adopt performance goals. Conversely, students who believe that ability is upgradable (incremental theory) would be more likely to adopt mastery goals (Wolters & Taylor, 2012). Concerning contextual factors, the literature indicates that instructional practices and group climate (oriented toward mastery or performance) are related to the achievement goal orientation that students are likely to adopt (mastery or performance goals) (Wolters & Taylor, 2012).

In the academic context, achievement goals have been reported to impact performance, behavior, cognition, and affect. Mastery-approach goals appear to be a good predictor of the level of effort and persistence dedicated to tasks as well as the use of deep cognitive, metacognitive, and self-regulating strategies. It is also related to positive affects and unrelated to negative affects. As a consequence, students would have a more adaptative approach to thorny situations, which eventually would result in better learning experiences and academic performance (Low & Jin, 2012; Wolters & Taylor, 2012). Mastery-avoidance approach is rather associated with more surface cognitive strategies, less intrinsic motivation, and more negative emotions (e.g., anxiety, worry) (Wolters & Taylor, 2012). Performance-approach also appears to have some beneficial effects on learning, such as deep-learning strategies.

These effects would be, however, counterbalanced by increased anxiety, less long-term memorization, and more disruptive behaviors (Mcinerney, 2012). Performance-approach would also promote better performance (Wolters & Taylor, 2012). Finally, performance-avoidance approach is mainly associated with negative outcomes such as less intrinsic motivation or persistence, more procrastination and more negative emotions such as test anxiety. Some studies also report less deep cognitive strategies as well as reduced academic performance (Wolters & Taylor, 2012).

Expectancy-value theory In expectancy-value theory (Wigfield & Eccles, 2000), expecting and valuing success are thought to be two significant factors fostering motivation. High **success expectancies** involve strong belief to be able to be successful in a given activity. They are a prerequisite to motivation even though they are not sufficient in themselves. Indeed, high expectancies of success do not strengthen motivation if the activity is considered uninteresting. Expectancies of success are then to be combined with the **subjective value** assigned to the activity to result in motivation in individuals (Mcinerney, 2012; Svinicki & Vogler, 2012). More specifically, subjective value globally answers the reasons why individuals want to perform the task. Different criteria intervene to address this question. The first criterion is **utility value**, which represents the degree to which an activity is considered important, i.e., useful and relevant. Second, **intrinsic value** refers to whether the individual finds the task enjoyable and interesting per se. Finally, **attainment value** refers to the personal significance of the task or activity. The **cost** of engaging in the activity is also an important component that influences subjective value. For example, a negative previous experience or an overly-demanding task can decrease substantially subjective value. Besides subjective value, **success expectancies** are beliefs about the confidence an individual has to succeed in an activity. As subjective value, success expectancies are also affected by different sources. For example, prior success in the same kind of activity is likely to increase success expectancies. It is also the case when the requirements of the task match the learner's competencies (ability beliefs) or when a reliable source persuades the learners that they have the required skills (socialization influences) (Mcinerney, 2012; Usher & Morris, 2012).

Success expectancies and subjective value have academic consequences, shaping students' behaviors and choices. For example, expectancy-value theory predicts that if either success expectancies or subjective value are low, it should lower overall student's motivation. For example, if someone knows she is very good at playing the piano (high success expectancies) but does not enjoy this activity (low subjective value), she is expected to have low motivation (Svinicki & Vogler, 2012). Conversely, motivation can be enhanced by increasing either success expectancy and subjective value, although success expectancy would have a more significant impact on motivation (Mcinerney, 2012). In general, success expectancy and subjective value have been reported to impact engagement, persistence, choice of activity and performance (Usher & Morris, 2012).

Self-determination theory Self-determination theory proposes to explain human motivation by the fulfillment of psychological needs that drives individuals' engagement in a given activity. Deci and Ryan (2002) described three innate and universal needs that are thought to be the essence of self-motivation and self-determination. First, **autonomy** reflects the need to be the cause of one's behaviors. Second, **competence** relates to the need to feel to be needed and efficient in what one does. Third, **relatedness** refers to the need to be connected with others and belong to a group. The satisfaction of these three needs appears to be a prerequisite for people to engage in self-determined tasks. The basic premise of self-determination theory is that, in an environment that fully supports autonomy, competence and relatedness, individuals should have intrinsic motivation, i.e., a natural drive to engage in the task because it is interesting or satisfying per se (Mcinerney, 2012; Seel, 2012). Another type of motivation is called extrinsic motivation. Contrary to **intrinsic motivation** that is inherent to oneself, extrinsic motivation comes for external sources such as the prospect of obtaining external rewards. **Extrinsic motivation** can be conceptualized as a continuum as it contains different levels of self-determination. At one extreme is **externally regulated motivation**. In this case, motivation comes primarily from external rewards, pressures or constraints. Individuals experience little autonomy (e.g., a teenager tidies up his room to not be grounded). **Introjected regulated motivation** goes a step further in the sense that individuals are not motivated to pursue an activity only because of external constraints. Instead, the activity is performed to maintain self-worth, although it is not accepted as personally relevant (e.g., a teenager tidies up her room because she does not want to disappoint her parents). Then, **identified regulated motivation** implies that individuals attach personal importance to the activity. In other terms, they are motivated to perform the activity because they believe that it is essential to reach future goals (e.g., a teenager tidies up his room because it is a way for him to get permission to go out). Finally, **integrated regulated motivation** represents the highest level of self-determined extrinsic motivation. In this case, external reasons motivating the achievement of activity are fully integrated into the self so that individuals internalize and assimilate their actions as congruent with their personal beliefs and values (e.g., a teenager tidies up her room because she thinks she is a tidy person). This last kind of motivation shares some similarities with intrinsic motivation. However, intrinsic motivation implies inherent interest or pleasure from doing the activity, which is not the case of integrated regulated motivation. However, identified regulated motivation could also turn into intrinsic motivation (Deci & Ryan, 2002; Mcinerney, 2012). Globally, more self-determined students exhibit more in-depth cognitive strategies as well as better academic performance and well-being (Kusurkar et al., 2013).

2.2.3.3 Attributions about success and failure

Another construct that influences motivation is attribution. Attribution is an inference regarding the cause of a person's behavior. People tend to automatically find

explanations to events and attribute causes regarding why they succeeded or failed. These attributions can affect their future motivation. **Attribution theory** (Weiner, 1984) aims to explain why people use particular explanations for their outcomes. Individuals generally use various kinds of explanations (e.g., lack of studying, poor abilities, unfair grading, illness) (Mcinerney, 2012; Seel, 2012; Svinicki & Vogler, 2012). According to the attribution theory, these explanations or attributions are characterized along three dimensions, namely locus, stability, and controllability (Svinicki & Vogler, 2012; Usher & Morris, 2012).**Locus** refers to where individuals locate the source of their success or failure. Locus can be external (e.g., exam failure attributed to a too strict examiner) or internal (e.g., exam failure due to a lack of studying) (Seel, 2012). The dimension of **stability or constancy** corresponds to the degree to which a cause is understood as permanent or changeable (e.g., lack of effort may be seen as temporary while poor abilities as a permanent condition). This dimension has direct implications for future actions since individuals can anticipate stable cause, and especially prevent negative ones. Finally, controllability or control is related to how much control people think they have control over the situation (Svinicki & Vogler, 2012). For example, if a student failed an exam because he fell sick during the revision period, his degree of control over the situation was weak. Conversely, if he failed because he voluntarily skimped on course content, his degree of control of the situation was high. According to this theory, four main causes explain success and failure in achievement context: ability, task difficulty, luck, and effort. **Ability** is related to individuals' capacity to perform the task in question. **Task difficulty** represents the perceived degree of task difficulty (e.g., whether most people achieve it). **Luck** corresponds to all kinds of causes that are independent of one's control (e.g., physical constraints). Finally, **effort** refers to the amount of energy dedicated to the task. These different causes can be associated with one or several of the attribution dimensions of locus, stability, and consistency. For example, effort is internal and controllable, ability is internal and uncontrollable, while luck and task difficulty are viewed as external and uncontrollable (Mcinerney, 2012).

Attributions causes have different motivational impacts on subsequent behaviors and emotions. For example, attribution to internal factors (e.g.. poor ability) may have detrimental consequences on self-esteem in case of failure. Conversely, attribution to external factors (e.g., luck) can preserve self-esteem because failure is not seen as imputable to oneself. Attributions about stability also modulate variables such as persistence, as it is easier to persevere in the task after failure when it is attributed to exceptional circumstances such as bad luck or temporary lack of effort (Seel, 2012). Attributions may also have different emotional implications. For example, the feeling of guilt may emerge from failure due to internal and controllable causes such as carelessness. The feeling of shame also correlates with interval and uncontrollable causes leading to failure, such as poor abilities (Seel, 2012). Conversely, gratitude classically arises following success attributed to external and uncontrollable causes (other's abilities) (McCullough et al., 2002).

In summary, collaborative problem-solving is not only about the individual resolution of the problem at the cognitive level. Different motivational processes influence the initiation, intensity, and persistence of problem solvers' behavior. These motivational processes encompass a wide range of constructs, generally classified into three main categories, namely self-beliefs and attitudes (e.g., self-esteem, self-efficacy), achievement goals and values (e.g., mastery or performance approach, intrinsic or attainment value), and attributions about the causes of success or failure. All these motivational processes have direct implications on problem solvers' choice, effort and persistence in the problem-solving task.

2.2.4 Meta-motivational processes

Zimmerman (1995) highlights that meta-cognitive knowledge and strategies are insufficient to explain thoroughly effective self-regulation. For this author, having metacognitive knowledge and skills is way different than having the capacity to efficiently self-regulate, as learners may deal with different factors preventing the effective implementation of metacognitive strategies. Hence, self-regulation needs to be extended to other sources of personal influence, such as motivational components to address the complexity of learners and learning. While theories of motivation emphasize how self-beliefs, attitude, goals, attributions, among others, impact student choice, effort and persistence, the regulation of motivation focuses mainly on the explicit use of strategies that influence these different aspects (Kuhl, 1985).

Motivation regulation explains how people attempt to maintain a suitable level of motivation when solving a specific task (Miele & Scholer, 2018). As we have seen earlier, individual problem-solving involves not only cognitive but also metacognitive processes, allowing the problem solver to manage one's own cognitive processes. These meta-cognitive processes make problem-solving more efficient and successful. The same idea prevails regarding motivational processes. In this section, meta-motivational processes specifically refer to the processes by which individuals regulate their motivational states when pursuing goal-directed activities (Miele & Scholer, 2018; Wolters, 2003). It includes both thoughts and strategies aiming at initiating, monitoring and controlling the individuals' choice, effort and persistence to achieve their goals (Niemczyk, 2012).

A motivational strategy can be defined as "a procedure used by individuals in a purposeful and willful manner to influence their motivation" (Wolters, 2003, p. 190). This author identified several strategies to self-regulate motivation. **Self-consequating** refers to identifying and using verbal or concrete rewards and punishments as an incentive for achieving academic goals (e.g., not playing video games

as long as homework is not finished). **Goal-oriented self-talk** is another strategy that consists of thinking about good reasons for persisting and completing the task. These thoughts mainly relate to both performance (e.g., doing better than others) or mastery (e.g., becoming more competent) goals. **Interest enhancement** refers to the reinforcement of intrinsic motivation by trying to increase immediate enjoyment or situational interest while carrying out the task (e.g., turning a dull task into a game). **Environmental structuring** is concerned with the will to restrict off-task behavior to avoid distraction (e.g., put one's phone in another room when studying) as well as maintaining focus, physical and mental readiness (e.g., get an early night before an exam). Another counter-intuitive motivation strategy is called **self-handicapping**. In this case, individuals voluntarily create obstructions that make the task more complicated to achieve (e.g., start working on one's homework at the last minute). This strategy could help people to preserve self-esteem or self-worth when self-ability is threatened (i.e., failure can be ascribed to a lack of time rather than a lack of comprehension). In that sense, it could prevent a complete abandonment of the task. Another motivational goal of the self-handicapping strategy is that it could help learners to get rid of the pressure for success and promote more intrinsic interest and mastery goals. However, this strategy globally appears counterproductive. **Attribution control** refers to the kinds of explanations people use to justify their success or failure. To promote motivation, they tend to overlook internal, stable and uncontrollable causes (e.g., lack of ability) and favor internal and controllable factors (e.g., wrong learning strategy). **Efficacy management** encompasses three different ways to regulate motivation. First, **proximal goal setting** consists of breaking a complex or larger task into subtasks easier to complete. Second, **defensive pessimism** is a way to boost individual motivation in generating failure anxiety by highlighting one's unpreparedness or lack of ability. In this way, it could be used to motivate behavior aiming at reducing the occurrence of anticipated failure. Third, **efficacy self-talk** appears to be a somewhat reverse pattern of defensive pessimism. In this case, individuals converse with themselves to enhance their confidence in their ability to achieve the task. Wolters (2003) also mentions the role of emotion regulation, especially emotional control, as an important strategy influencing motivation. This aspect will be developed further.

2.2.4.1 Miele and Scholer's model

Miele and Scholer (2018) model describes three aspects of self-regulating motivation in academic settings, namely (a) the different components of motivation that may lead to regulation strategies, (b) the phenomenological experiences of the different motivational components (i.e., meta-motivational feelings) and (c) the strategies used to monitor and control the quantity as well as the quality of motivation. This model (Figure 2.2) aims to explain how people monitor their motivation and which motivational components they monitor, how they identify the source of a

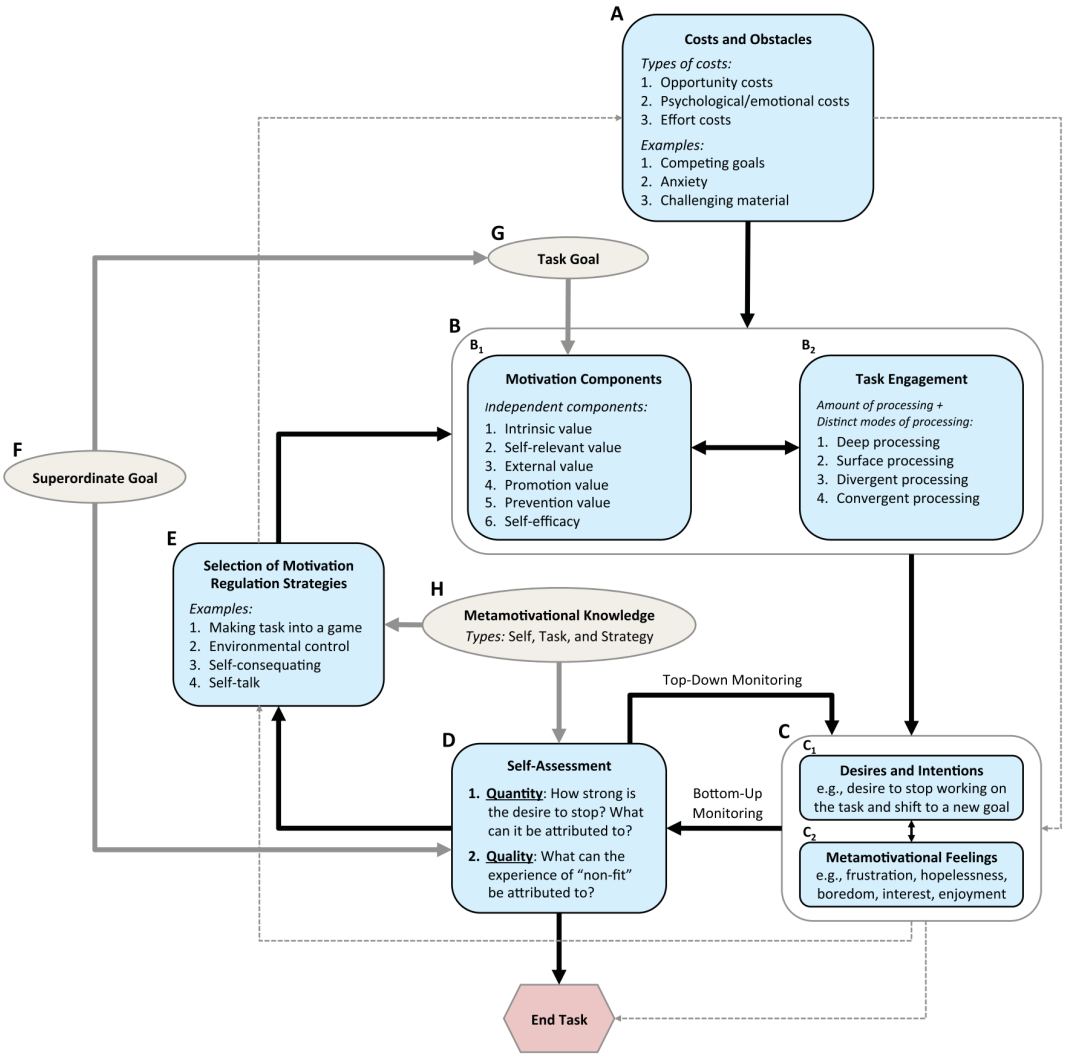

FIGURE 2.2: Miele and Scholer's model. Retrieved from Miele and Scholer (2018)

lack of motivation and how they choose effective strategies to counter it. The authors used three criteria to isolate significant motivation components. First, each motivation component is related to a unique set of meta-motivational feelings. Second, each motivation component is related to a relatively unique set of strategies to regulate it. Third, each motivation component is positively associated with the desire to pursue the task goal. Based on these criteria, the authors retained six different motivation components from different motivation theories (e.g., self-determination theory, expectancy-value theory): **self-efficacy**, **intrinsic value**, **self-relevant value** (similar to attainment value), **external value** (similar to extrinsic value), **promotion** value (value of task outcomes as ideals promoting realizing ambitions), and **prevention value** (value of task outcomes as responsibilities promoting safety and security). Each of these different motivation components is associated with more or less specific feelings. These meta-motivational feelings signal the level and the type of motivation typically experienced in a given motivation component. For example, frustration and hopelessness are typically induced by low self-efficacy. That way, they

orient individuals towards adequate motivation regulation strategies when needed. For example, self-efficacy can be enhanced by introducing proximal goals or efficacy self-talk (e.g., tells oneself, "I can do it"). In addition to meta-motivational feelings, the authors also described costs that can act as obstacles to motivation. Although costs share similar characteristics with meta-motivational components (i.e., they are related to specific meta-motivational feelings and regulating strategies), they are, however, negatively associated with the desire to pursue the task goal. Three different types of costs are classically reported in the literature. First, **opportunity costs** are about valuing the potential gain of alternative actions when engaging in a task (e.g., valuing the benefits of going to a party instead of staying in to study). Second, **emotional/psychological** costs are the psychological discomfort students may feel when engaging in a task (e.g., feeling anxious or being stressed). Third, **effort costs** represent the effort and the perseverance required by a task.

According to this model, students possess an initial superordinate goal that is divided into several subordinate goals (i.e., task goals). A superordinate goal can be, for example, succeeding in the final exam, whereas one of the subordinate goals can be to redo some classroom exercises. In order to regulate subordinate goals, two main meta-motivational processes are involved, namely meta-motivational monitoring and meta-motivational control. **Meta-motivational monitoring** is the process of monitoring both the quantity and the quality of one's own motivation when pursuing a task goal. **Quantity** refers to the amount of motivation. During the task, students monitor the quantity of motivation in the different motivation components described above (e.g., low intrinsic value, high self-efficacy). Besides, **quality** refers to the fit between the motivation components they adopt and the motivation components that are ideally required by the type of task they perform. Both quantity and quality are monitored through bottom-up (i.e., motivational information triggers self-assessment from a certain threshold) and top-down processes (i.e., a periodic self-assessment of motivational information is periodically triggered). When individuals undergo a lack of motivation, monitoring ponders the desire to disengage the task and the desire to achieve the superordinate goal. If the resulting decision is to continue the task, the sources of the motivational deficit have to be sought and alleviated, which involves identifying the motivation component(s) responsible for the reduced motivation as well as the potential costs involved (meta-motivational monitoring of quantity). It also potentially involves evaluating the "nonfit" between the adopted motivation component and the task demands (meta-motivational monitoring of quality). Once the necessity to bolster or change a motivational component becomes pregnant, **meta-motivational control** selects and executes strategies to reduce costs, enhance the amount of motivation in a given component, or switch the adopted motivation component. For example, when studying for an exam, a student who feels a lack of motivation can turn their cell phone off (reduce costs), tells themself, "I know I can do it" (bolster self-efficacy), or mobilize intrinsic instead of extrinsic value in finding reasons for

enjoying the course content (switch motivation component). Once the strategy has been implemented, meta-motivational monitoring intervenes again to evaluate the success of the strategy, i.e., whether the meta-motivational feeling associated with the targeted motivation component has increased or the new adopted motivational component fits with the goal demands. Thus, monitoring and control form a loop as monitoring takes the output of control as input and control the output of monitoring as an input. If motivation regulation is successful, no further regulation will be implemented. However, if the strategy mobilized has little success, the lack of motivation can lead individuals to give up the task. The effectiveness of meta-motivational monitoring and control depends on a large part of **meta-motivational knowledge**, i.e., the explicit and implicit knowledge about the type and level of motivation needed to perform a given task at one's best (task knowledge), the known regulating strategies (strategy knowledge) and the knowledge about how to implement them as effectively as possible (self-knowledge).

In summary, if collaborative problem-solving involves different motivational processes influencing the choice, effort, and persistence of individuals during the problem-solving task, individuals can also monitor and regulate their motivation to foster task achievement. Meta-motivational processes allow individuals to mobilize adequate type and level of motivation. This is achieved by implementing different types of strategies (e.g., efficacy management) detailed in Wolters (2003). Recently, Miele and Scholer's model (Miele & Scholer, 2018) proposes a comprehensive description of how motivational and meta-motivational processes interplay in goal achievement activities.

2.3 Interpersonal aspects of problem-solving

In section 2.2, we have focused on individuals because the understanding of how individuals solve problems alone is an essential step to understand how they solve problems together. However, collaboration generates emergent properties that go beyond a mere aggregation of individual work. In this section, we will attempt to highlight this aspect in presenting research contributions from the group problem-solving and learning fields.

As personal problem-solving implies both cognitive and motivational processes and meta-processes, interpersonal problem-solving also involve two levels of processing of the interpersonal information. One represent the performing activities and is more reactive (co-modulation) while the other represent the monitoring and control of this performing activities and is more proactive (co-regulation) (Isohätälä et al., 2019; Janssen et al., 2012; Volet et al., 2009). The next sections will describe these

two levels in the cognitive (socio-cognitive and socio-meta-cognitive processes), motivational (socio-motivational and socio-meta-motivational) and relational (socio-relational and socio-meta-relational) dimensions of collaboration.

2.3.1 Socio-cognitive processes

Socio-cognitive processes are bound to social cognition, which can be defined as cognitive processes that involve other people (Frith & Blakemore, 2006). More precisely, it relates to the perception, understanding and implementation of cognitive processes that involve interpersonal information (Suchy & Holdnack, 2013). In this perspective, socio-cognitive processes represent interpersonal behaviors complementing individual ones and interplaying with them (Dillenbourg, 1999). Indeed, socio-cognitive processes such as constructive conflict (see below) or mutual explanation (Dillenbourg et al., 1996) occur in addition to self-explanation or reasoning. For Decuyper et al. (2010), there is a need to focus on these socio-cognitive processes as they help to understand how the outputs of collaboration arise and why they are sometimes detrimental to group outcomes.

Socio-cognitive processes include three main activities, namely, knowledge acquisition, participation, and creation, that shape group collaboration. **Knowledge acquisition** involves developing a shared mental model of knowledge; it covers the sharing, storage, and retrieval processes. **Participation** refers to the creation of shared discourse; it includes team reflexivity, team activity, and boundary-crossing. Finally, **creation** relates to the co-creation of new knowledge. It encompasses co-construction and constructive conflict. Sharing, co-construction and constructive conflict are thought to be the core processes enabling high-quality interactions (Decuyper et al., 2010).

Knowledge acquisition **Sharing** relates to communication about non-previously shared knowledge, competencies, opinions, and creative thoughts from one person to another. **Storage** and **retrieval** concern group knowledge, learned procedures, and shared ideas produced in the group that must be stored to promote the persistence of the team over time. Storage can take the form of memory (individual or shared) or material artifacts (e.g., paper, computer). The way learners store and retrieve group information is of great importance. Notably, indexing, filtering and maintaining cues about group information improve the quality of both storage and retrieval (Wilson, Goodman and Cronin, as cited in Decuyper et al., 2010). (Cannon-Bowers & Salas, 2001) have classified stored information as task-specific, task-related, about teammates and attitudes/beliefs. **Task-specific knowledge** is tacit knowledge that does not imply group communication (e.g., procedures) and can be applied only to the current task. **Task-related knowledge** aims to promote the team's ability to carry out the task and holds between tasks (e.g., knowledge about teamwork functioning). **Teammates' knowledge** represents the knowledge

that learners have about each other (e.g., preferences, strengths, weaknesses, and tendencies). Finally, **shared attitudes and beliefs** may relate to task difficulty or group motivational tone. Knowledge acquisition processes promote the creation of **shared representations of group knowledge and understanding** (Decuyper et al., 2010). Different designations describe the same or a closely related concept, especially grounding (Baker et al., 1999), cognitive convergence (Jorczak, 2011; Teasley et al., 2008), or mutual knowledge or understanding. These shared representations involve the creation of mental models. They combine information coming from both oneself and the other group members. Self-modelling is an integrated representation of personal task-processing. Besides, partner-modeling builds on inferences regarding one's partner's mental states (Dillenbourg et al., 2016). Mental models are built and updated through stored information throughout the collaborative task. This process usually implies to facilitate mutual exchanges, promote intercomprehension) and promote role change (Decuyper et al., 2010). The capacity that groups members have to align their mental models of each other's appear is an important aspect of successful collaboration (Sangin et al., 2007).

Participation **Team reflexivity** is socio-meta-cognitive process that will be addressed in section 2.3.2. **Team activity** refers to the mobilization of the physical and psychological means necessary for task achievement. It involves a progressive mutual adaptation to each other's behaviors leading towards more coordination and efficiency. This process is partially unconscious as it often relies on implicit knowledge and communication that people do not realize. Following Arrow and Cook (2008), Decuyper et al. (2010) distinguish between coordinated activity and chaotic activity and support the idea that both of them contribute to team efficiency in groups. Indeed, coordinated activity benefit to the group as it promotes the development of routines that help teammates to operate smoothly. However, it may in return hinder creativity. On the other hand, although a lack of coordination may disrupt team functioning by increasing errors, for example, it may also lead to the emergence of constructive conflict that promotes creative thought. Besides team activity, groups generally learn within boundaries (e.g., domain-knowledge or expertise). Moving beyond these boundaries, i.e., create boundary-crossing, may enhance group learning and therefore represents another facilitating process in group learning. More specifically, **boundary-crossing** refers to the process of "transporting ideas, concepts, and instruments from seemingly unrelated domains into the domain of focal inquiry" (Engeström et al., 1995, p. 321). As reported in Akkerman and Bakker (2011), boundary-crossing pushes teammates to achieve hybrid learning, combining ingredients from different contexts. These authors discern four mechanisms of boundary-crossing, namely identification, coordination, reflection, and transformation. **Identification** means defining one practice in light with another. It involves identifying

identities based on each other's practices. **Coordination** includes processes dedicated to facilitating boundary-crossing. It implies communicative connection (promotion of mutual exchanges), translating effort (promotion of intercomprehension), enhancement of boundary permeability (e.g., promotion of role change) and routinization (promotion of automatized procedures). The third mechanism is **reflection**. It highlights the importance of a reflexive effort, especially perspective-taking, i.e., to see one's own practice through the other's point of view. Finally, boundary-crossing also implies **transformation**, which refers, for example, to the creation of new in-between practices. Boundary crossing research has shown to promote the provision and dissemination of information in the group as well as group efficiency across time (Brooks and Edmondson, as cited in Decuyper et al., 2010).

Creation **Co-construction** implies elaborating knowledge, competencies, opinions, and creative thoughts through others. It refers to repeated cycles where learners acknowledge, repeat, paraphrase, enunciate, question, concretize, and complete shared knowledge, competencies, opinions or creative thoughts. **Constructive conflict** involves that learners have diverse opinions that require negotiation, and the overcoming of disagreement enhance group learning, learning going beyond their comfort zone. Contrary to a regular conflict, where learners face personal and emotional rejection, leading at best to leaving off the source of conflict, constructive conflict is rather seen as a difference in the interpretation of the problem. This divergence leads to integrate viewpoints differences in promoting the exploration of the same problem from different perspectives. Co-construction and constructive conflict can be integrated into the concept of transactivity (Teasley, 1997; Weinberger & Fischer, 2006). Transactivity (Berkowitz & Gibbs, 1983) refers to "the degree to which a person uses his or her conversational turn to operate on the reasoning of the partner or to clarify ideas" (Teasley, 1997, p. 362). It has emerged from research in various domains that highlights that students who engage in highly transactive discussions learn more from the collaboration than those who do not (Teasley, 1997). Hence, it reflects the quality of the conversational actions taking place in a group (Zoethout et al., 2017). Berkowitz and Gibbs (1983) highlight different types of transactive behaviors or transacts divided into two main types, namely representational and operational. Representational transacts refer to a lower level of transactivity because they elicit or represent other's reasoning. Instead, operational transacts operate on or transform other's reasoning. Examples of representational transact are feedback request, paraphrase or competitive juxtaposition, i.e., the learner can concede a point while reaffirming his or her position. On the other hand, examples of operational transacts can be clarification, extension, or critical reasoning, i.e., the learner points out that other's thinking is questionable in some way. Lately, Weinberger and Fischer (2006) have reviewed the concept of transactivity and described five processes ranging from no transactive to highly transactive, namely externalization, elicitation, quick consensus building,

integration-oriented consensus building, and conflict-oriented consensus building. **Externalization** implies that learners provide contributions that are not related to previous contributions. These contributions usually take place at the beginning of the discussion. **Elicitation** involves asking questions to receive help and can be used to improve co-construction. **Quick consensus** refers to a rapid agreement of the other's contribution. In this case, it does not change the learner's perspective but instead helps to prolong the discussions of ideas (Barron, 2003). In this sense, it can be seen as an essential process contributing to a successful collaboration (Damsa et al., 2013). However, it may also become detrimental if learners remain in that mode and fail to move towards higher levels of transactivity. In contrast to quick consensus building, **integration-oriented consensus-building** relates to an integrative form of reasoning. In this case, learners operate actively on the other's reasoning. They are responsive to persuasive argument and change or give up their initial view when it is appropriate. Finally, **conflict-oriented consensus building** is assumed to be the higher level of transactivity and is consistent with the concept of constructive conflict described above. In this kind of interaction, learners receive critiques that challenge their perspective and push themselves to refine the pros or cons of their views. In this way, they operate deeper on their reasoning and that of their partner. Greater transactivity has been shown to stimulate productive collaborative learning (Noroozi et al., 2013b; Teasley, 1997). However, learning gains are assumed to be higher when learners succeed to strike a balance between consensus, conflict, and sharing. On the other hand, too much consensus, conflict, or sharing appear to be detrimental to collaborative learning.

In summary, collaborative problem-solving involve socio-cognitive processes, i.e., cognitive processes involving others (Suchy & Holdnack, 2013). They complement and interplay with individual cognitive processes (Dillenbourg, 1999). Socio-cognitive processes include three main activities, knowledge acquisition, participation and creation (Decuyper et al., 2010). Knowledge acquisition includes sharing, storing and retrieving information contributing to creating shared mentals models. Participation refers to the creation of a shared discourse through mutual adaptation and coordination. Finally, creation refers to the co-creation of new knowledge among group members through co-construction and constructive conflict.

2.3.2 Socio-meta-cognitive processes

At the collaborative level, problem-solving involve not only socio-cognitive but also socio-meta-cognitive processes, allowing the problem solver to coordinate and monitor socio-cognitive processes. The knowledge and the ability to use socio-metacognitive processes to foster high-quality collaborative activities can be called

socio-metacognitive expertise (Borge et al., 2019). As outlined by Järvelä et al. (2013), successful collaboration not only implies that collaborators self-regulate but also **co-regulate** (i.e., support each other self-regulation) and **socially shared regulate** (i.e., collectively regulate learning as a team).

Decuyper et al. (2010) also underline team reflexivity as an essential basis for promoting efficient learning. **Team reflexivity** represents a management task process where teammates develop a vision of what they have already achieved (current situation), what they plan to do (objectives) and how they are going to do it (strategies). It can be defined as "the extent to which group members overtly reflect upon the group's objectives, strategies and processes, and adapt them to current or anticipated endogenous or environmental circumstances" (West, as cited in Gurtner et al., 2007). Some authors highlight two aspects of reflexivity (Arrow et al., 2000), arguing that teammates both compare the extent to which the objectives meet the expected goals and question the adequacy of these goals. The impact of reflexivity on performance has been demonstrated in several studies (Gurtner et al., 2007).

Järvelä et al. (2013) have uncovered through multiple and repetitive coding sessions different challenges that regularly emerge in collaborative learning, namely time (e.g., difficulty to find a joint work time), external constraints (e.g., disease or stress at work), weak study strategies (e.g., difficulty to manage studying), collaboration (e.g., absence of one group member), motivation (e.g., no interest on the topic), and technology (e.g., technology does not work well). In the same way, they have also uncovered recurrent group strategies to tackle them, i.e., performing (i.e., find a routine solution to answer the issue), planning (i.e., implement a group strategy to answer the issue), cognitive processing (i.e., brainstorm a solution), asking for external help, task and environmental structuring (i.e., change some aspects of the task or environment to tackle the problem), and motivation regulation (i.e., partners motivate each other). They uncovered three types of shared regulation. The first one was called strong shared regulation. In this case, the group used deep-level regulatory processes and planning rather than routine regulation. They monitored their perception of the task, revised their cognitive strategy and plan future strategies in a collective way. The second type of regulation was called weak shared regulation. In this case, the students used many routine regulation strategies to counter challenges but did not collectively monitor group understanding or progress. They were also unable to explicate future strategies. Finally, the third type of regulation was called progressing shared regulation. In this case, groups were situated between the two above-described regulation profiles. They were able to implement collective strategies to tackle challenges at the time but failed to collectively plan future strategies.

2.3.2.1 Borge's model of socio-cognitive regulation

Building on the description of Winne and Nesbit (2009) regarding the factors maximizing the occurrence of cognitive self-regulation, namely the recognition of the

problematic state, an accurate appraisal of the problem, the ability and desire to apply a strategy and the access to sufficient cognitive capacity to do it, Borge et al. (2018) have proposed a model of regulatory process during collaboration. This model involves both simultaneous individual and group regulation (Figure 2.3) First, **joint attention** is a prerequisite to group regulation in the same way that at-

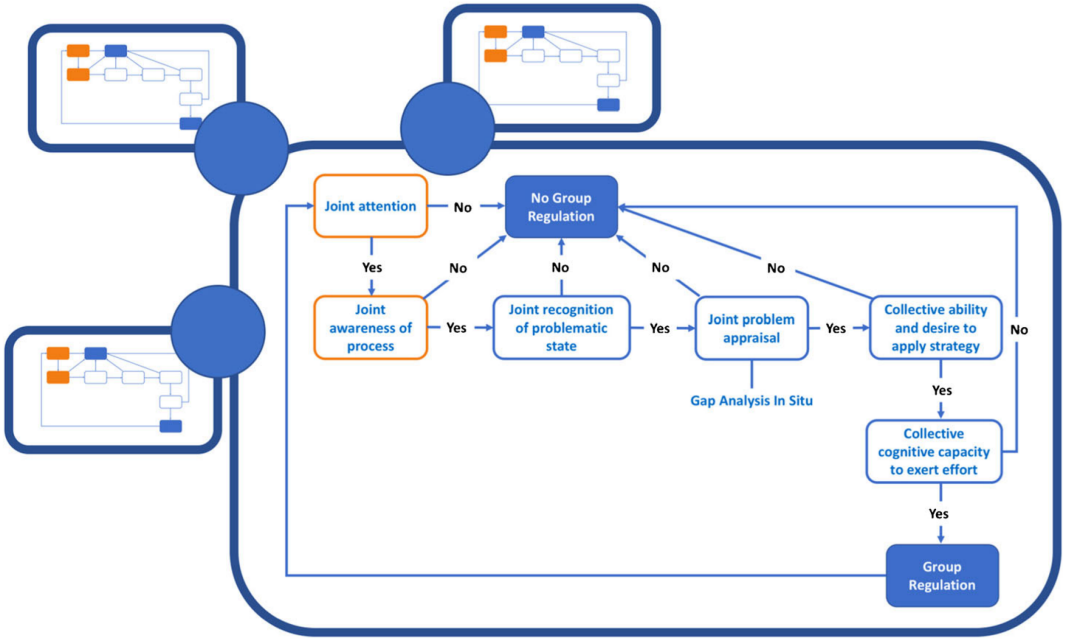

FIGURE 2.3: Model of socio-cognitive processes regulation during collaboration. Retrieved from Borge, Shiou Ong, and Peinstein Rosé (2018)

tention is a prerequisite to individual regulation. In the absence of this joint attention towards one's own and others' behaviors and their interactions, group regulation cannot take place. Second, joint attention gives the possibility for the group to bring into consciousness their collaborative processes, what Borge and colleagues call **joint awareness of process**. Third, joint awareness of process in itself is not enough as problem-solvers also need to recognize inefficient patterns of collaboration, i.e., **joint recognition of problematic state**. At this point, problem solvers may have a joint recognition of collaborative difficulties but different perceptions about what they actually are or how to solve them. Therefore, the joint recognition of an inefficient collaborative pattern is not enough to trigger adequate collaborative changes. Fourth, a step of **joint problem appraisal** is needed, where problem solvers collectively address the problem and elaborate on a common strategy to correct it. Fifth, this strategy can be implemented only if problem solvers have the **ability and the desire to apply it** and, finally, if they all have the **cognitive capacity to exert effort to this end**. According to the authors, the difficulty to solve problems collaboratively emerges from the difficulty to successfully complete all these steps, which comes in addition to individual regulation. As a consequence, collective regulation can fail for several reasons. One is that an efficient socio-meta-cognitive resolution of an arising collaborative issue requires socio-meta-cognitive knowledge that is rarely

addressed in the school curriculum. As a result, problem solvers may have difficulties to recognize inefficient patterns of collaboration. Another is that socio-meta-cognitive knowledge requires to be practiced so as to develop automatic skills that preserve cognitive load. Last but not least, pre-existing good self-regulation skills must be a prerequisite to provide an opportunity for socio-meta-cognition to take place. For all these reasons, problem solvers may focus more on the individual processing and regulation of the problem and frequently neglect socio-meta-cognitive aspects.

Borge et al. (2019) identified what they call socio-meta-cognitive sense-making talk. It refers to "a type of process talk where students think about their collaborative processes to try to understand or modify them" (p. 323). According to Borge et al. (2018), these processes allow students to bring out collective knowledge impairing group performance. The authors describe 5 types of socio-meta-cognitive processes, namely Reporting, Process monitoring, Process reflection, Process planning, and Process revising. **Reporting** occurs when students report their opinion concerning collaboration quality. In this case, they do not justify their judgment based on concrete observations. The authors give examples of reporting such as "We sure we covered a lot" or "We like to keep each other's opinion and ideas in mind while implementing our own". In **process monitoring**, students show evidence that they pay attention to the collaboration process by indicating actual collaborative events or patterns. An example provided of this socio-meta-cognitive process is "For question 2, we did not bring in additional resources such as citing from the internet". **Process reflection** goes on step beyond monitoring in the sense that students overtly reflect on the collaborative discussion and provide justifications about why some events occurred. Examples of this process are "I think the problem is that we read two different things" or "It's just difficult to debate when we agree with the author. This wasn't a real debatable subject in my mind". **Process planning** refers to discussing the organization of the activity in order to achieve the goal. Contrary to process reflection that highlights past events, process planning mainly focuses on forward-thinking and considers goal, strategy or plan to solve the problem raised. In this case, examples given by the authors are "To begin, we definitively need to work on time management. Our communication skills are sufficient when it comes to the subject matter, but we definitively need to get tasks done with a sense of urgency" or "Proposing a goal: we just need to be more critical on each other's judgments and be holistic.". Finally, **process revising** reflects the reconsideration of the planning process as well as its alteration considering new information that arises during collaboration. An example is "I'm not sure our last approach worked. Maybe we have to assign outside reading too.".

In summary, collaborative problem-solving also requires socio-meta-cognitive processes to monitor and control socio-cognitive processes. These socio-meta-cognitive processes involve team reflexivity, i.e. understanding the joint situation, setting common objectives and implementing group strategies (Decuyper et al., 2010). Three different levels of shared regulation have been highlighted depending on how group members commit to monitor and plan strategies to deal with the emerging challenges (Järvelä et al., 2013). More recently, Borge et al. (2018) and Borge et al. (2019) have described the different processes shaping group regulation (e.g., joint recognition of problematic state) and the different communicative exchanges that implement them (e.g., process reflection).

2.3.3 Socio-motivational processes

When groups learn or work together, personal motivational aspects pervade each group member and can lead to the emergence of a collective motivational dynamics. External constraints can also shape group members' motivation. These factors are assumed to modulate group members' task commitment. In this section, we broadly describe some research contributions in this domain that are relevant as part of this thesis. Some concepts appear to be at the crossroads of socio-motivational and socio-relational processes (e.g. group cohesion) and will be also addressed in section 2.3.5.

2.3.3.1 Collective beliefs and attitudes

Collective self-esteem Aside from self-esteem, Crocker and Luhtanen (1990) proposed the existence of another concept called collective self-esteem. It refers to the level of esteem that individuals have for their belonging group. In the same way that individuals seek to maintain a satisfactory level of self-esteem (beliefs concerning skills, abilities or attractiveness), they are also motivated to maintain a good level of collective self-esteem. The will of preserving collective self-esteem generates behaviors aiming at praising one's group (i.e., ingroup members) and derogating others (i.e., outgroup members). As a consequence, individuals will tend to evaluate ingroup members more favorably than outgroup members, even if they do not get any personal benefit from it. As for self-esteem, the authors also postulated that collective self-esteem is an individual characteristic that shows interindividual differences. In other words, some people attempt to enhance their collective self-esteem more than others when it is threatened. For example, contrary to people with a lower level of collective self-esteem, people with a higher level of collective self-esteem tend to exhibit biases (e.g., in-group favoritism) or distortions of reality (e.g., overestimation of ingroup value) when their belonging group in threatened (i.e., failure feedback). Collective self-esteem would be positively associated with task performance (Ko & Choi, 2019).

Collective efficacy Another well studied collective belief is collective efficacy. It is the collective counterpart of self-efficacy (see section 2.2.3). It can be defined as "a group's shared belief in its conjoint capability to organize and execute the courses of action required to produce given levels of attainments" (Bandura, 1977, p. 477). The overall idea behind collective efficacy is that common beliefs regarding how individuals think that they can overcome challenges as a unit influence how the group function more or less well together (Lent et al., 2006). As an example, positive beliefs about the team's capabilities increase creativity and productivity among its members (Donohoo et al., 2018). Collective efficacy has been related to numerous variables such as team cohesion, affective outcomes, or group performance. Group members' perception of collective efficacy may have significant effects on learning outcomes (Kreijns et al., 2003; Mullins et al., 2013). In general, meta-analyses report effect sizes around .40, and collective efficacy would account for twenty percent of group performance variance (Lent et al., 2006). Moreover, collective efficacy would relate more highly to group performance than self-efficacy measures (Lent et al., 2006).

Positive interdependence Positive interdependence implies that group members have a high degree of interdependence and rely strongly on each other to achieve their desired goal. Interdependence among members is an essential character of cooperation as a change in the state of any member or subgroup changes the state of any other member or subgroup. In the social interdependence theory, Johnson and Johnson (2009) posits that cooperation [1] enables positive interdependence, i.e., a perception of a common goal that closely links individuals' successes. This positive interdependence is considered as an active promoter of the benefits of cooperation. Mutual learning goals, joint rewards, divided resources, and complementary roles are crucial components leading to its emergence, as well as the creation of a collective identity, space, fiction, and challenge.

Group cohesion Positive interdependence can generate group cohesion, that refers to both the task (task cohesion) and the relationship among members (social cohesion). Task cohesion has a strong motivational nature as it refers to the commitment of a group to achieve a goal in a collective effort. Social cohesion has a more relational nature and will be addressed in section 2.3.5. A high degree of group cohesion promotes individual accountability (i.e., group member are accountable for group success or failure), which prevents social loafing (Karau & Williams, 1993). It also bolsters promotive interaction, i.e., the ongoing effort in encouraging and facilitating each other's attempt to achieve the task, which is crucial for collaborators to be efficient.

[1] The Johnson and Johnson' definition of cooperation is close to our definition of collaboration as part of this thesis

Groupthink However, group cohesion can also a double-edged effects. Although it can enable the willingness to help each other, it could also promote groupthink when task cohesion is too strong. Groupthink can be defined as "a mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when the members' strivings for unanimity override their motivation to realistically appraise alternative courses of action" (Janis, 2008, p. 237). Groupthink happens particularly when group cohesion is high, which implies a strong feeling of solidarity among group members. The presence of a structural fault in the group such as poor decision-making procedures as well as the emergence of a provocative situation causing stress to the group (e.g., challenging group project) may precipitate groupthink (Littlejohn et al., 2017). As a result, the group may become overly tolerant and lose critical thinking about group members' ideas. Negative outcomes of groupthink could be: only considering a limited number of apparent alternatives instead of a broad range of creative possibilities, not reviewing a consensual decision critically, not considering previously ignored minority opinions, neglecting expert opinion, only considering information in favor of the consensual decision, not considering a plan B, failure being considered as impossible (Littlejohn et al., 2017).

Social loafing and free-riding Another barrier to efficient group collaboration includes two close phenomena, namely social loafing and free riding. Both of them represent a lack, deliberate or not, of personal investment. In social loafing, individuals invest unconsciously less energy when they collaborate than when they work alone (Decuyper et al., 2010; Linnenbrink-Garcia & Pekrun, 2011; Mullins et al., 2013). This effect could be due to the group size, which may decrease the personal significance of group members and makes personal contributions more challenging to emerge (Kreijns et al., 2003). Therefore, their motivation to contribute implicitly decreases. To counter this effect, Mullins et al. (2013) emphasize the necessity for group members to be made to feel that their personal effort is indispensable for the group's success. In the free-rider or hitchhiking effect, a member deliberately takes credit for the group achievement without having participated in group work (Decuyper et al., 2010; Kreijns et al., 2003). Kreijns et al. (2003) specify that group members diminish their effort as they perceive that their effort becomes non-essential to group success. In other terms, if the group is doing enough to succeed, some people do not intend to continue to contribute. Therefore, their will to contribute explicitly decreases. Thus, the social loafer and the free-rider differ in that the former lacks the motivation to contribute, while the latter takes advantage of the group to avoid contributing (Kreijns et al., 2003). Both free-riding and social loafing may give rise to the sucker effect. As the more productive group members note that some other group members are less active in the group work, the former refuse to support non-contributing members anymore (Mullins et al., 2013). As a consequence, they also reduce their personal effort, contributing to jeopardize the collaboration (Kreijns et al., 2003).

In summary, collaborative problem-solving also involve socio-motivational processes that permeate the group and create a collective motivational tone. These processes include collective phenomena such as beliefs, attitudes, interdependence, group cohesion, social loafing, which can foster or hinder group performance.

2.3.4 Socio-meta-motivational processes

In section 2.2.4, we have seen that individuals involved in goal-directed activities attempt to maintain an appropriate level of effort and persistence by employing strategies to regulate their motivation. However, collaboration also involve co-regulation of motivation among group members. Although the existing literature about these socio-meta-motivational processes is still scarse, some authors have explored these aspects in recent years. For example, Järvelä and Järvenoja (2011) have described five major challenges that group members may experience in collaborative goal-oriented activities, which can require the regulation of motivation among group members.

The first one concerns the fact that group members can have **different goals, priorities or expectations**. For example, some students want to get high marks, while some others just want to pass. A second challenge arises regarding how people are different in terms of **working styles** or ways of communicating. For example, overtly contradicting someone with whom we disagree can be judged as too confrontational for some people. The third challenge highlighted by these authors concerns the way group members are **committed to the task**. For example, some people do not attend to meetings, rely on others to do their part. Fourth, group members also differ in terms of their capacity to **reach a common ground**, which can compromise group understanding and reflection. For example, group members can struggle to agree on whether a concept should be covered as part of their group work. They can also have different knowledge or meaning regarding a critical concept. Finally, some **external practical constraints** can compromise the capacity to find joint schedules. All these challenges can drastically dampen the motivation to work together and even lead to group breakdown. Therefore motivation has to be co-regulated among group members, i.e., fostered, shaped and maintained throughout the group activity (Järvelä et al., 2008).

To account for the social aspect of motivation regulation, these authors have adapted Wolter's framework (Wolters, 2003, and section 2.2.4) to socially shared goal-oriented situations. **Social reinforcing strategy** refers to identify and produce exchanges dedicated to reinforce and shape a secure or positive atmosphere as well as to draw attention to the positive aspects of the challenging situations (Järvenoja et al., 2019). **Socially shared goal-oriented talk** strategy concerns the

use of exchanges dedicated to highlighting reasons for persisting or completing the task. **Interest enhancement** strategy consists of bolstering group motivation in increasing personal (intrinsic motivation) or situational interest (i.e., temporary interest arising spontaneously from the characteristics of the task) regarding the task. **Task structuring** strategy focuses on producing exchanges that structure and coordinate the group work or the environment in order to mitigate off-task behavior. **Efficacy management** strategy are dedicated to managing (monitor, evaluate and control) the motivational beliefs, self and collective efficacy. Finally, **handicapping of group functioning** strategy aim at highlighting or providing obstructions to task completion. Its role could be twofold. First, it could preserve collective self-esteem in providing good reasons to legitimate an expected failure. Second, it could promote a switch towards mastery goals in leaving aside performance expectations.

In summary, collaborative problem-solving also requires socio-meta-motivational processes to monitor and control socio-motivational processes. Järvelä and Järvenoja (2011) have described five major challenges requiring the regulation of motivation among group members (different expectations, different working styles, different task commitment, different abilities to reach a common ground, external constraints). These authors have adapted Wolter's framework (Wolters, 2003) to account for the different ways group members can regulate their motivation together.

2.3.5 Socio-relational processes

Being in a group involves an additional dimension that emerges from group interaction. This dimension refers to processes that are non-reducible to purely socio-cognitive or socio-motivational aspects, even though they can emerge from and interact with them. As pointed out by Isohätälä et al. (2019), socio-relational processes have been addressed in the literature under various headings such as socio-emotional processes, social and relational aspects, group processes, affective dimensions, relational space or social and behavioral engagement. Altough socio-relational processes are sometimes merged with socio-affective ones, we propose to circumscribe more clearly these two types of processes. As part of this thesis, socio-relational processes refer to the kinds of relationships existing between group members, whereas socio-emotional processes refer to the emotional processes taking place between interactants (see section 2.4). In collaborative problem-solving, relationships do not involve, most of the time, enduring bonds or a strong emotional attachment (Guerrero et al., 2017). Rather, collaborative relationships are functional and often temporary. In that sense, it can be close to what is called role relationships (i.e., involving a mere behavioral interdependence such as bank tellers and

customers). Nevertheless, collaboration may also include some elements of interpersonal relationships. In such relationships, interactions are repeated over time, imply a connection at a relational level, and a unique interaction pattern (i.e., unique relational history) (Guerrero et al., 2017).

Socio-relational aspects that take place in collaborative settings are about specific dimensions (e.g., sympathy, politeness, responsiveness) that pervade a group and constrain how group members will interact to solve problems (Baker & Andriessen, 2009). As relationship is an inherently communicative phenomenon (Guerrero et al., 2017), interpersonal communication plays a central role in spreading socio-relational messages within the group (Hale et al., 2005).

2.3.5.1 Relational dimensions of communication

Socio-relational dimensions concern how people regard each other, their relationship, and themselves within the context of the interaction. Their function is not to transmit content information but to define the nature of the relationship binding the persons involved in the interaction (Burgoon & Hale, 1984). In an extensive literature review, Burgoon and Hale (1984) addressed the predominant themes that pervade relation communication. According to Hale et al. (2005), three main dimensions are remarkably consistent across literature, namely dominance, inclusion and affection. Besides, empirical evidence shows that some other dimensions also emerge consistently. In total, the authors highlight twelve dimensions, which are **dominance**, **emotional arousal**, **composure**, **formality**, **orientation**, **intimacy**, **involvement**, **trust**, **affection**, **depth**, **similarity** and **inclusion**. These dimensions will be described in detail below, complemented by some examples taken from the Relational Communication Scale (Hale et al., 2005), a questionnaire that allows for empirically investigating them.

The most widely recognized, **dominance**, also called relational control, reflects a need to develop some degree of influence over other's actions. It reflects how powerful, controlling and influential is a person in the interaction, i.e., who directs, delimits, and defines actions in an interpersonal situation. This dimension can be conceptualized along a continuum ranging from highly dominant (e.g., "he/she took the control of the conversation") to highly submissive relationship ("he/she was very submissive toward me"). **Emotional arousal** involves the degree to which people appear active or in a state of tension. It is closely related to but non-completely comparable to **composure**, which reflects the capacity to stay calm under tension and pressure. As outlined by Burgoon and Hale (1984), it is possible to be highly tensed and highly in control, which demonstrates a certain independence between these two relational dimensions. Emotional arousal and composure can be assessed through sentences such as "he/she was calm and poised with me" or "he/she revealed feelings of tension while talking with me". **Formality** reflects how people are

more or less formal or informal in their communication style. It tells the degree of reserve, personalism or polite behavior. Formality is reflected through sentences such as "he/she tried to make the interaction easygoing and relaxed" or "he/she kept the conversation to a formal level". **Task/social orientation** concerns how people judge the work orientation of group partners. It focuses on the fact that partners could be more inclined either to solve the task or to manage the social or personal aspects of the relationship. An illustration of task orientation could be "he/she was very task-oriented" while an illustration of social orientation could be "he/she was more interested in having a social conversation than completing the assigned task". **Intimacy**, in itself, reflects a general judgment concerning the degree of attachment in the relationship. This dimension appears to encompass several subcomponents that are closely related to each other, each of them contributing to form the global feeling of intimacy towards someone (Burgoon & Hale, 1984). These dimensions are **involvement**, **receptivity/trust**, **affection**, **depth**, and **similarity/inclusion**. **Involvement** is the degree to which people are engaged in the conservation (e.g., "he/she was highly involved in the conversation" or "he/she act bored by the conversation"). Another dimension is **receptivity**, reflecting the degree of attentiveness, accessibility, openness and interest to the conversation (e.g., "he/she was open to my ideas" or "he/she was unreceptive to what I had to say"). Very close to that dimension is the notion of **trust** that entails attributes such as sincerity, honesty and generally described people who are seen as trustworthy (e.g., "he/she appeared honest and truthful when communicating with me" or "he/she tried to win my trust"). Receptivity and trust have been grouped in the Relation Communication Scale (Hale et al., 2005). **Affection** highlights the desire to have a closer relationship with oneself and the effort to initiate and maintain intimate relationships. It is related to how much people like someone else (e.g., "he/she seemed to dislike me" or "he/she showed affection toward me"). **Depth** highlights the fact that the relationship is not superficial and people have the desire for further interaction (e.g., "he/she kept the conversation at an impersonal level" or "he/she created an air of familiarity between us"). Finally, **similarity/inclusion** represents how people share attitudes, beliefs, personal characteristics or experiences. Although conceptually different in their theoretical paper (Burgoon & Hale, 1984) from inclusion-exclusion, which refers to one's accessibility to others and the preservation of a feeling of mutual interest with others, the two dimensions have been grouped into the same cluster in last version of the Relation Communication Scale (Hale et al., 2005). Examples of similarity/inclusion are "he/she made me feel we were very similar" or "he/she made differences between us evident".

2.3.5.2 Relational phenomena in collaboration

The dimensions above described can be thought of as core socio-relational dimensions pervading any interaction, and therefore any collaboration. One or more of

these socio-relational dimensions are involved in diverse socio-relational phenomena that contribute to influence collaborative relationships. If some may hinder collaborative learning, some others have well-known facilitatory effects on group learning (e.g., psychological safety). The following paragraphs will review some of them in the context of collaborative learning and problem-solving. Some appear very close or even identical to the core socio-relational dimensions afore-described. Some others involve combinations of these dimensions in more complex phenomena.

In a pioneering work on the role of socio-relational processes in interaction, Bales (1950b, 1970) defined what he called positive and negative socio-emotional areas that actually contain specific socio-relational phenomena occurring in group interaction. His process analysis method is based on the analysis of communication acts, i.e., communication that is comprehensive enough to allow reaction in relation to its content by the receiver. Positive communication includes **showing solidarity**, **tension release** and **agreement** while negative communication is about **disagreement**, **showing tension** and **showing antagonism**. Since agreement/disagreement refers more to the socio-cognitive domain than on the socio-relational one (i.e., agreement and disagreement have to do with the content and not with the relationship between people), we do not develop them here as socio-relational processes. Tension release/showing tension may be related to emotional arousal/composure. The shows solidarity category (later recalled as **seems friendly**) concerns mostly communication acts intended to improve interpersonal relationships such as raising other's status, expressing sympathy, encouraging others, reassuring others, expressing gratitude, expressing satisfaction etc. Shows tension release (later recalled as **dramatizes**) includes communication acts such as jokes or laughs dedicated to alleviating tension in the group. Dramatizing particularly implies wordplay, double entendre, figure of speech, analogy, anecdote, etc. (Hirokawa & Poole, 1996). Shows tension reflects acts that exhibit conflict between people. Communicative acts may include a request for help, withdrawal from the interaction or marks of disconcertment or confusion. Finally, show antagonism (later recalled as **seems unfriendly**) overtly refers to personal attacks. It concerns any communication act intended to deteriorate interpersonal relationships such as deflating other's status, interrupting the other, discrediting the person, placing him or her at a disadvantage, etc.

Bales also characterized the socio-relational position of an individual in a group along three basic continuums: dominant-submissive, friendly-unfriendly, instrumental-emotional. Different combinations of these three dimensions are intended to shape the socio-relational profile of an individual. For example, a dominant, unfriendly and emotional person will probably be seen as hostile and non-cooperating (Littlejohn et al., 2017). Each of these dimensions has to be considered along a continuum, which means that an optimum has to be found to ensure an optimal socio-relational profile. For example, a too dominant leader or a too

diffuse group responsibility both appear detrimental to collaboration. In the first case, group participants will experience difficulty to contribute to the group, as the leader's opinions will generally get the upper hand. This phenomenon sometimes goes hand in hand with the Abilene paradox, a situation where group members do not manage to express their true feelings. Therefore, most group members follow a path that the majority disapproves. Conversely, when the responsibility is too disseminated into the group, no one will take responsibility for the group advancement.

Attentional engagement and willingness to negotiate In Barron (2003), twelve triads of 6th-grade students (ages 11–13) with high-potential in mathematics should resolve mathematical problems elaborated from the video *Journey to Cedar Creek*. These problems consisted of solving problems regarding the main character's trip Jasper Woodbury. For example, Jasper, who had just bought a boat, would like to take it home before sunset but different concerns arose (time, fuel, lights). The students, equipped with the relevant numerical information and the different concerns had to decide about the feasibility of the plan in answering different questions. The author computed a score allowing her to differentiate the more from the less-successful groups. Then she assessed some potential variables that could explain the observed outcomes discrepancies between groups. No difference was found between the more and the less-successful groups regarding prior mathematical achievement, the total number of turns, the mean number of turns per person and the number of correct proposals. They also considered the differences in terms of interaction patterns between higher and lower successful groups. Results showed that more-successful groups accepted three times more correct proposals than less-successful groups, discussed correct proposals two times more and rejected or ignored correct proposals two times less. Moreover, in the more-successful groups, almost all the correct proposals were considered (accepted or discussed) by at least two of the other group members (i.e., those who did not give the proposal). In the less-successful groups, two-third of the correct proposals were not considered by the two other group members. Thus, Barron highlighted a critical lack of transactivity (see section 5.1.1) in less-successful groups. The author proposed a hypothesis that could explain this lack of transactivity in less-successful groups. She examined whether students' correct proposals were directly or non-directly related to the immediately preceding problem space (i.e., the subproblem at stake). She showed that it was the case 98% of the time in the more-successful groups compared to only 40% in the less-successful groups. Therefore, a possible explanation for the lack of transactivity could be that less-successful groups are not topically aligned, i.e., correct proposals are not in line with the subproblem at stake in these groups. However, this finding cannot fully explain the lack of transactivity occurring in less-successful groups since almost 50% of the correct proposals were actually topically aligned and still rejected. According to

the author, two main socio-relational causes may explain this finding. First, joint attention hardly occurs in less-successful groups, despite the use of strategies (nonverbal and verbal) for recruiting and maintaining it. The lack of attentional engagement appears to be due to both implicit (some students were sometimes too self-focused to pay attention to others' ideas) and explicit (some students did not have the will to dedicate attention to others) reasons. The other socio-relational cause outlined by the author was the unwillingness to negotiate a shared problem space in less-successful groups. This was revealed by the tendency of some students to dominate the problem solving task, preventing the willingness and openness to be influenced by the others.

Social support and resistance Janssen et al. (2012) analyzed collaborative processes from 101 groups of secondary education students in a computer-based environment (VCRI) designed to support collaborative learning on inquiry tasks and research projects. They developed a coding scheme in which they categorized collaborative messages into predefined task-related (content space) and social activities (relational space). In this study, the relational space included both the processes related to managing group behavior (e.g., grounding, group coordination) as well as what we refer to as socio-relational processes as part of this thesis. These socio-relational activities such as greetings, social support (e.g., joking, social talk, disclosing personal information) or social resistance (e.g., swearing, cursing) accounted for 15.3% of the messages. Exploratory factor analysis showed that these activities can be grouped into a single factor that the researchers called performing social activities. Furthermore, using multiple regression analysis, researchers uncovered that these social activities negatively predicted group performance.

Respect Rogat and Linnenbrink-Garcia (2011) used the term socioemotional interactions to describe what we call socio-relational processes as part of this thesis, i.e., the extent to which group members are respectful and supportive of each other and get along as a group. In the study, researchers focused on the following specific positive interactions: active listening and respect, inclusion (including a group member or the whole group), and group cohesion. Conversely, negative interactions were also considered and the following interactions were especially targeted: exclusion (explicitly discouraging other's participation), disrespect, low group cohesion. In general, groups with high social regulation quality (i.e., monitoring, planning, and behavioral engagement) have more positive socio-relational interactions. These positive socio-relational interactions tend to decrease along with group socio-cognitive regulation quality.

Management of face The management of the images of ourselves and others, i.e., the management of "face" is also a socio-relational phenomenon that can affect collaboration. Baker et al. (2013) reported that the way people challenge an idea affects

how much the owner will defend it. Notably, the degree of aggressiveness is likely to change the argumentative strategy used. For example, a harsh way of disagreeing (e.g., claiming that the other's idea is useless) makes it more likely that the one who proposed the idea would defend it even harder. In this case, challenging the others' ideas can involve more than a mere epistemic conflict and people may take it as a personal attack. Therefore, in defending their idea, people mostly defend themselves. At the same time, the informational benefit coming from the person challenging the idea is largely overlooked by the one who feels devalued, who may become stubborn and even rebellious (Linnenbrink-Garcia & Pekrun, 2011).

Tension and relaxation Andriessen et al. (2011) also emphasized the need to consider the role of socio-relational aspects in collaborative interactions, as a way to gain insight into the collaborative dynamics. These authors define collaborative learning as a continuous cycle of tensions and relaxations at both cognitive and relational levels. The different utterances that occur in the collaboration each embed an idiosyncratic potential to increase or alleviate tensions. For example, tensions may arise at a socio-relational level from touches of sarcasm or personal attacks, while irrelevancy claims and questions may provoke tensions at a socio-cognitive level. Conversely, making jokes, at a socio-relational level, or finding a compromise, at a socio-cognitive level, may alleviate such tension. More generally, the authors postulate that the level of tension is likely to increase in collaborative settings when individuals' knowledge, intentions or way of communicating diverge. Although this tension may be a source of collaborative gain since it correlates with socio-cognitive conflict and triggers mutual adaptation, it could also be detrimental to the collaboration if too much tension occurs. Conversely, a too low level of tension or the unwillingness to increase tension between collaborators may hinder collaboration quality as well, leading to more quick consensus building. Hence, an appropriate level of tension has to be found to ensure optimal collaboration. Furthermore, tension is not an all or nothing phenomenon. Remanent tension can diffuse in time and interfere with the next argumentative episodes. For example, as the authors observed it in case studies, the argumentative process may go deeper if it follows an episode of high tension. In other terms, social tension would precede and stimulate socio-cognitive conflict. The authors claim that collaborators need to establish an optimal level of tension between them to build an efficient collaborative working relationship.

Psychological safety Wegerif (as cited in Kreijns et al., 2003, p. 341) stresses that "forming a sense of community, where people feel they will be treated sympathetically by their fellows, seems to be a necessary first step for collaborative learning. Without a feeling of community, people are on their own, likely to be anxious, defensive and unwilling to take the risks involved in learning". This statement is consistent with the idea that group members need some degree of psychological safety

when it comes to collaborating. Team psychological safety is a shared belief that the group is safe and allows for risk-taking. It reflects the possibility for the teammates to adopt behaviors such as experimenting, trying things and make mistakes, asking for help, or reflecting critically without having to deal with group disapproval or being seen as ignorant, incompetent, harmful or disruptive. The role of the group leader appears crucial in this process, promoting or inhibiting psychological safety within the group (Decuyper et al., 2010)

Conflict escalation When social cohesion (i.e., emotional bonds between group members such as liking, caring, closeness) is too low, conflict escalation may arise in groups. It can be defined as a progressive increase in both the intensity of the conflict and the severity of tactics used in pursuing it (Jordan, 2000; Rispens et al., 2010). Conflict escalation can take form, for example, when mutual negative attitudes and suspicion pervade each other's intentions, obstructiveness and lack of helpfulness increase, repeated episodes of critical rejection of ideas appear or conflicting group members want to take power at the expense of the other using threats or coercion (Deutsch, 2008).

In summary, collaborative problem-solving implies a relational dimension, which refers to the kind of relationships that exists between group members. This dimension is distinct from but interacts with socio-motivational and socio-cognitive dimensions. Socio-relational processes include relational themes highlighted by Burgoon and Hale (1984) (e.g., dominance, trust) that combine each other to create various relational phenomena (e.g., psychological safety, conflict escalation).

2.3.6 Socio-meta-relational processes

Similarly to cognitive and motivational processes, socio-relational processes can be distinguished from socio-meta-relational processes, which refer to the appraisal, monitoring and control of socio-relational processes in order to promote beneficial outcomes for the group. To our knowledge, socio-meta-relational processes appear little studied to date. However, some authors include these meta-processes into socio-relational or socio-emotional processes without distinction (e.g., Isohätälä et al., 2019).

2.4 A three-level model of collaborative problem-solving

This section describes a new model (Figure 2.4) that addresses the functioning of collaborative problem-solving. The model is anchored and draws on various empirical and theoretical research to propose an integrative representation of the phenomenon. The three-level model seeks to highlight that personal (individual processing and mental models) and interpersonal (observable outputs) are inseparable aspects of collaborative problem-solving. It also clarifies what is commonly referred to as the socio-cognitive and social/relational spaces of collaboration in differentiating more clearly cognitive, motivational, and relational dimensions. Besides, emotional and relational aspects of collaborative problem-solving, which are mostly assimilated to each other in the literature, are addressed separately. Notably, it is argued that emotions have a pervasive impact on every dimension of collaborative problem-solving through different personal and interpersonal phenomena (see Chapter 3). Overall, our framework generates new research avenues for collaborative problem-solving.

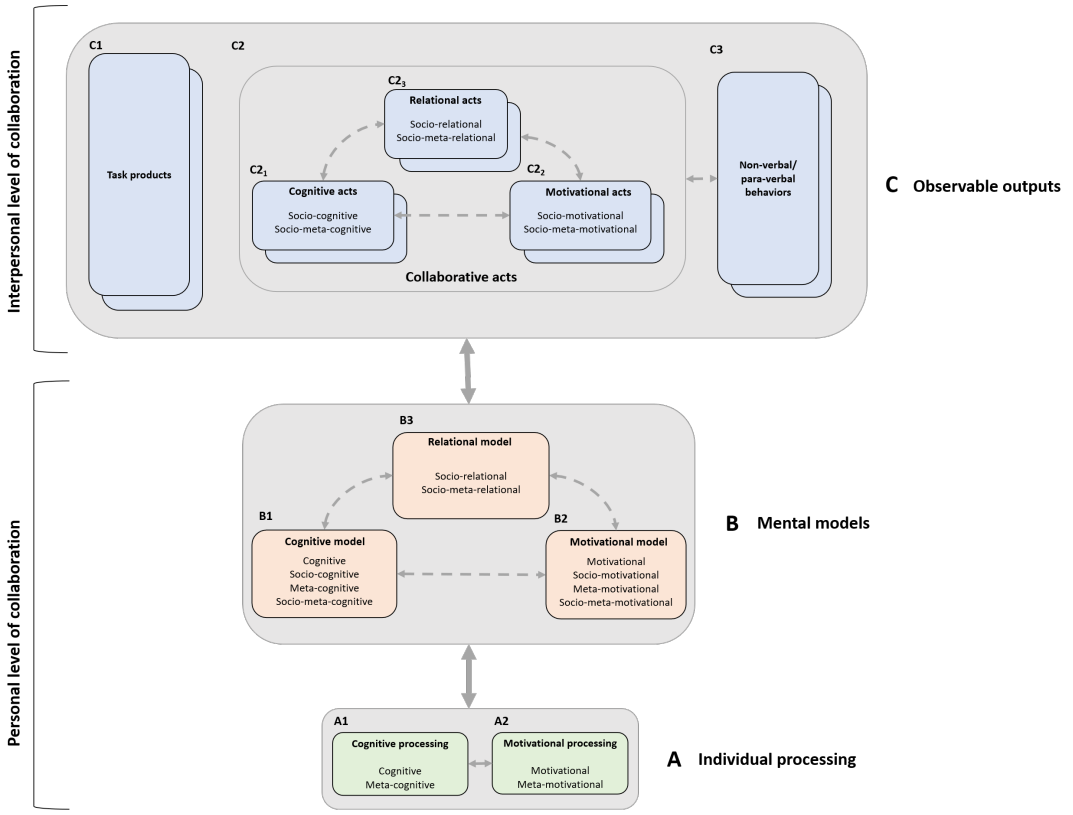

FIGURE 2.4: A three-level model of collaborative problem-solving

2.4.1 Individual processing (A)

2.4.1.1 Cognitive processing (A1)

The cognitive processes refer to the manipulation of information and the implementation of strategies to solve the problem (Robinson, 2012). It involves the processing of task-related information through lower-level (e.g., attention, short-term and long term memory; Fleck, 2008) and higher-level (e.g., decision making, inductive, abductive and deductive reasoning; Douven, 2017; Hayes et al., 2010; Sternberg et al., 2011) cognitive processes. Problem-solving mobilizes two well-known types of thinking that are based on the aforementioned inductive, abductive and deductive reasoning, namely divergent and convergent thinking. Divergent thinking represents the generation of many new possible solutions to a specific problem in a short period of time (Razumnikova, 2012). It is classically associated with four types of cognitive processes, namely fluency (i.e., ability to produce a large number of ideas rapidly), flexibility (i.e., the ability to generate multiple problem solutions), originality (i.e., the ability to generate genuine ideas) and elaboration (i.e., the ability to detail a problem solution) (Guilford, 1967; Razumnikova, 2012). Although divergent thinking appears to be an essential component of creativity in problem-solving, it cannot be reduced entirely to it. Especially, along with divergent thinking, creative efficiency also demand the ability to figure out rapidly a solution by applying established rules and logical reasoning, called convergent thinking (Acar & Runco, 2012). While divergent thinking deals with creating new ideas in an associative way (DeYoung et al., 2008), convergent thinking is oriented towards searching for a single best solution to the problem (Cropley, 2006). Hence, these two types of thinking are complementary and usually co-occur in problem-solving, especially in ill-defined problems, where the path to the solution may be unclear. For example, while building an initial representation of a problem involves logical analysis and reasoning, the inefficiency of a possible solution often compels problem solvers to abandon their previous strategies and discover new outlooks.

The meta-cognitive processes refer to strategies dedicated to monitoring and controlling cognitive processes (Veenman et al., 2004). These stages of metalevel executive processes are also called metacomponents and guide problem-solving (Sternberg et al., 1985). It includes strategies that are used for the regulation of cognition, such as problem analysis, orienting, planning, monitoring, checking, and recapitulation (Efklides, 2011). These strategies are defined as sequential processes that help to check if problem-solving goals have been adequately performed (Livingston, 2003). For example, self-explanation, i.e., the fact that we explain the meaning of information to oneself, is a part of the metacognitive strategies as it helps to update one's own understanding.

2.4.1.2 Motivational processing (A2)

Motivation is fundamental for problem-solving because it promotes engagement, which is a necessary condition to become proficient in whatever effortful activity (Fortus, 2015). The motivational processes involve different psychological states promoting the initiation, intensity, and persistence of goal-oriented behaviors (Usher & Morris, 2012). They include diverse beliefs about self in the context of solving the task (e.g., self-efficacy; Zimmerman, 2000), purposes for achieving the task (e.g., mastery or performance goals; Pintrich, 2000), attributions about success and failure (Weiner, 1984), incentives fostering task accomplishment (e.g., intrinsic and extrinsic values; Wigfield and Eccles, 2000) and various costs (e.g., opportunity, psychological/emotional, effort; Miele and Scholer, 2018).

The meta-motivational processes refer to the explicit use of strategies dedicated to monitoring and controlling motivational processes (Kuhl, 1985). A motivational strategy can be defined as a procedure used by individuals in a purposeful and willful manner to maintain a suitable level of motivation when solving a specific task (Miele & Scholer, 2018; Wolters, 2003). Monitoring strategies assess the quantity (i.e., the amount of motivation) and the quality (i.e., the fit between the current type of motivational state and the ideal state required to solve the task) of one's own motivation (Miele & Scholer, 2018). When individuals undergo a lack of motivation, monitoring ponders the desire to disengage the task and achieve it. If the resulting decision is to continue the task, controlling strategies are implemented. Controlling strategies include, for example, self-consequating (i.e., identifying and using verbal or concrete rewards and punishments as an incentive for achieving the task), goal-oriented self-talk (i.e., thinking about good reasons for persisting and completing the task), interest enhancement (i.e., reinforcement of intrinsic motivation by trying to increase immediate enjoyment or situational interest) or efficacy self-talk (i.e., enhancing one's confidence in the ability to achieve the task) (Wolters, 2003).

2.4.2 Mental models (B)

Mental models are individual in-memory representations of the collaborative problem-solving task. They combine information coming from both oneself and the collaboration partners. Self-modelling is an integrated representation of personal task-processing. Besides, partner-modeling builds on inferences regarding one's partner's mental states (Dillenbourg et al., 2016). The propensity to initiate actions to enrich the mental models that partners make of each other depends on the perceived necessity to do so and is pondered by the physical and cognitive costs it implies (Dillenbourg et al., 2016). Mental models are not complete or detailed from the outset. Group members generally start with an initial model relying on assumptions they make upon each other based on cues (e.g., age, number of years of education) and stereotypes (e.g., impressions of warmth and competence; Fiske et al., 2007). Mental models are then built and updated throughout the collaborative

problem-solving task (Dillenbourg et al., 2016). The content of the partner mental models is various and may include both dispositional (e.g., long-term knowledge, skills, or traits) and situational aspects (e.g., real-time knowledge, behavior, or intentions). Mental models encompass three distinct (but interrelated) dimensions (i.e., cognitive, motivational, and relational).

2.4.2.1 Cognitive modeling (B1)

The cognitive modeling integrates cognitive knowledge coming from personal task-processing (e.g., answer to a mental calculation, ideas; Winne, 2011), meta-cognitive knowledge (e.g., task-cognitive constraints, knowledge about personal problem-solving strategies; Efklides, 2011) on socio-cognitive knowledge coming from other group members cognitive acts and non-verbal behaviors (e.g., ongoing information or ideas from other group members), and group task products and socio-meta-cognitive knowledge (e.g., knowledge about group problem-solving strategies, dispositional cognitive knowledge about the group members).

2.4.2.2 Motivational modeling (B2)

The motivational modeling integrates motivational knowledge coming from oneself (e.g., ongoing beliefs about self in the context of solving the task such as self-efficacy, values, goals), on meta-motivational knowledge (e.g., task-motivational constraints, knowledge about personal motivational strategies; Miele and Scholer, 2018; Wolters, 2003), on socio-motivational knowledge coming from other group members through motivational acts and non-verbal behaviors (e.g., ongoing motivational information from other group members) and socio-meta-motivational knowledge (e.g., knowledge about group motivational strategies and dispositional motivational knowledge about the group members).

2.4.2.3 Relational modeling (B3)

Being in a group involves an additional dimension that emerges from group interaction. This dimension refers to processes that are non-reducible to the cognitive or motivational dimensions, even though they can emerge from and interact with them. As pointed out by Isohätälä et al. (2019), socio-relational processes have been addressed in the literature under various headings such as socio-emotional processes, social and relational aspects, group processes, affective dimensions, relational space or social and behavioral engagement. As part of the three-level model, the relational modeling integrates knowledge about relational stances between group members. In an extensive literature review, Burgoon and Hale (1984) addressed the predominant themes that pervade relation communication. Hale et al. (2005) highlight several relational dimensions that are consistent across literature, such as dominance (i.e., the influence over other's actions), emotional arousal (i.e., the degree to which individuals appear active or in tension), composure (i.e., the capacity to stay calm

under stress and pressure), intimacy (i.e., the degree of each other's attachment) which includes, for example, involvement (i.e., the degree to which people are engaged in the conversation), receptivity (i.e., the degree of attentiveness, accessibility, openness, and interest), trust (i.e., the degree of sincerity and honesty), affection (i.e., the degree of closeness in the relationship), depth (i.e., the degree of authenticity in the relationship) and similarity (i.e., the degree of shared attitudes, beliefs, personal characteristics or experiences). The relational model integrates socio-relational knowledge, which refers to how these foregoing relational dimensions are perceived by group members (i.e., ongoing relational stance) and socio-meta-relational knowledge (e.g., knowledge about group relational strategies and dispositional relational knowledge about the group members).

2.4.3 Observable outputs (C)

Based on the contrast between oneself (through individual processing) and partners (through observable outputs) mental models, group members can infer and mobilize actions to respond appropriately to the ongoing group needs to meet the task goals. These actions produce outputs which are visible by the other group members. They include task products, collaborative acts, and non-verbal behaviors.

2.4.3.1 Task products (C1)

Task products represent a series of incremental outputs and achievements produced by the group (Decuyper et al., 2010). These task products can take the form of written outputs of personal work, completed objectives and milestones, and all sorts of joint productions arising throughout the collaborative problem-solving task and accessible to everyone. The accumulation of task products builds a final product (e.g., a final solution to the problem), which has to be judged satisfying enough by group members to end the collaborative problem-solving task.

2.4.3.2 Collaborative acts (C2)

Communication is a continuous process, i.e., the sender and the receiver are highly co-active and continuously intertwined in a mutual coordination process (Fogel, 2017). During collaborative problem-solving, individuals dynamically alter their behaviors with respect to the ongoing and anticipated actions of their partners (Fogel, 2017). Communicative exchanges can be considered as actions that shape collaborative problem-solving, i.e., speech acts. Speech act theory (Austin, 1975) postulates that every utterance can be considered as acts, i.e., they are used to perform in the world. They involve verbal communication (locution) conveying intention (illocution) from the speaker (e.g., provide information, clarify an idea, ask for help, encourage). These speech acts are intended to produce effects, i.e., consequences on feelings, thoughts, and actions of others (perlocution) (Sbisà, 2009). In the three-level model, we propose to call these different speech acts collaborative

acts as they represent a sub-category of speech acts involving collaborative intentions (in contrast with competitive intentions, for example). The term collaborative act rarely appears in the literature (see, e.g., Singley et al., 2000; Tausczik et al., 2014). According to Tausczik et al. (2014), it can be considered as the most basic element of collaboration. Collaborative acts have different foci that refer to the different dimensions afore-described, i.e., cognitive, motivational, and relational. Therefore, collaborative problem-solving involves socio-cognitive and socio-meta-cognitive acts, socio-motivational and socio-meta-motivational acts, socio-relational and socio-meta-relational acts. As part of the three-level model, we define socio-collaborative acts as acts representing a mutual adaptation to each other's exchanges. In this case, although group members dynamically alter their collaborative acts in response to those of their partners, there are not explicit intentions to redirect the course of collaboration to ensure the achievement of the task goal, i.e., socio-meta-collaborative acts. As the notion of co-regulation is ambiguous in the literature and refers to both socio-collaborative and socio-meta-collaborative acts (see, e.g., Fogel, 2017; Hadwin et al., 2011), we propose to distinguish more clearly these two aspects. In our view, collaborative co-modulation reflects the use of socio-cognitive, socio-motivational, and socio-relational acts. In contrast, collaborative co-regulation reflects the use of socio-meta-cognitive, socio-meta-motivational and socio-meta-relational acts.

Cognitive acts ($C2_1$) The cognitive acts refer to the socio-cognitive and socio-meta-cognitive exchanges dedicated to solving the problem. In a broad sense, the socio-cognitive acts involve the processing of interpersonal cognitive information that complements the individual cognitive processes (Dillenbourg, 1999) afore-described. Socio-cognitive acts serve three main activities, namely, knowledge acquisition, participation, and creation that shape group collaboration (Decuyper et al., 2010). Knowledge acquisition is dedicated to promoting the creation of a shared representation of the problem. This shared representation helps to acquire a cognitive mutual understanding of the problem to be solved. It involves socio-cognitive acts dedicated to sharing useful information, such as raising task-related difficulties or highlight task-information. Participation is about promoting mutual coordination. It involves acts promoting a progressive mutual adaptation to each other's behaviors to encourage a smooth interaction between group members. It also includes acts dedicated to promoting the understanding of one's own thoughts by the others and vice versa. Creation is about the co-construction of new knowledge and ideas to solve the problem. It involves acts dedicated to acknowledging, repeating, paraphrasing, enunciating, questioning, challenging, negotiating. The notion of transactivity (Weinberger & Fischer, 2006) highlights the incremental nature of these socio-cognitive acts. Indeed, socio-cognitive acts can convey different levels of co-construction, from new and unconnected to highly integrated ideas or knowledge.

The socio-meta-cognitive acts are dedicated to monitoring and controlling socio-cognitive acts, which is also called team reflexivity (Decuyper et al., 2010). They reflect group members' will to reorient collective cognition to tackle cognitive interpersonal challenges (Järvelä et al., 2013) and meet the superordinate goal of solving the problem. Socio-meta-cognitive acts serve five different levels of co-regulation of socio-cognitive acts, namely, reporting, process monitoring, process reflection, process planning, process revising (Borge et al., 2019). Reporting involves reporting one's own opinion concerning collaboration quality. In this case, group members do not justify their judgment based on concrete observations but share general statements such as "We covered a lot" or "We like to keep each other's opinion and ideas in mind while implementing our own". Process monitoring involves acts indicating evidence that group members pay attention to the collaboration process by underlying ongoing collaborative events or patterns of collaboration such as "We did not bring in additional resources such as citing from the internet". Process reflection goes on step beyond monitoring in the sense that group members mobilize acts that overtly reflect on the collaborative discussion and provide justifications about why some events occurred, such as "I think the problem is that we read two different things" or "It's just difficult to debate when we agree with the author. This wasn't a real debatable subject in my mind". Process planning refers to acts discussing the organization of the activity in order to achieve the task goal. Contrary to process reflection that highlights past events, process planning mainly focuses on forward-thinking and considers goal, strategy, or plan to solve the problem, such as "To begin, we definitively need to work on time management. Our communication skills are sufficient when it comes to the subject matter, but we definitively need to get tasks done with a sense of urgency" or "We just need to be more critical on each other's judgments and be holistic". Finally, process revising involves acts dedicated to the reconsideration of the planning process as well as its alteration considering new information that arises during collaboration, such as "I'm not sure our last approach worked. Maybe we have to assign outside reading too".

Motivational acts ($C2_2$) The motivational acts refer to the socio-motivational and socio-meta-motivational exchanges mobilized when solving the problem. The socio-motivational acts naturally occur during collaborative problem-solving and are not explicitly dedicated to monitoring and controlling the group motivation but instead expressing the current motivational state of group members regarding the task. They can include acts such as "That is a very complex task!" or "Oh, I'm not very focused today". They are thought to co-modulate the group's commitment to achieving the task in creating a motivational tone involving different motivational components such as collective beliefs about self-esteem (i.e., the level of esteem that individuals have for their group; Crocker and Luhtanen, 1990), self-efficacy (i.e., how group members think they can overcome challenges as a group; Bandura, 1977) or values. They also contribute to the emergence of some phenomena that constraints the

group's effort and persistence to achieve the task, such as task cohesion (i.e., the commitment of a group to achieve a goal in a collective effort; Guzzo et al., 1995), positive interdependence (i.e., the fact that group members strongly rely on each other to achieve their common goal; Johnson and Johnson, 2009) or social loafing (i.e., "a mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when the members strivings for unanimity override their motivation to realistically appraise alternative courses of action"; Janis, 2008, p.237).

Similar to socio-meta-cognitive acts, the socio-meta-motivational acts involve monitoring and controlling socio-motivational acts. They reflect group members' will to reorient collective motivation to tackle motivational challenges (Järvelä et al., 2008). Some socio-meta-motivational acts (Järvelä et al., 2008) adapted from Wolters' meta-motivational strategies (Wolters, 2003) have been described (Järvenoja & Järvelä, 2009). The social reinforcing strategy refers to identify and produce acts dedicated to reinforcing and shaping a secure or positive atmosphere as well as to draw attention to the positive aspects of the challenging situations. The socially shared goal-oriented talk strategy concerns exchanges dedicated to highlighting reasons for persisting in the task. The interest enhancement strategy consists of bolstering group motivation in increasing personal (e.g., intrinsic motivation) or situational interest (i.e., temporary interest arising spontaneously from the characteristics of the task) regarding the task. The task structuring strategy focuses on producing acts that structure and coordinate the group work or the environment in order to mitigate off-task behavior. The efficacy management strategy is dedicated to managing the motivational beliefs, self, and collective efficacy. Finally, the handicapping of group functioning strategy aims at highlighting or providing obstructions to task completion. Its role could be twofold. First, it could preserve collective self-esteem in providing good reasons to legitimate an expected failure. Second, it could promote a switch towards mastery goals in leaving aside strong performance expectations.

Relational acts ($C2_3$) As building relationship is an inherently communicative phenomenon (Guerrero et al., 2017), interpersonal communication also plays a central role in spreading socio-relational messages within the group (Hale et al., 2005). The relational acts refer to the socio-relational and socio-meta-relational exchanges mobilized when solving the problem. The socio-relational acts naturally occur during collaborative problem-solving and reflect the current relational states of group members along the different core relational components outlined earlier. They can include acts such as "I like to work with you" or "We understand each other really well". They are thought to co-modulate the group's relationship in creating a relational tone that reflects the integration of one of several of these components. It can induce facilitatory or hindering effects on collaborative problem-solving. For example, psychological safety (i.e., a sense of community where group members feel they are treated sympathetically by their fellows; Kreijns et al., 2003), social cohesion (i.e.,

the sense of unity between group members; (Carron & Brawley, 2000) can be understood as phenomena emerging from high levels in some relational components, such as receptivity, affection, similarity.

2.4.3.3 Non-verbal and para-verbal behaviors (C3)

Non-verbal behaviors (e.g., facial expression, gesture, posture, proxemics, eye gaze, appearance, haptics) and para-verbal components (e.g., pitch, volume, speaking rate) are others sources of observable outputs that may convey information that can substitute, contradict, reinforce or complement the information provided by the collaborative acts. The expression of emotions through non-verbal and para-verbal communication is an important source of information sharing in collaborative problem-solving. As part of the three-level model, we postulate that non-verbal and para-verbal communication are used differently according to the type of collaborative dimension involved. This assumption seems supported by the fact that individuals need predominantly cognitive acts to solve the task. Therefore, motivational and relational co-modulation may be mainly expressed through non-verbal and para-verbal communication. Conversely, verbal communication could be mostly used to co-regulate motivation and relationship when needed (i.e., socio-meta-motivational and socio-meta-relational acts).

2.4.4 Interaction between the three levels

The three levels afore-described (individual processing, mental models, and observable outputs) interact with each other throughout collaborative problem-solving. Observable outputs are shared among the group members (interpersonal level of collaboration) while there are as many mental models and individual processing as group members (personal level of collaboration) (Figure 2.4). During the collaborative problem-solving task, each group member continuously emits different types of observable outputs. These observable outputs represent a series of pieces of information that can be taken into consideration by the other group members. These pieces of information first include cognitive, motivational, and relational information conveyed through collaborative acts and non-verbal/para-verbal behaviors. After a while, they also ongoing task products created throughout the collaborative problem-solving task. Group members use observable outputs to elaborate and update several mental models of the collaborative problem-solving task. As described earlier, these models include various knowledge and meta-knowledge about incoming cognitive, motivational, and relational information. The cognitive, motivational, and relational mental models are assumed to be interrelated (e.g., the quality of the cognitive outputs can inform the degree of motivation or the relational tone between group members).

Considering the latest update of the interpersonal knowledge and meta-knowledge, group members can decipher a current need and possible personal contributions

to advance the resolution of the problem. These contributions could be of a cognitive, motivational, or relational nature. Therefore, group members can co-modulate (through socio-cognitive, socio-motivational, and socio-relational acts and/or non-verbal/para-verbal behaviors) or co-regulate (through socio-meta-cognitive, socio-meta-motivational and socio-meta-relational acts and/or non-verbal/para-verbal behaviors) the collaborative problem-solving or produce a new task product. Sometimes, however, group members cannot provide an interpersonal output solely based on their mental models. In this case, group members must rely on individual processing. Cognitive processing can mobilize both cognitive processes and meta-cognitive processes to regulate them to generate adequate cognitive knowledge. Accordingly, motivational processing can mobilize motivational processes and meta-motivational processes to regulate them to generate adequate motivational resources. The cognitive and motivational processes can interact with each other (e.g., self-efficacy can influence cognitive processing; Low and Jin, 2012; Valentine et al., 2004).

Finally, individual processing allows group members to update their mental models regarding cognitive knowledge and/or motivational resources and make possible new observable outputs at the interpersonal level. The interaction between the three levels of collaboration ends when task products are judged satisfying enough to solve the problem.

2.4.5 Sources of collaborative dysfunctionality

The three-level model assumes that the efficient resolution of a collaborative problem-solving task (i.e., collaborative functionality) depends on different personal and interpersonal aspects that cannot be considered independently.

First, collaborative functionality can suffer from inefficient individual processing, i.e., poor or inadequate use of cognitive and meta-cognitive processes to solve the problem at the personal level (e.g., wrong way of calculating a result, lack of monitoring of outcomes). This aspect can reduce the production of adequate cognitive knowledge. Besides, poor or inadequate motivation (e.g., low self-efficacy), as well as little or inadequate use of meta-motivational processes (e.g., poor use of meta-motivational strategies), can also limit the quality of individual processing.

Second, collaborative functionality can also suffer from inefficient observable outputs. In the same way that group members must mobilize efficient individual processing, they also need to emit adequate observable outputs regarding the cognitive, motivational and relational aspects of the collaboration. In the cognitive dimension, collaborative problem-solving can suffer from poor use of socio-cognitive acts (e.g., poor exchange of cognitive information). Socio-cognitive acts may also not provide meaningful information to the other group members. Besides, meta-socio-cognitive

acts can be underused (e.g., group members do not attempt to monitor and control the course of the collaborative problem-solving task) or used in the wrong way (e.g., group members propose inadequate changes to solve the problem). In the motivational dimension, collaborative problem-solving can be affected by poor use of socio-motivational acts (e.g., a group member shares little sign of motivation) or inadequate use of socio-motivational acts (e.g., a group member shows an individualistic interest to solve the task). Besides, reduced use of socio-meta-motivational acts allowing group members to enhance or maintain group motivation or inadequate attempts to bolster motivation (e.g., threatening people about incoming failure) can also worsen collaborative functionality. In the relational dimension, poor socio-relational acts (e.g., low exchanges related to trust or respect between group members) or inadequate ones (e.g., too playful exchanges in a working context) are also an important aspect that can prevent efficient collaborative problem-solving. The group relational tone also needs to be monitored and controlled. A lack of socio-meta-relational acts (e.g., failure to preserve mutual respect when challenging each other's ideas) or inadequate use of such acts (e.g., trying to limit socio-cognitive conflict by making jokes) can also be detrimental to collaborative problem-solving. In addition to collaborative acts, non-verbal/para-verbal behaviors also represent observable outputs that can convey cognitive, motivational, and relational messages that do not necessarily benefit to collaborative problem-solving (e.g., fake attitude regarding the understanding of the problem, disinterested attitude toward the task, attitude of domination over the other group members). Finally, sharing too few or inadequate task products can also limit the capacity to complete the collaborative problem-solving task. The difficulties in the cognitive, motivational, or relational dimensions can also affect the other dimensions. For example, the inability to receive meaningful cognitive information from others can decrease the motivation to carry on with the task or reduce trust among group members. Lack of engagement in the group can also increase relational tensions and limit the transfer of cognitive information towards idle group members.

Third, even if group members can build accurate mental models through efficient individual processing and observable outputs, it does not guarantee collaborative functionality. Indeed, efficient collaborative problem-solving also relies on the capacity to reach a sufficient degree of mutual understanding between group members, i.e., to mobilize observable outputs dedicated to tuning each other's mental models to meet task goals. This tuning implies both to share an accurate representation of the task, oneself, and the others and mobilize perspective-taking, i.e., to see one's own actions through the other's point of view. This process usually implies collaborative acts dedicated to facilitating communicative connection (i.e., promotion of mutual exchanges), translating effort (e.g., promotion of intercomprehension), or boundary permeability (e.g., promote role change) (see Decuyper et al., 2010). The inability for group members to align their mental models is assumed to hinder collaborative functionality and increase the likelihood of a mere gathering

of individual work (i.e., shift towards cooperation instead of collaboration; Dillenbourg, 1999).

2.5 Conclusion

Although in the last decades, the interest in how people solve problems together has risen in the fields of problem-solving, collaborative and cooperative problem-solving, computer-supported cooperative work, and computer-supported collaborative learning, a comprehensive understanding of collaborative problem-solving is still in an immature stage. Notably, if the research has described the cognitive aspects of collaborative problem-solving in some detail (e.g., Decuyper et al., 2010) and converges around the idea that collaboration mobilizes two main spaces, i.e., socio-cognitive and socio-relational (e.g., Janssen et al., 2012), new research in this field is highly important to deepen the understanding of the different processes underlying collaborative problem-solving and finding new avenues to make it more efficient. After reviewing the literature on various scientific contributions related to collaborative problem-solving at the personal and interpersonal levels, this chapter described a new model to capture its functioning. This model represents a dynamic process that illustrates how team members engaged in a collaborative problem-solving task build and update mental models, i.e., individual in-memory representations, combining general knowledge and incoming information from both self (via individual processing) and other group members (through observable outputs) regarding cognitive, motivational, and relational aspects of the collaborative problem-solving task. The next chapter will focus more specifically on the literature regarding the role of emotional processes in collaborative problem-solving at the personal and interpersonal levels. These contributions will be then integrated to the three-level model of collaborative problem-solving.

Chapter 3

EMOTIONAL PROCESSES IN COLLABORATIVE PROBLEM-SOLVING

In the previous chapter, we presented three key components of collaborative problem-solving, namely the cognitive, motivational and relational dimensions of collaboration. This chapter explores how emotional processes can pervade each of these dimensions in presenting a literature review in the domain of personal and interpersonal emotional processes. These different processes are then integrated into the three-level model of collaborative problem-solving (Figure 3.8). In line with this model, the theoretical contributions reviewed are divided into two major sections dedicated to emotional processes at the personal and interpersonal levels.

3.1 General definitions

3.1.1 What is emotion?

First, affect refers to any experience of feeling (Gläser-Zikuda, 2012) and is generally used as an umbrella term to refer to several phenomena such as moods, preferences, affect dispositions or emotions (Scherer, 2005). The word emotion comes from the Latin word emovere, meaning "to move away from" (LeDoux & Hofmann, 2018). The question "What is an emotion?" has different answers depending on who is asked (Scherer, 2005) and, amusingly, Fehr and Russell, as cited in Smith, Lazarus, et al. (1990), noted that "everyone knows what an emotion is until asked to give a definition". In the everyday vernacular speech, emotion mainly refers to the conscious experience of feeling. In the scientific community, emotion is seen as a multicomponent process that entails, at least, subjective experience, physiological, and behavioral responses (LeDoux & Hofmann, 2018). Other authors also include cognitive (Lazarus, 2006; Scherer, 2009) and motivational (Frijda, 1987) components. Nowadays, it is generally accepted that emotion is a whole-body and mind phenomenon characterized by "an episode of interrelated, synchronized changes in the

states of all or most of five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism" (Scherer, 2005, p. 697). Each subsystem is dedicated to a given function that refers to an emotion component. The five components described by Scherer (2005) are the **cognitive component** (i.e., the subjective interpretation of the goal-relevant situation, also called appraisal), the **neurophysiological** component (i.e., the bodily symptoms), the **motivational component** (i.e., the action tendencies), the **motor expression component** (i.e., the emotional expressions), and the **subjective feeling** component (the phenomenological experience).

The multi-component model explains how emotion is formed. However, it does not inform about the quality of emotion. Several criteria can thus be taken into account to described it, such as the **valence** (pleasant or unpleasant), the **arousal** (activating or deactivating), the **intensity**, the **duration**, the **frequency**, the **focus** (prospective or retrospective), the **point of reference** (self or other), and the **context** (e.g., social interaction, learning) (Hascher, 2010). More generally and contrary to other emotion-related constructs such as mood, which is more diffuse with a less identifiable cause, emotion is focused on a specific event. In addition, the subjective feeling of emotion is generally intense, relatively limited in time, and can be described quite accurately. Emotion also inclines us to prepare adaptive action tendencies and their motivational underpinnings that enable individuals to resolve difficulties. In goal-directed contexts such as learning or problem-solving, the discrepancy between actual and expected progress triggers emotions and further influence motivation. In other words, emotion contributes to motivation in providing information related to goal pursuit. In this sense, it has a substantial effect on goal-directed behavior, often interrupting ongoing behavior sequences and generating new goals and plans (Bagozzi & Pieters, 1998; Crocker et al., 2013; Scherer, 2005). In addition to its relationships with action tendencies, emotion also appears to have substantial effects on other cognitive processes.

3.2 Emotions at the personal level

3.2.1 Emotions and other cognitive processes

A growing interest in the relationship between emotion and cognition has emerged over the last twenty years, shifting the research on learning and problem-solving from a strictly cognitive point of view, where rational and objective thinking was opposed to irrational and emotional thinking, to a cognitive-emotional approach, where emotions complement and modulate cognitive work (Järvelä et al., 2013). Emotions are now thought of as pervading a broad range of cognitive processes (Ashby, Isen, et al., 1999; Clore & Huntsinger, 2007; Damasio, 1994; Phillips et al., 2002).

First, significant effects of emotions have been uncovered from lower to higher-level cognitive processes. For example, positive emotions have been shown to expand the scope of attention, whereas the reverse effect is found for negative emotions (Fredrickson & Branigan, 2005). In visual perception, angry and happy faces are detected faster than neutral stimuli (Eastwood et al., 2001). In long-term memory, as reported in the review of Hamann (2001), emotional arousal globally enhances episodic memory. In addition, individuals encode more information if their emotional state fits with the valence of the material (see also mood-congruence-hypothesis; Bower, 1981). Similar emotional effects have also been found regarding the retrieving of information in episodic memory. For example, Cahill et al. (1996) found that emotional video clips are better remembered than neutral ones, even after three weeks. Individuals also tend to retrieve information more quickly if it is congruent with their current emotional states (Chaffar & Frasson, 2012). Regarding executive functions, Phillips et al. (2002) showed that subjects positively induced are worse in cognitive inhibition and better in fluency comparing to non-induced subjects. Positive emotions also promote cognitive flexibility (Chaffar & Frasson, 2012). In working memory as well, positive and negative emotions have differential effects, as demonstrated by Gray et al. (2002). Working memory performance decreases with positive mood and increased with negative one for spatial items while the reverse is found for verbal items.More recently, Spachtholz et al. (2014) showed that negative emotions would decrease the capacity of working memory but, in the other hand, increase its precision. Other evidence on the effect of emotions also comes from the decision-making field (see George & Dane, 2016, for a review). Emotions are assumed to be an essential driver of most decisions in life (Lerner et al., 2015). The stereotypical idea that emotions harm reasoning has been challenged, especially in Damasio's works (Damasio, 1994). This author showed, for example, that patients having difficulties to feel emotions due to brain damage take more financially risky decisions. It seems that these patients could have lost the fear of high risks. However, if emotions and decision making go hand in hand, it does not necessarily mean that every emotional decision is right. Emotions may also trigger cognitive heuristics, which may lead to suboptimal reasoning in specific contexts (Lerner et al., 2015). A striking example is the fear of flying. People generally are much less afraid by road than plane trips, even if air crashes are exceedingly rarer than car accidents. Indeed, in 2011 in France, people dying in transport (5647 people) were 76% car drivers or accompanying persons and 0% air passengers (Lebufnoir, 2013).

As a result, emotions also modulate cognitive styles. In a study, Isen et al. (1987) showed that inducing positive affects makes subjects think more creatively. According to the broaden-and-build theory (Fredrickson, 2013), positive emotions would expand the "array of thoughts, action urges and percepts that spontaneously come to mind" and promote heuristic-based strategies. Under positive emotions, patterns of thoughts would be more flexible and inclusive, integrative, open to information and efficient. Enjoyment and pride, in particular, would be correlated

with more profound and more integrated information processing, which could positively impact the process of elaboration (i.e., the ability to detail a problem solution) (Gläser-Zikuda, 2012; Pekrun et al., 2002). However, these effects of positive emotions would be more prominent if the contents have personal relevance (Hascher, 2010). Regarding negative emotions, negatively induced participants would adopt a more systematic gathering of information and more rigid and careful processing of information (Fredrickson & Branigan, 2005; Gläser-Zikuda, 2012; Spering et al., 2005). That would also go hand in hand with less inductive reasoning (Chaffar & Frasson, 2012).

In summary, emotions affect collaborative problem-solving because they have significant effects on individual processing of information. Emotions modulate lower and higher-level cognitive processes such as perception, long-term memory, and executive processes, decision making. As a result, they impact the cognitive and reasoning style of individuals (e.g., creativity, inductive vs. deductive reasoning).

3.2.2 Emotions in learning and problem-solving

In the previous section, we have highlighted the close relationship between emotions and cognitive processes. Until recently, learning was mainly analyzed solely in terms of cognitive or motivational aspects. However, as we have seen in previous sections, both of these aspects are significantly modulated by emotions. In agreement with the broaden-and-build theory, positive emotions in academic context would provide benefits for tasks requiring exploration and creation of new ideas (i.e., divergent thinking). Positive emotions are also mainly reported to lead to positive learning outcomes (Rowe & Fitness, 2018). However, despite the fact that negative effects of negative emotions on learning outcomes are often reported (due to adverse effects on attention, memory, motivation, self-regulation, and self-efficacy) (Rowe & Fitness, 2018), a strong dichotomy between positive effects of positive emotions and negative effects of negative emotions should be avoided. For example, negative emotional state would have an advantage for tasks requiring to perform effectively within the provided rules (i.e., convergent thinking) (Hascher, 2010; Rowe & Fitness, 2018). Therefore, negative emotions could lead to adaptative behaviors in some circumstances (Hascher, 2010; Rowe & Fitness, 2018). Several reasons can be advanced to substantiate this point. First, depending on the type of task, some negative emotions could enhance learning performance, whereas some positive emotions could dampen it. For example, fear would lead to a better prioritizing of information, while anger would increase attention to the goals and actions of others (Rowe & Fitness, 2018). Conversely, some positive emotions (e.g., amusement) increase the urge to be playful and social and, therefore, promote distraction, which would disrupt

the processing of tasks requiring high focus, especially when the learning topic has low subjective relevance or low challenge (Fredrickson & Branigan, 2005; Hascher, 2010). Second, emotions do not solely impact cognitive performance but also motivational processes. Therefore, the same emotion could have a detrimental impact on cognitive processes while having a positive impact on motivational processes and vice versa. For example, anxiety would globally reduce cognitive resources and trigger more task-irrelevant thinking due to worries about failure (Pekrun, 2012). However, it would also promote motivation to avoid failure (Rowe & Fitness, 2018). Third, an essential component of efficient learning and problem-solving is cognitive conflict, i.e., a psychological state involving a discrepancy between new information and prior beliefs and ideas (Braasch & Scharrer, 2020; Waxer & Morton, 2012). For example, cognitive disequilibrium can generate confusion that could benefit to learning (D'Mello et al., 2014) in promoting, for example, knowledge exploration (Vogl et al., 2019).

Therefore, as outlined by Pekrun and Perry (2014, p. 134), "with few exceptions; any emotion can prove to be either adaptative or maladaptive in terms of achievement outcomes". Therefore, understanding the role of emotions in learning and problem-solving requires adopting a more fine-grained level of analysis, taking into account the functional aspect of different types of emotions in different types of academic settings. In a first approach, Pekrun and Linnenbrink-Garcia (2012) have proposed to distinguish four main types of emotions that occur in different spheres of academic activity. They can be called academic emotions (Pekrun, 2006). **Epistemic emotions** "have as an object focus the knowledge-generating aspects of learning that arise as a result of cognitive and epistemic qualities of information and the processing of that information" (Chevrier et al., 2019, pp. 2-3). For example, incongruity can elicit surprise and curiosity. **Achievement emotions** relate to achievement activities (e.g., problem-solving) and achievement outcomes (success or failure). For example, students may experience hope or pride related to task success. **Social emotions** are related to the relationship with others. For example, a student may admire a classmate or feels jealous of their academic success. Finally, topic emotions are related to the appealing effect that academic content can have (Boekaerts & Pekrun, 2015) on learners. For example, when reading a novel, the protagonist's fate can trigger empathy from students. In the two following sections, we will mainly focus on describing in more detail how epistemic and achievement emotions intervene during learning and problem-solving activities, which will be particularly relevant as part of this thesis work. First, D'Mello and Graesser's model will focus on some epistemic during complex learning tasks such as complex problem-solving (D'Mello & Graesser, 2012). Second, Pekrun's Control-Value theory will describe emotions related to achievement activities and achievement outcomes (Pekrun, 2006).

3.2.2.1 D'Mello and Graesser's model

D'Mello and Graesser (2012) proposed a dynamic and fine-grained model (Figure 3.1) to explain how emotional, cognitive (e.g., causal reasoning, deliberation,

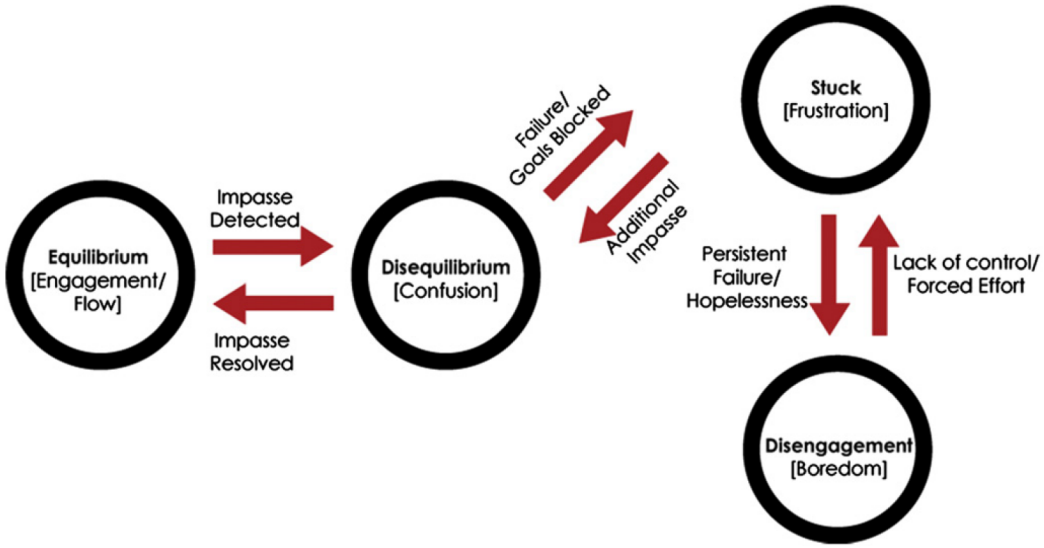

FIGURE 3.1: D'Mello and Graesser's model. Retrieved from D'Mello and Graesser (2012)

planning) and achievement (e.g., achievement goals) processes are intertwined during deep or complex learning. Learners involved in such learning tasks are subject to a host of positive and negative emotions. Some are consistently observed, such as confusion, frustration or boredom, depending on what learners experience during the task (e.g., misunderstanding, impasses or success). These epistemic affective (e.g., surprise) and cognitive-affective (e.g., confusion or flow) states are preferentially associated with different cognitive phases. In this model, several recurring phases are described in the course of complex achievement tasks.

Prototypical paths involve **equilibrium**, **disequilibrium**, **stuck**, and **disengagement**. When learners are engaged in the task, they experience a cognitive state of **equilibrium**. It refers to a state where new knowledge acquisition fits with prior knowledge so as no uncertainty or obstacles emerge during the learning activity. In this situation, a feeling of flow (i.e., the feeling to be wholly involved in the activity; Schüler, 2012) is likely to be experienced. However, some obstacles can arise during the activity. When discrepant information provokes misunderstanding, uncertainty, or interruptions of coordinated actions, attention is directed towards this discrepant information. These cognitive issues may create a state of cognitive disequilibrium. Referring to Piaget's theory (Kibler, 2011), cognitive **disequilibrium** is defined as a state of cognitive imbalance when individuals face a problem that requires to go beyond existing knowledge schemas. Such cognitive disequilibrium is known to be inherent and beneficial to deep learning. When learners experience such a state, they are likely to feel several emotions, depending on the nature of the disequilibrium. For example, if the disequilibrium results in an impasse, a cognitive-affective state of

confusion arises. Individuals then engage in effortful reasoning (e.g., think, deliberate, problem solve) to restore equilibrium (productive confusion hypothesis). If the impasse is overcome, learners return in a state of equilibrium, confusion decreases accordingly, and the task may continue. Alternatively, impasses cannot always be quickly resolved, and learners may get **stuck** as no plan is currently available (hopeless confusion hypothesis). If this situation persists, learners are likely to experience frustration. Persistent blocking may result in **disengagement** (i.e., abandonment of the superordinate learning goal) with a prototypical feeling of boredom (disengagement hypothesis). Additionally, just like learners in a disequilibrium state may return in an equilibrium one, learners getting stuck can also re-experience a state of disequilibrium of an additional impasse is detected. Also, disengaged learners may re-experience a state of stuck, for example, if they are forced to continue the task.

Alternatively, D'Mello and Graesser's model postulates alternative paths. For example, if an event appears unexpected, learners experience novelty, which goes hand in hand with a feeling of surprise. Novelty may lead to a state of disequilibrium and confusion if it leads to an impasse. In addition, if an overcome impasse results in the fulfillment of an important sub-goal, learners generally do not return immediately to a state of equilibrium but experience a state of achievement accompanied by a feeling of delight. This state then dissipates into equilibrium as long as the superordinate goal is not achieved. Novelty and achievement have not been included in the final model due to their low frequencies in naturalistic complex learning.

3.2.2.2 Pekrun's Control-Value theory

In contrast to D'Mello and Graesser's model, which integrates epistemic emotions into a dynamic model, Pekrun's Control-Value theory (Pekrun, 2006) focuses on achievement emotions. This theory relies on appraisal theories by contrasting the different causes (appraisal antecedents) that lead to the emergence of achievement emotions in the context of learning and achievement (e.g., personal competencies, value of outcomes, probability of success and failure). In this way, the model provides strong hypotheses on the emergence of specific emotions in certain achievement situations. Pekrun's Control-Value theory builds on various theories coming from the motivation field, such as attribution theory, expectancy-value theory, perceived control, or self-concept.

The object focuses of achievement emotions are achievement activities and achievement outcomes. Activity emotions relate to ongoing achievement (e.g., enjoyment of learning, anxiety when dealing with a tricky task), whereas outcome emotions refer to the outcomes of these activities (e.g., disappointment following a failing grade). Moreover, outcome emotions can be either prospective or retrospective, depending on their temporal focus (e.g., hope of future success or pride for past success). These emotions can also be classified along two axes, namely valence (positive vs. negative) and activation (physiologically activating vs. deactivating) (Pekrun &

Linnenbrink-Garcia, 2012; Pekrun & Perry, 2014). Activation refers to the arousal dimension of emotions (Fontaine et al., 2007). Therefore, achievement emotions can be positive and activating (e.g., enjoyment), positive and deactivating (e.g., relaxation), negative and activating (e.g., frustration) and negative and deactivating (e.g., boredom) (Table 3.1).

	Positive[a]		Negative[b]	
Object Focus	**Activating**	**Deactivating**	**Activating**	**Deactivating**
Activity	Enjoyment	Relaxation	Anger	Boredom
				Frustration
Outcome/Prospective	Hope	Relief[c]	Anxiety	Hopelessness
				Joy[c]
Outcome/Retrospective	Joy	Contentment	Shame	Sadness
	Pride	Relief	Anger	Disappointment
				Gratitude

[a]Positive = pleasant emotion. [b]Negative = unpleasant emotion. [c]Anticipatory joy/relief.

TABLE 3.1: Achievement emotions depending of the different levels of object focus, valence and activation. Retrieved from Pekrun and Perry (2014)

A central idea of this theory is that learners experience specific achievement emotions when they feel "in control of, or out of control of, achievement activities and outcomes that are subjectively important to them" (Pekrun & Perry, 2014, p. 122). This assertion implies that subjective control and subjective value of achievement activities are the proximal determinants of emotional experience (Gläser-Zikuda, 2012, p. 122). **Subjective (or perceived)** value relates to the perceived valence of ongoing actions and accomplished outcomes. **Subjective (or perceived) control** refers to an overall evaluation of control over the task. Subjective value is appraised before subjective control (Pekrun, 2012).

Subjective value: When learners focus on what they are doing, subjective value emerges from either intrinsic (value of the activity per se) or extrinsic (instrumental usefulness of the activity) values. When the learner's focus is on prospective or retrospective outcomes, subjective value emerges from achievement expectancies in terms of success or failure.

Subjective control: When learners focus on what they are doing or what will be accomplished (activity or prospective perspective), subjective control emerges from several expectancies regarding actions and outcomes (Pekrun, 2006). First, action-control expectancies are beliefs about the self-capability to initiate and perform an action (similar to self-efficacy; Bandura, 1977). Second, action-outcome expectancies are beliefs that self-actions will produce some positive outcomes or prevent negative ones. Third, situation-outcome expectancies are beliefs that the situation will produce positive or negative outcomes by itself whatever the actions performed. In

addition, when the learner focuses on what has been accomplished (retrospective perspective), subjective control implies retrospective appraisals of the causes of success or failure (Pekrun, 2006), i.e., causal attributions of outcomes (self or external circumstances; similar to locus; Weiner, 1984). If learners expect that they can make efforts to solve the task (high action-control expectancies) and think that these efforts will lead to success (high action-outcome expectancies), they should perceive high controllability, i.e., high subjective control. On the other hand, if learners cannot obtain success through their efforts, but the situation is, nevertheless, leading to success (high and positive situation-outcome expectancies), they should perceive high subjective control. In a prospective and activity perspective, subjective control is posited to be high when (1) learners have high action-control and high action-outcome expectancies, (2) the situation has high positive situation-outcome expectancies, or (3) both of the previous conditions are met. Conversely, subjective control is posited to be low in the following cases when (1) learners have low action-control or low action-outcome expectancies, and (2) the situation has high situation-outcome expectancies of failure. For example, if learners cannot obtain success through their efforts and the situation is failing, they should perceive low controllability, i.e., low subjective control. Besides, from a retrospective perspective, external attribution (i.e., external circumstance has caused the outcome) or internal attribution (i.e., the self has caused the outcome) define subjective control.

Subjective control x subjective value: Achievement emotions are the results of the different combinations of subjective control and value afore-described. For example, in a prospective perspective, when learners have high expectancies of success (positive subjective value) but the perception of controllability appears to be low (low subjective control), it is expected that success will not occur and hopelessness is predicted to arise. In a retrospective perspective, if failure has occurred (negative subjective value) and causal attributions are internal (self), shame is predicted to arise. Finally, in an activity perspective, if intrinsic and/or extrinsic value are positive (positive subjective value) but the perception of controllability is low (low subjective control), frustration is assumed to arise (Table 3.2).

Several studies have provided elements that substantiate Control-Value theory. Considered separately, more subjective control would alleviate test anxiety in academic achievement. In addition, subjective control would be positively related to student's enjoyment, hope and pride and negatively correlated to anger, anxiety, shame, hopelessness and boredom. Subjective value would also relate to both positive and negative achievement emotions. When considering subjective control and value together, subjective control appears positively correlated with positive emotions and negatively correlated with negative emotions, whereas subjective value is positively correlated with both types of emotions, which suggests that high task importance could also trigger negative emotions (e.g., fear of failure) (Pekrun & Perry, 2014).

	Appraisals		
Object focus	Value	Control	Emotion
Outcome/prospective	Positive (success)	High	Anticipatory joy
		Medium	Hope
		Low	Hopelessness
	Negative (failure)	High	Anticipatory relief
		Medium	Anxiety
		Low	Hopelessness
Outcome/retrospective	Positive (success)	Irrelevant	Joy
		Self	Pride
		Other	Gratitude
	Negative (failure)	Irrelevant	Sadness
		Self	Shame
		Other	Anger
Activity	Positive	High	Enjoyment
	Negative	High	Anger
	Positive/Negative	Low	Frustration
	None	High/Low	Boredom

TABLE 3.2: Achievement emotions depending of the different levels of object focus, subjective value and subjective control. Retrieved from Pekrun (2006)

Besides proximal factors, which are subjective control and value, a host of more distal mechanisms intervene in the appearance of achievement emotions. For instance, some motivational processes have supposed or confirmed mediating effects on the relationships between subjective control and value and achievement emotions. For example, self-concepts of ability mediate the relationship between achievement appraisals and achievement emotions.This could explain why class performance positively predicts positive emotions in language class, but negatively predict positive emotions in mathematics class (Goetz et al., 2008). Achievement goals (cf. achievement goal theory, see section 2.2.3.2 on achievement goal theory) would also modulate achievement emotions. Mastery-approach goals would reinforce the positive value of the activity by reinforcing attentional focus on mastery of activity. This is posited to foster positive activity emotions (e.g., enjoyment) and decrease negative activity emotions (e.g., boredom). Mastery-avoidance goals are positive predictors of prospective outcomes emotions such as anxiety or worry (Elliot & Pekrun, 2007). Learners with performance-approach goals focus would value more success by outperforming others, implying they could experience more outcome emotions such as hope and pride (in case of success) or anxiety and shame (in case of failure). Finally, performance-avoidance goals would foster perceived uncontrollability and negative value of failure outcomes, leading to anxiety, shame, and hopelessness (Pekrun & Perry, 2014). By extension, learners who attend academic environments that promote mastery or performance goals also experience different achievement

emotions. For example, competitive environments lead learners to experience more failure, which would bolster negative outcome emotions such as anxiety and hopelessness. Autonomy (see section 2.2.3.2 on self-determination theory) also appears to be involved in the modulation of achievement emotions by promoting intrinsic value and subjective control of activities when task demands are manageable (Pekrun & Perry, 2014). In addition to motivational processes, cognitive factors are also posited to be mediational factors of achievement emotions. The more the task appears straightforward, the more subjective control increases, promoting positive achievement emotions. Conversely, perceived difficulty dampens subjective control, leading to more negative achievement emotions. The intrinsic value of tasks is also related to task difficulty and attractiveness. Thus, a too annoying or too complicated task may reduce its intrinsic value, then triggers more negative activity emotions such as frustration or boredom (Pekrun & Perry, 2014).

Pekrun's Control-Value theory also highlights the reciprocal and cyclical nature of achievement emotions. As achievement activities and outcomes and their appraisal trigger achievement emotions, achievement emotions also influence following achievement activities and outcomes (reciprocal causation). On the one hand, some negative emotions experience after failure (e.g., shame) may dissuade learners from repeating similar or even non-related tasks. Some positive emotions (e.g., hope) could also leverage more optimistic appraisals concerning the task at hand. On the other hand, as some cognitive and motivational factors mediate achievement emotions, some others are also impacted in return by achievement emotions.

Regarding cognitive aspects, Control-Value theory also postulates a beneficial effect of some positive emotions on learning, predominantly positive activating emotions (e.g., enjoyment) due to an increase in working memory resources through an increase of attentional focus on the task. However, some other achievement emotions could disrupt this attentional focus (e.g., anxiety, boredom or hopelessness) and lead to task-irrelevant thinking (e.g., worrying about failure, criticizing oneself) that consumes cognitive resources and may be detrimental to the achievement of complex tasks. Emotions also stimulate different cognitive styles (see section 3.2.1). Positive and activating emotions (e.g., enjoyment) are also posited to promote the use of more flexible, creative and deep learning and problem-solving strategies. In contrast, negative and activating emotions (e.g., anxiety) would lead to more rigid and analytical ways to solve problems. However, as noted earlier, some positive and activating emotions may also promote extraneous thoughts (e.g., a too high level of pride may induce persistent thoughts about earlier success), and dampen further effort. Finally, deactivating emotions such as relief or boredom could reduce task attention and promote superficial processing of information (Pekrun & Perry, 2014).

Regarding motivational effect, positive activating emotions (e.g., enjoyment, hope, pride) are, in general, posited to be a positive driver of learning, reinforcing interest

and intrinsic motivation, whereas negative deactivating emotions (e.g., hopelessness, boredom) are thought to undermine motivation. Positive deactivating and negative activating would have more complex effects on motivation. For example, short-term loss of motivation can be postulated for positive and deactivating emotions (contentment, relief, relaxation). Among these emotions, outcomes emotions such as relief and contentment could have beneficial long-term effects in promoting future engagement. However, activity emotions such as relaxation could undermine task outcomes in reducing effort (rest on one's laurels effect) on the task. Some negative and activating emotions seem to have opposite effects. For example, anxiety, shame and anger are posited to foster effort to avoid failure and overcome difficulties (Rowe & Fitness, 2018). Some learners could also seek anxiety as a source of motivation (Strack et al., 2017), although anxiety could also dampen intrinsic motivation on some others (Pekrun & Perry, 2014).

In summary, emotions affect collaborative problem-solving because they impact individual learning and problem-solving. The same emotion, positive or negative, can have beneficial or detrimental effects on various cognitive or motivational processes. Therefore, a more fine-grained analysis is needed to understand better how emotions affect collaborative problem-solving. Pekrun and Linnenbrink-Garcia (2012) proposed to consider emotions according to their object focus (achievement emotions, epistemic emotions, topic emotions, social emotions). D'Mello and Graesser's model (D'Mello & Graesser, 2012) highlights how different affective states permeate with different cognitive states during effortful reasoning. Pekrun's Control-Value theory (Pekrun, 2006) explains how different appraisals related to task-achievement (control, value, object focus) trigger different types of emotions. These emotions affect cognition and motivation of individuals when learning and solving problems.

3.2.3 Meta-emotional processes

As outlined by Gross (2014), if emotion has undoubted adaptational effects, it may be harmful as well as helping when it is not suited to the situation, comes at the wrong time or with the wrong intensity (Peña-Sarrionandia et al., 2015). Therefore, emotional processes also need to be appraised, monitored, and controlled through meta-emotional processes (Koole, 2009). Beyond self-regulation that refers to how effectively individuals manage their emotions, emotional intelligence also encompasses other meta-emotional processes (also referred as emotional competencies), reflecting how individuals process emotions, including emotion regulation (Peña-Sarrionandia et al., 2015). In this section, we will present the theoretical aspects

of emotional intelligence and self-regulation, as well as their impacts on individual learning and problem-solving.

3.2.3.1 Emotional intelligence

Emotional intelligence is at the intersection between emotion and cognition (Mayer et al., 2011). It is seen as different dispositions and competencies, including both learned abilities and personal traits (Vaida & Opre, 2014). Emotional intelligence can be defined as the "ability to perceive and express emotions, assimilate emotions in thought, understand and reason with emotion, and regulate emotion in the self and others" (Mayer et al., 2000, p. 396). Emotional intelligence models globally examine three connected levels. The first level focuses on knowledge relative to emotions. It covers what people know about emotions and ways to manage them constructively. The second level refers to the ability to use this knowledge in emotional situations. Finally, the last level concerns the emotion-related dispositions to act in specific ways in emotional situations (Peña-Sarrionandia et al., 2015, p. 396).

The Four-Branch model of Emotional Intelligence The Four-Branch model of Emotional Intelligence adopts an integrative approach and considers emotional intelligence as a general mental ability that underlines four main branches or emotional competencies (Mayer et al., 2011). These four branches are organized in a hierarchy of complexity, from the most basic level (perception of emotions) to the highest one (regulation of emotions) (Fernández-Berrocal & Extremera, 2006).

The first branch, called **perception and expression of emotion**, concerns the ability to perceive and express emotions. It involves attending to, identifying, and interpreting emotions from diverse sources. It includes different skills such as the ability to identify emotions in self and others' physical and psychological states, the ability to express emotions accurately as well as the needs related to them, or the ability to discriminate between accurate and inaccurate feelings according to the context. This branch is a core competency that makes possible further emotional processing. The second branch, called **assimilating emotion in thought**, is the ability to harness emotions to promote thinking in various cognitive activities, such as problem-solving. It includes weighing emotions against one another and use them to choose tasks that best fit to one's current emotional state. The third branch, called **understanding and analyzing emotions**, involves comprehending, recognizing and describing emotions using language, including complex emotions. It also implies understanding how emotions combine together and the relationships between them. Finally, the fourth branch, called **reflective regulation of emotions**, globally refers to emotional regulation as we will describe it in the next section. In a nutshell, it includes the capacity to monitor and manage emotions to achieve intended goals and promote emotional and intellectual growth.

3.2.3.2 Emotion self-regulation

Emotion regulation refers to all manner of efforts to shaping emotional responses (Gross, 2014; Pekrun & Linnenbrink-Garcia, 2012). Emotion regulation is a subpart of affective regulation focalizing on emotions. It allows individuals to manage their emotions, i.e., make an offset correction of an emotional response by increasing, maintaining or decreasing both positive and negative emotions towards a more desirable emotional state. Therefore, emotion regulation generates changes in the way individuals experience and express their emotions (Gross, 2014; Koole, 2009). Emotion regulation mobilizes down-regulation (i.e., restore a neutral baseline), maintenance (i.e., maintain a given emotional response over a more extended period of time) and up-regulation (i.e., increase the magnitude of a given emotional response) processes. However, emotion regulation does not always guarantee to reach the desired emotional state and may even have drawback effects (e.g., irrepressible laughing at funerals) (Koole, 2009). As emotion is a multicomponent phenomenon (involving cognitive, experiential, motivational, behavioral and physiological components), emotion regulation is intended to be observed across each of these components. Besides, emotion is also characterized by its intrinsic dimensions (e.g., valence, arousal, control). Accordingly, emotional regulation targets these different dimensions (Koole, 2009). This process can take place along a continuum from explicit, conscious, effortful and controlled attempt to control emotion (e.g., trying to lower one's anxiety before an exam) to implicit, unconscious, effortless and automatic regulation (Gross, 2014; Koole, 2009). Three factors come into play in an emotion regulation episode, which are the awareness of one's emotion and the context (bringing information about the need to regulated it), the activation of a regulatory goal (determining the form of the regulation; e.g., up or down-regulation), and the engagement of regulatory strategies (specifying the means to reach the goal) (Gross, 2014; Peña-Sarrionandia et al., 2015).

Individuals mobilize a host of implicit or explicit strategies, which refer to the concrete ways of managing their emotions. These strategies can be grouped along several criteria. According to Koole (2009), the first criterion that may be considered is the emotion-generating systems targeted by emotion regulation, such as attention, knowledge or bodily expressions. As attention highlights emotional responses, emotion regulation modulates attention to change emotional responses. Emotion regulation also targets emotion knowledge that emerges from cognitive appraisals or memory. Finally, emotion regulation also focuses on bodily manifestations that convey emotions (e.g., facial expressions). A second criterion that can be used to classify emotion regulation strategies is to consider the different functions they play or the goals they aim to achieve. Functions are independent of emotion-generating systems as a given psychological outcome can be obtained through the modulation of one or several of them. A first function (need-oriented or hedonic regulation)

consists of mobilizing emotional regulation to promote a fast return to an agreeable state following an aversive emotional state or to boost positive emotions. This process, mainly implicit and automatic, could help to preserve cognitive resources, overused to cope with negative states. However, hedonic regulation is not systematically suited. For example, individuals sometimes try to maintain some negative emotions to fulfill particular goals (goal-oriented or instrumental regulation). For example, video game players may downregulate a positive emotion (e.g., amusement) to stay focused on the game. In this case, emotion regulation responds to specific goals, and that regulation may imply going beyond basic hedonic needs. Besides, another function of emotion regulation is to facilitate personality functioning (person-oriented regulation) (see Kuhl, 2000, for more details). These different functions may align or conflict with one another. For example, emotion regulation regarding the fulfillment of a given goal can go against automatic hedonic regulation.

The Process model of emotion self-regulation The Process Model (Gross, 1998) distinguishes five different types of emotion regulation strategies referring to five ways to regulate a situation. These families of strategies are used at a micro-level (i.e., in the milliseconds or seconds following an emotion-eliciting event) and a macro-level (i.e., in the minutes, hours or days following the emotional situation) (Peña-Sarrionandia et al., 2015). (Figure 3.2). The first family of strategies is **sit-**

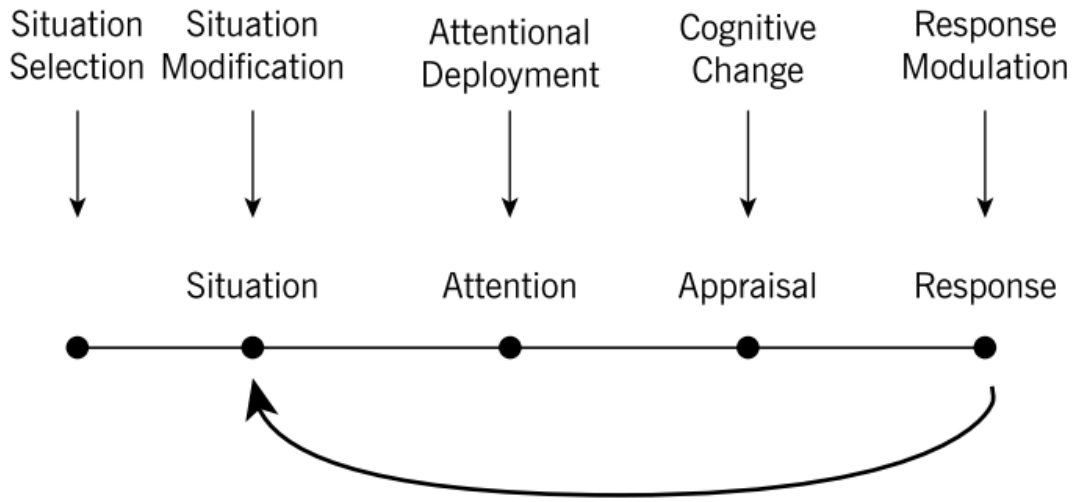

FIGURE 3.2: The process model of emotion self-regulation. Retrieved from Gross (1998)

uation selection. It consists of selecting situations that increase the likelihood of meeting relevant emotions. On a reciprocal basis, it also involves avoiding situations that increase the likelihood of irrelevant emotions. Situation selection is directed toward the future as it involves individuals to guess the course of their emotions if no action alters their default trajectory in a given situation (Gross, 2008).

Some examples are avoiding candy aisles not to feel guilty of having bought unhealthy food (avoidance) or prioritizing homework in order to avoid negative emotions coming from dull but necessary tasks (confrontation). The second family is **situation modification**. It refers to the modification of the external or physical environment to alter its emotional impact. Contrary to situation selection, changes are made within the situation. As an example, alleviate tension during a tough meeting or ask one's neighbor to turn the volume down are ways to anticipate the onset of negative emotions in situation. Examples of situation modification strategies are direct situation modification (i.e., taking direct action to change the situation), help-seeking (i.e., seeking assistance in changing the situation), and conflict resolution (i.e., finding a solution to a conflict causing negative emotions). The third family is **attentional deployment**. It is particularly suited when situation modification is not possible or desired (Gross, 2008). It involves directing one's attention toward or away from a given situation to influence one's emotions. Attentional deployment may take several forms. For example, distraction consists of moving one's attention away from the emotional situation or refocusing on non-emotional aspects. For example, individuals can alleviate boredom during some meetings by looking at their emails. Thought suppression refers to substitute negative thoughts or mental images to modify one's emotional state. For example, people can stop focusing on an upcoming stressful event by imagining themselves in a pleasant situation. Rumination is the opposite phenomenon that consists of focusing repetitively on the same specific feeling and its consequences (e.g., continually thinking about a traumatic event). It generally increases the intensity of emotions (Gross, 2008). The fourth family is **cognitive change**. It concerns the modification of how the situation is appraised to alter its emotional significance, and therefore the way we feel about it. It may refer to both the way individuals think about the situation or their ability to manage the situation demands (Gross, 2008). One major form of cognitive change is known as reappraisal, which consists of changing the meaning of an event to alter its emotional impact more positively or negatively. For example, a student can down-regulate positive feelings arising after receiving an A grade by considering that he/she does not deserve it. Other forms of reappraisal, such as distancing (i.e., adopting a third-person perspective regarding an emotional event) or using humor, can also help to up-regulate positive emotions and down-regulate negative emotions. Finally, the last family is called **response modulation**. It involves attempts to directly influencing experiential, behavioral, and physiological emotional responses. As depicted in Figure 3.2, it happens last in the emotion-generation process. A type of response modulation strategy is emotion sharing (e.g., call someone after having experienced a highly emotional situation). If emotion sharing does not allow individuals to foster emotional recovery, it is beneficial to mental health or social bonds. Another well-known response modulation is expressive suppression, which refers to inhibit unwanted emotional expressions. Expressive suppression would not change the emotional experience and may even increase sympathetic arousal,

as individuals try to suppress effortfully ongoing emotions. Expressive suppression is considered as a less adaptive emotion regulation strategy than cognitive reappraisal (Gross, 2008). Other responses modulation techniques are, for example, drug use (aiming mainly at altering negative emotional responses) or exercise (allowing individuals to down-regulate the physiological and experiential effects of negative emotions) (Gross & Thompson, 2007).

In academic settings, as in life, the capacity to manage one's emotions is thought to influence how students learn and solve problems (Boekaerts & Pekrun, 2015). For example, emotional regulation is related to higher problem-solving ability (Carlson & Bloom, 2005). However, little is known to date about emotion regulation in learning (Pekrun, 2012). In learning situations, emotion regulation can be defined as the "students' capacity to use their emotions as a source of energy, yet modify aspects of the emotional experience when it interferes with the pursuit of important goals" (Boekaerts & Pekrun, 2015, p. 83).

Boekaerts' dual processing model Boekaerts' dual processing model (Figure 3.3) proposes a dynamic model that highlights how emotions intervene in learning contexts and how they influence cognitions and actions, leading to different achievement and performance. It also explains how students regulate their emotions during learning tasks.

A major tenet of this model is that students experience, during learning, a dilemma between two main priorities, namely achieving learning gains (**growth or master pathway**) and safeguard their well-being (**well-being pathway**) (Boekaerts, 2007; Boekaerts and Pekrun, 2015). Therefore, students try to balance these two goals priorities. When getting into a learning activity, students forge a mental representation of the task-in-context according to three sources of information. The first source of information comes from the **current perceptions of the task and its context**. The second source relates to **domain-specific knowledge and meta(cognitive) strategies** related to the task. The third source refers to **domain-specific motivational beliefs** about self-ability, interest, effort, etc. These different sources of information are activated in working memory (WM) when students get into the learning task and represent the proximal determinants of prospective academic emotions as well as learning or coping intentions. When this representation matches their own goals, needs and aspirations, students experience positive cognitions and emotions that encourage them to commit to the task. In this case, they activate cognitive and metacognitive strategies aiming at broadening knowledge and competence (learning intentions in the growth pathway). However, when this representation goes against students' well-being, negative cognitions and emotions emerge that encourage students to activate strategies aiming at safeguarding their well-being (coping intentions in the well-being pathway). In addition, these evaluations occur throughout the task, and initial representations may change. For example,

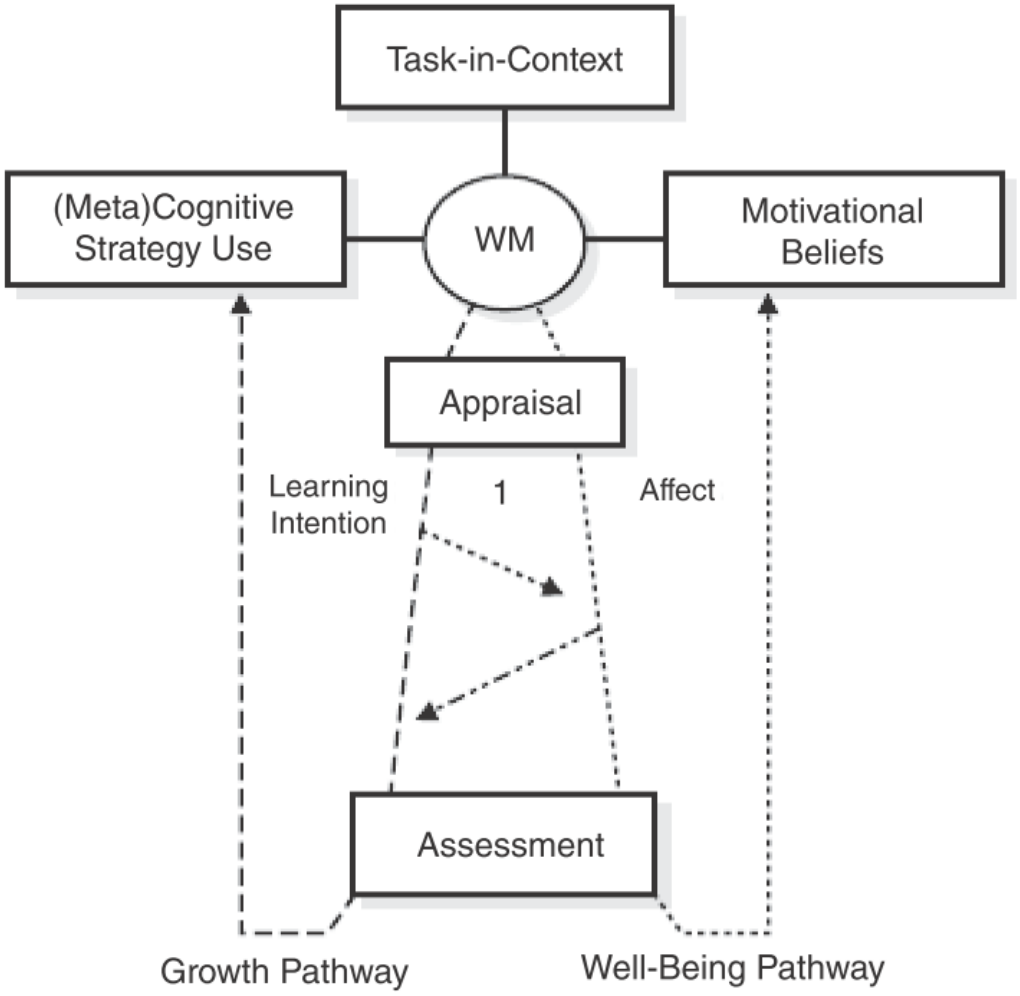

FIGURE 3.3: The dual processing model. Retrieved from Boekaerts (2011)

threats to well-being may appear, such as poor self-efficacy, negative outcomes expectations, reduced interest, and lead to the emergence of negative emotions (e.g., worry, anticipated embarrassment, disappointment, sadness, irritation, boredom, hopelessness). In contrast, positive cues such as high self-efficacy, positive outcomes expectations, increased interest can trigger hopefulness, satisfaction or anticipated pride (Boekaerts, 2007, 2011).

In summary, emotions need to be adequately appraised, monitored and controlled by individuals to foster their beneficial effects and prevent their detrimental effects on collaborative problem-solving. Emotional intelligence encompasses different emotional competencies (perception and expression of emotions, assimilating emotions in thought, understanding and analyzing emotions and reflective regulation of emotions) underlying the capacity of individuals to manage emotions in context constructively. More specifically, the regulation of emotions includes different processes allowing to make an offset correction of an occurred or anticipated emotional response (situation selection, situation modification, attentional deployment, cognitive change and response modulation) (Gross, 1998). Boekaerts' dual processing model (Boekaerts, 2007) describes how emotions inform learners regarding positive or negative events and trigger strategies dedicated to balancing both well-being and learning intentions.

3.3 Emotions at the interpersonal level

In section 3.2, we have focused on how emotional processes impact individuals. Early studies about emotions focused mainly on intrapersonal functions of emotions, investigating how emotions influence one's own cognition, motivation and behavior, without considering the social aspects of them. However, numerous studies carried out during the past 30 years have since highlighted the necessity to consider emotions from an interpersonal point of view. In this section, different contributions, models and theories regarding how emotions intervene in groups will be addressed.

3.3.1 Socio-emotional processes

3.3.1.1 Social functions of emotions

Social functions of emotions can be defined as the socio-relational goals inherent to a given emotion, involving specific appraisal and action tendencies. A core idea of the functionality of emotions is that they increase individuals' chances of survival and reproduction. However, several authors have also emphasized a social functional approach (Fischer, Manstead, et al., 2016; Keltner & Haidt, 1999) regarding the role of emotions. As humans are social creatures, survival also implies social survival, i.e., the capacity to build social bonds and to overcome social problems (e.g., dealing with injustice, maintaining relationships, negotiating status hierarchies). However, social survival does not only imply cooperation and affiliation. Social survival also requires distancing from others in order to reach goals. For this reason, people both affiliate with others and competing against others. According to Fischer, Manstead,

et al. (2016), **affiliation function** refers to forming and maintaining positive relationships. For example, an emotion such as admiration has a social function of sharing positive experiences with or communicating positive experience to others. On the other hand, **social distancing function** concerns the establishment or maintenance of social position, preservation of self-esteem or identity, and demonstration of power, sometimes at the expense of others. For example, an emotion such as anger has a social function of confrontation, attacking or criticizing. The social function of an emotion is not entirely related to its positive or negative valence. For example, some negative emotions can have an affiliation function. It is the case of shame, having the social function of acknowledging one's faults. Some positive emotions can also have a social distancing function, such as pride, which signals a higher status. Furthermore, the same emotion can serve both affiliation and social distancing function according to the context. For example, pride related to oneself mainly serves the social distancing function, whereas pride directed toward the group serves the affiliation function. However, the fact that emotions have social functions does not mean that emotions are always functional. Indeed, the social function of emotion must be differentiated from the social effects or consequences of emotions. The social effects of emotions are tight to the way emotions are expressed in a given group. They are concrete and context-specific. For example, scolding a friend because she is late does not have the same effects as reprimanding one's supervisor for the same reason. Therefore, social dysfunctionality can occur when individuals do not appraise the situation correctly, do not take into account the social consequences of the emotion, or when social functions of emotions confront each other at different levels. For example, an emotion such as love can have detrimental effects when inappropriate in some circumstances.

Keltner and Haidt (1999) describe the social functions of emotions across different levels. At the personal level, the conscious feeling of emotions informs individuals about social matters that need to be dealt with and prepares them to respond to these social matters. For example, love informs individuals about their level of commitment to another person. At the interpersonal level, emotions help to draw the other's attention implicitly and explicitly on interpersonal matters. In this way, it helps to understand the other's emotions, beliefs or intentions and organize the interactions by triggering coordination. According to Fischer, Manstead, et al. (2016), all kinds of social relationships have a tone involving a certain degree of emotion. The number and type of emotions expressed indicate the nature of the relationships as well as their strength. For example, love affairs show more intense emotions related to intimacy (e.g., closeness and harmony) than work relationships. In general, the more the level of intimacy is, the more the number of expressed emotions increases. The suppression of emotional expressions may be dysfunctional both in intimate and stranger relationships as it decreases the perception of rapport between individuals and eventually worsens long-term relationships. In general, the expression of

positive emotions promotes stabler and more long-term relationships. The expression of some negative emotions also promotes social bonds in allowing senders to give valuable information to others through their emotional state (e.g., fear signals a danger situation). They can also promote support from others (e.g., distress elicits help) (Van Kleef, 2009). Finally, some negative emotions elicit affiliative behaviors from the sender as a way to repair social bonds in promoting apologize, submission, or concessions from others (e.g., guilt motivates efforts to make amends). At the group level, emotions help to make and unmake groups. For example, the induction of some emotions (e.g., the fear of death) has been shown to increase ingroup solidarity and outgroup rejection. Moreover, inside groups, negative emotions also regulate roles and social statuses (e.g., shame mark lower status).

3.3.1.2 Social sharing of emotions

As we have seen in the previous section, emotions have social functions, which can be separated into affiliation and social distancing functions. At the interpersonal level, the explicit sharing of emotions is a critical aspect of the social function of emotions. Rimé (2009) focuses mainly on the affiliation function in describing the social sharing of emotions. For this author, people have a natural need to share their emotional experiences (see also Van Kleef & Fischer, 2016). In this sense, emotions are an essential trigger of social communication and verbal exchanges through the social sharing of emotions.

The social sharing of emotions can be defined as a "process that entails a description of the emotional event in a socially shared-language by the person who experienced it to another" (Rimé, 2009, p. 65). This process can take place both in synchronous or asynchronous settings (e.g., letters or diaries). Findings show that almost all the emotions (positive or negative) are socially shared. This process generally occurs early, on a recurring basis, and proportionally to the intensity of the emotion-elicited event. Emotional valence does not influence the proportion of sharing (fear is shared as often as happiness) with the only exceptions of shame and guilt. However, it is preferentially addressed to intimates (i.e., parents, brothers, sisters, friends, or spouse/partner), whereas non-intimates hardly share emotions (Rimé, 2009). Although the social sharing of emotions appears to be a strong component of the emotional experience, some circumstances sometimes prevent its occurrence. As mentioned above, people who experience shame or guilt often refrain from sharing these emotions, probably because it would provoke fear of rejection. People who receive little attention to their emotions in their social environment also share fewer emotions. Finally, extremely intense emotions, as in the case of traumatic events, can also stay unuttered.

Different motives for socially sharing emotions have been identified and classified into eleven different categories (Rimé, 2009) (Table 3.3). In general, positive emotional experiences are shared to leverage their positive impacts. By sharing positive

Classes of motives	*Typical members of the class*
Rehearsing	Reminding, re-experiencing, remembering
Venting	Expressing, looking for relief, letting off steam, alleviating, looking for catharsis
Help and support	Obtaining comfort, support, sympathy, help, receiving comprehension, being listened to
Comfort/consolation	Receiving consolation, receiving comfort
Legitimization, validation	Being legitimized, approved, understood
Clarification and meaning	Finding understanding, finding explanation, clarification, meaning
Advice and solutions	Obtaining advice, feedback, guidance, receiving the perspective of another person, receiving advice, finding solutions, suggestions
Bonding, strengthening social ties	Being in touch, relating, escaping loneliness or the feeling of abandonment, strengthening social ties, decreasing interpersonal distance, feeling closer to others
Arousing empathy	Touching/moving others, affecting the target, moving the listener
Gaining attention	Receiving attention, eliciting interest, impressing others, distinguishing oneself
Entertaining	"Lubricating" social interactions

TABLE 3.3: Motives for socially sharing emotions. Retrieved from Rimé (2009)

emotions to others, people seek another new opportunity to savor and even revive a positive emotional experience. On top of that, sharing positive emotions, when it triggers an enthusiastic response from the listener, is assumed to reinforce intimacy and enhance social bonds within individuals. Conversely, negative emotions arising from goal impediments have a destabilization effect, undermining self-confidence and self-beliefs about efficacy or esteem. However, although feeling negative emotions is painful, people are generally eager to share them. Indeed, negative emotions are assumed to promote social exchanges as distress generates socio-affective needs. Sharing negative emotions in these situations would bring relief and help to buffer emotional distress. However, the literature suggests that emotional sharing would not liken emotional recovery (catharsis effect). If the social sharing of emotions temporarily alleviates the affective burden, emotional recovery also requires cognitive work (e.g., abandon of the frustrated goal, reappraisal). This cognitive work would hardly be promoted through emotional sharing, at least in the early times following the emotional experience. This aspect could explain why the social sharing of emotions is likely to be repeated as long as it takes the form of socio-affective elicitation and does not imply cognitive-oriented aspects. However, this cognitive orientation should not be possible just following intense emotional distress, which suggests that a specific timing for the onset of the socio-affective and cognitive modes should exist (Rimé, 2009).

If people have a natural tendency to share their emotions, there have also a natural tendency to pay special attention to others' emotions. Emotional responses give rise to an interpersonal dynamics between emitters and receivers (Figure 3.4) . Firstly, the receiver experiences interest in the other's emotions. This interest plays an enhancing role for the emitter who share more emotions. As the intensity of emotion sharing increases, the receiver experiences a similar emotional pattern to that of the emitter through emotional contagion. This creates an emotional communion that promotes a feeling of unity, empathy, and perceived similarity. In the case of negative emotions, empathy triggers a willingness to help that take form through prosocial behaviors. As a result, the receiver experience more affection for the emitter.

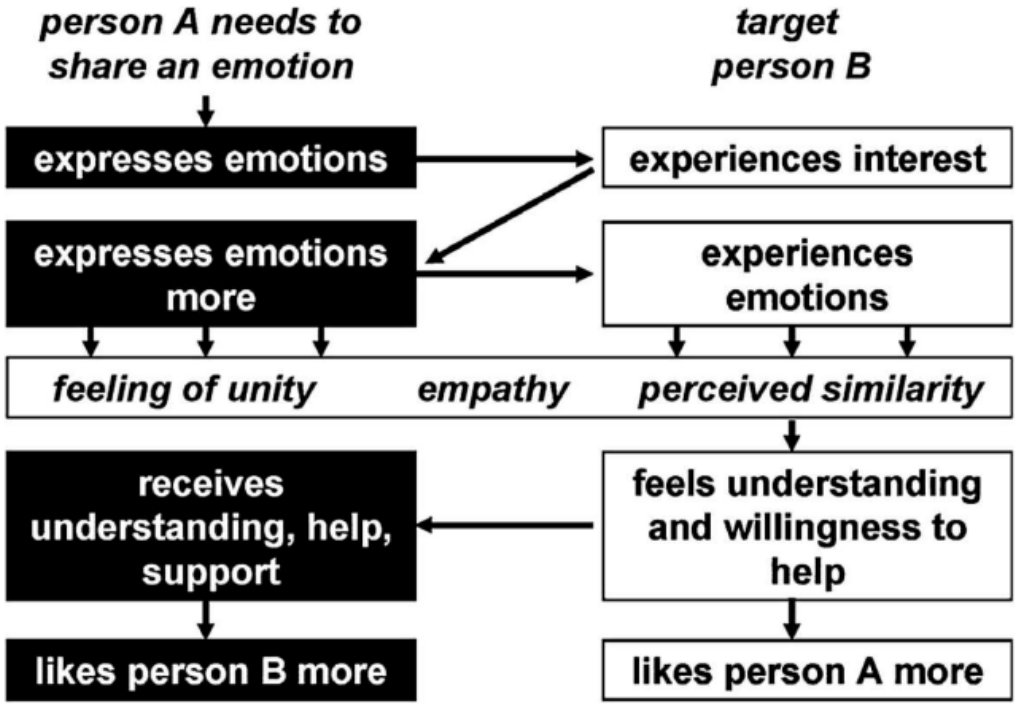

FIGURE 3.4: Dynamics of social sharing. Retrieved from Rimé (2009)

As the emitter receives understanding and help, the emitter also appreciates the receiver more. This dynamics is posited to bolster social bonds and reinforce intimacy within individuals.

3.3.1.3 Collective emotions

Research has also studied what is classically called collective emotions (Goldenberg et al., 2020). If the term collective emotions can be confusing as it may give the impression that a single emotion exists outside of each individual's minds, it actually refers to various co-modulating effects occurring when individuals interacting together experience emotions. Goldenberg et al. (2020) underline three emerging properties of collective emotions. First, emotions of each other's tend to become either more similar or more polarized (i.e., change of quality). Second, emotions tend to increase in intensity with others. Third, emotion tends to last longer, especially because individuals tend to re-activate each other's emotions across time.

3.3.1.4 EASI model

Van Kleef (2009, 2010) proposed a model (Figure 3.5) that unifies several findings in the role of emotions at the interpersonal level. The EASI model builds on research regarding emotion in a social functional perspective. Contrary to Rimé (2009), this author focuses on both explicit and implicit expressions of emotions. He also highlights the fact that emotional expression serves affiliation as well as social distancing

(Fischer, Manstead, et al., 2016). It highlights that verbal and non-verbal expressions of emotions convey social information to observers, which in turn affect their behavior. In other words, people observe the emotional expressions of others and are influenced by them. This process takes place consciously but also unconsciously.

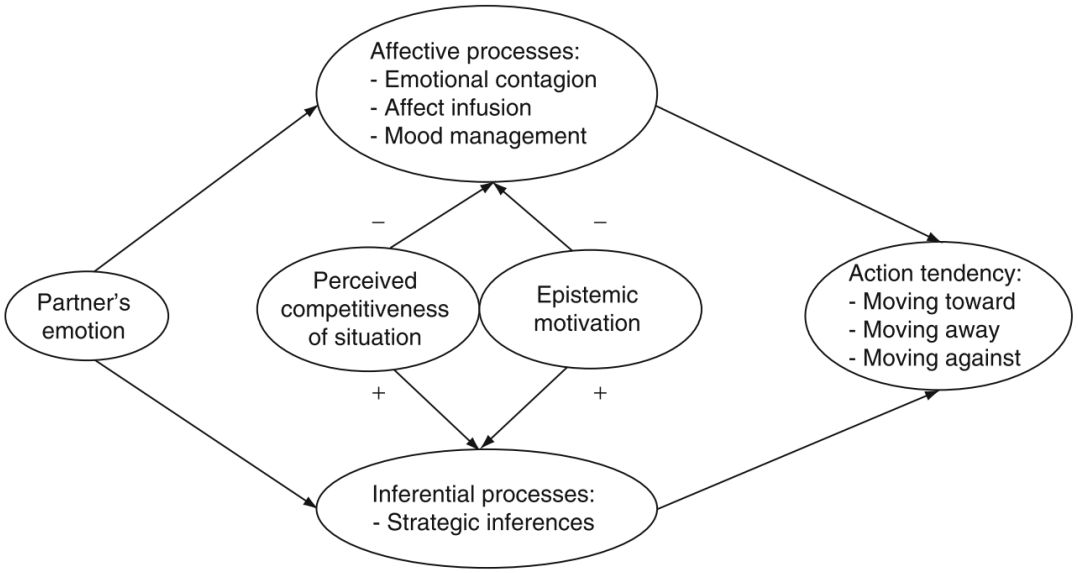

FIGURE 3.5: EASI model. Retrieved from Van Kleef, De Dreu, & Manstead (2010)

According to the model, two core processes are mobilized when people come across emotional expressions. Firstly, emotional expression triggers **inferential processes**. Individuals use emotional expressions as cues allowing them to infer social information. This social information can naturally concern the subjective feeling of the emoter but not only. Emotional expressions also help the observer to understand the status of the interpersonal interaction more deeply. These inferences may relate to the relational orientation (e.g., openness), attitudes (e.g., motivational disposition), and behavioral intentions. Consequently, the observer regulates their behavior accordingly. For example, anger expression leads to infer that the observer has done something wrong and may elicit apologizing behavior. Conversely, an expression of happiness is a signal that things are going well for the emoter, which may make possible cooperative behaviors. On a reciprocal basis, expressing emotions is also a way to elicit a desired behavior from the observer. For example, in negotiation settings, expressing anger involves more concessions from the other party than expressing happiness (Van Kleef, 2009). Secondly, emotional expressions elicit **affective reactions** in observers. First, emotional expressions involve **emotional contagion**, i.e., "the tendency to unintentionally and automatically "catch" other people's emotions through their facial expression, vocalizations, posture or bodily movements" (Van Kleef et al., 2010, p. 54). For example, negotiators than express anger tend to elicit anger from their counterparts (Van Kleef, 2009). According to Van Kleef et al. (2010), emotional contagion can pervade the observer's judgment through different types of affect infusion. Individuals would tend to use a "how I feel about it" heuristic to

infer the general tone of the interpersonal situation. For example, if positive feelings arise from the other's emotional expression, the observer is likely to assume that the situation is safe and exploration is possible (see Broaden-and-Build theory, Fredrickson, 2013). Futhermore, emotion experienced through emotional contagion can also last and shape the observer's personal mindset through the creation of mood (mood management). People observing and feeling negative mood in return are likely to exhibit behaviors that relieve this feeling (e.g., helping others), whereas people who see and experience positive mood are willing to avoid strenuous activities that could spoil this interpersonal feeling (Van Kleef et al., 2010). Second, apart from emotion contagion, affective reactions generated in the observer may also affect the **building of impressions** regarding the emoter (e.g., personal liking). For example, employees form a more favorable impression of a happy leader than a stingy one (Van Kleef, 2009). Inferential processes and affective reactions can converge, oppose or influence each other. First, these two modes can converge each other when emotional expression leads the observer to make inferences (e.g., she is confused) and elicit feelings (e.g., I feel empathy) that both provoke the same kind of behavior (e.g., give help). Second, they can oppose each other when emotional expression lead the observer to feel a similar emotion that the emoter (e.g., I am angry because she looks angry to me) but make inferences (e.g., she is angry because she feels overwhelmed) that could provoke opposite behavior (e.g., support or fight). Finally, these two modes can influence each other when inferential processes themselves generate affective reactions (e.g., I think she is angry because she is disappointed by me, I feel shameful) (Van Kleef, 2009; Van Kleef et al., 2010).

The authors also assume that the motivation to process emotional expression predicts the resulting social decisions. Therefore, strategic inferences are more predictive of social decisions in competitive situations because observers would be more eager to analyze the meaning of their counterparts' emotional expressions. In addition, affective reactions such as emotional contagion are less present in this case. In contrast, affective reactions are more predictive of social decisions when the situation is perceived as cooperative because this motivation is reduced. Therefore, the perceived competitive or collaborative tone of the situation appears to be an essential determinant influencing the observer's reaction to emotional expressions. Depending on the type of situation (cooperative vs. competitive) and the type of emotional expression, different actions tendencies appear more or less prevalent (Table 3.4) (Van Kleef et al., 2010). **Moving toward** refers to cooperative actions such as negotiate, make cooperative decisions, promote equity. **Moving away** implies non-cooperative behaviors such as interaction avoidance, emotional suppression, passivity. **Moving against** includes confrontation behaviors such as refusal to make concessions, refusal to coordinate, threatening postures.

Finally, as emotion is seen as information, the model assumes that the effects of emotional expressions are proportional to the thoroughness of the observer's processing.

		Dominant action tendencies and associated behavior	
Emotion	Social signal	*Cooperative setting*	*Competitive setting*
Happiness, joy, contentment	Opportunity, affiliation	Move toward => Increased cooperation	Move against => Increased competition
Anger, frustration, irritation	Dominance, aggression	Move against/away => Reduced cooperation/inaction	Move toward/away => Increased cooperation/inaction
Sadness, distress, disappointment, worry	Supplication	Move toward => Increased cooperation	Move away/against => Inaction/increased competition
Guilt, regret, embarrassment	Appeasement	Move away/toward => Inaction/reduced competition	Move against => Increased competition

TABLE 3.4: Social signals of emotions in cooperative versus competitive settings. Retrieved from Van Kleef, De Dreu, & Manstead (2010)

According to the authors, this processing depends mainly on the individual's epistemic motivation, i.e., "his or her willingness to expend effort to achieve a rich and accurate understanding of the world, including interdependent others" (Van Kleef et al., 2010, p. 62). Cognitive styles influence epistemic motivation, which is more frequent in individuals exhibiting higher need to engage and enjoy "brainy" activities, lower need for definite conclusions and structure and openness to experience. In addition, a host of situational constraints can also influence epistemic motivation such as cognitive load, noise, time pressure, fatigue, social power differences are posited to alter how much the observer processes emotion information. For example, people who feel in power over someone are less motivated to understand others' emotional suffering. Competitive situations are also more likely to enhance epistemic motivation than cooperative ones (Van Kleef, 2009; Van Kleef et al., 2010).

3.3.1.5 Kelly and Barsade's model

Kelly and Barsade's model (Figure 3.6) provides an integrated representation of the impact of emotions in goal-oriented activities. It describes how individuals' emotions (from diffuse moods to intense emotions) and contextual factors operate in such a context to forge group emotion.

First, the model highlights some individual factors which intervene as initial inputs of the group's affective experience. The authors point out five of these factors, namely dispositional affect, mood, acute emotions, sentiments, and emotional intelligence. **Dispositional affect** represents an affective personality trait and its behavioral tendencies that people tend to exhibit in stable and predictable ways (e.g., a person who has low frustration tolerance can have a heated argument with someone more quickly). **Mood** is a diffuse and long-lasting state where some subjective feelings predominate in mind, without apparent causes. **Emotion** is a strong and short-lasting affective reaction to a clear cause or object. **Sentiment** refers here to a valence evaluation of whether something is liked or disliked and is quite similar to what Scherer (2005) calls preferences. Finally, **emotional intelligence** refers to the four competencies highlighted by Mayer et al. (2011) in their Four-Branch model (see section 3.2.3), namely the ability to perceive and express emotions, to harness emotions to promote thinking, to understand and analyze emotions and to regulate

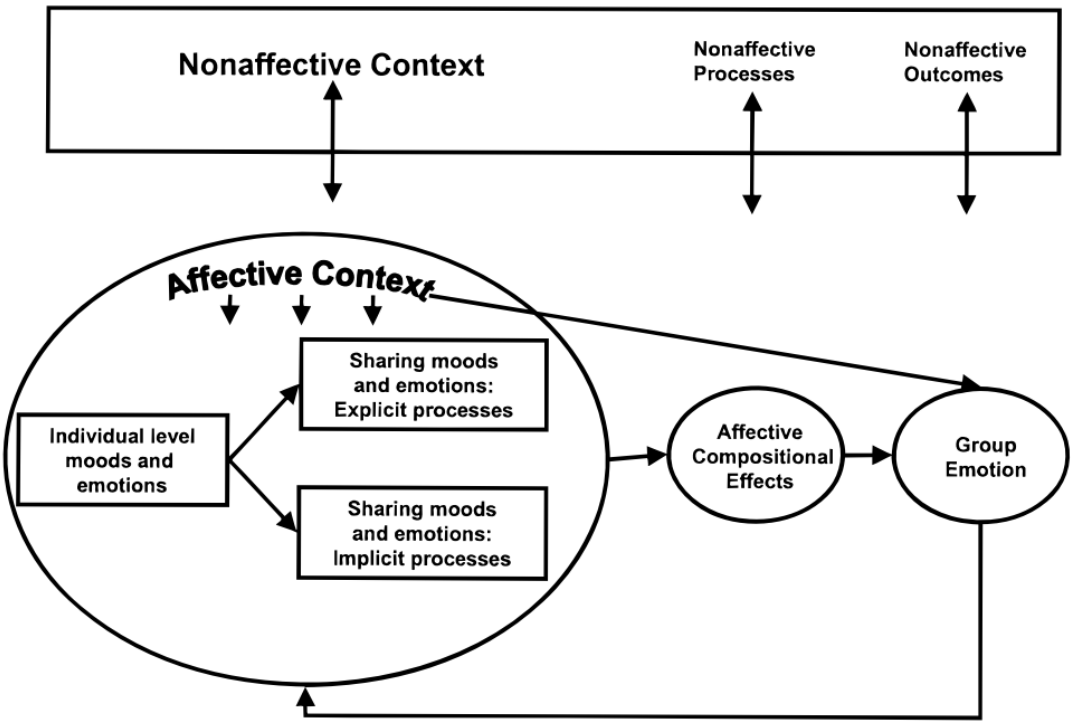

FIGURE 3.6: Kelly and Barsade's model. Retrieved from Kelly and Barsade (2001)

emotions. The authors propose that these individual affective experiences are shared among group members to shape the affective composition of the group through implicit and explicit processes. **Implicit processes** are subconscious processes where individuals are not necessarily aware of the dissemination of affect and their consequences on the group. These processes are close to the incidental modulation of the group through emotions referred to as interpersonal emotion modulation (Zaki & Williams, 2013). They encompass emotional contagion, automatic vicarious effect such as empathy and emotional synchrony, i.e., the coordination of affect and attitudes between interacting partners. **Explicit processes** are conscious processes. These kinds of processes involve that people actively attempt to influence others' emotions. They are close to what is referred to as interpersonal emotion regulation (Niven, 2017; Zaki & Williams, 2013). These aspects will be developed in more detail in section 3.3.2. The model underlines that the sharing of affect by each of the group members through implicit and explicit processes creates a group affective tone. Notably, the authors describe the affective mean, which represents the average affective tonality (positive or negative) of the group. **Affective mean** would influence several work outcomes such as group spontaneity or absenteeism behaviors or group performance. Second, besides individual factors, the model also emphasizes contextual factors regarding affect that intervene in groups. These factors mainly relate to implicit or explicit group norms, such as display rules (i.e., shared expectations about which emotions ought to be expressed or hidden) or feeling rules (i.e., expectations about what emotions ought to be experienced). Throughout the interactions, groups also construct emotional history. This emotional history, whether it is more positive

or negative, can reinforce group dynamics beneficially or detrimentally. The combination of individual (bottom-up) and contextual (top-down) factors create group emotion. It refers to a shared experience of affect within the group. The authors emphasize the reality of this shared perception as it is phenomenologically experienced as real by group members. Furthermore, group emotions (shared anger, stress or euphoria) can strongly influence the group's future affective and non-affective behaviors (emotional sharing, cooperation).

Finally, Kelly and Barsade's model also describe the interrelationships that take place between the affective afore-mentionned and some non-affective factors. For example, intergroup context, i.e., the relationship between the group its surrounding, especially other groups can have an influence on group emotion. Thus, **intergroup conflict** can shape intragroup emotions (e.g., hostility toward the other group in question or in-group favoristism and the emotions that accompany such phenomena). On the other hand, intragroup emotions can modulate intergroup behaviors (e.g., anger and anxiety could lead to more extreme out-group evaluations). Another non-affective factors, the **physical context** is also reported to modulate group emotion. For example, noisy environment could trigger more negative affect. Finally, the study of technological conditions have revealed how they can influence emotional variables. For example, computer-mediated interaction offers less richness regarding non-verbal signals than face-to-face setttings (Stewart et al., 2019). This aspect could influence the way people interact to provide the missing cues need for the emotional experience of the group (e.g., more emotional verbalization, use of emoticons, etc.).

In summary, emotions impact not only intrapersonal processes but also have social functions in collaborative problem-solving. Emotions can serve both affiliation and social distancing functions (Fischer, Manstead, et al., 2016). They also inform individuals about social matters such as the nature and the strength of relationships (Keltner & Haidt, 1999). Rimé (2009) described how individuals use the social sharing of emotions to meet different affiliative motives with others, such as seeking support or receiving advice. Van Kleef et al. (2010) pointed out that different emotions trigger different approach, avoidance or confrontation behaviors in cooperative and competitive settings. Finally, Kelly and Barsade's model (Kelly & Barsade, 2001) highlights how the sharing of emotions through implicit and explicit processes can create a shared experience of emotions in the group.

3.3.2 Socio-meta-emotional processes

Individuals do not always regulate emotions alone. On the contrary, there is a continuum between intra and interpersonal emotion regulation (Zaki & Williams, 2013)

and people can also regulate their emotions through others. On the other hand, people also attempt to regulate others' emotions. These two processes fall in what is called interpersonal emotional regulation, which refers both to the attempt to initiate, maintain, modulate, or change one's own emotions through someone else (intrinsic interpersonal regulation) and someone else's emotions (extrinsic interpersonal regulation) (Fischer, Manstead, et al., 2016; Niven et al., 2011; Zaki & Williams, 2013). It is directed toward a goal, with the aim to be socially functional, i.e., helping to maintain closeness and cooperation as well as separation and distance when needed (Fischer, Manstead, et al., 2016; Zaki & Williams, 2013). It is also a deliberate process that involves explicit attempts to influence emotions. For this reason, it is a resource-consuming process that can deplete self-regulation performance and provoke emotional exhaustion (Niven, 2016; 2017). However, according to Niven (2017), some forms of interpersonal emotion regulation are more depleting than others. For example, worsening other's emotions is more demanding than improving other's emotions. As a deliberate phenomenon driven by a goal in order to alter one's own or other's emotional states, it should be distinguished from incidental modulation of social interaction through emotions (e.g., emotion contagion), which can be called interpersonal emotion modulation (Zaki & Williams, 2013). Zaki and Williams (2013) have defined a framework (Figure 3.7) clarifying some distinctive characteristics that make it possible to unify various phenomena falling within interpersonal emotional regulation (e.g., emotion sharing, attenuation of negative emotions in the presence of others, motivation to change other's emotional states).

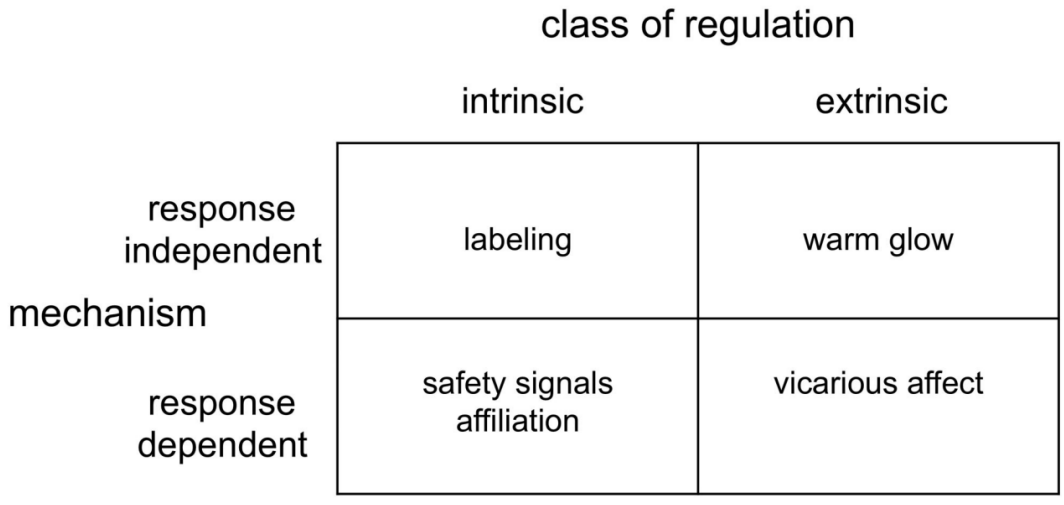

FIGURE 3.7: The different types of interpersonal emotion regulation. Retrieved from Zaki and Williams (2013)

These authors highlight four types of interpersonal emotion regulation based on these two criteria. **Intrinsic and response-dependent** regulation aims at triggering safety signals from others when confronting to threatening experience. It can also

serve affiliation or distancing functions due to the sharing of experiences and opinions with others. **Intrinsic and response-independent** regulation can be found, for example, when people label their own emotions in the presence of others in order to refine the causes and consequences of their own emotional state. **Extrinsic and response-dependent** regulation can be represented by what is called vicarious effect. In this case, people can, for example, experience a reduction of their negative emotions after having reduced successfully someone's else negative emotions. Finally, **extrinsic and response-independent** regulation is about seeking personal effects from interpersonal emotion regulation irrespective of consequences for others (e.g., warm glow).

Niven (2016) has highlighted eight types of motives that underlie interpersonal emotion regulation. She drew on the three innate and universal needs emphasized in the self-determination theory (Deci & Ryan, 2002), namely autonomy, competence and relatedness (see section 2.2.3.1). Autonomy is high when regulation is internally motivated. In this case, individuals feel themselves to be the cause of their attempts to regulate others. On the contrary, low autonomy leads individuals to feel that regulation is externally motivated, i.e., imposed on themselves by an external person or force. Relatedness is high when the act of regulation aims at forming attachments with others, i.e., prosocial. In contrast, relatedness is low when regulation follows egoistic motives. Competence is high when regulation is concerned with achieving performance-oriented goals. Conversely, low competence reflects pleasure-oriented goals. Every attempt to regulate other's emotions can be derived from the level of these needs in combination. In this way, high and low autonomy, relatedness and competence reveal eight prototypical motives for interpersonal emotion regulation.

Coaching motives show a high level of autonomy, relatedness and performance. The higher-order goal is to promote other's performance. In this case, people try without external constraints and selflessly to regulate other's emotions to help them perform better (e.g., a father trying to improve his son's emotions when doing homework). **Compassion motives** show a high level of autonomy and relatedness and a low need for competence. The higher-order goal is here to promote other's well-being. In this case, people try without external constraints and selflessly to regulate other's emotions to help them to feel better (e.g., a girl trying to improve her friend's emotions after a failed love affair). **Instrumentality motives** show a high level of autonomy, a high level of competence, and a low level of relatedness. The higher-order goal is to promote one's own performance. In this case, people try without external constraints to regulate other's emotions to improve their own performance (e.g., a boss trying to improve team members' emotions to make them work harder). **Hedonism motives** show a high level of autonomy and a low level of relatedness and competence. The higher-order goal is to promote one's personal well-being. In this case, people try without external constraints to regulate other's emotions to improve

their own well-being (e.g., a person making his or her enemy feels worse to get satisfaction from it). **Emotional labor motives** show a low level of autonomy and a high level of relatedness and competence. The higher-order goal is to promote organizational performance. In this case, people try with external constraints and selflessly to regulate other's emotions to help them to perform better (e.g., an employee dampening her colleague's emotions to make her more focused on the boss's instructions). **Conformity motives** show a low level of autonomy and competence and a high level of relatedness. The higher-order goal is to promote the smooth running of social situations. In this case, people try with external constraints and selflessly to regulate others' emotions to help them to behave according to informal social scripts (e.g., an employee improving the emotions of a colleague she does not like to promote group cohesion). **Impression management motives** show a low level of autonomy and relatedness and a high need for competence. The higher-order goal is to promote a professional plan or reputation. In this case, people try with external constraints but selfishly to regulate others' emotions to comply with the norms of their professional role (e.g., a colleague improving his colleague's emotions to project the image of a good coworker). Finally, **identity construction motives** show a low level of autonomy, relatedness and competence. The higher-order goal is to promote a sense of self. In this case, people try with external constraints but selfishly to regulate other's emotions to forge their own identity (e.g., an employee improving others' emotions to be seen as the colleague who set the mood).

Interpersonal emotion regulation has socio-relational and socio-cognitive implications. Some benefits have been highlighted when it is used appropriately, such as facilitating the formation of new relationships or improving the quality of existing ones (e.g., building trust between coworkers) or improving group performance (Niven, 2017; Niven et al., 2011).

In summary, despite their social functions, emotions are not always functional. Therefore, they can have detrimental effects on collaborative problem-solving when they are not appropriately appraised, monitored and controlled at the interpersonal level. Individuals regulate both their own emotions through others and others' emotions (Zaki & Williams, 2013). This process can be implicit (e.g. emotional contagion) or explicit (e.g., communication of emotion). Niven (2016) described eight different explicit self-interested or other-interested motives of interpersonal emotional regulation (coaching, instrumentality, hedonism, emotional labor, conformity, impression management and identity construction).

3.4 Emotional processes in the three-level model of collaborative problem-solving

In chapter 2.4, we have proposed a new model[1] addressing collaborative problem-solving into an integrative representation at three levels. In this chapter, we have highlighted the pervasive role of emotional states, not only in relation to the socio-relational but also the socio-cognitive and socio-motivational aspects of group interaction. In this section, we describe how these research contributions can be integrated to this model (Figure 3.8).

In the collaborative problem-solving field, emotional processes are often assimilated to the relational aspects of the collaboration (e.g., Baker et al., 2013). This is even more pregnant when non-cognitive aspects of collaboration are referred to as the socio-emotional or affective space of collaboration (Isohätälä et al., 2019). If the role of emotions in the relational aspects of the collaboration is undeniable, we argue that emotions have a pervasive role in every aspect of the collaborative problem-solving, at both the personal and interpersonal levels, not only in the relational but also in the cognitive and motivational dimensions of collaborative problem-solving. Therefore, there is a need to describe more accurately how emotions impact these different dimensions differentially to gain a better understanding of their various impacts on collaborative problem-solving.

3.4.1 Emotions and individual processing (E1)

Pekrun and Linnenbrink-Garcia (2012) have proposed to distinguish different types of emotions occurring in different spheres of academic activity. They are referred to as academic emotions (Pekrun, 2006). At the cognitive level, two main types of academic emotions can be distinguished. The first type is called epistemic emotions. They "have as an object focus the knowledge-generating aspects of learning that arise as a result of cognitive and epistemic qualities of information and the processing of that information" (Chevrier et al., 2019, pp. 2-3). On the one hand, problem-solving can trigger cognitive disequilibrium or impasses in individuals that may trigger emotions such as confusion or frustration. On the other hand, when cognitive processing appears straightforward, group members can experience a feeling of flow. Furthermore, surprise can also emerge when group members experience cognitive novelty (D'Mello & Graesser, 2012). Second, topic emotions (Pekrun et al., 2002) can also arise in response to the contents of the problem-solving task (e.g., sadness about violence at school when designing a slogan about this topic).

At the motivational level, emotions can emerge from the monitoring of the different components of motivation as well as the psychological and effort costs associated with the task (Miele & Scholer, 2018). They signal the presence or resolution

[1] *Avry, S. (2020). A three-level model of collaborative problem-solving. Manuscript submitted for publication in Educational Psychologist.*

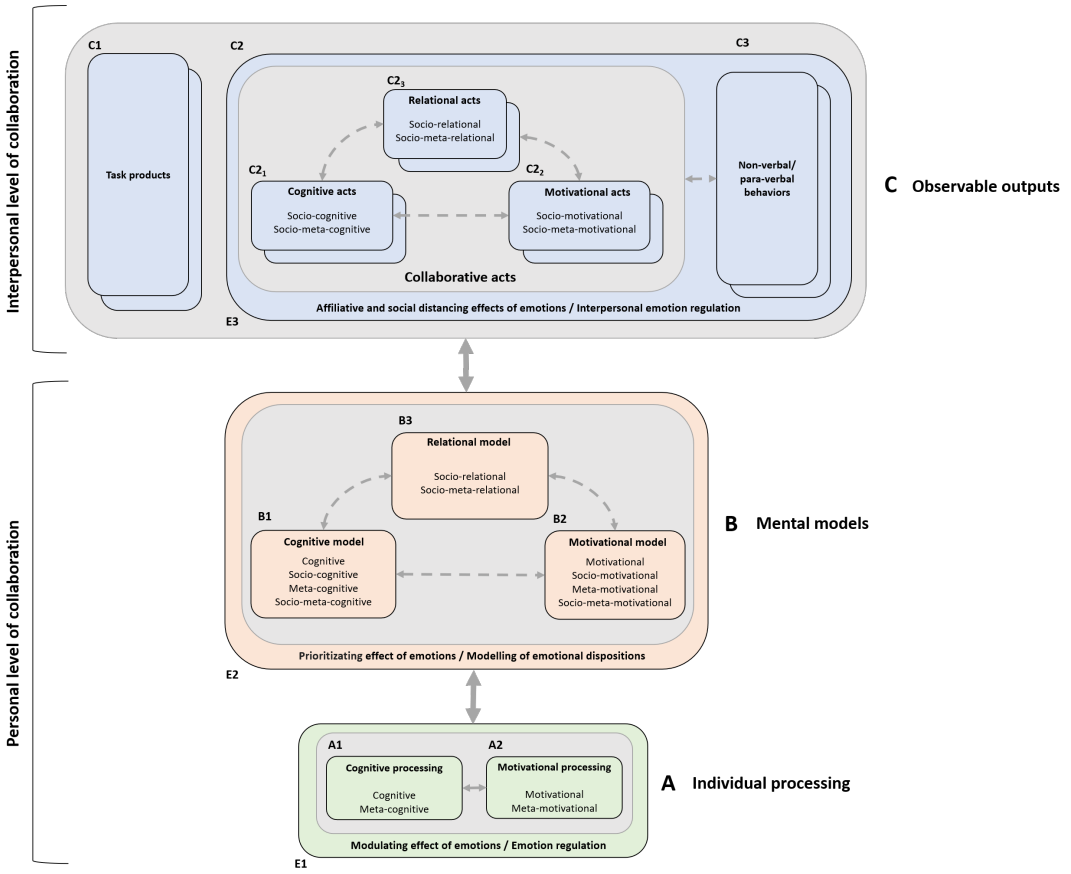

FIGURE 3.8: Emotional processes in the three-level model of collaborative problem-solving

of motivational concerns. Some feelings are associated with reduced motivation. They are generally deactivating and signal a desire to disengage from the activity (e.g., low intrinsic value is associated with boredom). Some others are associated with a motivational increase (e.g., feeling of interest or enjoyment). Finally, in goal-directed activities, a kind of emotion is at the convergence of cognitive and motivational dimensions. They relate to how group members perceive their own and group achievement. Achievement emotions involve both cognitive and motivational appraisals of the situation. Pekrun (2006) proposes that achievement emotions emerge from the perceived value of actions and accomplished outcomes and perceived control regarding actions and outcomes. Perceived value is strongly related to cognitive (e.g., success vs. failure) and motivational components (e.g., intrinsic vs. extrinsic value, attributions about success and failure). Perceived control also involves appraisals regarding both cognitive aspects (e.g., action-outcome or situation-outcome expectancies) and motivational aspects (e.g., action-control expectancies). Various emotions can emerge according to how individuals appraise task achievement (see Pekrun, 2006, for a complete description of achievement emotions).

In general, positive and activating emotions (e.g., enjoyment) are assumed to have beneficial effects on individual cognitive processing, while negative and deactivating emotions (e.g., boredom) would globally have disruptive effects (Gläser-Zikuda,

2012; Pekrun et al., 2002). Some positive or negative emotions can also influence cognitive styles (e.g., flexible and creative thinking vs. systematic and careful thinking) (Fredrickson & Branigan, 2005). However, even though negative effects of negative emotions are often reported (due to adverse effects on attention, memory, motivation, self-regulation, and self-efficacy) (Rowe & Fitness, 2018), a strong dichotomy between beneficial effects of positive emotions and detrimental effects of negative emotions should be avoided. As outlined by Pekrun and Perry (2014, p. 134), "with few exceptions, any emotion can prove to be either adaptative or maladaptive in terms of achievement outcomes". Therefore, understanding the role of emotions in problem-solving requires adopting a more fine-grained level of analysis, considering the functional aspect of different types of emotions in various kinds of settings. For example, negative emotional states would have an advantage for tasks requiring to perform effectively within provided rules (i.e., convergent thinking) (Hascher, 2010; Rowe & Fitness, 2018). Several reasons can be advanced to substantiate this point. First, depending on the type of task, some negative emotions could enhance learning performance, whereas some positive emotions could dampen it. For example, fear would lead to a better prioritizing of information, while anger would increase attention to the goals and actions of others (Rowe & Fitness, 2018). Conversely, some positive emotions (e.g., amusement) increase the urge to be playful and social and, therefore, can promote distraction, which would disrupt the processing of tasks requiring high focus, especially when the learning topic has low subjective relevance or low challenge (Fredrickson & Branigan, 2005; Hascher, 2010). Second, emotions do not solely impact cognitive performance but also motivational processes. Therefore, the same emotion could have a detrimental impact on cognitive processes while positively impacting motivational processes and vice versa. For example, anxiety would globally reduce cognitive resources and trigger more task-irrelevant thinking due to worries about failure (Pekrun, 2012). However, it would also promote motivation to avoid failure (Rowe & Fitness, 2018). Third, an essential component of efficient learning and problem-solving is cognitive conflict, i.e., a psychological state involving a discrepancy between new information and prior beliefs and ideas (Braasch & Scharrer, 2020; Waxer & Morton, 2012). For example, cognitive disequilibrium can generate confusion that could benefit learning (D'Mello et al., 2014) in promoting, for example, knowledge exploration (Vogl et al., 2019). In general, the literature suggests that emotions must be maintained to an optimal level according to the situation to bolster their positive effects and prevent their harmful ones. This emotional tuning requires the regulation of emotions.

The way individuals manage their own emotions strongly depends on their capacity to use appropriate real-time self-regulation strategies when needed. For this reason, emotional competencies play a crucial role in individual problem-solving. They first consist of identifying and discriminating emotions clearly, then understanding the causes and possible consequences of emotions, harness them according to the situation, and regulate them when needed (Fernández-Berrocal & Extremera, 2006).

Indeed, individual problem-solving often trigger pleasant and unpleasant emotions which have to be managed to foster task achievement. Group members generally tend to regulate their emotions in a hedonic way, i.e., they try to decrease negative emotions (e.g., frustration due to persistent cognitive difficulties) and increase or maintain positive emotions (e.g., happiness due to success) (Koole, 2009). To this end, they mobilize different implicit or explicit strategies. The Process Model (Gross, 1998) of emotion regulation have distinguished five different types of emotion (situation selection, situation modification, attentional deployment, cognitive change and response modulation) regulation strategies referring to five ways to regulate their emotions (see Gross, 1998 for a complete description of the emotion regulation strategies). However, we argue that a hedonic regulation is not always suited to problem-solving and can even go against personal performance. As highlighted in research on individual learning (e.g., D'Mello and Graesser, 2012, unpleasant emotions are part of the normal process of complex cognition and should not be avoided. Indeed, a too strong tendency to inhibit some negative emotions or enhance some positive emotions can prevent problem solvers from reaching task goals. For example, systematically alleviating frustration due to cognitive difficulties can lead to implementing surface cognitive strategies that may impair problem-solving. Thus, another crucial aspect is to choose appropriate strategies in response to emotions and sometimes consider strategies that do not have an immediate hedonic effect. For example, enduring unpleasant feelings and using cognitive change techniques to appraise and implement meta-motivational strategies (e.g., persistence enhancement) could be more beneficial to performance than response modulation techniques dedicated to directly suppressing unpleasant feelings. Furthermore, the regulation of emotions is not only concerned with dealing with unpleasant emotions. Sometimes, even positive emotions must be regulated when they appear inappropriate to the problem-solving task. For example, a too strong feeling of pride, although pleasant, can trigger extraneous thoughts about earlier success and consumes attentional resources. Thus, implementing strategies in response to emotions is not an easy process and can fail for different reasons such as a faulty interpretation of emotions, a tendency to automatically use hedonic strategies, a lack of knowledge about effective strategies, or a lack of sufficient superordinate motivation to endure unpleasant emotions or abate pleasant emotions when needed (Koole, 2009).

3.4.2 Emotions and mental models (E2)

Research indicates that emotional events are more likely to be remembered than neutral events (LaBar & Cabeza, 2006). Therefore, the three-level model assumes that the intensity of emotions highlights essential issues to be taken into consideration and constrain the kind of information stored in the collaborative mental models. In other words, the personal and interpersonal events that are more emotionally tinted are thought to be prioritized when modeling the collaborative problem-solving task.

For example, the more the level of frustration regarding a cognitive difficulty during the task is high, the more this information is likely to be memorized as relevant information in the cognitive mental model. In the same vein, the more the level of embarrassment associated with some socio-relational acts is high, the more this information is likely to be stored in the relational mental model as an essential aspect of the collaboration. Consequently, emotionally tinted knowledge in the mental models is thought to drive more strongly the kind of following collaborative actions mobilized through individual processing and observable outputs (Avry et al., 2020b).

In addition, individuals are also thought to refine their modeling of self and other's emotions over time (see dispositional affect; Scherer, 2005). In other words, they develop meta-knowledge about self and others regarding the relationships between the emotions they perceive and the cognitive, motivational, and relational dimensions of collaborative problem-solving. For example, a particular emotional expression from the collaboration partner can be consistently associated with cognitive difficulties he or she encounters. Therefore, emotions can help collaborators to build faster inferences regarding the state of the collaborative problem-solving and act accordingly.

3.4.3 Emotions and observable outputs (E3)

The sharing of emotions is embedded in verbal, para-verbal and non-verbal behaviors. Collaborative acts convey verbal and para-verbal communication of emotions. First, emotions can be conveyed through words (e.g., "I'm happy", "I'm frustrated") belonging to a given collaborative act. Second, emotional meaning can also come from para-verbal components (e.g., pitch, volume, speaking rate). Non-verbal behaviors also convey emotional meaning regarding how their partner solve the task (e.g., facial expression of confusion can indicate a difficulty to understand an aspect of the problem), how they are motivated (e.g., a posture of boredom can indicate low intrinsic value) or how they regard the relationship (e.g., facial expression of contempt can indicate low liking for another partner). Therefore, verbal and para-verbal communication of emotions can complement, strengthen, substitute, or contradict the collaborative intentions conveyed by non-emotional verbal communication. Besides, non-verbal emotional communication can also provide additional information that may also complement, strengthen, substitute, or contradict the meaning of collaborative acts (Jones, 2013).

Van Kleef (2009) and Van Kleef et al. (2010) proposed a model that unifies several findings regarding the expression of emotions at the interpersonal level. It highlights that verbal and non-verbal expressions of emotions convey social information to observers, which in turn affect their behaviors. In other words, people observe the emotional expressions of others and are influenced by them. According to the

model, two core processes are mobilized when people come across emotional expressions. Firstly, emotional expression triggers inferential processes. Individuals use emotional expressions as cues allowing them to infer social information. This social information concern not only the type of emotion observed but also various inferences about the causes and consequences of it. In other words, emotional expressions also help the observer to understand the status of the interpersonal interaction more deeply. Secondly, emotional expressions can also elicit affective reactions in observers. They involve emotional contagion, i.e., "the tendency to unintentionally and automatically catch other people's emotions through their facial expression, vocalizations, posture or bodily movements" (Van Kleef et al., 2010, p. 54). According to Van Van Kleef et al. (2010), emotional contagion can pervade the observer's judgment through different types of affect infusion. For example, if positive feelings arise from the other's emotional expression, the observer is likely to assume that the situation is safe and exploration is possible (see Broaden-and-Build theory, Fredrickson, 2013). Second, affective reactions experienced by the observer may also affect the building of impressions regarding the other group members (e.g., dispositional knowledge about the other group members). The three-level model assumes that these inferences and affective reactions of expression of emotions can relate to cognitive, motivational and relational aspects of collaborative problem-solving.

The expression of emotions can serve both affiliative and social distancing functions (Fischer, Manstead, et al., 2016). As describe by Pekrun and Linnenbrink-Garcia (2012), individuals experience a wide range of emotions related to the relationship they have (e.g., admiration, envy), called social emotions. Therefore, inferences about others' emotions and affective reactions resulting from others' emotional expressions can promote affiliation or social distancing between group members. However, this aspect is not only circumscribed to the relational dimension between individuals. For example, satisfaction can indicate that people are willing to negotiate or make collaborative decisions in the cognitive dimension. Affiliative and social distancing functions of emotions can result in three kinds of action tendencies in the context of work interactions (moving toward, moving away, moving against; Van Kleef et al., 2010). We propose that, in collaborative problem-solving, moving toward action tendencies promote collaborative behaviors (i.e., group members primarily rely on each other to solve the common problem). Conversely, moving away action tendencies promote cooperative behaviors (i.e., group members primarily rely on themselves to solve the common problem). Finally, moving against action tendencies promote competitive behaviors (i.e., group members primarily seek personal benefits in solving the common problem).

As the expression of emotions can have disruptive effects on collaborative problem-solving, it needs to be regulated to prevent their disruptive effects on collaborative problem-solving (e.g., provoking social distancing and moving away or against action tendencies). Similarly to the personal level, emotional competencies also have

a key role at the interpersonal level, and group members can benefit from harnessing the expression of emotions according to the situation and regulating them to foster goal achievement. Some motives for interpersonal regulation have been described in Niven (2016) and Rimé (2009) and are particularly relevant in the framework of collaborative problem-solving. Affiliative positive emotions are thought to be primarily shared because they promote moving toward action tendencies in the cognitive (e.g., seek advice and solutions, obtain feedback, advice or guidance from others, seek legitimization or validation of one's ideas), motivational (e.g., seek or bring support) or relational (e.g., revive positive experience, seek comfort, arouse empathy, build trust) that benefit collaborative problem-solving. Affiliative negative emotions (e.g., shame, guilt, confusion, distress) can also be shared as they can trigger others' attention and help. However, sharing affiliative negative emotions often requires good preexisting socio-relational quality (e.g., trust, respect, empathy) as they can involve more intimate disclosure. Conversely, when positive or negative emotions are shared, interpersonal emotional regulation allows group members to prevent their social distancing effect, i.e., moving away or against action tendencies (e.g., the expression of excessive pride following success or irritation following a socio-cognitive conflict). Failure to regulate interpersonal emotions appropriately can be a source of collaborative dysfunctionality and impair group performance.

3.5 Conclusion

A growing interest in the role of emotions has emerged over the last twenty years. Various research in diverse disciplines (cognitive psychology, cognitive neurosciences, social psychology, educational psychology) has highlighted how emotions affect thoughts and behaviors at the personal and interpersonal levels. However, these numerous contributions have not been yet integrated to capture how they impact the functioning of collaborative problem-solving. After reviewing diverse scientific work related to emotions in personal and interpersonal settings, this chapter enriches the model described in the previous chapter in describing how emotions impact the three levels (individual processing, mental models, observable outputs) of collaborative problem-solving afore-described. This work organized the research presented in the rest of this manuscript.

Chapter 4

OBJECTIVES OF THE EMPIRICAL RESEARCH

The model we have described in the foregoing sections aims at creating a testable framework that addresses a comprehensive picture of the different aspects that intervene in the dynamics of collaborative problem-solving, including both **personal** and **interpersonal processes**. The emphasis was also put on separating the collaboration process into three distinct levels, namely the **individual processes** mobilized by the group members, the **mental models** where personal and interpersonal information are aggregated, weighed and assessed to trigger personal and interpersonal behaviors, and the **observable outputs** available to all group members. This model also clearly distinguishes three types of collaborative matters that have specific functions in collaborative problem-solving, namely the **cognitive dimension** that allows group members to solve the problem in question, the **motivational dimension** that allows them to persevere in the task, and the **relational dimension** that refers to the relationship between collaborators. Based on this model, different assumptions about how the different levels intervene and interact during collaborative problem-solving can be raised and experimentally tested. The objective of the empirical research reported in the present dissertation is to focus on some of these assumptions. As only some aspects of this model have been explored as part of this thesis, several directions for further research will be proposed in section 8.3.

The **main purpose** of this thesis work is to highlight the pervasive role of emotional processes in collaborative problem-solving. We have focused mainly on the cognitive and relational aspects from the viewpoint of mental models (i.e., perception of collaboration) and collaborative acts (real-time communicative exchanges). More specifically, we have tried to deepen the understanding of the role of emotions in collaborative problem-solving in exploring how three kinds of emotional processes (i.e., self-experienced emotions, explicit sharing of emotions and disposition to regulate self and others' emotions) play a role in the co-modulation/co-regulation of the cognitive and relational dimensions.

Study 1 (Chapter 5) focused on the interaction between the interpersonal level (observable outputs) and the personal level of collaboration (mental models) and more specifically on the perception of socio-cognitive and socio-meta-cognitive acts. We analyzed how self-experienced achievement emotions (Pekrun & Linnenbrink-Garcia, 2012) triggered by task-achievement appraisals influence how group members use collaborative acts during a problem-solving task. The experiment involved pairs of participants solving a simulation of a collaborative problem-solving task (3D puzzle game).

This study aimed to address the following research questions:

- How different group task-achievement appraisals (low vs. high control and failure vs. success) trigger various achievement emotions?
- How different group task-achievement appraisals change group members' perception of how they use collaborative processes?
- Do achievement emotions have a modulation effect on the relationship between task-achievement appraisals and collaborative processes?

Study 2a and **Study 2b** (Chapter 6) focused in the interpersonal level (observable outputs) and more specifically on actual socio-cognitive and socio-meta-cognitive acts. We analyzed how the explicit sharing of emotions influences the use of collaborative acts in a collaborative problem-solving task where pairs of participants created a slogan together. Two different ways of analysis have been adopted. In study 2a (see section 6.1), we explored how the sharing of emotions influences how dyads mobilize collaborative acts globally.

This study aimed to address the following research question:

- How the explicit sharing of emotions through an emotion awareness tool shapes the general use of collaborative acts?

In study 2b (see section 6.2), we investigated the dynamics of collaborative problem-solving exchanges in addressing whether and how explicit sharing of emotional sharing induces real-time adaptation of both emitter's and receiver's collaborative acts.

This study aimed to address the following research questions:

- Do emotion sharing modulates collaborative acts in real-time?
- Do specific patterns of collaboration can be highlighted, considering the triad emitter's collaborative acts, emotional sharing, and receiver's collaborative acts?

Finally, **Study 3** (Chapter 7) focused on the interaction between interpersonal level (observable outputs), the personal level of collaboration (mental models and individual processing), more specifically, interpersonal emotion regulation dispositions

and explicit sharing of emotions in relation to the relationship between group members during collaborative problem-solving. The experiment involved pairs of participants solving a collaborative problem-solving task (optimization problem).

This study aimed to address the following research questions:

- How explicit sharing of emotions and interpersonal emotion regulation dispositions interact to influence the perception of the relationship between group members?

To avoid some redundancy, the hypotheses for each of these studies are detailed in their corresponding chapters. The main contributions are summarized in section 8.1 and discussed in relation to the three-model of collaborative problem-solving.

Chapter 5

STUDY 1: Self-experienced emotions and collaborative problem-solving[1]

5.1 Introduction

Team collaboration is often an efficient way to deal with complex problems. In recent years, collaboration has increased all around the world, as more and more students and employees work together to solve non-routine problems (Fiore et al., 2017). Collaboration refers to the "synchronous activity that occurs as individuals engage in collective thought processes to synthesize and negotiate collective information in order to create shared meaning, make joint decisions, and create new knowledge" (Borge & White, 2016, p.324). It is a multicomponent phenomenon that involves the interplay of both cognitive (e.g., self-explanation of content) and socio-cognitive (e.g., information sharing, constructive conflict; Decuyper et al., 2010, Dillenbourg, 1999). It also implies (socio-)motivational (e.g., self-values, motivational discourse) and socio-relational processes (e.g., solidarity, trust, liking, tension release; Bales, 1950a; Hale et al., 2005). Therefore, collaboration involves the management of not only the problem to be solved (i.e., cognitive dimension) but also the relationship with others (i.e., relational dimension) (Andriessen et al., 2011; Barron, 2003; Kreijns et al., 2003). In general, emotional aspects have been largely linked and very often assimilated to the relational dimension in (computer-supported) collaborative learning ((CS)CL) literature (Barron, 2003; Järvelä et al., 2013; Linnenbrink-Garcia and Pekrun, 2011). Indeed, research in this domain is primarily focusing on the sharing/regulation of emotions in the promotion of favorable or unfavorable group attitudes (Isohätälä et al., 2019). However, a long tradition of research also studies the role of emotions in cognition such as reasoning, decision-making, or problem-solving strategies (Fredrickson, 2013; George and Dane, 2016; Labroo and Isen, 2003;

[1]The study presented in this chapter is published in *Avry, S., Chanel, G., Bétrancourt, M., & Molinari, G. (2020). Achievement appraisals, emotions and socio-cognitive processes: How they interplay in collaborative problem-solving?. Computers in Human Behavior, 107, 106267, doi: 10.1016/j.chb.2020.106267*

Spering et al., 2005). Surprisingly, this research is scarcely referred to in (CS)CL literature and not extended to group cognition (Mullins et al., 2013). In other words, if one assumes that emotions interplay with socio-cognitive processes, one still does not know clearly in which ways. Therefore, we need at this point more evidence-based knowledge about how emotions and group cognition are bound together, especially in group problem-solving. As Calvo (2009) highlighted, this current state of affairs hampers the development of tools using emotions as a way to promote efficient collaboration because the role of emotions in collaborative mechanisms stays largely unexplored. At this point, deepening knowledge in this domain is, therefore, an essential step for building efficient tools and training dedicated to fostering collaboration (Borge and White, 2016; Järvelä et al., 2015). In this study, we aimed at increasing the understanding of the interplay between how problem-solvers evaluate task achievement, what kind of emotions it triggers, and what impact such an evaluation has on socio-collaborative processes. To this end, we examined the relationship between task-achievement appraisals, achievement emotions and emotional dimensions (valence, activation, dominance) and the perception of socio-cognitive processes in a dyadic computer-supported collaborative problem-solving task. What follows is a review of the relevant literature, namely socio-cognitive processes (section 5.1.1), emotions in task-achievement settings (section 5.1.2), and the impact of emotions and especially achievement emotions in (CS)CL settings (section 5.1.3).

5.1.1 Socio-cognitive processes

Collaboration is undeniably grounded on communication. Throughout the collaboration, the different meanings conveyed by communicative exchanges constrain and forge the construction of a joint problem space (Roschelle & Teasley, 1995). In this perspective, collaboration relies critically on real-time communicative exchanges (Dechant et al., 1993). In (CS)CL, studying the nature of those communicative exchanges and their consequences on group collaborative processes is therefore of great interest, as it helps to better apprehend the course of collaboration (Decuyper et al., 2010; Meier et al., 2007; Wilson et al., 2007). Referring to the speech act theory (Austin, 1975), communicative exchanges taking place during collaboration are dedicated to doing something (e.g., providing information, clarifying ideas, asking for help, encouraging others) and produce perlocutionary effects, i.e., consequences on feelings, thoughts, and actions of others (Sbisà, 2009). Several frameworks have been developed in (CS)CL to classify these communicative exchanges and grouped them into meaningful collaborative processes (e.g., Bales, 1950a; Baker et al., 2007; Hughes et al., 2007; Meier et al., 2007; Noroozi et al., 2013b). In such classifications, categories generally refer to both socio-cognitive (e.g., information pooling, argumentation, transactivity) and socio-relational processes (e.g., group integration). In order to capture not only which processes problem-solvers engage but also how well they do it, Meier et al. (2007) have developed a rating scheme that allow computer-supported collaborative processes to be quantified according to nine qualitative (i.e.,

adding a plus value on collaboration outcomes) dimensions of collaboration, namely **sustaining mutual understanding**, **dialogue management**, **information pooling**, **reaching consensus**, **task division**, **time management**, **technical coordination**, **reciprocal interaction**, and **individual task orientation**. Some of them are of particular interest in the present contribution as problem-solvers have reported how they perceived communicative exchanges related to these following socio-cognitive processes (cf. section 5.2.5 and Table 5.1). These socio-cognitive processes are described below.

5.1.1.1 Sustaining mutual understanding

Sustaining mutual understanding includes communicative exchanges related to the creation of shared mental models, i.e., shared representations of group knowledge and understanding that both result from and shape learning processes in the group (Decuyper et al., 2010). Different designations refer to the same or a closely related concept, especially grounding (Baker et al., 1999), cognitive convergence (Teasley et al., 2008), or mutual knowledge or understanding. It includes, for example, exchanges dedicated to making one's contributions understandable or asking for clarification.

5.1.1.2 Information pooling

Information pooling refers to exchanges related to the sharing process that involves communication about non-previously shared knowledge, competencies, opinions, and creative thoughts from one person to others (Decuyper et al., 2010). It is a component of the construction of shared mental models. It includes, for example, exchanges dedicated to gathering relevant pieces of information or making links between different pieces of information.

5.1.1.3 Reaching consensus

Reaching consensus involves communicative exchanges dedicated to critically assessing information. The process of co-construction implies elaborating knowledge, competencies, opinions, and creative thoughts through others. It refers to repeated cycles where learners acknowledge, repeat, paraphrase, enunciate, question, concretize, and complete shared knowledge, competencies, opinions, or creative thoughts (Decuyper et al., 2010). On the other hand, constructive conflict involves that learners have diverse opinions that require negotiation and the overcoming of disagreement. This divergence leads to integrate viewpoint differences in promoting exploration of the same problem from different perspectives. It includes, for example, exchanges dedicated to justifying the validity of a proposed solution.

5.1.1.4 Transactivity

The reaching consensus process does not address co-construction nor constructive conflict processes very explicitly (Baker et al., 2007). Co-construction and constructive conflict can be refined in different social modes of co-construction, representing varying degrees of transactivity (Teasley, 1997; Weinberger and Fischer, 2006). Transactivity or transactive discussions (Berkowitz & Gibbs, 1983) refers to the degree to which a person "uses his or her conversational turn to operate on the reasoning of the partner or to clarify his or her ideas" (Teasley, 1997, p.362). It has emerged from research highlighting that students who engage in transactive discussions learn more from the collaboration than those who do not (Teasley, 1997, p.364). Therefore, it reflects the quality of the conversational exchanges taking place in a group (Zoethout et al., 2017, p.362). Weinberger and Fischer (2006) have reviewed the process of transactivity and describe five sub-processes ranging from no transactive to highly transactive, namely externalization, elicitation, quick consensus building, integration-oriented consensus, and conflict-oriented consensus building. In the two latter forms of consensus, problem-solvers actively operate on the other's reasoning, are mutually responsive to persuasive arguments, change or give up their first view when it is appropriate. In conflict-oriented consensus building, a constructive conflict arises where problem-solvers receive critiques that challenge their perspective, leading them to operate deeper on their reasoning as well as that of their partner. Greater transactivity has been shown to stimulate productive collaborative learning (Noroozi et al., 2013b; Teasley, 1997). It includes, for example, exchanges dedicated to enriching a proposition by challenging the validity of a partner's previous proposition.

5.1.1.5 Task and time management

Task management refers to team reflexivity, i.e., the consideration of what participants have already achieved (current situation), what they still plan to make (objectives), and how they are going to do it (strategies). It can be defined as "the extent to which group members overtly reflect upon the group's objectives, strategies, and processes and adapt them to current or anticipated endogenous or environmental circumstances" (West, as cited Gurtner et al., 2007, p.128). Finally, time management refers to exchanges that allow participants to manage time constraints adequately.

5.1.2 Emotions and emotional dimensions in task-achievement settings

Emotions are of critical importance in learning and problem-solving activities. During deep learning activities, that include effortful problem-solving, D'Mello and Graesser (2012) showed that emotions and cognitive states go hand in hand throughout task achievement. For example, a state of persistent failure can trigger hopelessness, which can lead to disengagement and boredom. On the contrary, resolving a problem and attaining one's goal can trigger delight. In the same vein, Pekrun

Sustaining Mutual understanding
- Make my contributions understandable for the other
- Make sure being understood by the other
- Give verbal feedback on my understanding or ask for clarification

Information pooling
- Gather as many relevant pieces of information as possible
- Relate new information to facts that have already been established
- Point out the relevance of new information
- Give an explanation to the other about what I'm currently doing

Reaching consensus
- Find the best arguments for and against a solution
- Look for facts that confirm or invalidate a solution to prevent errors
- Try to convince the other by justifying my proposed solution
- Question a decision only if valid reasons

Transactivity
- Build on other's propositions by adopting or integrating them to mine
- Build on other's propositions by rejecting or modifying them

Task management
- Define clearly subtasks with fair burden-sharing
- Co-ordinate the work
- Be careful about other's actions and needs

Time management
- Allocate enough time and resources for each step
- Monitor remaining time for preventing time waste

TABLE 5.1: Socio-cognitive processes (in bold) and their related communicative exchanges.

and Linnenbrink-Garcia (2012) reported a variety of emotions occurring in learning activities (e.g., studying or taking exams), such as achievement emotions (related to achievement activities or outcomes), epistemic emotions (related to the cognitive processing of information) or social emotions (related to interpersonal relationships) (Pekrun & Linnenbrink-Garcia, 2012). Achievement emotions are the focus of this study.

5.1.2.1 Control-value theory (CVT) of achievement emotions

The CVT provides a framework explaining how achievement emotions emerge at the individual level through task-achievement appraisals. Achievement emotions relate to either the ongoing activity or its prospective or retrospective outcomes, depending on the learner's focus. Examples of activity-related achievement emotions are the enjoyment of learning new things or the frustration of not finding a solution to a problem. Disappointment following a failing grade, on the other hand, is an

example of retrospective outcome-related achievement emotions. In addition to discrete labels, achievement emotions have also been described according to emotional dimensions, especially valence and activation (Pekrun & Linnenbrink-Garcia, 2012). The latter dimension refers to the arousal dimension of emotions (Fontaine et al., 2007). Hope, anger, pride, gratitude, frustration or joy are examples of activating emotions. Relief, sadness, boredom, contentment are examples of deactivating emotions. According to their valence and activation, achievement emotions are expected to have differential effects on motivational, cognitive and socio-cognitive processes (Pekrun & Linnenbrink-Garcia, 2012) (see Table 5.2 for a comprehensive description of achievement emotions). According to the CVT, control and value are subjective cognitive appraisals that lead to the emergence of achievement emotions. Subjective control refers to an overall evaluation of the control over the task, while subjective value relates to the perceived valence of the actions performed during the task as well as the outcomes accomplished. Subjective control and value emerge from different expectancies and attributions, which are task-achievement appraisals.

Control expectancies and attributions When learners focus on what they are doing or what will be accomplished (activity or prospective perspective), subjective control emerges from several expectancies regarding actions and outcomes (Pekrun, 2006). First, action-control expectancies are beliefs about the self-capability to initiate and perform an action (similar to self-efficacy; Bandura, 1977). Second, action-outcome expectancies are beliefs that self-actions will produce some positive outcomes or prevent negative ones. Third, situation-outcome expectancies are beliefs that the situation will produce positive or negative outcomes by itself whatever the actions performed. In addition, when the learner focuses on what has been accomplished (retrospective perspective), subjective control implies retrospective appraisals of the causes of success or failure (Pekrun, 2006), i.e., causal attributions of outcomes (self or external circumstances).

Value appraisals When learners focus on what they are doing, subjective value emerges from either intrinsic (value of the activity per se) or extrinsic (instrumental usefulness of the activity) values (Zimmerman, 2002). When the learner's focus is on prospective or retrospective outcomes, subjective value emerges from achievement expectancies in terms of success or failure. In this study, different levels of action-outcome, situation-outcome and success expectancies have been manipulated (see Section 5.1.4 and Table 5.3).

5.1.3 Emotions in (computer-supported) collaborative learning settings

Although a clear vision of the interplay between emotions and socio-cognitive processes is still underway, research on individual and group converges around the idea that emotions and especially achievement emotions significantly impact cognitive and socio-cognitive strategies during individual and collaborative problem-solving.

	Positive		Negative	
Object focus	Activating	Deactivating	Activating	Deactivating
Activity	Enjoyment	Relaxation	Anger Frustration	Boredom
Outcome / Prospective	Hope Anticipatory joy	Anticipatory relief	Anxiety	Hopelessness
Outcome / Retrospective	Joy Pride Gratitude	Contentment Relief	Shame Anger	Disappointment Sadness

Note. Pekrun & Linnenbrink-Garcia, (2012), Pekrun (2006)

TABLE 5.2: Achievement emotions

5.1.3.1 Emotions in individual learning

The CVT assumes that achievement emotions affect learning, especially the use of learning strategies in problem-solving settings. For example, positive and activating emotions (e.g., enjoyment, hope, pride) may foster flexible, holistic and creative strategies such as elaboration (e.g., relating the studying material to previous knowledge, paraphrasing, summarizing; Artino, 2009) or critical thinking whereas both negative (e.g., hopelessness, boredom) and positive (e.g., relaxation) deactivating emotions may discourage learners from investing in an effortful processing of information. Negative activating emotions (e.g., frustration, anger, anxiety and shame) could motivate learners to avoid failure but may promote more rigid learning strategies like the rehearsal of information (Pekrun et al., 2011; Pekrun and Linnenbrink-Garcia, 2012). In addition, using a questionnaire developed by Greene, Miller, Crowson, Duke and Akey (2004) measuring meaningful cognitive strategies used by learners (e.g., "I make sure I understand the ideas that I study"). Marchand and Gutierrez (2012) showed that three achievement emotions (hope, frustration, anxiety) have an impact on such strategies. While hope and anxiety correlate positively and significantly with the use of efficient learning strategies, frustration appears to correlate with a decrease in the use of such strategies.

In studies focusing on emotions more broadly, it seems quite clear that negative emotions stimulate a more careful and bottom-up processing as well as a more systematic gathering of information, in contrast to positive emotions, that lessen systematic information processing and promote heuristic-based processing strategies (Spering et al., 2005). Isen and Labroo (2003) also showed that people experiencing positive emotions are more flexible, inclusive, creative, integrative, open to information, and efficient (see also Hascher, 2010). Up to now, evidence for a reverse effect concerning negative emotions appears less clear. However, according to Hascher (2010), negative emotions (e.g., anxiety) may direct the student's attention to themselves and their subjective feelings. Therefore, it can induce task-irrelevant thoughts that may interfere with task completion as it consumes additional cognitive resources (Pekrun & Linnenbrink-Garcia, 2012).

5.1.3.2 Emotions in group learning

Andriessen et al. (2011) have also explicitly linked the affective states of tension and relaxation to specific socio-cognitive behaviors such as questioning, compromising, or requesting justifications or clarifications. In their theoretical model of social and cognitive functions of emotions in collective argumentation, Polo, Lund, Plantin and Niccolai (2016) also postulate that, in the cognitive side, emotions are involved in a schematization process. In such a process, participants attach emotional tonalities to discourse objects (e.g., arguments), that act as a cognitive filter, orienting the choice of a given argumentative option. Other authors (Molinari et al., 2013) showed that the emotional intensity of shared emotions correlates with the

perception of some socio-cognitive processes as understanding and building upon the partner's ideas or challenging the partner's ideas (referring to co-construction and constructive conflict). Finally, sharing positive emotions also impacts positively the number of communicative exchanges dedicated to giving and eliciting information about how partners process task information (Avry & Molinari, 2018).

5.1.4 Research question and hypotheses

The literature shows that (achievement) emotions are related to cognitive and socio-cognitive strategies during individual and collaborative problem-solving. However, there are still little findings regarding the role of achievement emotions as well as their emotional dimensions (valence, activation, and dominance) in group cognition. As research demonstrates, affective aspects are crucial in cognitive processes but the extensive research regarding emotional aspects of individual learning and problem solving is little extended to socio-cognitive processes.

In a first approach, and in line with previous studies considering relationships between achievement emotions and cognitive or socio-cognitive processes (Marchand and Gutierrez, 2012; Pekrun et al., 2011), we relied on participants' self-reporting. However, we are deeply aware that the socio-cognitive processes people think they mobilize (our approach) may differ from what they actually do. Both perspectives are crucial because implicit and explicit systems intertwine in learning (Hogarth, 2011). For example, a discrepancy can be found between how people link their subjective feeling (i.e., conscious frustration) to their collaborative judgments (e.g., inefficient) and how their emotions actually influence their cognitive (i.e., more systematic gathering of information) and socio-cognitive processes (e.g., stimulating information pooling). This point will be discussed further in section 5.4.3.

Besides, self-experienced emotions are not the only source of influence of cognitive and socio-cognitive processes. In the EASI -Emotion As Social Information- model, Van Kleef, De Dreu and Manstead (2010) point out that, in social interaction, the emotions perceived in others are also used in a controlled and strategic way to adjust one's own behavior. Therefore, we considered in this study both self-experienced emotions as well as emotions perceived in the partner and their relationships with the perception of both self and partner's socio-cognitive processes. In the following hypotheses, achievement emotions and emotional dimensions, as well as perceived socio-cognitive processes, refer to both self and partner reports. Furthermore, although our hypotheses are based mainly on results referring to achievement emotions in individual learning, we are strongly aware that learning together implies processes that are unique to the group (e.g., relatedness to others, Mullins et al., 2013) and may influence socio-cognitive processes in different ways, comparing to what was previously found in some research findings focalizing only on individuals. This point will be discussed further in section 5.5.

5.1.4.1 Research questions and hypotheses regarding the effects of achievement appraisals on emotional dimensions, achievement emotions and the perception of socio-cognitive processes

In this study, the focus is on achievement emotions (Pekrun and Linnenbrink-Garcia, 2012; Pekrun, 2012) and three emotional dimensions (valence, activation and dominance). Dominance was also considered in addition to valence and activation as it has a strong relationship with control, which has an essential role in the emergence of achievement emotions (cf. subjective control).

The research question here is to know whether different task-achievement appraisals modulate achievement emotions as well as their emotional dimensions in collaborative problem-solving. We relied on the CVT as it provides a clear theoretical framework for the emergence of achievement emotions, which can be used to make testable hypotheses. On the other hand, we focused on socio-cognitive processes that are known to be central and beneficial to group learning (cf. section 5.1.1), referring to the rating scheme developed by Meier et al. (2007). In this case, the research question is to know whether different task-achievement appraisals modulate the perception of socio-cognitive processes. The socio-cognitive processes described in section 5.1.1 includes several socio-cognitive communicative exchanges (Table 5.1). Based on the CVT, we have considered different levels of action-outcome and situation-outcome expectancies, as well as different levels of success expectancies. They reflect four different situations that can be encountered in face-to-face and computer-supported collaboration. In the present research, an experimental design was set up to simulate these situations. According to their experimental condition, participants received different false feedback about task-achievement (task mastery and position in a ranking reflecting the degree of success) aiming at skewing action-outcome, situation-outcome and success expectancies (cf. section 5.2.4 and Table 5.4 for a description of the experimental design). Table 5.3 summarizes the different hypotheses about their effects on emotional dimensions, achievement emotions, and perceived socio-cognitive processes. In these hypotheses, we assume no specific difference between self and partner reports. In each case, action-control expectancies are assumed to be high (i.e., the problem-solver is able to solve the task). The following situations correspond to the different experimental conditions.

Situation 1 The first experimental condition (Table 5.3, first row) refers to the high task mastery and high ranking (HMHR) condition (see section 5.2.4 and Table 5.4). It corresponds to a situation where problem-solvers think that their efforts can produce positive outcomes (high action-outcome expectancies, self-action is useful) and those efforts are a necessary condition to get positive outcomes (low situation-outcome expectancies, i.e., the situation, by itself, does not lead to positive outcomes). The situation also turns to be successful so they have high expectancies of success. This

situation can be related to any problem-solving situation where problem-solvers receive feedback indicating positive outcomes and think that they are the cause of those positive outcomes. In this case, we hypothesize that activation, dominance, and valence will be high, and positive activating emotions will predominate. We also assume that this experimental condition will lead to promoting socio-cognitive exchanges as the need to collaborate is a necessary condition to be ultimately successful in this situation.

Situation 2 The second experimental condition (Table 5.3, second row) refers to the low task mastery and high ranking (LMHR) condition. It corresponds to a situation where problem-solvers think that the situation has been producing positive outcomes (high and positive situation-outcome expectancies, i.e., the situation, by itself, leads to positive outcomes) despite their self-action (low action-outcome expectancies, self-action is useless). In addition, the situation also turns to be successful so they have high expectancies of success. This situation can be related to any problem-solving situation where problem-solvers receive feedback indicating positive outcomes but think they are not the cause of those positive out-comes. In this case, we hypothesize emotional activation to be low. Indeed, as positive outcomes result from the situation and not themselves, problem-solvers should be less involved in the task. However, emotional dominance is posited to be high due to positive situation-outcome expectancies (i.e., they feel as they master the task even though it is not due to them, cf. Pekrun, 2006). We also hypothesize emotional valence to be high as success is expected. Therefore, we expect that deactivating positive emotions will predominate in this case. We assume that this experimental condition will lead to decreasing the perception of socio-cognitive exchanges. Indeed, the need to collaborate in a situation known to be successful by itself should appear of little use.

Situation 3 The third experimental condition (Table 5.3, third row) refers to the high task mastery and low ranking (HMLR) condition. It corresponds to a situation where problem-solvers think that the situation has been producing negative outcomes (high expectancies of negative situation-outcome, i.e., the situation, by itself, leads to poor results) despite their self-action (low action-outcome expectancies, self-action is useless). In addition, the situation also turns to be unsuccessful so they have low expectancies of success. This situation can be related to any problem-solving situation where problem-solvers receive feedback indicating negative outcomes but think they are not the cause of those negative outcomes. In this case, we hypothesize emotional activation to be low. Indeed, as negative outcomes result from the situation whatever their self-action, problem-solvers should be less involved in the task. Emotional dominance is also posited to be low due to low action-outcome and high and negative situation-outcome expectancies, as well as emotional valence due to low success expectancies. Therefore, we expect that deactivating negative emotions

will predominate. We assume that this experimental condition will lead to decreasing socio-cognitive exchanges. Indeed, the need to collaborate in a situation already known to be unsuccessful should appear of little use.

Situation 4 The fourth experimental condition (Table 5.3, fourth row) refers to the low task mastery and low ranking (LMLR) condition. It corresponds to a situation where problem-solvers think that their efforts cannot produce positive outcomes (low action-outcome expectancies, i.e., self-action is useless) but those efforts are necessary to get positive outcomes (low situation-outcome expectancies, i.e., the situation, by itself, does not lead to positive outcomes). In addition, the situation also turns to be unsuccessful so they have low expectancies of success. This situation can be related to any problem-solving situation where problem-solvers receive feedback indicating negative outcomes and think they are the cause of those negative outcomes. In this case, we hypothesize that activation, dominance, and valence will be low, and deactivating negative emotions will predominate. We assume that this experimental condition will lead to decreasing socio-cognitive exchanges as the collaboration should appear unsatisfying in this case.

5.1.4.2 Research question and hypothesis regarding the mediating effect of emotional dimensions and achievement emotions

Achievement emotions are assumed to mediate the relationships between several variables as achievement goals (Hall et al., 2016) or individual variables (e.g., utility value, academic self-efficacy; Marchand and Gutierrez, 2012) and several mechanisms, that in turn affect task achievement. These mechanisms include cognitive resources, motivation to learn, learning strategies, and regulation of learning (Pekrun, 1992; Pekrun, 2006; Pekrun et al., 2009). The research question here is to know whether achievement emotions and their emotional dimensions also have a role in the relationship between task-achievement appraisals and the perception of socio-cognitive processes. As these affective states occur in-between task-achievement and socio-cognitive processes, the question is to know whether they change how participants see what they are doing in different task-achievement situations. Drawing on the previous results reported above, we postulate that emotional dimensions and achievement emotions mediate the relationship between how people appraise task achievement and how they perceive their socio-cognitive exchanges. In other words, people are assumed to perceive, at least partially, what they do through the prism of what they feel. For example, positive emotions like enjoyment could skew the perception of how participants perceive socio-cognitive processes even though they may not perform notably better (cf. cognitive bias and emotions, Blanco, 2017). As no study has investigated this possible effect yet, strong assumptions cannot be made, and mediation effects will be investigated in an exploratory way. Mediating effects are assumed for both emotional dimensions and achievement emotions, for both self-experienced emotions as well as emotions perceived in the partner.

	Task-achievement appraisals			Hypotheses				
	Success	Action-Outcome	Situation-outcome	Activation	Dominance	Valence	Achievement emotions	Perception of socio-cognitive processes use
Situation 1	High	High	Low	High	High	High	Joy/Pride/Gratitude[1]	High
Situation 2	High	Low	High (positive)	Low	High	High	Relaxation/Contentment/Relief[2]	Low
Situation 3	Low	Low	High (negative)	Low	Low	Low	Boredom/Hopelessness Sadness/Disappointment[3]	Low
Situation 4	Low	Low	Low	Low	Low	Low	Boredom/Hopelessness Sadness/Disappointment[3]	Low

Note. [1]activating positive emotions, [2]deactivating positive emotions, [3]deactivating negative emotion

TABLE 5.3: Task-achievement appraisals in each of the four collaborative situations and hypotheses concerning achievement emotions, emotional dimensions and the perception of collaborative processes based on the control-value theory

5.2 Method

5.2.1 Participants

Fifty-six participants, mainly students in computer sciences at the University of Geneva (10 women and 46 men; M = 22.02 years, SD = 3.49 years), grouped into same-sex dyads, took part voluntarily to the experiment. The low proportion of women reflects the imbalance found in the computer sciences population. Each pair received 50 CHF as an inconvenience allowance. The members of each pair were acquainted. They had never played Portal 2®, according to the recruitment form.

5.2.2 Procedure

Participants took part in a collaborative problem-solving task in a 3D first-person puzzle-platform video game called Portal 2® (Figure 5.1) through networked computers. The collaborative mode of Portal 2® was chosen as a generic computer-supported collaborative problem-solving task. Indeed, it meets the defined criteria of a collaborative problem-solving task, namely symmetry of actions, symmetrical knowledge, pursuit of a shared goal, spontaneous division of flexible and interchangeable roles (Dillenbourg, 1999; Roschelle and Teasley, 1995). It also requires cognitive and motivational skills usually involved in learning such as problem-solving, spatial cognition, and persistence (see Shute et al., 2015, for a complete description).

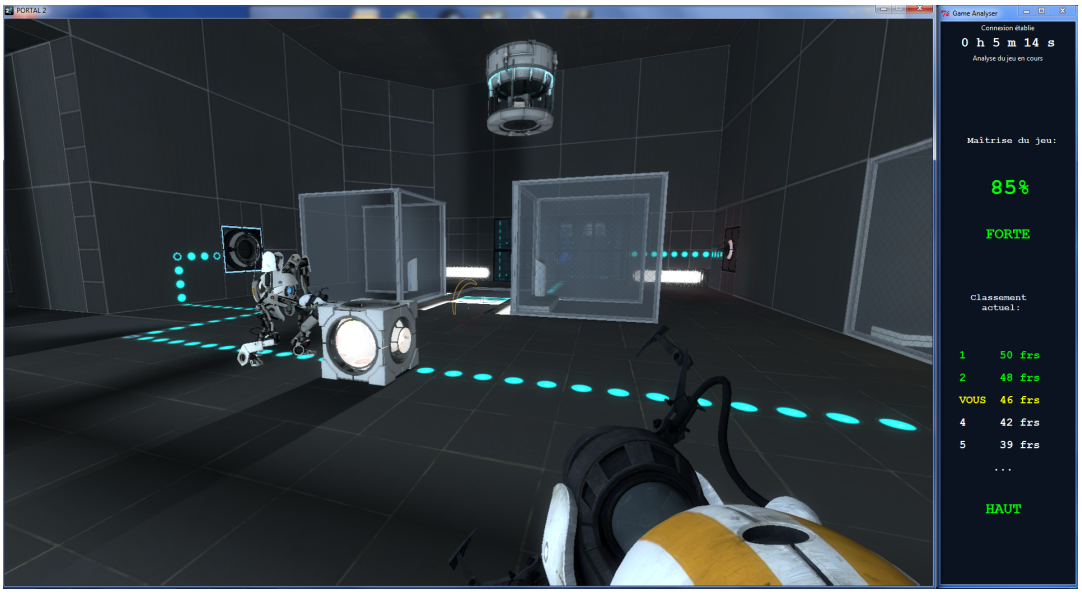

FIGURE 5.1: The collaborative video game Portal 2® (left) and the feedback window (right)

5.2.3 False feedback

During the collaborative task, participants received false feedback about task achievement, displayed through a window on the right side of their respective

screen (Figure 5.1). In the instructions (oral and written), it was explained to the participants that an algorithm would track their group's actions during the game. From these actions, the algorithm was supposed to compute an estimation of group task mastery. A percentage of 100% indicated a complete task mastery (participants did precisely what was expected) while a percentage of 0% indicated no task mastery (participants did not do at all what was expected). Based on this task-mastery evaluation, the algorithm was also supposed to compute a rank and display a dyad's ranking among 14 previous dyads of participants. The ranking was also associated with an estimation of the final gain. Feedback information was the same for both participants in the dyad and was displayed six times during the task, that is, every five minutes. In reality, the algorithm just displayed dummy information. Indeed, participants received predefined feedback in each experimental condition (cf. section 5.2.4). The level of task mastery displayed varied randomly from 10 to 20% for the low task mastery conditions, and from 80 to 90% for the high task mastery conditions. The ranking varied randomly from 12^{th} to 15^{th} (10 to 12 CHF) in the low ranking conditions and from 1^{st} to 3^{rd} (46 to 50 CHF) in the high ranking conditions (Figure 5.1). Slight randomized variations of percentage and ranking were introduced to enhance the perceived feedback credibility. At the very end of the task, participants were asked if they had noticed that the given feedback was false. Regardless of the experimental condition, all dyads actually received the same final remuneration (50 CHF).

5.2.4 Design

5.2.4.1 Experimental conditions

Participants received feedback according to four combinations of high or low task mastery and ranking: high task mastery and high ranking (HMHR) corresponding to **situation 1** (see section 5.1.4), low task mastery and high ranking (LMHR) corresponding to **situation 2**, high task mastery and low ranking (HMLR) corresponding to **situation 3**, and low task mastery and low ranking (LMLR) corresponding to **situation 4**. These different situations represented the different modalities (HMHR, HMLR, LMHR, and LMLR) of the independent variable (task-achievement situations) of the study.

The overall combination of different task-mastery and ranking levels was intended to generate different combinations of success, action-outcome, and situation-outcome expectancies (Table 5.4). In addition, the repetition of feedback information (six times) throughout the task aimed at reinforcing high situation-outcome expectancies in incongruent conditions (LMHR and HMLR). In these conditions, there was a discrepancy between task mastery and ranking. Indeed, participants saw that their task mastery (high or low) did not produce the expected result (positive or negative). Therefore, they were led to think that the outcome depended more on the situation than on their self-action. For example, in the HMLR condition, high task

mastery led to low ranking, leading participants to believe that other previous dyads were in any event better than them. Feedback information was regularly repeated throughout the task to reinforce this belief and therefore maintain situation-outcome expectancies high. In congruent conditions (LMLR and HMHR) though, there was no discrepancy between task mastery and ranking (e.g., a low task mastery led logically to a low ranking). In these conditions, situation-outcome expectancies were intended to be low as participants could directly associate the outcome to their self-action. In this case, the repetition of feedback information was not supposed to influence situation-outcomes expectancies.

		Ranking			
		Low		High	
Task mastery	Low	LMLR condition	**Situation 4**	LMHR condition	**Situation 2**
			Low action-outcome Low success Low situation-outcome		Low action-outcome High success High and positive situation-outcome
	High	HMLR condition	**Situation 3**	HMHR condition	**Situation 1**
			Low action-outcome Low success High and negative situation-outcome		High action-outcome High success Low situation-outcome

TABLE 5.4: Experimental design

5.2.4.2 Variables

Dependent variables were the rating scores to the questionnaires concerning achievement emotions and emotional dimensions (Questionnaire 1), and the perception of socio-cognitive processes (Questionnaire 2) (cf. section 5.2.5). The participants' gaming experience was controlled in the following ways: participants had never played at the game; they all had previous experience of 3D first-person shooter games; they completed individual 15-minute training before the collaborative task where game basics and objects manipulation were addressed; participants with too much difficulty to master the game basics were excluded a priori (after training) or a posteriori (after the task). The perception of progress into the game map was also controlled as follows: participants did not previously know the game map; they were told in the instructions to go as far as possible without receiving any indication of their actual progress; the game map could not be fully completed within the

time allowed. Besides, fluid intelligence (i.e., the capacity to adapt one's own reasoning to new ideas and situations) was evaluated through the Raven's progressive matrices test (Raven et al., 1998) (Raven, 1998). No significant difference was found between the experimental groups: $F(3, 51) = 1.12$, $p = 0.35$. A performance score was also computed to test a difference in performance between experimental conditions. No significant difference was found: $F(3, 24) = 0.97$, $p = 0.42$.

5.2.5 Questionnaires

Participants completed two questionnaires just after the task, an emotion questionnaire (Questionnaire 1) and a socio-cognitive exchanges questionnaire (Questionnaire 2). Questionnaire 1 was divided into two sections. The first section focused on the three emotional dimensions, namely valence, dominance, and activation. Participants were asked to answer three questions with 5-point Likert scales: "How did you rate the overall situation you have just been in?" (from *very negative* to *very positive*; Valence question); "To what extent have you been able to maintain or improve the situation you have just been in?" (from *very slightly* to *very strongly*; Dominance or power question); "How much did you feel aroused by the situation you have just been in?" (from *very slightly* to *very strongly*; Activation question). The second section was derived from the Achievement Emotions Questionnaire (Pekrun et al., 2011) and aimed at measuring the achievement emotions experienced during the game. Participants were asked to assess the intensity of their emotions using a list of 16 emotions with 7-point Likert scales (from *not at all* to *very strongly*): 4 negative and activating emotions (anxiety, anger, frustration, shame), 4 negative and deactivating emotions (disappointment, hopelessness, boredom, sadness), 5 positive and activating emotions (hope, pride, joy, enjoyment, gratitude), and 3 positive and deactivating emotions (relaxation, relief, contentment). The questionnaire 2 was based on the rating scheme developed by Meier et al. (2007). This questionnaire aimed at measuring the perceived use of computer-supported socio-cognitive exchanges. It addressed six socio-cognitive processes: sustaining mutual understanding, information pooling, transactivity, reaching consensus, task management, and time management (cf. section 3.3.1). Each of these processes includes 2 to 5 socio-cognitive exchanges with 7-point Likert scales (Table 5.1). Participants had to indicate with which frequency (from *never* to *every time*) they and their partner have used the collaborative exchanges in question. Frequency measure was preferred to an overall judgment of quality to enhance participants' focus on their actual communicative exchanges. The sustaining mutual understanding dimension concerned the participants' readiness to make contributions understandable to the partner (e.g., making sure to be well understood). Information pooling referred to the sharing of relevant information (e.g., gathering as many important pieces of information as possible). Transactivity was defined as the process through which participants reason and build on their partner's contributions (e.g., building on partner's ideas by adopting

or integrating them). Reaching consensus was the process by which common decisions were taken based on a critical discussion about the pros and cons (e.g., looking for facts that confirm or invalidate a solution). Task management focused on the ability to manage efficiently what needs to be done to achieve the task (e.g., defining clear subtasks with fair burden-sharing). Finally, time management referred to the ability to take into account the time available and manage the collaborative work accordingly (e.g., allocating enough time and resources for each step).

5.3 Results

Three dyads were excluded from the analyses. One dyad had difficulty to manage the game basics and remained blocked at the early beginning of the game. Another one was excluded due to technical problems during the game. Finally, one dyad identified that feedback information was false.

5.3.1 Unit of analysis

In order to assess the (non-)independence of peers' measures and confirm the possibility to use the individual as unit of analysis (see Kenny et al., 2006 for further discussion), intraclass correlation was performed between subject A and subject B's data (A and B being of the same pair). We computed the ICC for all the dependent variables of interest. No evidence of a dyad effect was supported by these analyses (cf. Appendix A). Therefore, individual-level measures were used as unit of analysis with standard inferential statistical methods.

5.3.2 Descriptive statistics

Descriptive statistics are reported in Table 5.8. A series of one-sample t-tests was conducted to test, for each condition, which emotions were self-experienced and perceived in the partner at least more than a "weak" level. These emotions are reported in Table 5.9 for each condition. Achievement emotions that were not reported more than a "weak" level in each condition are reported in Appendix B.

5.3.3 Effect of task-achievement situations on emotional dimensions

A series of ANOVAs was conducted to test the effects of Task-achievement situations on the rating scores of the emotional dimensions evaluated by participants. Inferential statistics are reported in Table 5.9. Significant effects are depicted in Figure 5.2 and described in detail below.

5.3.3.1 Activation dimension

Overall, participants self-experienced a rather "strong" level of activation (M = 3.80, SD = 0.92). An effect of the Task-achievement situations on the activation self-experienced by participants was found ([$F(3, 52) = 3.60$, $p = .02$, $\eta_p^2 = .17$]). As depicted in Figure 5.2 A, participants in HMHR (high task mastery high ranking) condition self-experienced a higher level of activation (M = 4.18, SD = 0.65) than participants in LMLR (low task mastery low ranking) condition (M = 3.16, SD = 1.19) (Post hoc t-test: $p = .01$). The same pattern was found for participants in the LMHR (low task mastery high ranking) condition (M = 4.00, SD = 0.81) (Post hoc t-test: $p = .01$). No difference was found between HMLR (high task mastery low ranking) (M = 3.66, SD = 0.77) and LMLR conditions (Post hoc t-test: $p = .16$). Overall, participants also perceived a rather "strong" level of activation in their partner (M = 3.71, SD = 0.94). An effect of the conditions on the activation perceived in their partner was found ([$F(3, 52) = 4.00$, $p < .01$, $\eta_p^2 = .24$]). As depicted in Figure 5.2 D, participants in HMHR (M = 4.00, SD = 0.81), LMHR (M = 3.87, SD = 0.50) and HMLR (M = 4.00, SD = 0.81) conditions perceived in their partner a higher level of activation than participants in LMLR condition (M = 2.83, SD = 1.11) (Post hoc t-test: $p < .01$ for HMLR and LMHR, $p < .001$ for HMHR).

5.3.3.2 Dominance dimension

Overall, participants self-experienced a "moderate" level of dominance (M = 2.94, SD = 1.09). An effect of the Task-achievement situations on the dominance self-experienced by participants was found ([$F(3, 51) = 3.16$, $p = .04$, $\eta_p^2 = .14$]). As depicted in Figure 5.2 B, participants in LMHR condition self-experienced a higher level of dominance (M = 3.18, SD = 0.83) than participants in LMLR condition (M = 2.25, SD = 1.21) (Post hoc t-test: $p = .02$). The same pattern was found for participants in the HMLR condition (M = 3.41, SD = 0.51) (Post hoc t-test: $p < .01$). No difference was found between HMHR (M = 2.86, SD = 1.35) and LMLR conditions (Post hoc t-test: $p = .13$). Overall, participants also perceived a "moderate" level of dominance in their partner (M = 3.24, SD = 1.01). An effect of the Task-achievement situations on the dominance perceived in their partner was found ([$F(3, 49) = 3.28$, $p = .03$, $\eta_p^2 = .17$]). As depicted in Figure 5.2 E, participants perceived a higher level of dominance in their partner in the LMHR condition (M = 3.60, SD = 0.73) than in the LMLR condition (M = 2.58, SD = 0.99) (Post hoc t-test: $p < .01$). The same pattern was found for participants in the HMLR condition (M = 3.63, SD = 0.67) (Post hoc t-test: $p = .01$). No difference was found between HMHR (M = 3.13, SD = 1.24) and LMLR conditions (Post hoc t-test: $p = .14$).

5.3.3.3 Valence dimension

Overall, participants self-experienced a "moderate" level of valence (M = 3.32, SD = 1.20). An effect of the Task-achievement situations on the valence self-experienced

by participants was found ([$F(3, 51) = 5.56$, $p < .01$, $\eta_p^2 = .24$]). As depicted in Figure 5.2 C, participants in HMHR ($M = 3.62$, $SD = 1.31$), LMHR ($M = 3.43$, $SD = 0.96$) and HMLR ($M = 3.90$, $SD = 0.83$) conditions self-experienced the situation as more positive than participants in LMLR condition ($M = 2.25$, $SD = 1.05$) (Post hoc t-test: $p < .01$ for HMHR and LMHR, $p < .001$ for HMLR). Overall, participants perceived a "moderate" level of valence ($M = 3.25$, $SD = 1.14$) in their partner. An effect of the Task-achievement situations on the valence perceived in their partner was found ([$F(3, 51) = 5.35$, $p < .01$, $\eta_p^2 = .22$]). As depicted in Figure 5.2 F, participants in HMHR ($M = 3.50$, $SD = 1.21$), LMHR ($M = 3.43$, $SD = 1.03$) and HMLR ($M = 3.72$, $SD = 1.21$) conditions perceived in their partner a more positive situation than participants in LMLR condition ($M = 2.25$, $SD = 0.96$) (Post hoc t-test: $p < .01$ for HMHR, LMHR and HMLR).

	Self					Partner				
Dependent variables	*df*	*SS*	*F*	*p*	*Partial* η^2	*df*	*SS*	*F*	*p*	*Partial* η^2
Activation	52	8.07	3.60	**0.02**	0.17	52	12.01	5.56	**0.00**	0.24
Dominance	52	9.50	2.92	**0.04**	0.15	49	9.02	3.28	**0.03**	0.17
Valence	51	19.26	5.56	**0.00**	0.25	51	16.07	5.35	**0.00**	0.23

Note. Significant effects (p<=.05) are in bold

TABLE 5.5: ANOVA results for the reported intensities of activation, dominance and valence for self and partner

5.3.4 Effect of task-achievement situations on emotional dimensions

A series of ANOVAS was conducted to test the effects of the Task-achievement situations on the rating scores of the achievement emotions. Inferential statistics are reported in Table 5.6. Significant effects are depicted in Figure 5.2 and described in detail below. No effect of the Task-achievement situations was found for the following achievement emotions: anxiety, anger, frustration, disappointment, boredom, hope, pride, enjoyment and relaxation.

5.3.4.1 Shame

Overall, participants self-experienced a "very low" level of shame ($M = 2.16$, $SD = 1.49$). An effect of the Task-achievement situations on the shame self-experienced by participants was found ([$F(3, 52) = 7.30$, $p < .001$, $\eta_p^2 = .29$]). As depicted in Figure 5.2 A, participants in HMHR ($M = 1.50$, $SD = 0.89$), LMHR ($M = 2.25$, $SD = 1.29$) and HMLR ($M = 1.50$, $SD = 0.79$) conditions self-experienced significantly less shame than participants in LMLR condi-tion ($M = 3.58$, $SD = 1.97$) (Post hoc t-test: $p < .001$ for HMHR, HMLR, $p < .01$ for LMHR). Overall, participants also perceived a "very low" level of shame ($M = 1.91$, $SD = 1.40$) in their partner. An effect of the Task-achievement situations on the perceived shame in their partner was found ([$F(3, 52) = 3.85$, $p = .01$, $\eta_p^2 = .18$]). As depicted in Figure 5.2 B, a similar pattern to self-experienced shame was found for the shame perceived in the partner. Participants in HMHR ($M = 1.43$, $SD = 0.81$), LMHR ($M = 1.56$, $SD = 0.96$) and HMLR ($M =$

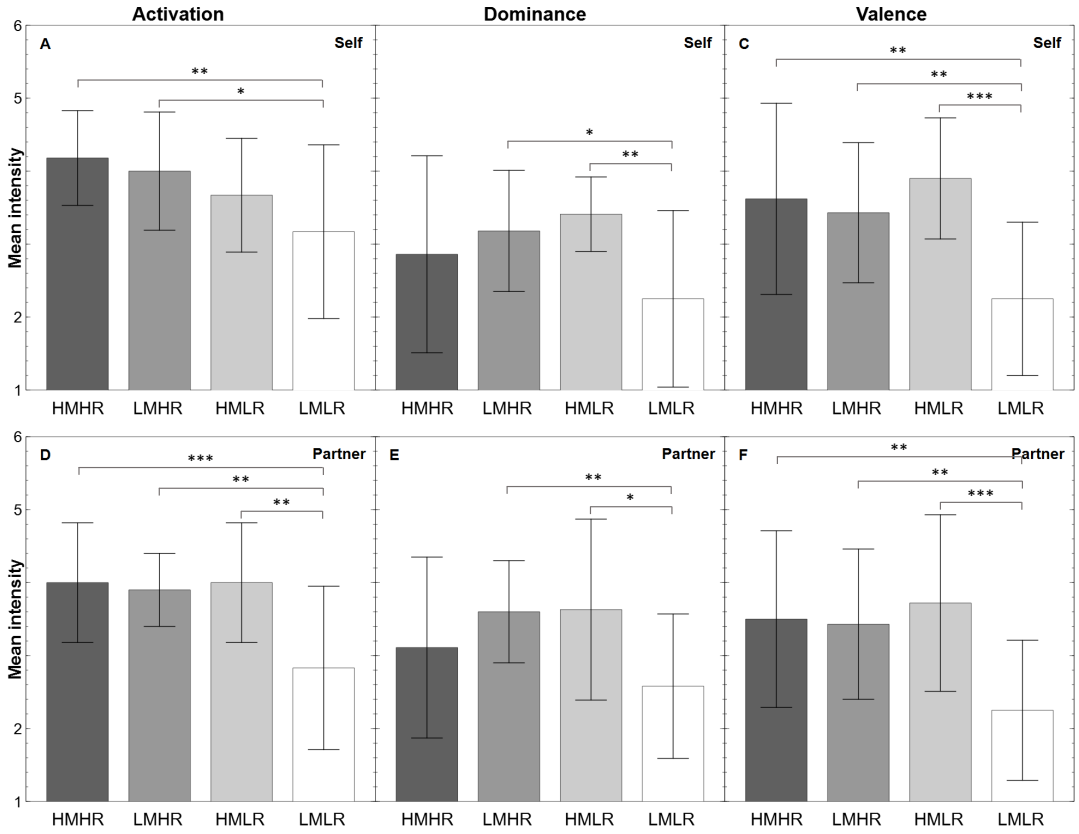

FIGURE 5.2: Mean intensities on 5-point Likert scales of activation, dominance and valence according to the different condi-tions of Task-achievement situations (HMHR : high task mastery, low ranking; LMHR: low task mastery, high ranking; HMLR: high task mastery, low ranking; LMLR: low task mastery, low ranking) ; *: p <= .05, **: p <= .01, ***: p <= .001

1.91, SD = 0.81) conditions perceived in their partner significantly less shame than participants in LMLR condition (M = 3.00, SD = 1.90) (Post hoc t-test: p < .01 for HMHR, LMHR, p = .04 for HMLR).

5.3.4.2 Joy

Overall, participants self-experienced a "moderate" level of joy (M = 4.39, SD = 1.66). An effect of the Task-achievement situations on the shame self-experienced by participants was found ([$F(3, 52) = 2.98$, p = .03, η^2_p = .14]). As depicted in Figure 5.2 D, participants in HMHR (M = 4.50, SD = 1.36) and HMLR (M = 5.25, SD = 1.28) conditions self-experienced significantly more joy than participants in LMLR condition (M = 3.33, SD = 1.55) (Post hoc t-test: p = .05 for HMHR, p < .01 for HMLR). However, no difference was found between LMHR (M = 4.43, SD = 1.96) and LMLR condi-tions (Post hoc t-test: p = .07). Overall, participants also perceived in their partner a "moderate" level of joy (M = 4.29, SD = 1.61). An effect of the Task-achievement situations on the joy perceived in the partner was found ([$F(3, 51) = 3.31$, p = .02, η^2_p = .16]). As depicted in Figure 5.2 E, participants in HMHR (M = 4.56, SD = 1.50), LMHR (M = 4.31, SD = 1.57) and HMLR (M = 5.00, SD = 1.50) conditions perceived in their

partner significantly more joy than participants in LMLR condition (M = 3.09, SD = 1.13) (Post hoc t-test: $p < .05$ for HMHR, LMHR, $p < .01$ for HMLR).

5.3.4.3 Hopelessness

Overall, participants self-experienced a "low" level of hopelessness (M = 2.53, SD = 1.66). No effect of the Task-achievement situations on the hopelessness self-experienced by participants was found ([$F(3, 52) = 2.61$, $p = .06$]). Overall, participants also perceived in their partner a "very low" level of hopelessness (M = 2.25, SD = 1.51). An effect of the Task-achievement situations on the hopelessness perceived in the partner was found ([$F(3, 51) = 4.13$, $p = .01$, $\eta_p^2 = .19$]). As depicted in Figure 5.2 C, participants in HMHR (M = 2.31, SD = 1.40), LMHR (M = 1.93, SD = 1.28) and HMLR (M = 1.50, SD = 1.40) conditions perceived in their partner significantly less hopelessness than participants in LMLR condition (M = 3.45, SD = 1.96) (Post hoc t-test: $p < .01$ for HMLR, LMHR, $p < .05$ for HMHR).

5.3.4.4 Sadness

Overall, participants self-experienced a "very low" level of sadness (M = 1.55, SD = 1.21). No effect of the Task-achievement situations on the sadness self-experienced by participants was found ([$F(3, 52) = 1.89$, $p = .14$]). Overall, participants also perceived a "very low" level of sadness in their partner (M = 1.64, SD = 1.27). An effect of the Task-achievement situations on the sadness perceived in the partner was found ([$F(3, 52) = 2.92$, $p = .04$, $\eta_p^2 = .14$]). As depicted in Figure 5.2 E, participants in HMHR (M = 1.43, SD = 1.09) and LMHR (M = 1.18, SD = 0.54) conditions perceived in their partner significantly less sadness than participants in LMLR condition (M = 2.50, SD = 1.50) (Post hoc t-test: $p < .01$ for LMHR, $p < .05$ for HMHR). However, no difference was found between HMLR (M = 1.66, SD = 1.09) and LMLR conditions (Post hoc t-test: $p = .09$).

5.3.4.5 Gratitude

Overall, participants self-experienced a "low" level of gratitude (M = 3.30, SD = 1.66). No effect of the Task-achievement situations on the gratitude self-experienced by participants was found ([$F(3, 51) = 1.53$, $p = .21$]). Overall, participants also perceived a "low" level of gratitude in their partner (M = 2.86, SD = 1.55). An effect of the Task-achievement situations on the gratitude perceived in the partner was found ([$F(3, 49) = 4.26$, $p < .01$, $\eta_p^2 = .20$]). As depicted in Figure 5.2 G, participants in HMHR (M = 2.86, SD = 1.84), LMHR (M = 2.66, SD = 1.39) and LMLR (M = 2.00, SD = 1.12) conditions perceived in their partner significantly less gratitude than participants in HMLR condition (M = 4.09, SD = 1.84) (Post hoc t-test: $p < .001$ for LMLR, $p < .05$ for HMHR and LMHR).

5.3.4.6 Relief

Overall, participants self-experienced a "low" level of relief (M = 3.12, SD = 1.79). No effect of the Task-achievement situations on the relief self-experienced by participants was found ([$F(3, 50) = 2.19$, $p = .09$]). Overall, participants also perceived a "low" level of relief in their partner (M = 3.33, SD = 1.88). An effect of the Task-achievement situations on the relief perceived in the partner was found ([$F(3, 49) = 3.05$, $p = .03$, $\eta^2_p = .15$]). As depicted in Figure 5.2 H, participants in HMHR (M = 3.85, SD = 2.34), LMHR (M = 3.81, SD = 1.42) and HMLR (M = 3.45, SD = 2.34) conditions perceived in their partner significantly more relief than participants in LMLR condition (M = 2.00, SD = 1.65) (Post hoc t-test: $p < .05$ for HMHR, LMHR and HMLR).

5.3.4.7 Contentment

Overall, participants self-experienced a "moderate" level of contentment (M = 4.07, SD = 1.82). No effect of the Task-achievement situations on the contentment self-experienced by participants was found ([$F(3, 52) = 2.27$, $p = .09$]). Overall, participants also perceived a "moderate" level of contentment in their partner (M = 4.00, SD = 1.66). An effect of the Task-achievement situations on the contentment perceived in the partner was found ([$F(3, 52) = 3.92$, $p = .01$, $\eta^2_p = .18$]). As depicted in Figure 5.2 I, participants in HMHR (M = 4.75, SD = 1.98), LMHR (M = 4.12, SD = 1.36) and HMLR (M = 4.08, SD = 1.98) conditions perceived in their partner significantly more contentment than participants in LMLR condition (M = 2.75, SD = 1.60) (Post hoc t-test: $p < .05$ for LMHR and HMLR, $p < .01$ for HMHR).

	Self					Partner				
Dependent variables	*df*	*SS*	*F*	*p*	*Partial* η^2	*df*	*SS*	*F*	*p*	*Partial* η^2
Anxiety	51	2.2	0.34	0.80	0.02	50	4.33	0.95	0.42	0.05
Anger	52	1.66	0.18	0.91	0.01	52	5.97	0.71	0.55	0.04
Frustration	52	15.82	1.48	0.23	0.08	52	8.94	0.96	0.42	0.05
Shame	52	36.64	7.30	**0.00**	0.30	52	19.76	3.86	**0.01**	0.18
Disappointment	51	17.66	1.76	0.17	0.09	52	12.29	1.29	0.30	0.07
Hopelessness	52	19.91	2.61	0.06	0.13	51	24.33	4.13	**0.01**	0.20
Boredom	52	7.55	2.50	0.07	0.13	51	3.76	1.23	0.31	0.07
Sadness	52	8.05	1.89	0.14	0.10	52	12.82	2.92	**0.04**	0.14
Hope	50	8.43	1.12	0.35	0.06	50	6.02	0.91	0.44	0.05
Pride	52	13.81	1.21	0.31	0.07	51	14.59	1.35	0.27	0.07
Joy	52	22.50	2.98	**0.04**	0.15	51	23.06	3.31	**0.03**	0.16
Enjoyment	52	5.15	1.07	0.37	0.06	52	14.86	2.23	0.1	0.11
Gratitude	51	12.41	1.54	0.22	0.08	49	26.10	4.26	**0.01**	0.20
Relaxation	52	6.61	0.76	0.52	0.04	49	13.55	1.38	0.26	0.08
Relief	50	19.83	2.20	0.10	0.12	49	29.01	3.06	**0.04**	0.16
Contentment	52	21.30	2.27	0.09	0.12	52	28.08	3.93	**0.01**	0.18

Note. Significant effects (p<=.05) are in bold

TABLE 5.6: ANOVA results for the reported intensities of the achievement emotions for self and partner

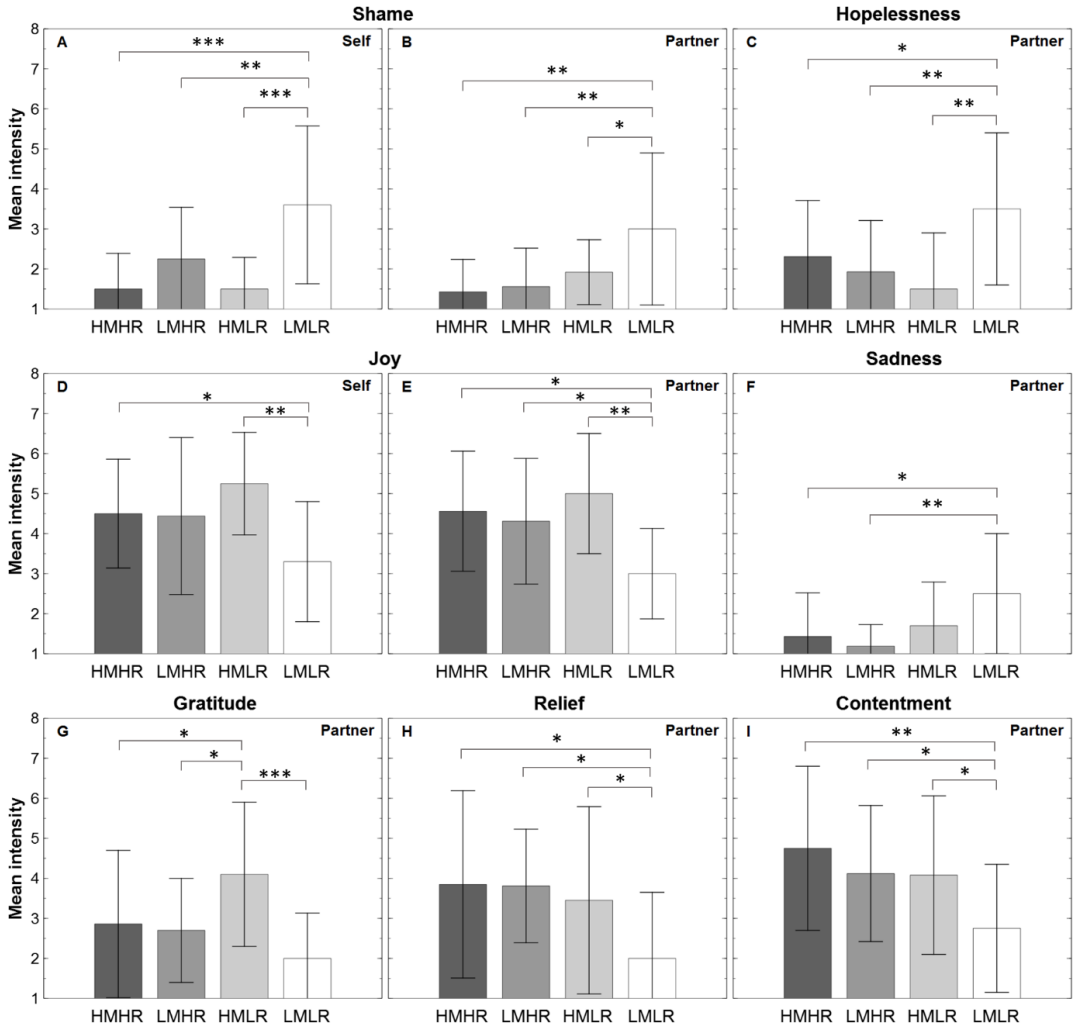

FIGURE 5.3: Mean intensities on 7-point Likert scales of emotions according to the different conditions of Task-achievement situations (HMHR : high task mastery, low ranking; LMHR: low task mastery, high ranking; HMLR: high task mastery, low ranking; LMLR: low task mastery, low ranking); *: $p <= .05$, **: $p <= .01$, ***: $p <= .001$

5.3.5 Effect of the task-achievement situations on the perception of socio-cognitive processes

A series of ANOVAS was conducted to test the effects of the Task-achievement situations on the average scores corresponding to the different socio-cognitive processes. For a given socio-cognitive process, the average score corresponds to the average rating scores of its constitutive communicative socio-cognitive exchanges (cf. Table 5.1). Inferential statistics are reported in Table 7. Significant effects are depicted in Figure 4 and described in detail below. No effect of the Task-achievement situations was found for the following socio-cognitive processes: sustaining mutual understanding, information pooling, reaching consensus, and time management.

Dependent variables	Self					Partner				
	df	*SS*	*F*	*p*	*Partial* η^2	*df*	*SS*	*F*	*p*	*Partial* η^2
Sustaining mutual understanding	52	7.14	1.69	0.18	0.09	52	6.79	1.39	0.25	0.07
Information pooling	52	10.77	2.28	0.09	0.12	52	8.41	1.69	0.18	0.09
Transactivity	52	19.62	3.46	**0.02**	0.17	52	20.71	3.29	**0.03**	0.16
Reaching consensus	52	8.80	1.80	0.16	0.09	52	10.34	1.94	0.14	0.10
Task management	52	13.94	3.32	**0.03**	0.16	52	11.37	2.58	0.06	0.13
Time management	51	6.75	1.13	0.35	0.06	52	2.04	0.33	0.80	0.02

Note. Significant effects (p<=.05) are in bold

TABLE 5.7: ANOVA results for the perception of self and partner-use of the different socio-cognitive processes

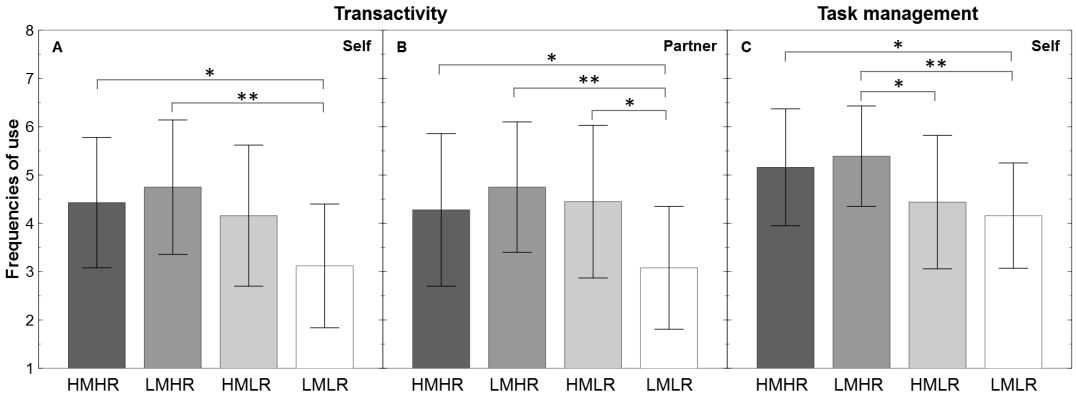

FIGURE 5.4: Mean frequencies on 7-point Likert scales of the perception of socio-cognitive processes use according to the different conditions of Task-achievement situations (HMHR : high task mastery, low ranking; LMHR: low task mastery, high ranking; HMLR: high task mastery, low ranking; LMLR: low task mastery, low ranking); *: p <= .05, **: p <= .01, ***: p <= .001

5.3.5.1 Transactivity

Overall, participants reported a "moderately often" self-use of transactive exchanges (M = 4.18, SD = 1.46). An effect of the Task-achievement situations was found ([F(3, 52) = 4.46, p = .02, η^2_p = .16]). As depicted in Figure 5.4 A, participants in HMHR (M = 4.43, SD = 1.35) and LMHR (M = 4.75, SD = 1.39) conditions reported significantly more self-use of transactive exchanges than participants in LMLR condition (M = 3.12, SD = 1.28) (Post hoc t-test: p < .01 for LMHR, p < .05 for HMHR). However, no difference was found between HMLR (M = 4.16, SD = 1.46) and LMLR conditions (Post hoc t-test: p = .06). Overall, participants also reported a "moderately often" partner-use of transactive exchanges (M = 4.19, SD = 1.53). An effect of the Task-achievement situations was found ([F(3, 52) = 3.28, p = .02, η^2_p = .15]). As depicted in Figure 5.4 B, participants in HMHR (M = 4.28, SD = 1.58), LMHR (M = 4.75, SD = 1.35) and HMLR (M = 4.45, SD = 1.58) conditions perceived significantly more partner-use of transactive exchanges than participants in LMLR condition (M = 3.08, SD = 1.27) (Post hoc t-test: p < .05 for HMHR, HMLR, p < .01 for LMHR).

5.3.5.2 Task management

Overall, participants reported a "quite often" self-use of task management exchanges (M = 4.86, SD = 1.25). An effect of the Task-achievement situations was found ([F(3, 52) = 3.32, p = .02, η^2_p = .16]). As depicted in Figure 5.4 C, participants in HMHR (M = 5.16, SD = 1.25) and LMHR (M = 5.59, SD = 1.09) conditions reported significantly more self-use of task management exchanges than participants in LMLR condition (M = 4.16, SD = 1.09) (Post hoc t-test: $p < .01$ for LMHR, $p < .05$ for HMHR). Participants also reported more self-use of task management in LMHR condition than in HMLR condition (Post hoc t-test: $p < .05$). However, no difference was found between HMLR (M = 4.44, SD = 1.38) and LMLR conditions (Post hoc t-test: p = .06).

5.3.6 Mediation effects

Mediation analyses were carried out to test the hypothesis that emotions have a key role in collaboration, acting as go-betweens between task-achievement appraisals and the perception of socio-cognitive processes. Following Baron and Kenny's (1986) requirements, a mediation model was tested when a significant effect of the Task-achievement situations on the collaborative process (Figure 5.5, C Path) and a significant effect of the Task-achievement situations on the emotion (Figure 5.5, A Path) were found. Applying these requirements, 45 models were tested in total. A mediation effect was validated when the effect of the emotion (or emotional dimension) on the collaborative process (controlling the effect of the Task-achievement situations) was significant (Figure 5.5, B path), the effect of the Task-achievement situations on the collaborative process (controlling the effect of the emotion) (Figure 5.5, C' path) was not significant anymore or reduced and the indirect effect (AB path) was significant (as showed through a Sobel test). As the independent variable (Task-achievement situations) implied more than two modalities, the following contrasts of the independent variable were chosen: LMLR versus LMHR (Figure 5.5, X1), LMLR versus HMLR (Figure 5.5, X2), LMLR versus HMHR (Figure 5.5, X3). Only models involving the emotional dimension of activation gave rise to significant mediation effects. They are described in detail below and reported in Appendix C. For the sake of brevity, non-significant models are not reported here (overall results are available upon request to authors).

5.3.6.1 Mediation effects of self-experienced activation

The level of self-experienced activation by participants appeared to mediate the relationship between the Task-achievement situations and the self-use perception of the transactivity process in the HMHR (Figure 5.5 A X1) and LMHR (Figure 5.5 A X3) conditions. However, the Sobel tests were not significant in these two cases (z^{X1} = 1.85, p = .09; z^{X3} = 3.09, p = .06). Therefore, one cannot conclude to a mediation effect. The level of self-experienced activation appeared to mediate the relationship between the Task-achievement situations and the partner-use perception of the

transactivity process in the HMHR (Figure 5.5 B X1) and LMHR (Figure 5.5 B X3). This is confirmed for HMHR (z^{X3} = 1.90, p = .05) but not for LMHR (z^{X1} = 1.74, p = .08). Therefore, one can conclude to a mediation effect only in HMHR condition. Finally, no mediation effect was found for the self-use perception of the task management process as B path was not significant (Figure 5.5 C).

5.3.6.2 Mediation effect of activation perceived in the partner

The level of activation perceived in the partner appeared to mediate the relationship between the Task-achievement situations and the self-use perception of the transactivity process in HMHR (Figure 5.5 D X1), HMLR (Figure 5.5 D X2) and LMHR (Figure 5.5 D X3) conditions. This is confirmed in these three cases by the Sobel tests (z^{X1} = 1.99, p = .04; z^{X2} = 2.02, p = .04; z^{X3} = 2.07, p = .03). Therefore, one can conclude to a mediation effect in this case. The level of activation perceived in the partner appeared to mediate the relationship between the Task-achievement situations and the partner-use perception of the transactivity process in HMHR (Figure 5.5 E X1), HMLR (Figure 5.5 E X2) and LMHR (Figure 5.5 E X3) conditions. This is confirmed in these three cases by the Sobel tests (z^{X1} = 2.00, p = .04; z^{X2} = 2.04, p = .04; z^{X3} = 2.09, p = .03). Therefore, one can conclude to a mediation effect in this case. The level of activation perceived in the partner appeared to mediate the relationship between the Task-achievement situations and the self-use perception of the task management process in HMHR (Figure 5.5 F X1) and LMHR (Figure 5.5 F X3) conditions. This is confirmed in these two cases by the Sobel tests (z^{X1} = 2.92, p = .03; z^{X3} = 2.72, p = .02).

5.4 Discussion

5.4.1 Hypotheses and findings

At a descriptive level, a wide range of emotions (positive and negative) were self-experienced and perceived in the partner more than "weakly" in every condition, contrasting, with the few polarized emotions highlighted in the CVT (Pekrun, 2006). Indeed, our study shows that even "fully positive" situations (HMHR) are prone to elicit negative emotions and "fully negative" situations (LMLR) are prone to elicit positive emotions (Table 5.9). In our view, several reasons may explain this result: (1) all participants, regardless of task achievement, enjoyed, on average, "quite strongly" the task (Table 5.8), (2) some emotions are not exclusively related to task achievement (e.g., frustration may also reflect cognitive processing of information) and therefore occurs no matter how well the task is achieved, (3) most of the time (and in our task as well), success and failure are probabilistic. Indeed, even when failure is almost inevitable, there is always some hope that the situation may improve or some relief after an almost certain success. Therefore, it makes sense that some positive and negative, activating and deactivating emotions are reported in each experimental condition more than "weakly". This result supports the idea that an emotional

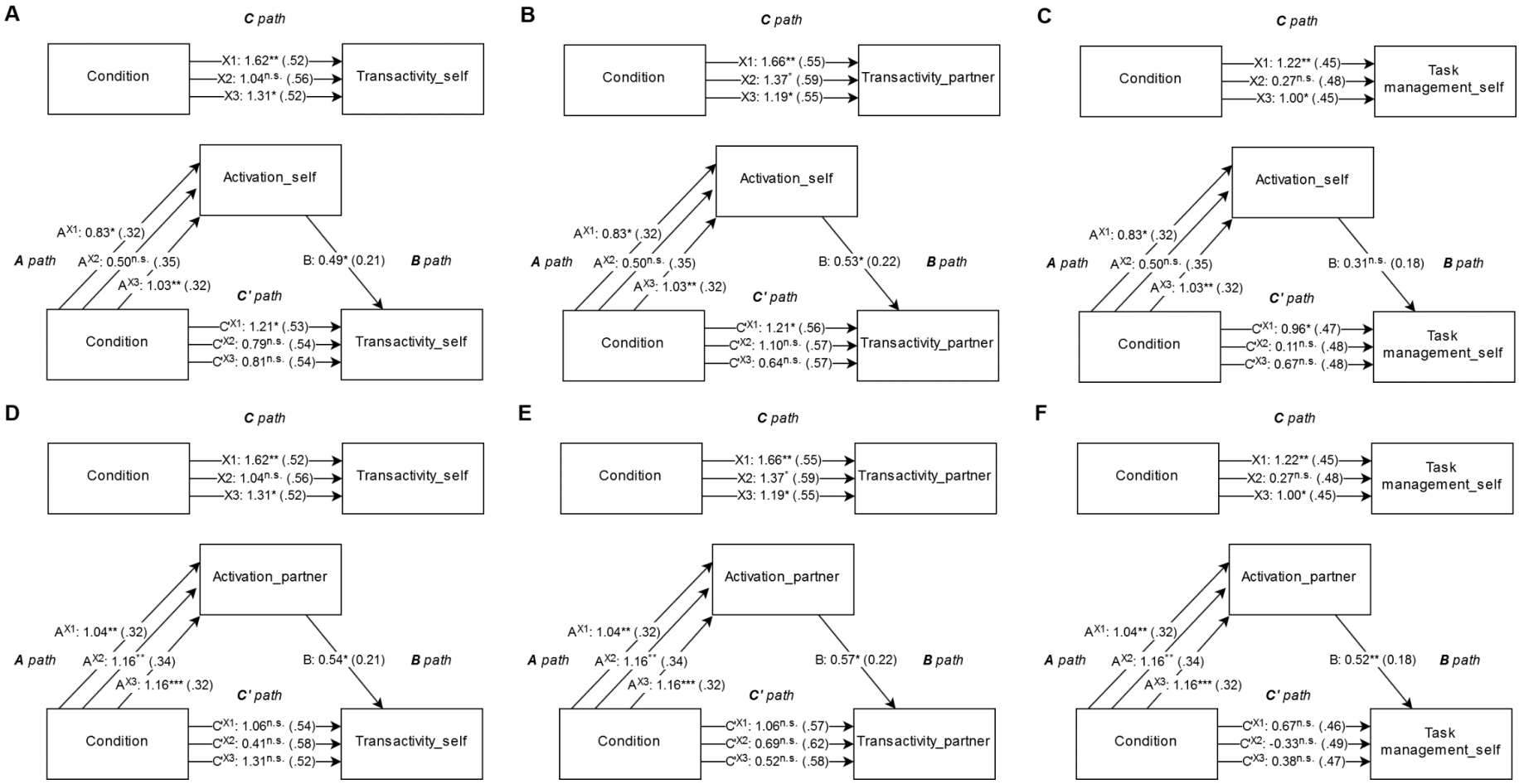

FIGURE 5.5: Mediation effects of Activation

profile is better suited than a single emotion to plainly explain how people's emotions relate to task achievement (Jarrell et al., 2016). However, it is worth noting that some emotions are highly unlikely to emerge in certain situations (e.g., shame and hopelessness when task mastery and ranking are high or pride or relief when task-mastery and ranking feedback are low). As proposed in the CVT, some emotions, therefore, appear prototypical to specific task-achievement situations. Therefore, these prototypical emotions were posited to significantly differ according to the different levels of action-outcome, situation-outcome and success expectancies. For the sake of clarity, assumptions regarding emotional dimensions, achievement emotions and the perception of socio-cognitive processes (Table 5.1) are compared with actual findings (Table 5.9) and discussed in the following sections, also considering how the collaborative situations may explain some observed discrepancies.

5.4.1.1 Low task mastery low ranking condition

In this condition, participants were intended to think that their work was producing negative outcomes due to their poor self-action. As expected, participants self-experienced and perceived in their partner the lowest level of activation. This result is consistent with a situation where participants disengage the task (i.e., give up when faced with dull or difficult tasks; Liem et al., 2008). Participants also self-experienced and perceived in their partner the lowest level of dominance, which is also consistent with the combination of low action-outcome and low situation-outcome expectancies. Consistently, participants also self-experienced and perceived in their partner this situation as the most negative, in line with low success expectancies. Regarding achievement emotions, negative and deactivating emotions were expected to be self-experienced more intensively in this condition comparing to the other conditions. It is the case for the hopelessness and sadness perceived in the partner. However, shame (activating emotion) was self-experienced and perceived in the partner at a relatively high level in this condition, indicating, as expected, that participants attribute negative outcomes to themselves and not to external circumstances. Finally, and in line with the assumption proposed, the use of the socio-cognitive processes transactivity and task-management was perceived as relatively low compared to the other conditions, consistently with false feedback. Therefore, this condition seems to decrease how participants reason and build on their partner's contributions and manage group work.

5.4.1.2 High task mastery high ranking condition

In this condition, participants were intended to think that their work was producing positive outcomes and that their self-action was necessary for these positive outcomes. As expected, participants self-experienced and perceived in their partner a relatively high level of activation, compared to LMLR condition. This result denotes a higher level of engagement in this condition. Participants also self-experienced

the situation as more positive and perceived the same thing in their partner, consistently with high success expectancies. However, and as opposed to the assumption made, they did not feel and perceive a higher level of dominance compared to LMLR condition. This result could be explained in terms of loss aversion (i.e., the tendency for losses to have a more significant hedonic impact than comparable gains; Rick, 2011), as success was just expected and not guaranteed. As loss aversion has a tight connection with fear (Schulreich et al., 2016), a low coping potential emotion (Broekens, 2012), the dread of seeing a highly positive situation deteriorate could have lessened the overall dominance perception. Regarding achievement emotions, positive and activating emotions were expected to be self-experienced more intensively in this condition comparing to the other conditions. If participants indeed self-experienced and perceived in their partner a higher level of joy (activating) compared to LMLR condition, they also perceived relief and contentment (retrospective and deactivating) in their partner. This result seems to go hand in hand with a weaker level of dominance. However, and interestingly, these emotions are more intensively perceived in their partner rather than self-experienced (self-reported results are marginally significative, Table 5.5). This result could indicate that, in this collaborative context, participants could primarily focus on their partner's emotions rather than theirs. Finally, and in line with the assumption made, the use of the socio-cognitive processes transactivity and task-management was perceived as relatively high in this condition. Therefore, this condition seems to increase how participants reason and build on their partner's contributions and manage the group work.

5.4.1.3 Low task mastery high ranking condition

In this condition, participants were intended to think that the situation was producing positive outcomes in any case despite their poor self-action. As expected, participants self-experienced and perceived in their partner a relatively high level of dominance compared to LMLR condition. This result is consistent with the combination of low action-outcome and high and positive situation-outcome expectancies (Pekrun, 2006). Participants also self-experienced the situation as more positive than in the LMLR condition and perceived the same thing in their partner, consistently with high success expectancies. However, and contrary to what was expected, participants self-experienced and perceived in their partner a higher level of activation (compared to LMLR condition). This result contradicts our assumption because, in a kind of situation where one's own work is poor and no self-action is needed to succeed, participants should tend to disengage and reduce group work, leading to low activation. One possible explanation for this result could be the expected high reward. Indeed, the unexpected possibility to be successful against the run of play could have kept the participants aroused. Regarding the achievement emotions, positive and deactivating emotions were expected to be self-experienced and perceived in the partner more intensively in this condition than in LMLR condition. This hypothesis appears correct for the perception of contentment and relief in their

partner. However, participants also self-experienced and perceived a relatively high level of joy (retrospective and activating) in their partner. Finally, and in disagreement with the assumption made, the use of the socio-cognitive processes transactivity and task-management was perceived as relatively high in this condition. A positive outcome could, therefore, contribute to increasing how participants reason and build on their partner's contributions and manage the group work, despite low task mastery. This point will be discussed in section 5.4.2.

5.4.1.4 High task mastery low ranking condition

In this condition, low action-outcome expectancies were the result of high and negative situation-outcome despite high task mastery. In other words, even if participants had a good task mastery, it was useless as the ranking was staying low, leading them to believe that other previous dyads (i.e., external circumstances, the situation) were better than them (high and negative situation-outcome expectancies). As expected, participants did not self-experience a higher level of activation compared to LMLR condition. However, they perceived a higher level of activation in their partner. In addition, and contrary to our assumption, participants self-experienced and perceived in their partner a relatively high level of dominance despite low action-outcome expectancies. Counterintuitively also, participants self-experienced the situation as more positive than LMLR condition and as positive as the other conditions, despite low success expectancies. They also perceived the same thing in their partner. More surprising still, participants self-experienced (joy) and perceived in their partner positive emotions (relief, contentment, gratitude) at a relatively higher level than LMLR condition and at the same level than conditions with high success expectancies. It was also the only condition where gratitude was perceived in the partner at a higher level than all the other conditions. Finally, although participants did not perceive an increase in their own use of socio-cognitive processes, they perceive a higher partner-use of processes dedicated to reason and build on the partner's contributions (transactivity process). Taken as a whole, these results seem to show that 1) participants seem to overlook task outcomes and focus on task mastery and 2) see task mastery mainly through their partner. These points will be discussed in section 5.4.3.

5.4.2 Does achievement emotions skew the perception of socio-cognitive processes?

Activation (especially activation perceived in the partner) is the only emotional dimension mediating the relation between task-achievement appraisals and the perception of the use of the socio-cognitive processes transactivity and task-management. No other emotional dimensions nor achievement emotions appeared to mediate this relationship. In our view, this result reinforces the idea that people hardly associate their own or partner's conscious discrete emotions with the use of

specific socio-cognitive processes. Indeed, although people deliberate actions based on what is available to conscious awareness (e.g., subjective feeling), an implicit system also process complex information that can influence actions below the level of consciousness (Sentman et al., 2007). Therefore, the cognitive and socio-cognitive effects of specific emotions, although significant, could operate mostly under the level of consciousness and be challenging to report explicitly. Instead, at a conscious level, participants seem to rely on vaguer affective states to evaluate how they use some socio-cognitive processes during collaborative problem-solving. In our case, high levels of activation mediating the relationship between task-achievement appraisals and the perception of socio-cognitive processes could, therefore, interfere with that perception. Indeed, participants in LMHR condition perceive that they reason and build more on their partner's contributions and manage more the group work in a situation where they regularly received low task mastery feedback. We propose that, as participants self-experienced and perceived in their partner a high level of activation due to positive expected outcomes in this condition, they also tend to perceive themselves as collaborating more efficiently. One question then arises: to what extent is this perception in line with the actual use of socio-cognitive exchanges? Affective arousal (identical to activation) is known to influence judgments, learning, and memory (Tyng et al., 2017). For Storbeck and Clore (Storbeck and Clore, 2008), arousal can serve as information and influence judgments by indicating the importance of an event. However, these authors also outline that the cause of increased arousal can sometimes be misattributed and transferred to another contiguous but unrelated events (Dutton & Aron, 1974). In LMHR condition, we assume that a similar process could have occurred. Indeed, activation elicited by high success expectancies could have led the participants to evaluate a greater use of some collaborative processes. However, this evaluation could be more or less disconnected from what they really did. This possible explanation must, of course, be deepened (cf. section 5.5).

5.4.3 Do partner's emotions influence group achievement goal?

Another unexpected result is how participants perceive task achievement in HMLR condition. In this condition, participants, according to feedback, fail to reach a positive outcome despite high task mastery. The combination of low action-outcome and high and negative situation-outcome expectancies should have led them to decrease group work and, hence, the perception of the use of the socio-cognitive processes. This is found at an individual level since participants did not evaluate themselves as reasoning and building on the partner's contributions or manage the group work more than in LMLR condition. However, in this collaborative condition (HMLR), although participants did not feel particularly aroused by the task, they perceived in their partner a relatively high level of dominance and valence. Why do participants perceive high dominance and valence in their partner when failure is expected?

We propose that some emotions perceived in the partner intervene in these circumstances. First, activation perceived in their partner may lead participants to evaluate their partner as reasoning and building more on their contributions (mediating effect, Figure 5.5 E). Second, participants perceive a higher level of gratitude from their partner only in this condition (Figure 5.3 G). Taken as a whole, these results are consistent with some findings concerning group influence in collaborative learning and problem-solving. According to Mullins et al. (2013), collaboration with a partner may increase the feeling of relatedness when group activity appears positively valued by the other, promoting task enjoyment, collective efficacy, and group cohesiveness. In doing so, it could strengthen motivation and engagement, reinforce group persistence and effortful learning, leading to appraise a difficult situation more as a challenge than a predictable failure (Kaplan and Maehr, 2002; Mullins et al., 2013). In our view, these different aspects intervened in the HMLR condition and drove the group focus towards a mastery (i.e., the desire to understand the task and develop abilities) rather than a performance goal (i.e., the desire to obtain positive outcomes) (Darnon et al., 2007; Pintrich et al., 2003). What we found is in line with the fact that a mastery goal drives people to associate their performance with individual standards. In other words, they could compare their performance, not to inter-groups (the previous dyads in our study) but intra-group standards (Hall et al., 2016). In this way, participants could not have considered the ranking as relevant to reflect their performance. Instead, they may have self-experienced and perceived in their partner high dominance and positive valence related to their group standards (e.g., high task mastery). We propose that activation and gratitude perceived in the partner could facilitate a switch toward a mastery goal in difficult collaboration when collective efficacy is preserved (i.e., the conviction that the group is able to perform a given task; Mullins et al., 2013).

5.5 Further considerations

As with any research involving human subjects, the present study is not without limitations. This is especially true in this experiment as we tried to preserve both experimental (in order to identify causal relationships) and ecological (in order to assess genuine collaboration) sides in the assessment of the perception of socio-cognitive processes. Several limitations to the present study should be noted.

First, although several methodological precautions have been taken to maximize the belief that feedback was true, we cannot be sure that participants have entirely related their achievement to it. In addition, some confounding variables such as the experience with similar problem-solving collaborative games or the perception of the actual progress in the game map could have weakened the feedback effect (perceived progress is also related to task-achievement appraisals and achievement emotions; see Hall et al., 2016). Thus, a manipulation check should have been used to determine the effectiveness of the experimental manipulation.

Second, our study included a vast majority of men (46) and only a few women (10). In addition to limiting the scope of the results obtained, the low number of women prevented us from evaluating a potential gender effect.

Third, another limitation is the sample size that allowed us to uncover findings with only large effect sizes. Therefore, some interesting but more moderate effects could not be considered in this study, which limits the global comprehension of the investigated phenomenon. Besides, as our experiment focused on the perception of socio-cognitive processes, we did not investigate the actual socio-cognitive exchanges nor their relationship with group performance. However, as outlined above, we assume that, in at least one condition (LMHR), the activation could have skewed judgment regarding the use of socio-cognitive processes. It is also difficult to clearly explain why the perception of only two socio-cognitive processes (viz., transactivity and task management) were mediated by emotional activation. Drawing on our findings, it is, in fact, possible that all socio-cognitive processes are influenced by emotions but only some are related to the subjective feeling of emotional activation. Transactivity (as it may involve constructive conflict) and task management (as it may involve negotiation and compromise) could be more related to arousal than other socio-cognitive processes, such as sharing mutual understating or information pooling for example. In this regard, we plan to compare the participants' self-evaluation and the actual use of socio-cognitive processes through an objective assessment (e.g., by transcribing and categorizing all the communicative exchanges). This could help to deeply enrich the relationships between emotions (self-experienced and perceived in the partner) and their impact (implicit or explicit) on socio-cognitive processes.

Fourth, another issue is the use of mediation analyses in the context of cross-sectional studies. Recent findings show that cross-sectional mediation could lead to biased estimates and falsely revealed a possible mediator (see Maxwell et al., 2011). Thus, our mediation results need to be reproduced in a longitudinal analysis to assess their reliability.

Fifth, metacognitive aspects have not been considered as part of this study. Metacognitive processes refer to the knowledge of one's own cognitive processes (Davidson et al., 1994), and precisely, higher-order thinking directed to the appraisal, monitoring, and control of the cognitive processes involved in problem-solving (Livingston, 2003). Similarly, socio-metacognition refers to the learner's abilities to regulate group processes to optimize collaboration (Hogan, 1999), especially regarding socio-cognitive processes. In our study, we only focused on "default" socio-cognitive behaviors under some task-achievement appraisals constraints. In other terms, we have not systematically analyzed how participants explicitly change their socio-cognitive processes to adapt to the different situations encountered. However, socio-metacognitive abilities are of growing interest in (CS)CL and people's ability to monitor and regulate socio-cognitive collaborative processes is a major component of efficient collaboration (Borge and White, 2016; Järvenoja and Järvelä, 2013). In this

regard, the results uncovered in this study outline that meta-emotional monitoring and regulation could play an important role in socio-metacognition. Especially, stimulating the sharing (regulation aspect) of emotion such as gratitude or taking into account the possible skewing effect of some affective states such as group arousal (monitoring aspect) could lead to better regulation of socio-cognitive processes in (CS)CL.

Finally, although we do not think that this specific experimental design can be used as it stands for practical purposes, we believe that more research in this area could lead to a better understanding of collaborative problem-solving and enrich the development of collaborative tools integrating these research findings in their design. For example, in difficult collaborative tasks, developing tools promoting the sharing of social emotions such as gratitude to foster a feeling of relatedness and persistence between group members, which could, as our results suggest, preserve the use of qualitative socio-cognitive processes. Also, the possible skewing effect of activation on the perception of some socio-cognitive processes leads us to believe that the perception of some socio-cognitive processes could not be always in line with what is really done by collaborators. In our opinion, tools should be developed to counterbalance this effect. For example, some computational linguistic techniques such as semantic analysis of discourse could provide cues about real-time use of socio-cognitive processes and help problem-solvers to increase awareness and usage of qualitative socio-cognitive processes.

5.6 Conclusion

Drawing on the CVT that highlights the role of achievement emotions in learning, we elaborated an experiment aiming at studying the relationships between task-achievement appraisals, emotions, and the perception of the socio-cognitive processes use in group problem-solving. Four different collaborative situations were built by the manipulation of action-outcome, situation-outcome, and success expectancies through false feedback concerning group task mastery and group expected ranking. Emotional dimensions, achievement emotions and socio-cognitive processes, both self-experienced and perceived in the partner, were compared in these different conditions. Besides, the mediating effects of emotions on the relationship between task-achievement appraisals and the perception of the socio-cognitive processes have been tested. In general, four main results can be highlighted. First, we confirm that group task achievement is related to emotions. Both emotional dimensions and achievement emotions are influenced by task-achievement appraisals. In addition, this effect is not limited to self-experienced emotions but also found for the emotions perceived in the partner. Self-experienced activation, dominance, valence, shame, and joy, as well as activation, dominance, valence, hopelessness, sadness, gratitude, relief, and contentment perceived in the partner, were significantly influenced by task-achievement appraisals.

Second, no mediating effects of achievement emotions have been found. This seems to demonstrate that subjective feelings of achievement emotions do not intervene to evaluate how participants mobilize socio-cognitive processes during real-time collaborative problem-solving. In our view, this can be explained through at least two reasons: 1) discrete emotions are too specific to be related to particular socio-cognitive processes in synchronous collaboration and 2) the effects of achievement emotions on the perception of socio-cognitive processes could be mostly unconscious, or at least implicit.

Third, what we found, however, is that the level of activation (especially perceived in the partner) could serve as a heuristic giving an overview of the socio-cognitive involvement. This could be depicted as follows: "If my partner and I are aroused by what we are doing, then our group has a valuable collaborative involvement". In this way, activation could skew how people appraise collaboration and may lead to inaccurate judgments under certain circumstances. For example, in our experiment, a high level of activation probably induced by high success expectancies could have skewed the participants' perception regarding their use of some socio-cognitive processes (transactivity and task management). Fourth, the partner's emotions could change the group achievement goal (towards mastery) in a difficult collaborative situation when collective efficacy is preserved. Indeed, activation and gratitude perceived in the partner could enhance group relatedness and stimulate mastery rather than performance goals. In this way, the group could exhibit more persistence than what we could expect in individual settings.

	Overall		HMHR		LMHR		HMLR		LMLR	
	Self	*Partner*	*Self*	*Partner*	*Self*	*Partner*	*Self*	*Partner*	*Self*	*Partner*
Dependent variables	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Emotional dimensions										
Activation	3.80 (0.92)	3.71 (0.94)	4.18 (0.65)	4.00 (0.81)	4.00 (0.81)	3.87 (0.50)	3.66 (0,77)	4.00 (0.81)	3.16 (1.19)	2.83 (1.11)
Dominance	2.94 (1.09)	3.24 (1.01)	2.86 (1.35)	3.13 (1.24)	3.18 (0.83)	3.60 (0.73)	3.41 (0.51)	3.63 (0.67)	2.25 (1.21)	2.58 (0.99)
Valence	3.32 (1.20)	3.25 (1.14)	3.62 (1.31)	3.50 (1.21)	3.43 (0.96)	3.43 (1.03)	3.90 (0.83)	3.72 (1.21)	2.25 (1.05)	2.25 (0.96)
Achievement emotions										
Anxiety	2.49 (1.45)	1.96 (1.22)	2.75 (1.23)	1.81 (1.10)	2.31 (1.49)	1.66 (1.11)	2.27 (1.73)	2.09 (1.10)	2.58 (1.50)	2.41 (1.37)
Anger	2.71 (1,69)	2.41 (1.65)	2.68 (1.13)	2.75 (1.43)	2.87 (1.96)	2.25 (2.01)	2.41 (1.97)	1.91 (1.43)	2.83 (1.80)	2.66 (1.82)
Frustration	4.14 (1.91)	3.67 (1.75)	3.56 (1.99)	3.62 (1.66)	4.43 (2.15)	3.43 (1.75)	3.75 (1.42)	3.33 (1.66)	4.91 (1.72)	4.41 (1.88)
Shame	2.16 (1.49)	1.91 (1.40)	1.50 (0.89)	1.43 (0.81)	2.25 (1.29)	1.56 (0.96)	1.50 (0.79)	1.91 (0.81)	3.58 (1.97)	3.00 (1.90)
Disappointment	3.49 (1.86)	3.00 (1.79)	2.68 (1.88)	2.81 (1.83)	3.46 (1.80)	2.43 (1.75)	4.00 (1.70)	3.33 (1.83)	4.08 (1.88)	3.66 (2.10)
Hopelessness	2.53 (1.66)	2.25 (1.51)	2.31 (1.35)	2.31 (1.40)	2.50 (1.63)	1.93 (1.28)	1.83 (1.26)	1.50 (1.40)	3.58 (2.06)	3.45 (1.96)
Boredom	1.44 (1.04)	1.47 (1.01)	1.31 (0.60)	1.31 (1.01)	1.06 (0.25)	1.56 (0.89)	1.50 (1.24)	1.16 (1.01)	2.08 (1.62)	1.90 (1.44)
Sadness	1.55 (1.21)	1.64 (1.27)	1.43 (0.89)	1.43 (1.09)	1.43 (1.09)	1.18 (0.54)	1.16 (0.38)	1.66 (1.09)	2.25 (1.95)	2.50 (1.50)
Hope	4 (1.59)	3.90 (1.48)	4.00 (1.60)	4.26 (1.48)	4.53 (1.50)	4.00 (1.50)	3.91 (1.67)	3.90 (1.48)	3.41 (1.56)	3.33 (1.37)
Pride	3.35 (1,95)	3.12 (1,91)	3.56 (2.50)	3.26 (2.43)	3.56 (1.86)	3.50 (1.89)	3.75 (1.13)	3.41 (2.43)	2.41 (1.83)	2.16 (1.33)
Joy	4.39 (1.66)	4.29 (1.61)	4.50 (1.36)	4.56 (1.50)	4.43 (1.96)	4.31 (1.57)	5.25 (1.28)	5.00 (1.50)	3.33 (1.55)	3.09 (1.13)
Enjoyment	5.35 (1.27)	4.67 (1.53)	5.56 (1.37)	5.18 (1.47)	5.31 (1.25)	4.75 (1.91)	5.66 (1.37)	4.8.3 (1.47)	4.83 (1,52)	3.75 (0.96)
Relaxation	3.35 (1.68)	3.32 (1.82)	3.12 (1.70)	2.66 (1.67)	3.00 (1.59)	3.62 (2.06)	3.75 (2.17)	4.00 (1.67)	3.75 (1.21)	3.09 (1.64)
Relief	3.12 (1.79)	3.33 (1.88)	3.43 (1.89)	3.85 (2.34)	3.40 (1.72)	3.81 (1.42)	3.54 (1.75)	3.45 (2.34)	2.00 (1.47)	2.00 (1.65)
Contentment	4.07 (1.82)	4.00 (1.66)	4.75 (2.04)	4.75 (1.98)	4.12 (1.70)	4.12 (1.36)	4.16 (1.33)	4.08 (1.98)	3.00 (1.80)	2.75 (1.60)
Gratitude	3.30 (1.66)	2.86 (1.55)	3.53 (1.95)	2.86 (1.84)	3.06 (1.52)	2.66 (1.39)	4 (1.41)	4.09 (1.84)	2.66 (1.55)	2.00 (1.12)
Socio-cognitive processes										
Sustaining mutual understanding	4.90 (1.21)	4.86 (1.28)	4.88 (1.10)	4.92 (0.95)	5.25 (1.18)	5.16 (1.43)	5.11 (1.18)	5.02 (0.95)	4.27 (1.30)	4.22 (1.38)
Information pooling	4.20 (1.29)	4.58 (1.25)	4.68 (1.22)	4.58 (1.25)	4.46 (1.21)	4.45 (1.21)	3.77 (1.28)	3.87 (1.25)	3.64 (1.31)	3.64 (1.35)
Transactivity	4.18 (1.46)	4.19 (1.53)	4.43 (1.35)	4.28 (1.58)	4.75 (1.39)	4.75 (1.35)	4.16 (1.46)	4.45 (1.58)	3.12 (1.28)	3.08 (1.27)
Reaching consensus	3.13 (1.30)	3.19 (1.36)	3.62 (1.10)	3.69 (1.10)	2.97 (1.26)	3.03 (1.38)	3.30 (1.44)	3.41 (1.10)	2.54 (1.31)	2.52 (1.38)
Task management	4.86 (1.25)	4.87 (1.26)	5.16 (1.21)	5.08 (1.27)	5.39 (1.04)	5.39 (1.13)	4.44 (1.38)	4.55 (1.27)	4.16 (1.09)	4.22 (1.24)
Time management	3.28 (1.41)	3.46 (1.40)	3.40 (1.41)	3.53 (1.39)	3.46 (1.25)	3.65 (1.41)	3.54 (1.78)	3.45 (1.39)	2.62 (1.20)	3.12 (1.36)

Note. **Activation and Dominance** (1 = *very weakly,* 2 = *weakly*, 3 = *moderately*, 4 = *strongly*, 5 = *very strongly*). **Valence** (1 = *very negatively,* 2 = *negatively*, 3 = *neither negatively nor positively*, 4 = *positively*, 5 = *very positively*). **Achievement emotions** (1 = *not at all,* 2 = *very weakly*, 3 = *weakly*, 4 = *moderately*, 5 = *quite strongly*, 6 = *strongly*, 7 = *very strongly*). **Socio-cognitive processes** (1 = *never,* 2 = *very rarely*, 3 = *rarely*, 4 = *moderately often*, 5 = *quite often*, 6 = *often*, 7 = *very often*)

TABLE 5.8: Descriptive statistics

	Emotional dimensions						Emotions		Socio-cognitive processes use		
	Activation		Dominance		Valence		Achievement emotions		Transactivity		Task management
Conditions	Self	Partner	Self	Partner	Self	Partner	Self	Partner	Self	Partner	Self
HMHR	High†	High†	**nd**	**nd**	High†	High†	Joy† *Anxiety Anger Frustration Enjoyment Relaxation Hope Sadness Pride Relief Contentment Gratitude*	Joy† Relief† Contentment† *Anger Frustration Enjoyment Hope Disappointment Pride Gratitude*	High†	High†	High†
LMHR	High†	High†	High†	High†	High†	High†	**Joy**† *Anger Frustration Boredom Enjoyment Relaxation Hope Pride Disappointment Relief Contentment Gratitude*	**Joy**† Relief† Contentment† *Frustration Enjoyment Relaxation Hope Pride Gratitude*	**High**†	**High**†	**High**†
HMLR	nd	**High**†	**High**†	**High**†	**High**†	**High**†	**Joy**† *Frustration Enjoyment Relaxation Disappointment Pride Relief Contentment Gratitude Hope*	**Joy† Relief† Contentment† Gratitude†** *Frustration Enjoyment Relaxation Hope Disappointment Pride*	nd	**High**†	nd
LMLR	Low	Low	Low	Low	Low	Low	Hopelessness‡ Sadness‡ *Frustration Enjoyment Relaxation Joy Hope Hopelessness Shame Disappointment*	*Frustration Enjoyment Relaxation Hope Shame Joy Disappointment*	Low	Low	Low

Note. LMLR is used as control condition (Low). †: significant difference with LMLR condition. ‡: significant difference with the other conditions. nd: no significant difference with LMLR condition. **bold:** non-expected significant results (contrary to hypotheses). *italic*: emotions self-experienced and perceived in partner at least more than a "weak" level.

TABLE 5.9: Results concerning emotional dimensions, achievement emotions, and perception of socio-cognitive processes use

Appendix A

Dependant variables	ICC	p-value
Activation_self	0,417289220917823	0,996909113824028
Dominance_self	0,650286819147686	0,999998308302363
Valence_self	0,737035500644138	0,999999985713471
Anxiety_self	0,306593503825315	0,975353778024148
Anger_self	0,253863134657837	0,946836870331608
Deception_self	0,535534326405373	0,99986420552872
Hopelessness_self	0,401133738918553	0,995625537586906
Boredom_self	0,407874420998456	0,996208023405852
Hope_self	0,24875246798104	0,943099326006245
Pride_self	0,563855215980878	0,999946576797504
Frustration_self	0,474014259943304	0,999207197107365
Gratitude_self	0,175680748821071	0,866043067941281
Shame_self	0,267725840336134	0,956034577750471
Joy_self	0,301263958767947	0,973206381602526
Enjoyment_self	0,257211538461538	0,949182274273816
Relaxation_self	0,152212939845283	0,830989323574365
Contentment_self	0,668216440795331	0,999999282441861
Relief_self	0,289897992760777	0,968125336080946
Sadness_self	0,288321167883212	0,967363749162101
Activation_other	0,526526001252056	0,999820379856196
Dominance_other	0,183674727819329	0,876797441955735
Valence_other	0,582233344404024	0,999972176823447
Anxiety_other	-0,0164948789344277	0,459513859430736
Anger_other	0,548622945067088	0,999910842404882
Deception_other	0,489689102899613	0,999478362295305
Hopelessness_other	0,213703198378005	0,911932588003048
Boredom_other	0,181795720377371	0,874323483112849
Hope_other	-0,184522336666673	0,123012380106421
Pride_other	0,298590807966487	0,972074148005347
Frustration_other	0,357303370786517	0,989636494904887
Gratitude_other	0,321783556305163	0,980722957120587
Shame_other	0,49540596287268	0,999554458558424
Joy_other	0,278800522911944	0,962454335481835
Enjoyment_other	0,143078712679333	0,815943951501539
Relaxation_other	0,116529137464281	0,767884019123022
Contentment_other	0,538277385647779	0,999875488770369
Relief_other	0,335784725238282	0,984786625206083
Sadness_other	0,0852696185883385	0,703675361334315
Reaching_consensus_self	0,183667093699473	0,876787457438374
Mutual_understanting_self	0,288833034128322	0,967612538482882
Transactivity_self	0,121259029927761	0,77690462669245
Task_management_self	0,221257247267444	0,919507588832159
Information_pooling_self	0,051842612661327	0,627553641166723
Time_management_self	0,406435189168062	0,996089605717987
Reaching_consensus_other	0,15453250681249	0,834685561478128
Mutual_understanting_other	0,267678127462687	0,956005189292426
Transactivity_other	0,293687282613041	0,969897899770278
Task_management_other	0,258477983285197	0,950048428985867
Information_pooling_other	0,0840014077923792	0,700914519889903
Time management_other	0,42644533485976	0,997480424830841

TABLE 5.10: ICC for all the dependent variables of interest

5.7 Appendices

Appendix B

In **HMHR condition**, shame $t(15) = -2.23$, $p = 0.97$, disappointment $t(15) = 1.45$, $p = 0.08$, hopelessness $t(15) = 0.92$, $p = 0.18$, boredom $t(15) = -4{,}56$, $p = 0.99$ and sadness $t(15) = -2.53$, $p = 0.33$ were not self-experienced by participants at more than a "weak" level. Boredom $t(15) = 1.23$, $p = 0.11$, sadness $t(15) = 1.60$, $p = 0.06$, anxiety $t(15) = -0.67$, $p = 0.74$, shame $t(15) = -2.76$, $p = 0.99$, hopelessness $t(15) = 0.89$, $p = 0.19$ and relaxation $t(14) = 1.54$, $p = 0.07$ were not perceived at more than a "weak" level in the partner.

In **LMHR condition**, boredom $t(15) = 1$, $p = 0.16$, sadness $t(15) = 1{,}60$, $p = 0.06$, anxiety $t(15) = 0.83$, $p = 0.20$, shame $t(15) = 0.77$, $p = 0.22$ and hopelessness $t(15) = 1.22$, $p = 0.11$ were not self-experienced by participants at more than a "weak" level. Sadness $t(15) = 1.37$, $p = 0.09$, anxiety $t(14) = -1.16$, $p = 0.86$, anger $t(15) = 0.49$, $p = 0.31$, shame $t(15) = -1.81$, $p = 0.95$, disappointment $t(15) = 1$, $p = 0.16$, hopelessness $t(15) = -0.19$, $p = 0.57$ and boredom $t(15) = -1.96$, $p = 0.96$ were not perceived at more than a "weak" level in the partner.

In **HMLR condition**, boredom $t(11) = 1.39$, $p = 0.09$, sadness $t(11) = 1.48$, $p = 0.08$, anxiety $t(10) = 0.52$, $p = 0.30$, anger $t(11) = 0.73$, $p = 0.24$, shame $t(11) = -2.17$, $p = 0.97$ and hopelessness $t(11) = -0.45$, $p = 0.67$ were not self-experienced by participants at more than a "weak" level. Boredom $t(11) = 1$, $p = 0.16$, sadness $t(11) = 1.43$, $p = 0.09$, anxiety $t(10) = 1.04$, $p = 0.15$, anger $t(11) = -0.23$, $p = 0.58$, shame $t(11) = -0.19$, $p = 0.57$ and hopelessness $t(11) = -2.17$, $p = 0.97$ were not perceived at more than a "weak" level in the partner.

In **LMLR condition**, anxiety $t(11) = 1.34$, $p = 0.10$, anger $t(11) = 1.60$, $p = 0.06$, boredom $t(11) = 0.17$, $p = 0.43$, sadness $t(11) = 0.44$, $p = 0.33$, pride $t(11) = 0.78$, $p = 0.22$, relief $t(11) = 0$, $p = 0.50$, contentment $t(11) = 1.62$, $p = 0.06$ and gratitude $t(11) = 1.48$, $p = 0.08$ were not self-experienced by participants at more than a "weak" level. Anxiety $t(11) = 0.15$, $p = 0.15$, anger $t(11) = 1.26$, $p = 0.11$, boredom $t(10) = -0.20$, $p = 0.58$, sadness $t(11) = 1.14$, $p = 0.13$, pride $t(11) = 0.43$, $p = 0.33$, relief $t(11) = 0$, $p = 0.50$, contentment $t(11) = 1.62$, $p = 0.06$ and gratitude $t(11) = 0$, $p = 0.5$ were not perceived at more than a "weak" level in the partner.

Appendix C

	Effect	Transactivity (self)				Transactivity (partner)				Task management (self)			
				95% CI				95% CI				95% CI	
		Estimate	*SE*	*Lower*	*Upper*	*Estimate*	*SE*	*Lower*	*Upper*	*Estimate*	*SE*	*Lower*	*Upper*
Activation (self)	*Indirect*												
	X1	**0.41**	**0.28**	**0.01**	**1.07**	**0.45**	**0.29**	**0.01**	**1.15**	0.26	0.18	-0.06	0.68
	X2	0.24	0.22	-0.17	0.71	0.27	0.24	-0.19	0.79	0.15	0.13	-0.15	0.42
	X3	**0.50**	**0.25**	**0.10**	**1.08**	**0.54**	**0.27**	**0.11**	**1.19**	0.32	0.19	-0.4	0.74
	Direct												
	X1	**1.21**	**0.53**	**0.14**	**2.28**	**1.21**	**0.56**	**0.09**	**2.34**	**0.96**	**0.47**	**0.21**	**1.90**
	X2	0.79	0.54	-0.30	1.89	1.10	0.57	-0.05	2.26	0.11	0.48	-0.85	1.08
	X3	0.81	0.54	-0.29	1.91	0.64	0.57	-0.50	1.80	0.67	0.48	-0.29	1.64
	Total												
	X1	**1.62**	**.52**	**0.57**	**2.67**	**1.66**	**0.55**	**0.55**	**2.77**	**1.22**	**0.45**	**0.32**	**2.13**
	X2	1.04	.56	-0.08	2.16	**1.37**	**0.59**	**0.18**	**2.56**	0.27	0.48	-0.69	1.24
	X3	**1.31**	**.52**	**0.25**	**2.36**	**1.19**	**0.55**	**0.08**	**2.30**	**1.00**	**0.45**	**0.09**	**1.90**
Activation (partner)	*Indirect*												
	X1	**0.56**	**0.26**	**0.11**	**1.15**	**0.60**	**0.28**	**0.14**	**1.23**	**0.55**	**0.23**	**0.14**	**1.04**
	X2	**0.63**	**0.35**	**0.82**	**1.46**	**0.67**	**0.7**	**0.10**	**1.53**	**0.61**	**0.29**	**0.11**	**1.25**
	X3	**0.63**	**0.31**	**0.12**	**1.34**	**0.67**	**0.32**	**0.14**	**1.40**	**0.61**	**0.27**	**0.15**	**1.20**
	Direct												
	X1	1.06	0.54	-0.03	2.15	1.06	0.57	-0.09	2.21	0.67	0.46	-0.24	1.60
	X2	0.41	0.58	-0.77	1.59	0.69	0.62	-0.54	1.94	-0.33	0.49	-1.33	0.65
	X3	0.68	0.55	-0.43	1.80	0.52	0.58	-0.65	1.70	0.38	0.47	-0.56	1.32
	Total												
	X1	**1.62**	**0.52**	**0.57**	**2.67**	**1.66**	**0.55**	**0.55**	**2.77**	**1.22**	**0.45**	**0.32**	**2.13**
	X2	1.04	0.56	-0.08	2.16	**1.37**	**0.59**	**0.18**	**2.56**	0.27	0.48	-0.69	1.24
	X3	**1.31**	**0.52**	**0.25**	**2.36**	**1.19**	**0.55**	**0.08**	**2.30**	**1.00**	**0.45**	**0.09**	**1.90**

Note. Estimate = unstandardized coefficient. When confidence interval does not cross 0, a significant effect (in bold) is found. Bootstrap method for confidence intervals (simulations = 5000). X1 (LMLR vs. LMHR), X2 (LMLR vs. HMLR), X3 (LMLR vs. HMHR)

Chapter 6

STUDY 2: Explicit sharing of emotions and collaborative problem-solving

6.1 Study 2a[1]

6.1.1 Introduction

There is still little research on how the real-time sharing of emotions impacts the way people interact with each other during collaborative problem-solving (Eligio et al., 2012). In a previous study (Molinari et al., 2013), researchers showed that an emotion awareness tool (EAT) allowing problem-solvers to share their emotions in real-time with their partner during collaborative problem-solving changes their perception of group collaboration. For example, the EAT increased the awareness of each other's emotions during interaction. It also had a positive effect on the perceived degree of transactivity, but only for women dyads. In the present paper, we analyzed verbal interaction data from that study to gain a better understanding of how the sharing of real-time emotions interact with different collaborative acts. We focused our analysis on both the socio-cognitive and socio-relational dimensions of collaboration (Bales, 1950b; Barron, 2003).

6.1.1.1 Emotions and emotion sharing in collaborative settings

In recent years, there has been a growing interest on the role of emotions in learning and problem-solving, shifting the research from a strictly cognitive point of view where rational and objective thinking is opposed to irrational and emotional thinking, to a cognitive-emotional approach where emotions complement and modulate

[1]The study presented in this chapter is published in *Avry, S., Molinari, G., Chanel, G., Pun, T., & Betrancourt, M. (2017). An Emotion Awareness Tool for the Sharing of Emotions: What Impact on Computer-Supported Collaborative Processes? Proceedings of 12th International Conference on Computer Supported Collaborative Learning (CSCL), vol.2, 789–790* and *Avry, S., & Molinari, G. (2018). Sharing emotions impacts computer-supported collaborative processes: effect of an emotion awareness tool. Travaux neuchâtelois de linguistique, (68), 85-96.*

cognitive work (Jarvela, 2012). Up to now, research has mainly focused on the role of emotional expression in collaborative settings (Barsade, 2002; Fredrickson and Branigan, 2005; Van Kleef et al., 2010). In general, studies showed that expressing positive emotions such as happiness increase approach (i.e., "moving toward others") behavior and cooperation. Prosocial behavior may be also triggered by specific negative emotions such as those signalling a need for help (e.g., sadness) or for appeasement (e.g., regret). In contrast, negative emotions such as anger indicating dominance or lack of affiliation generally provoke avoidance (i.e., "moving away/against others") behaviors, reduce cooperation and have a detrimental effect on group performance. Andriessen et al. (2011) as well as Järvenoja and Järvelä (2009) argued that collaboration requires a joint effort to address two types of challenges, those related to the divergence and convergence of ideas, and those related to the maintenance of an effective working relationship. Unsolved socio-relational tensions and the resulting negative emotions may be detrimental to collaborative learning.

Research has also focused on the expression of emotions through the use of computer-mediated tools. In this context, individuals can have difficulties to exchange nonverbal cues recognized as crucial to convey information about emotional states. This limitation may impair the quality of collaboration in reducing the possibility to use nonverbal cues to build and update socio-cognitive, socio-motivational and socio-relational models (Molinari et al., 2009; Sangin et al., 2011). According to the Social Information Processing Theory (Walther et al., 2015), individuals may compensate these limitations by translating their emotional expressions from nonverbal to verbal behaviors. This may explain why there is no real indication for difference between face-to-face and computer-mediated settings in terms of emotional communication, except for the time needed to share emotional information between collaborative partners (Derks et al., 2008). Eligio et al. (2012) have investigated in two studies the effect of sharing emotions in computer-mediated settings. Despite the fact that computer-mediated settings may involve some difficulty to accurately assess partner's emotions, results showed a positive effect of emotion sharing on group climate and performance. This result points out the idea that explicit emotion sharing (Buder, 2011; Molinari et al., 2009; Sangin et al., 2011) can be an effective mean to improve the modeling of partners' emotions in groups, and therefore the collaborative dynamics, both on socio-relational and socio-cognitive aspects.

Emotion awareness tools (EATs) can be designed so as to provide collaborators with information about their own emotions, their partner's emotions and/or the group emotions (Cernea et al., 2014; Chanel et al., 2013; Feidakis et al., 2014; Molinari et al., 2013). EATs can allow group members to share their emotional states explicitly or more implicitly, for example with adaptive systems able to automatically assess and display group members' emotions at critical moments of the interaction. In an experiment conducted by Molinari et al. (2013) and from which we have extracted the

data analyzed in this study, participants were provided with an EAT that gave them the possibility of (1) self-reporting their own emotions, (2) explicitly communicating their emotions to their collaborative partner, and (3) visualizing their partner's emotions while performing a remote collaborative task. Results demonstrated that the EAT influenced the participants' perception of the quality of interaction with their partner. First, compared to the participants without the EAT (control condition), those with the EAT reported spending more time (1) comparing their own emotions with their partner's emotions and (2) inferring their partner's reactions to emotions. Moreover, results showed that the EAT effect varied depending on gender. Women reported spending more time challenging and building on their partner's ideas in the EAT condition than in the control condition. The reverse pattern was found for men with a higher perceived degree of transactivity in the control condition.

6.1.1.2 Research questions and hypotheses

The aim of this study is to explore the impact an emotion awareness tool (EAT) on collaborative acts. In the present study, the verbal content from the study carried out by Molinari et al. (2013) has been transcribed and analyzed to explore how an emotion awareness tool (EAT) impacts the kinds of collaborative acts people use. More precisely, this study showed that EAT has different effects on the participants' perceptions of collaboration such as (a) more modeling of the partner's emotions and (b) an association between positive feelings and sharing of emotions. Perception of transactivity was also higher in women dyads. The general hypotheses are therefore as follows: 1) the EAT modulates the use of some collaborative processes, in particular those involved in the awareness of each other's emotions (H1); 2) men and women differ in the way they use some collaborative processes irrespective of the use of the EAT (H2); and 3) the EAT has a different impact on the use of some collaborative processes by men and women, especially in terms of transactivity (H3).

6.1.2 Method

6.1.2.1 Participants, Collaborative Task and Design

Participants were grouped into same-gender dyads, and performed a remote collaborative task . They were asked to create together a slogan against violence in schools using the DREW argument graph tool (Corbel et al., 2003). The task was divided into three steps: (1) generation of as many as possible of slogan ideas (corresponding to boxes in the graph), (2) evaluation of each idea based on 4 criteria (a "good" slogan is (a) persuasive, (b) original, (c) adapted to audience, and (d) triggers emotions); and (3) selection of the best slogan. During collaboration, participants could communicate with each other through microphone headsets, and their verbal exchanges were recorded. In the EAT condition, dyad members were provided with the EAT. The EAT was composed of three parts, one for the self-assessment of emotions, one for the visualization of the participants' own emotions and one for the visualization

of their partner's emotions. Participants were free to self-report their emotions at any time during the task. They could choose among 10 positive (delighted, focused, interested, satisfied, empathic, confident, amused, relaxed, grateful and relieved) and 10 negative (stressed, annoyed, surprised, disappointed, envious, anxious, dissatisfied, confused, frustrated, bored) emotions by clicking on them. In the control condition, participants were not provided with the EAT (see Molinari et al., 2013) for a complete description of the task and the EAT.

The analysis of collaborative processes presented in this paper was performed on a sample of 38 participants (24 women and 14 men; M = 24.05 years, SD = 9.55) taken from the experiment carried out by Molinari et al., (2013), 22 participants in the EAT condition (12 women grouped into 6 dyads and 10 men grouped into 5 dyads) and 16 participants in the control condition (12 women grouped into 6 dyads and 4 men grouped into 2 dyads). The number of participants/dyads was lower in the present study than in the previous one (N = 60) due to technical issues regarding the recordings of dyads' verbalizations. Thus, the selected participants were those for whom verbal interactions were available and transcribed.

6.1.2.2 Collaborative processes and collaborative acts

Coding scheme A coding scheme was designed so as to focus on both socio-relational and socio-cognitive processes. It was composed of 8 categories of collaborative processes and their associated 29 collaborative acts: (1) **Relationship management**, (2) **Interaction management**, (3) **Information management**, (4) **Argumentation management**, (5) **Task management**, (6) **Tool management** (7) **Other**, and (8) **Outside activity**. Three of the seven categories are from the Rainbow model (Baker et al., 2007). The Relationship management, Interaction Management, Information management and Argumentation management categories were divided into subcategories based on other coding schemes (Bales, 1950a; Hughes et al., 2007; Meier et al., 2007; Noroozi et al., 2013b). The different collaborative processes and collaborative acts are displayed in (Table 6.1).

Coding procedure For each dyad, the whole verbal interaction content was first transcribed with the ELAN software (Sloetjes & Wittenburg, 2008). Pauses and turn-taking served as a basis for segmenting the verbal interaction into collaborative acts. Two independent coders applied the coding scheme previously described. They were provided with verbal transcriptions combined with audio (voice) and video (face as well as actions during the construction of the DREW graph) recordings of dyad members. The verbal interactions of all dyads were analyzed by a first coder, whereas the second coder was in charge of coding interactions of 10 dyads. The inter-coder reliability for the 29 collaborative acts was calculated as the Cohen's kappa coefficient and was equal to 0.47 (moderate agreement; Viera, Garrett, et al., 2005).

Collaborative process	Collaborative act	Definition of the collaborative act
Relationship management	**Display solidarity**	Compliment or encourage partner or group
	Display hostility	Depreciate or disregard partner or group
	Relax atmosphere	Improve atmosphere or alleviate tensions (humor, laughs, teasing)
	Use social convention	Greet, display courtesy, introduce each other
Interaction management	**Check reception**	Initiate or check contact with partner
	Check comprehension	Check comprehension of what partner previously said
	Display active listening	Communicate attentive listening of partner
	Display reflection	Communicate moment of reflection to partner
	Coordinate teamwork	Manage role distribution
	Accept coordination	Accept group coordination
	Refuse coordination	Object to group coordination
Information management	**Give Task Information**	Give information that can help to solve the problem or remind the rules or task constraints
	Give Explanation	Clarify/elaborate one's own thinking
	Elicit Task Information	Ask information that can help to solve the task or reminding the rules or task constraints
	Give Self Information	Give an information about one's own knowledge or thinking
	Elicit Partner Information	Ask information about partner's knowledge or thinking
	Give recall	Repeat former information
	Elicit recall	Ask again former information
Argumentation management	**Give proposition**	Propose idea to resolve the task
	Give positive opinion	Support proposed idea
	Give negative opinion	Contradict proposed idea
	Elicit proposition	Elicit new idea from partner
	Elicit opinion	Elicit partner's opinion
	Agree	Agree with proposed idea
	Incorporate	Enriching proposed idea
Task management	**Manage task**	Manage task progress, what has been done and what still to be done
Tool management	**Manage tool**	Manage collaborative tool usage
Other	**Other**	Communication related to problem-solving task but not falling within any previous category
Outside activity	**Outside activity**	Communication unrelated with problem-solving task

TABLE 6.1: Coding scheme developed to code speech utterances into collaborative acts

6.1.3 Results

Descriptive results The coding scheme was applied to 4580 collaborative units in the EAT condition and to 3750 units in the control condition (this means a total number of 8330 events, a mean of 219 events per participants). There was a very low level of use (< 1 percent of the total number of acts) for processes such as *Display hostility*, *Refuse coordination*, *Elicit recall*, *Display solidarity*, *Give explanation*, *Check comprehension*, *Incorporate*, *Elicit proposition*, *Use social convention*, *Elicit partner information*, and *Outside activity*, and a low level of use (between 1 and 5 percent) for processes such as *Give negative opinion*, *Check reception*, *Elicit task information*, *Coordinate teamwork*, *Display active listening*, *Give recall*, *Elicit opinion*, *Give self information*, and *Relax atmosphere*. Some others can be considered as fairly well used (between 5 and 10 percent): *Give task information*, *Manage tool*, *Manage task*, *Give proposition*, *Display reflection*, and *Accept coordination*. Only two processes represented more than 10 percent of the total numbers of acts: *Agree*, *Give positive opinion*.

Inferential results A series of 2 (EAT) x 2 (Gender participant) ANOVAs were performed on the rate of use of each collaborative acts.

The EAT had a positive effect on the **Use social convention**, **Give self-information** and **Elicit-partner information** variables. More precisely, the rate of use was higher in the EAT condition than in the control condition for: (1) **Use social convention** (EAT: M = 0.96, SD = 0.56; Control: M = 0.52, SD = 0.60; $F(1, 34) = 4.75$, $p = .003$, $\eta^2_p = 0.12$), (2) **Give self-information** (EAT: M = 4.71, SD = 2.54; Control: M = 2.89, SD = 2.24; $F(1, 34) = 6.92$, $p = .012$, $\eta^2_p = 0.16$), and (3) **Elicit-partner information** (EAT: M = 0.81, SD = 0.12; Control: M = 0.36, SD = 0.57; $F(1, 34) = 5.43$, $p = .002$, $\eta^2_p = 0.13$). The EAT had a negative effect for **Coordinate teamwork**, with a higher rate in the Control condition (M = 2.89, SD = 1.28) than in the EAT condition (M = 2.04, SD = 1.59), $F(1, 34) = 3.85$, $p = .057$, $\eta^2_p = 0.10$.

Gender had an effect on 4 processes. For three of the four processes, the rate of use was higher for women than for men: (1) **Display solidarity** (women: M = 0.70, SD = 0.78; men: M = 0.20, SD = 0.35, $F(1, 34) = 4.81$, $p = .035$, $\eta^2_p = 0.12$), (2) **Give recall** (women: M = 4.06, SD = 1.8; men: M = 1.99, SD = 1.76, $F(1, 34) = 12.00$, $p = .001$, $\eta^2_p = 0.26$), and (3) **Tool management** (women: M = 6.18, SD = 3.16; men: M = 3.47, SD = 2.25, $F(1, 34) = 5.21$, $p = .028$, $\eta^2_p = 0.13$). On the other hand, men had a higher rate (M = 9.23, SD = 4.28) than women (M = 6.18, SD = 3.16) for **Give proposition**, $F(1, 34) = 8.64$, $p = .005$, $\eta^2_p = 0.20$.

In the EAT condition, men produced more **Relax atmosphere** acts compared to women, whereas it was the opposite in the control condition, $F(1, 34) = 6.59$, $p = .014$, $\eta^2_p = 0.16$. Post-Hoc tests showed a significant difference between the EAT and Control conditions for men ($M_{EAT} = 6.35 > M_{Control} = 0.92$), but no significant difference for women ($M_{EAT} = 4.75 \approx M_{Control} = 4.20$). The EAT * Gender interaction

was also significant for **Give negative opinion**, $F(1, 34) = 7.65$, $p = 0.009$, $\eta_p^2 = 0.18$. Post Hoc tests showed a difference between the EAT and Control conditions for men ($M_{EAT} = 0.92 < M_{Control} = 3.43$) but no difference for women ($M_{EAT} = 1.52 \approx M_{Control} = 1.55$). Both significant interactions are displayed in Figure 6.1.

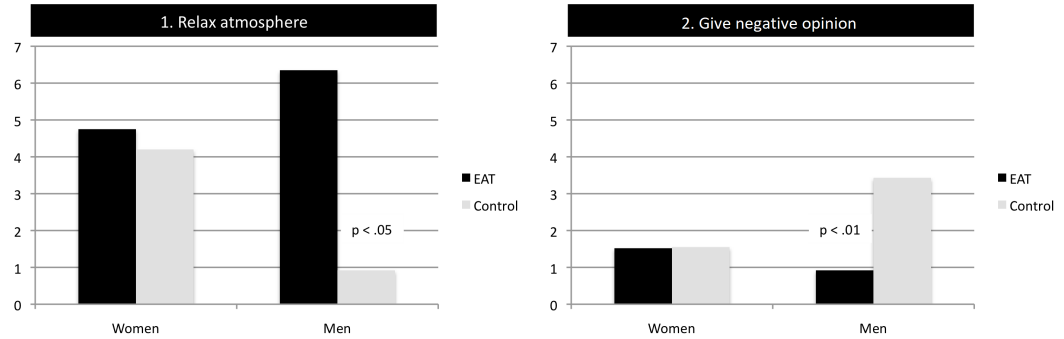

FIGURE 6.1: Interaction between EAT and Gender for (1) Relax Atmosphere and (2) Give Negative Opinion

6.1.4 Discussion

Results showed that a tool allowing the participants to share their emotions impact significantly the way they collaborate during a problem-solving task (H1). Indeed, participants will tend to use collaborative acts differently when they explicitly share their emotions. First, the main results showed a positive impact of the EAT on the socio-relational act **Use social convention** and the socio-cognitive acts **Give self-information** and **Elicit partner information**. This suggests that the participants using the EAT promotes the use of acts dedicated to improve the group relationship (e.g., greetings, displaying courtesy). Second, participants became more involved in the process of peer knowledge modeling, i.e., establishing and updating a mental model of each other's knowledge (Sangin et al., 2011). Therefore, sharing emotions could also have a beneficial effect on the exchange of socio-cognitive information between partners. Results also indicated that encouraging dyad members to share emotions decrease the use of exchanges dedicated to coordinate teamwork. This result may be explained by the fact that the sharing of emotion could provide additional information about the other regarding both the relationship and the problem-solving task. As a result, the need to coordinate explicitly the collaborative work though collaborative acts could be less necessary.

Results also showed that men and women use differently some collaborative acts irrespective to the use of the EAT (H2). Women tend to use more the socio-relational act **Display solidarity**. This result is consistent with the fact that women are globally more prone to use coping strategies and use preferentially verbal expressions to seek emotional support (Tamres et al., 2002). Women also use more the socio-cognitive act **Give recall**, i.e. communication whose the goal is to repeat previous information.

They also exchange more about the collaborative tool (**Tool management**). Conversely, men give more new ideas during collaboration (**Give proposition**). Thus, an opposite trend can be found between women and men. Indeed, women would be more prone to deepen previous ideas. However, men would be more prone to produce new ideas.

Finally, results also showed that the effect of the EAT on collaborative acts varied depending on gender, i.e., the use of the EAT influences differently the proportion of collaborative acts in men and women (H3). Indeed, while the EAT has no effect on the use of **Relax atmosphere** in women, it has a significant effect in men who use exchanges dedicated to improving the group atmosphere. In addition, in the EAT condition, men give less opinions against the ideas (**Give negative opinion**) of their collaborative partner, what is not the case in women.

6.1.5 Conclusion

Taken as a whole, results tend to support the hypothesis of a beneficial effect of the EAT on socio-relational and socio-cognitive processes. Results also point out the fact that men and women differ on the way they use socio-relational (more display of solidarity in women) and socio-cognitive processes (more recall of previous ideas women, more new propositions in men). In addition, the EAT induces more exchanges dedicated to improve the socio-relational climate in men. This aspect seems to be naturally more prevalent in women as they are willing to share emotions more easily (Kring & Gordon, 1998) and use more collaborative acts dedicated to displaying solidarity to their partner. The question of whether this result can be explained by a cultural bias needs further investigation. The possibility for men to share emotions during collaboration seems to lead to a better group atmosphere, but at the expense of socio-cognitive conflict, which is assumed to produce mutual gain in learning and problem solving tasks (Andriessen et al., 2011, p. 227). Thus, it is questionable whether the sharing of some emotions could have a detrimental effect on group outcomes in reducing socio-cognitive conflict in men. Accordingly, this effect could reduce also conflict in competitive settings. Further studies should be carried out to investigate this effect in more detail. All in all, the uncovered results are intended to improve the comprehension of emotions in collaborative learning and problem solving tasks and provide useful knowledge for the development of future emotion-based collaborative environments.

6.2 Study 2b[2]

6.2.1 Introduction

Problems are omnipresent throughout daily life. Getting into a given place in an unknown city or sending a rocket into space both imply problem-solving, at different levels of complexity. As problems we encounter tend to become more and more complex in today's world, they often require inputs from others. Therefore, collaboration is increasing all around the world, as more and more people work together to solve non-routine problems and lead innovation (Fiore et al., 2017; Graesser et al., 2018; Borge et al., 2018). In academic settings also, learners are regularly required to solve problems together. However, what makes a collaboration successful is still unclear since, as Barron (2003) raised, put problem-solvers together, as smart as they are, is not a guarantee of better success. On the contrary, group success heavily depends on the quality of real-time interaction (Barron, 2003; Borge et al., 2018), especially the responsiveness to the other group members. In such a context, the affective states shared in collaborative settings could play a crucial role in the collaborators' mutual adaptation, i.e., socio-metacognition (Borge et al., 2019). These adaptive changes could affect collaborative intentions (what we propose to call "collaborative acts") dedicated to both solving the problem and managing the relationship between problem solvers. In this study, we explore this question in analyzing a computer-supported collaborative problem-solving task, where real-time sharing of emotional labels were recorded during collaboration.

6.2.1.1 Collaborative acts instantiate collaborative processes

Collaborative problem-solving can be defined as to "engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution" (Fiore et al., 2017). In recent years, the idea that collaboration involves not only a cognitive but also a relational space, has been gaining ground (Andriessen et al., 2011; Barron, 2003; Roschelle and Teasley, 1995). The cognitive space globally refers to the processing of information dedicated to solving the problem, while the relational space is related to the peer relationship. Therefore, throughout the collaboration, problem-solvers mobilize processes dedicated to managing both the cognitive and the relational spaces. For example, in the cognitive space, a possible solution can be shared with the others to address the problem. At the same time, in the relational space, one can display responsiveness to other participants or some marks of solidarity.

[2]The study presented in this section is published in *Avry, S., Molinari, G., Bétrancourt, M., & Chanel, G. (2020). Sharing emotions contributes to regulating collaborative intentions in group problem-solving. Frontiers in Psychology, 11, 1160, doi=10.3389/fpsyg.2020.01160*

One question that arises from the above description is how the different processes take form in the discourse during collaboration. One proposition is that collaboration involves different collaborative processes (e.g., information management, argumentation management). These processes emerge iteratively and incrementally through communicative exchanges. These communicative exchanges can be considered as speech acts (Austin, 1975), i.e., they involve an intention from the speaker and an effect on the listener (e.g., provide information, clarify an idea, ask for help, encourage). These speech acts are intended to produce perlocutionary effects, i.e., consequences on feelings, thoughts, and actions of others (Sbisà, 2009). In the framework of collaboration, we propose to call them collaborative acts as they represent a sub-category of speech acts involving collaborative intentions (in contrast with competitive intentions, for example). These collaborative acts build socio-cognitive and socio-relational processes and shape the course of collaboration in feeding mutual models (Dillenbourg et al., 2016). Mutual modeling can relate to knowledge (Sangin et al., 2007). For example, collaborative acts dedicated to asking information could induce information sharing and update each other's knowledge model of the task (i.e., online task-specific knowledge; see Efklides, 2011), the self, and the partner (Sangin et al., 2007). If knowledge models relate to the cognitive space, similar models are also posited about the relational space (e.g., updates of group relational dimensions; Dillenbourg et al., 2016), even if no clear empirical evidence of such relational modeling is yet available in the literature.

A sequence of collaborative acts with the same perlocutionary effect can, therefore, be associated with a given socio-cognitive or socio-relational process. For example, a series of collaborative acts dedicated to collecting and evaluating an argument or critically assess a proposition may fall within the reaching consensus process (Meier et al., 2007). The understanding of how, and under which conditions, a sequence of collaborative acts can forge successful or unsuccessful collaborative patterns is an essential question in collaborative problem-solving. To this end, coding and categorizing collaborative acts into well-defined collaborative processes (e.g., socio-cognitive and socio-relational) can contribute to exploring the course of collaboration more finely. Several frameworks have been developed in the (computer-supported) collaborative learning field to extract meaning from collaborative exchanges occurring during collaboration (e.g., Bales, 1950a; Baker et al., 2007; Hughes et al., 2007; Meier et al., 2007; Noroozi et al., 2013a). The purpose of these frameworks is twofold. First, they help to classify speech utterances and group them into meaningful collaborative processes. Second, they give an overview of what is happening in the collaboration. By putting side by side group outcomes and collaborative processes profiles, it could thus be possible to get an idea about what are the dimensions of a good collaboration. For example, (Kahrimanis et al., 2009) characterized good collaboration along seven dimensions. Some dimensions refer to socio-relational processes (e.g., cooperative orientation) while some others to socio-cognitive processes (e.g., sustaining mutual understanding, knowledge exchange). Some of these dimensions

correlate positively with the mental representation of good collaboration held by the participants (Meier et al., 2007).

6.2.1.2 Emotional expression regulates social interactions

If cognition and emotion have historically been opposed, emotion being thought of as impeding cognition (Huntsinger & Schnall, 2013), the role of emotion in individual cognition is now well documented (e.g., Fredrickson, 2013; George and Dane, 2016; Isen and Labroo, 2003; Lerner et al., 2015; Spering et al., 2005). For example, evidence shows that emotions trigger prototypical cognitive dispositions to evaluate events in a way that modulates the interpretation of subsequent situations (Lerner et al., 2015). For example, anger tends to make negative events more predictable and under control Van Doorn et al., 2015. In return, that could eventually lead to underestimating risk (Lerner et al., 2015) and may serve a social distancing function toward people and situations (Fischer, Manstead, et al., 2008). In academic settings also, individual emotions are now considered critical for students' learning and problem-solving, especially academic achievement (Avry et al., 2020a; Pekrun, 2006; Pekrun and Linnenbrink-Garcia, 2012).

Interest in the social functions (beyond survival and reproduction) of emotions has emerged more lately (Keltner and Haidt, 1999; Morris and Keltner, 2000). However, emotions are nowadays also thought to have a significant role in social decision making. Morris and Keltner (2000) emphasize the social role of emotion as the consequences of emotion that occur between people who are observing and responding to each other's emotions, rather than consequences within one individual. Indeed, emotions are often elicited by others and expressed to influence others (Van Kleef et al., 2016). A crucial question thus concerns the function of emotional expressions in group settings, from both the emitter's and receiver's points of view. This is of great importance for the understanding of the role of emotions in collaboration since we know that emotions intervene in the coordination of group efforts to achieve shared goals (Van Kleef et al., 2016).

First, one can consider how the emitter uses emotions to convey messages to others. People have a natural tendency to share their emotions with others (Rimé, 2009). Emotional expressions allow people to regulate emotional (e.g., seeking for consolation), motivational (e.g., need for encouragement) and cognitive (e.g., looking for advice and solutions) aspects of interaction (see Rimé, 2007 for a comprehensive study of the different motives for socially sharing an emotion). However, depending on the group context, the willingness to share emotions is different (e.g., contrary to work meetings, group support meetings could promote the sharing of more negative emotions) (Van Kleef et al., 2016). In addition, Andriessen, Baker and van der Puil (2011) also emphasized the need to consider collaborative learning as a continuous cycle of tensions and relaxations at both cognitive and relational levels, which pervade the group through emotional expressions and contagion. Thus, different exchanges that

occur in the collaboration each have an idiosyncratic potential to increase or alleviate group tensions. For example, tensions may arise at a socio-relational level from touches of sarcasm or personal attacks, while irrelevancy claims, questions or deep reflection may provoke tensions at a socio-cognitive level.

Second, one can consider how the receiver uses emotional expressions to infer information (Van Kleef & Fischer, 2016). For example, in collaborative problem-solving, one can consider the kind of information that is inferred through emotional expressions. Some lines of response can be proposed to understand this issue. Perceived emotional expressions could serve as a social warning, inducing the observer to focus on the emotional state highlighted by the emotional expression. In this line, Van Kleef et al. (2016) outline that emotional expressions help to prove the expresser's interpretation of a situation. For example, during a collaborative problem-solving task, if a collaborator begins to frown, the others should be induced to put attention on it, as frowning is likely to be interpreted as negative affect in that context (see affective cognition; Ong et al., 2015). Therefore, collaborators can infer from a given emotional state the causes and future consequences of that emotional state and adapt themselves accordingly, considering the context that led to its emergence (Van Kleef et al., 2010). In this way, emotional expressions can help to infer not only the other's beliefs, social intentions, relationship orientations (e.g., dominant or submissive, receptive or indifferent;Keltner and Haidt, 1999) but also the degree of cooperativeness, the competence, the personality, among others (Van Doorn et al., 2015). Therefore, in collaborative settings, emotional expressions could, at specific points of time, 1) from the emitter point of view, help to draw the other's attention implicitly and explicitly on socio-relational and socio-cognitive matters and 2) from the receiver point of view, help to focus on other's emotional state to make inferences about the emitter, reduce ambiguity and adapt to the emitter's needs. Throughout the collaboration, group members dynamically switch their role of emitter or receiver.

6.2.1.3 Research questions and hypotheses

Various areas of research have linked cognitive processes to emotions (D'Mello and Graesser, 2012; Eastwood et al., 2001; Lerner et al., 2015; Spering et al., 2005). For example, D'Mello and Graesser (2012) explain how emotions and cognitive processing of information are intertwined in individual complex learning. In their model, specific emotional (or cognitivo-affective) states go hand in hand with specific cognitive states (flow with equilibrium, confusion with disequilibrium, frustration with stuck, disengagement with boredom). As cognitive reasoning is also conveyed through communicative exchanges in collaboration, a question that can be asked is whether similar findings can be found between emotion sharing and collaborative acts. Furthermore, as outlined in the previous section, emotional sharing is not only related to socio-epistemic matters. Literature also shows that socio-emotional matters are

a significant concern in social interaction (Rimé, 2007). In addition, Pekrun and Linnenbrink-Garcia (2012) distinguish several types of emotions occurring in individual and collective academic settings related to specific focuses of learning such as achievement emotions (related to the achievement of activity and outcomes; e.g., the frustration of not succeeding), epistemic emotions (related to the learner's cognitive processing of information; e.g., the confusion of not understanding a problem) or social emotions (related to the relationship with the others; e.g., the gratitude towards a peer). This categorization suggests that emotional sharing could also be related to different collaborative focuses, such as socio-cognitve and socio-relational, that could be shared preferentially in different phases of collaboration (e.g., when problem-solvers make acquaintance or try to find new ideas to solve the problem).

We proposed above that the emitter would use emotions to draw the receiver's attention regarding important emotional, motivational or cognitive matters, which would be intended to induce perlocutionary effects from the receiver. Consequently, emotional expressions would lead the receiver to make inferences about the emitter's needs, which would induce adaptive effects in return. These adaptive changes are posited to occur in real-time, before emotional sharing for the emitter and after emotional sharing for the receiver. Therefore, the first questioning that drives this study is whether emotion sharing modulate collaborative acts (RQ1). First, we assume that real-time changes of specific collaborative acts by the emitter precede specific emotional sharing by the emitter (H1a). From an operational point of view, specific collaborative acts should be subject to a significant increase (resp. decrease) preceding specific emotional sharing, compared to when no emotion is shared. For example, if the emitter has a strong positive opinion about a possible solution to solve the task, he/she should be more likely to draw the receiver's attention by sharing an emotion of interest. Second, we assume that real-time changes of some specific collaborative acts by the receiver follow specific emotional sharing bu the emitter (H1b). For example, if the emitter shares an emotion of interest, the receiver should adapt his/her collaborative acts accordingly.

A second issue that arises from the literature concerns the relationships between the sharing of some emotions and some patterns of collaboration. Therefore, the second questioning is whether specific patterns of collaboration can be highlighted, considering the triad emitter's collaborative acts, emotional sharing, and receiver's collaborative acts and if these patterns occur preferentially in specific collaborative phases (RQ2). We assume that specific triads relate more specifically to dealing with specific cognitive or relational matters (H2a). We also assume that some triads occur preferentially in specific collaboration phases (H2b).

6.2.2 Method

6.2.2.1 Participants

The analysis was performed on data provided from a sample of 22 participants (12 women and 10 men, M = 23.9 years; SD = 7.45) taken from the freely accessible EAT-MINT database (Chanel et al., 2013), regrouping multi-modal and multi-user data of affect and social behaviors recorded during a computer-supported creative problem-solving collaboration (Molinari et al., 2013), such as physiological signals (electrocardiogram, electrodermal activity, blood volume pulse, respiration, skin temperature), behaviors (eye-movements, facial expressions, software actions logs) and discourse (speech signals and transcripts).

6.2.2.2 Procedure

Eleven same-gender dyads of participants using networked computers were involved working together in the DREW software (Jaillon et al., 2002), a collaborative environment that includes an argument graph tool allowing collaborators to build a joint map of their argumentation. Participants could communicate through microphone headsets, and their verbal exchanges were recorded. They did not see each other. Participants were asked to use the argument graph tool to create a slogan against violence at school collaboratively (Figure 6.2, left). The group collaboration lasted for about 36 minutes on average. It was divided into three main phases. Participants should spend 2-fifths of the time in phase 1 where they should produce as many slogans ideas as possible, 2-fifths of the time in phase 2 where they should debate with each other and agree on three slogans, and 1-fifth of the time in the last phase where they should choose the best slogan.

Dyad members were also provided with a tool allowing them to share in real-time verbal labels of their emotions through an emotion awareness tool (Figure 6.2, right). They could choose among 10 positive (delighted, focused, interested, satisfied, empathic, confident, amused, relaxed, grateful and relieved) and 10 negative (stressed, annoyed, surprised, disappointed, envious, anxious, dissatisfied, confused, frustrated, bored) emotions by clicking on them. The emotions available in the emotion awareness tool were chosen based on a survey carried out on 59 participants regarding the most frequent emotions experienced during a collaborative task among the 36 emotions of the Geneva Emotion Wheel (Sacharin et al., 2012). Once participants selected an emotion, it was automatically displayed to them (green area in Figure 6.2) as well as their partner (blue area in Figure 6.2). Participants were instructed that they were free to self-report their emotions at any time they wanted during collaboration (for a complete description, see Molinari et al., 2013). In addition, they were prompted with a pop-up window to share their emotions at the beginning of the interaction and every 5 minutes during the collaboration.

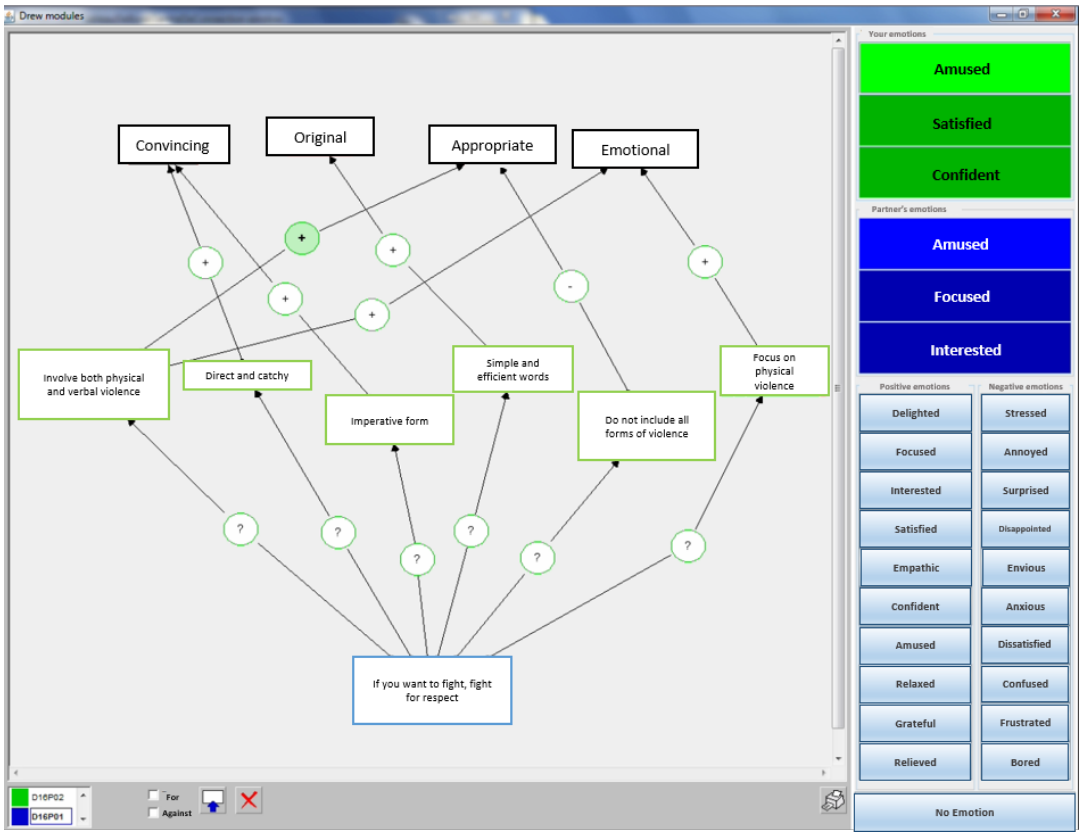

FIGURE 6.2: The Drew interface coupled with an emotion awareness tool for sharing verbal labels of emotions in real-time during the collaborative problem-solving task.

6.2.2.3 Analyses

Speech coding A coding scheme was developed to code speech utterances into different collaborative acts during collaboration. It was composed of 27 collaborative acts grouped into 6 collaborative processes (Table 6.1). In this coding scheme, a collaborative process is composed of one or several collaborative acts that have specific perlocutionary effects. For instance, collaborative acts aiming at complimenting or encouraging collaborators are combined into a collaborative process called relationship management. The Rainbow model (Baker et al., 2007) was chosen as a working basis for the creation of the coding scheme. This model was initially developed for coding speech utterances from chat interactions in seven broad collaborative processes: outside activity, social relation, interaction management, task management, opinions, argumentation, and broaden and deepen. Only outside activity, social relation and interaction management categories were retained while information, argumentation management and tool management categories were added afterward. Some categories were refined in sub-categories based on other coding schemes (Bales, 1950a; Hughes et al., 2007; Meier et al., 2007; Noroozi et al., 2013b). The final coding scheme (Table 6.1) obtained provides a functional classification (each collaborative act refers to a particular collaborative process) aiming at covering

the largest possible types of collaborative acts occurring in collaborative problem-solving. Emphasis was also put on both socio-relational and socio-cognitive processes. For each dyad, the whole verbal content of interactions was transcribed with the ELAN software (Sloetjes & Wittenburg, 2008). Pauses and turns taking served as a basis for segmenting the verbal interaction into speech utterances. When appropriate, each speech utterance was coded as a collaborative act. Speech utterances related to problem-solving but not falling within any other collaborative act category were coded as *Other*. Speech utterances unrelated with the problem-solving were coded as *Outside activity*. Speech content was categorized by a first expert coder whereas a second naive coder with no prior experience on collaborative processes coding scheme literature was in charge of 10 dyads. The inter-coder reliability for the 27 collaborative acts on these 10 dyads was calculated as the Cohen's kappa coefficient and was equal to 0.52 (moderate agreement; Viera, Garrett, et al., 2005). The inter-coder reliability for the 6 collaborative processes was equal to 0.61 (substantial agreement). The categorization carried out by the first expert coder was used as part of this study.

Computation of real-time collaborative acts use (RTU) In order to measure the real-time impact of emotional sharing on collaborative acts, we computed the number of collaborative acts of a given type produced by the emitter before one's emotion sharing and by the receiver after the emitter's emotional sharing (Figure 6.3 A). Emotion windows (i.e., the n collaborative acts preceding or following the sharing of a given emotion) were first created Figure 6.3 A). Initially, different windows size (5, 10, 15 collaborative acts) were tested. Windows of 5 collaborative acts were retained as the effect of emotion sharing were the strongest for this size.

To determine the beginning of an emotion window, the shared emotion was associated with the temporally closer collaborative act. No-emotion windows were then created for the remaining collaborative acts. When the number of collaborative acts was inferior to 5 (e.g., between two emotion windows), a window was not created (cf. skipped collaborative acts in Figure 6.3 A). Furthermore, when two emotion windows overlapped, the second one was skipped to avoid dependencies between emotional windows. The creation of windows gave the possibility to focus on collaborative acts changes in real-time (5 acts lasted 13.2 seconds on average).

After the creation of windows, a Real-Time Use (RTU) was then computed for each window, defined as the number of occurrences of a given collaborative act in the window of 5 collaborative acts. For example, if the collaborative act Give proposition occurred 3 times among 5 consecutive collaborative acts, the RTU for this given collaborative process in this sample was 3. Then, the different RTUs scores for the emotion and no-emotion windows were averaged (Figure 6.3 B). Therefore, as part of a given shared emotion, each participant was associated, for each type of collaborative act, with a pair of two dependent scores, a score representing the averaged

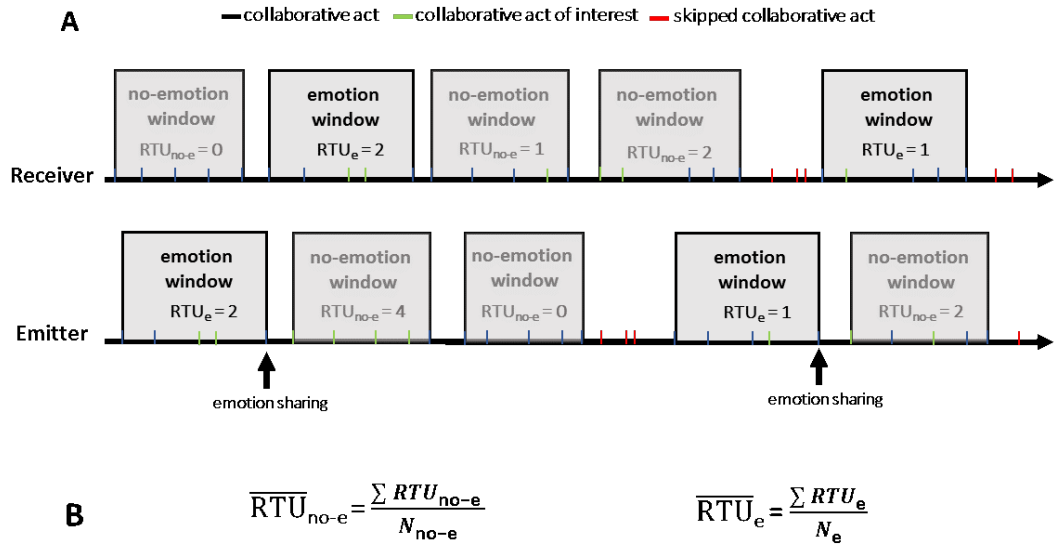

FIGURE 6.3: Example showing collaborative acts divided into windows of 5 consecutive collaborative acts. In **A**, the **emotion windows of the emitter** include 5 collaborative acts preceding the sharing of a given emotion by the same emitter. The **emotion windows of the receiver** include 5 collaborative acts following the sharing of a given emotion by the emitter. In this case, the collaborative acts of interest are those emitted by the receiver. In **B**, $\overline{\text{RTU}}_{no-e}$ is equal to the sum of the RTU_{no-e} divided by the number of non-emotion windows (N_{no-e}). $\overline{\text{RTU}}_{e}$ is equal to the sum of the RTU_{e} divided by the number of emotion windows (N_{e}).

RTU for the emotion windows ($\overline{\text{RTU}}_{e}$) and a score representing the averaged RTU for the no-emotion windows ($\overline{\text{RTU}}_{no-e}$) (Figure 6.3 B). This process of creation of windows and computation of the RTUs were carried out for all the shared emotions considered in this study.

6.2.3 Results

6.2.3.1 Overall descriptive statistics

The whole sample contained 5141 collaborative acts that participants have initiated during collaboration (467.36 $\pm$ 194.18 collaborative acts per dyad). The number of collaborative acts per participant ranged from 63 to 380. A collaborative act lasted 2.64 sec $\pm$ 2.80 sec and the cumulated duration of collaborative acts was on average 20 min 3 sec $\pm$ 8 min 43 sec. Table 6.5 in Appendix A reports the number of collaborative acts in each category in the whole sample, as well as the percentage of each act relative to the total number of acts.

The whole sample studied contained 262 (232 positive and 30 negative) shared emotions (23.90 $\pm$ 9.78 emotions per dyad). The number of shared emotions per participant ranged from 5 to 29. On average, the absolute difference in the number of shared emotions by each participant within the same dyad was 4.63 $\pm$ 4.20, ranging from 0 (i.e., both partners shared the same number of emotions) to 13. The absolute difference in the number of negative shared emotions by each participant within the

same dyad was 1.81 ± 1.53, ranging from 0 to 4. The absolute difference in the number of positive shared emotions by each participant within the same dyad was 2.91 ± 3.17, ranging from 0 to 9. Table A2 reports the number of emotions in each category in the whole sample as well as the percentage of each emotion relative to the total number of emotions. An emotion was released every 1 min 43 sec ± 38 sec on average, ranging from 57 sec to 2 min 45 sec.

Given that all the emotions were not shared by all the participants (see Table 6.6 in Appendix A), analyses were carried out when emotion was shared at least once in at least 10 participants, to preserve statistical power. Under this constraint, the following emotions were retained: *interest*, *focused*, *amused*, *relaxed*, *satisfied*, and *delighted*. These six emotions were not shared equally in each collaborative phase (Table 6.2). Similarly, because some collaborative acts were shared very rarely, only collaborative acts used more than 4% of the time were retained, i.e., *Relax atmosphere*, *Display reflection*, *Accept coordination*, *Give task information*, *Give self information*, *Give proposition*, *Give positive opinion*, *Agree*, *Manage task*, and *Manage tool*. *Relax atmosphere* relates to the relational space and the other collaborative acts to the epistemic space.

Phase	Interested	Focused	Amused	Relaxed	Satisfied	Delighted
Produce as many slogans ideas as possible	22	24	22	9	10	8
Debate with each other and agree on three slogans	14	20	6	4	14	1
Choose the best slogan	3	8	6	6	16	11

TABLE 6.2: Number of emotion sharing according to the different phases of collaboration

6.2.3.2 Randomization tests

For each couple of shared emotion and collaborative act, a randomization test was carried out to test a significant difference between $\overline{\text{RTU}}_{no-e}$ and $\overline{\text{RTU}}_{e}$ across the sample. Randomization test allows for testing relationships equality of means when one cannot assume the normality of test statistic. First, the true difference of means was computed in the sample of size N. Second, the set of $\overline{\text{RTU}}_{e}$ and the set of $\overline{\text{RTU}}_{no-e}$ were shuffled together and a random difference of means $\overline{rand.diff}$ was computed in the same way. This operation was repeated 9999 times, resulting in a sampling distribution of random differences. The *p-value* was computed as the proportion of permuted datasets which produced a mean difference at least as extreme as the true difference (two-tailed testing) using to the following formula:

$$p.value = \frac{\sum_{i=1}^{10000}(|\overline{rand.diff}| \geq |\overline{true.diff}|)}{N} \tag{6.1}$$

Third, the set of *p-values* obtained for each shared emotion obtained has been corrected for multiple comparisons with the Benjamini-Hochberg procedure.

6.2.3.3 Relationship between emotion sharing and real-time collaborative acts use

A series of randomization tests was conducted to test 1) the relationship between emotion sharing and the $\overline{\text{RTU}}s$ of the previous emitter's collaborative acts and 2) the relationship between emotion sharing and the $\overline{\text{RTU}}s$ of the following receiver's collaborative acts. Comprehensive descriptive results are reported in Table 6.3 and Table 6.4.

Interested The sharing of *interested* occurred mostly during phase 1 (generation of ideas) and 2 (debate about best ideas). Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing concern *Give proposition* (from 0.29 to 0.55; +89%). Major decreases concern *Relax atmosphere* (from 0.26 to 0.12; -53%), *Give self information* (from 0.21 to 0.10; -52%), and *Accept coordination* (from 0.46 to 0.31; -32%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Relax atmosphere* (from 0.24 to 0.39; +62%), *Give task information* (from 0.21 to 0.32; +52%), and *Accept coordination* (from 0.40 to 0.59; +47%). Major decreases concern *Manage task* (from 0.28 to 0.12; -57%) and *Give positive opinion* (from 0.66 to 0.39; -41%).

Focused The sharing of *focused* occurred mostly during phase 1 and 2. Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing *Manage task* (from 0.28 to 0.40; +42%) and *Give proposition* (from 0.28 to 0.39; +39%). Major decreases concern *Relax atmosphere* (from 0.24 to 0.11; -54%), *Give positive opinion* (from 0.69 to 0.32; -53%), and *Manage tool* (from 0.26 to 0.16; -38%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Give proposition* (from 0.28 to 0.60; +114%) and *Give task information* (from 0.22 to 0.41; +86%). Major decreases concern *Manage tool* (from 0.31 to 0.03; -90%) and *Manage task* (from 0.30 to 0.06; -80%). A significant decrease in the $\overline{\text{RTU}}s$ of the emitter was found for the collaborative act *Give Positive Opinion* ($p = 0.02$). For the receiver, significant decreases were found for the collaborative acts *Manage task* ($p < 0.001$) and *Manage tool* ($p < 0.001$).

Amused The sharing of *amused* occurred mostly during phase 1. Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing concern *Relax atmosphere* (from 0.25 to 0.54; +116%), *Give self information* (from 0.20 to 0.35; +75%) and *Agree* (from 0.46 to 0.61; +32%). Major decreases concern *Accept* (from 0.42 to 0.22; -47%) and *Manage task* (from 0.30 to 0.20; -33%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Relax atmosphere* (from 0.25 to 0.44; +76%), *Display reflection* (from 0.34 to 0.53; +55%) and *Give task information* (from 0.24 to 0.37; +54%). Major decreases concern *Give positive opinion* (from 0.68 to 0.29; -57%) and *Give self information* (from 0.21 to 0.13; -38%). A significant decrease in the $\overline{\text{RTU}}s$ of the receiver was found for the collaborative act *Give positive opinion* ($p = 0.03$).

Relaxed The sharing of *relaxed* occurred in roughly equivalent proportions across phases. Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing concern *Give task information* (from 0.28 to 0.50; +78%), *Accept coordination* (from 0.34 to 0.56; +64%), *Manage task* (from 0.28 to 0.44; +57%), and *Give proposition* (from 0.28 to 0.39; +39%). Major decreases concern *Display reflection* (from 0.44 to 0.17; -61%) and *Relax atmosphere* (from 0.23 to 0.11; -52%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Manage tool* (from 0.23 to 0.42; +82%) and *Give self information* (from 0.17 to 0.29; +70%). Major decreases concern *Give task information* (from 0.22 to 0; -100%), *Relax atmosphere* (from 0.26 to 0.08; -69%), *Agree* (from 0.47 to 0.29; -38%) and *Manage task* (from 0.31 to 0.21; -32%). A significant decrease in the $\overline{\text{RTU}}s$ of the receiver was found for the collaborative act *Give positive opinion* (from 0.71 to 0.63; -11%; $p = 0.03$).

Satisfied The sharing of *satisfied* occurred in roughly equivalent proportions in each phase, with a slight increase across phases. Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing concern *Give self information* (from 0.21 to 0.43; +104%) and *Manage task* (from 0.25 to 0.36; +44%). Major decreases concern *Give proposition* (from 0.31 to 0.10; -67%) and *Accept coordination* (from 0.41 to 0.22; -46%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Relax atmosphere* (from 0.23 to 0.33; +43%), *Give positive opinion* (from 0.63 to 0.90; +42%) and *Display reflection* (from 0.37 to 0.49; +32%). Major decreases concern *Give self information* (from 0.23 to 0.09; -60%), *Give proposition* (from 0.34 to 0.18; -47%), and *Give task information* (from 0.27 to 0.16; -40%). A significant decrease in the $\overline{\text{RTU}}s$ of the receiver was found for the collaborative act *Give proposition* ($p = 0.02$).

Delighted The sharing of *delighted* occurred mostly during phase 1 and 3 (choose final idea). Major increases in the $\overline{\text{RTU}}s$ occurring just before the emitter's sharing concern *Display reflection* (from 0.41 to 0.77; +87%), *Give self information* (from 0.21 to 0.36; +71%), *Give task information* (from 0.25 to 0.36; +44%), and *Relax atmosphere* (from 0.25 to 0.36; +44%). Major decreases concern *Manage task* (from 0.24 to 0.05; -79%), *Give positive opinion* (from 0.65 to 0.18; -72%), and *Accept coordination* (from 0.43 to 0.24; -44%). Major increases in the $\overline{\text{RTU}}s$ of the receiver occurring just after the emitter's sharing concern *Manage tool* (from 0.33 to 0.64; +93%), *Relax atmosphere* (from 0.22 to 0.36; +63%), and *Agree* (from 0.44 to 0.64; +45%). Major decreases concern *Display reflection* (from 0.42 to 0.05; -88%), *Manage task* (from 0.28 to 0.09; -67%), and *Give task information* (from 0.32 to 0.18; -43%). Significant decreases in the $\overline{\text{RTU}}s$ of the emitter were found for the collaborative acts *Give Positive Opinion* ($p = 0.03$) and *Manage task* ($p = 0.03$). A significant decrease in the $\overline{\text{RTU}}s$ of the receiver was found for the collaborative act *Display Reflection* ($p = 0.02$).

Collaborative acts	Interested (N=19)				Focused (N=21)				Amused (N=18)				Relaxed (N=12)				Satisfied (N=16)				Delighted (N=11)			
	p	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*		*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*
Agree	0.89	0.51 (0.26)	0.54 (0.67)	+5,88	0.86	0.51 (0.25)	0.46 (0.62)	-9,80	0.81	0.46 (0.13)	0.61 (0.85)	+32,61	1.00	0.48 (0.08)	0.44 (0.68)	-8,33	0.91	0.52 (0.25)	0.56 (0.88)	+7,69	0.87	0.44 (0.10)	0.53 (0.70)	+20,45
Accept Coordination	0.51	0.46 (0.22)	0.31 (0.39)	-32,61	0.69	0.43 (0.22)	0.54 (0.48)	+23,26	0.39	0.42 (0.22)	0.22 (0.36)	-47,62	0.85	0.34 (0.11)	0.56 (0.53)	+64,71	0.20	0.41 (0.18)	0.22 (0.35)	-46,34	0.74	0.43 (0.19)	0.24 (0.56)	-44,19
Give Positive Opinion	0.89	0.67 (0.25)	0.57 (0.74)	-14,93	**0.02**	0.69 (0.25)	0.32 (0.41)	-53,62	0.88	0.67 (0.25)	0.62 (0.71)	-7,46	0.87	0.69 (0.28)	0.56 (0.85)	-18,84	0.91	0.66 (0.26)	0.56 (0.55)	-15,15	**0.03**	0.65 (0.26)	0.18 (0.40)	-72,31
Give Proposition	0.51	0.29 (0.16)	0.55 (0.79)	+89,66	0.74	0.28 (0.16)	0.39 (0.65)	+39,29	0.88	0.29 (0.15)	0.31 (0.55)	+6,90	0.87	0.28 (0.14)	0.39 (0.49)	+39,29	**0.02**	0.31 (0.15)	0.10 (0.20)	-67,74	0.87	0.31 (0.14)	0.35 (0.45)	+12,90
Give Self Information	0.51	0.21 (0.10)	0.10 (0.26)	-52,38	0.69	0.19 (0.10)	0.13 (0.29)	-31,58	0.62	0.20 (0.12)	0.35 (0.45)	+75,00	0.87	0.18 (0.09)	0.22 (0.44)	+22,22	0.20	0.21 (0.09)	0.43 (0.40)	+104,76	0.74	0.21 (0.06)	0.36 (0.50)	+71,43
Give Task Information	0.89	0.19 (0.18)	0.24 (0.53)	+26,32	0.75	0.24 (0.22)	0.19 (0.38)	-20,83	0.88	0.26 (0.23)	0.24 (0.51)	-7,69	0.85	0.28 (0.22)	0.50 (0.71)	+78,57	0.91	0.24 (0.23)	0.27 (0.46)	+12,50	0.87	0.25 (0.21)	0.36 (0.81)	+44,00
Manage Task	0.89	0.28 (0.17)	0.33 (0.77)	+17,86	0.69	0.28 (0.16)	0.40 (0.59)	+42,86	0.69	0.30 (0.15)	0.20 (0.36)	-33,33	0.85	0.28 (0.12)	0.44 (0.53)	+57,14	0.79	0.25 (0.13)	0.36 (0.43)	+44,00	**0.03**	0.24 (0.13)	0.05 (0.15)	-79,17
Relax Atmosphere	0.51	0.26 (0.16)	0.12 (0.27)	-53,85	0.23	0.24 (0.14)	0.11 (0.26)	-54,17	0.39	0.25 (0.13)	0.54 (0.66)	+116,00	0.85	0.23 (0.13)	0.11 (0.33)	-52,17	0.91	0.25 (0.17)	0.21 (0.26)	-16,00	0.87	0.25 (0.16)	0.36 (0.67)	+44,00
Display Reflection	0.89	0.34 (0.24)	0.37 (0.47)	+8,82	0.88	0.36 (0.28)	0.38 (0.43)	+5,56	0.78	0.32 (0.21)	0.23 (0.40)	-28,13	0.85	0.44 (0.31)	0.17 (0.50)	-61,36	0.91	0.38 (0.26)	0.40 (0.53)	+5,26	0.74	0.41 (0.30)	0.77 (0.93)	+87,80
Manage Tool	0.89	0.30 (0.23)	0.26 (0.40)	-13,33	0.69	0.26 (0.20)	0.16 (0.29)	-38,46	0.88	0.28 (0.20)	0.26 (0.35)	-7,14	1.00	0.27 (0.20)	0.28 (0.67)	+3,70	0.91	0.30 (0.24)	0.33 (0.47)	+10,00	0.87	0.32 (0.23)	0.27 (0.65)	-15,63

Note. p-values are corrected for multiple comparisons with the Benjamini-Hochberg procedure. Significant results are in ***bold*** *on grey background. M-:$\overline{RTU}$ when no-emotion sharing. M+:$\overline{RTU}$ when emotion sharing.*

TABLE 6.3: Comprehensive results for the emitter for each couple of shared emotion and collaborative act

Collaborative acts	Interested (N=19)				Focused (N=21)				Amused (N=18)				Relaxed (N=12)				Satisfied (N=16)				Delighted (N=11)			
	p	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*	*p*	*M-* *(SD)*	*M+* *(SD)*	*Variation %*
Agree	0.92	0.51 (0.24)	0.50 (0.61)	-1,96	0.97	0.49 (0.23)	0.48 (0.72)	-2,04	0.77	0.50 (0.24)	0.38 (0.48)	-24,00	0.77	0.47 (0.12)	0.29 (0.54)	-38,30	0.43	0.49 (0.26)	0.32 (0.33)	-34,69	0.67	0.44 (0.09)	0.64 (0.67)	+45,45
Accept Coordination	0.62	0.40 (0.23)	0.59 (0.58)	+47,50	0.70	0.43 (0.24)	0.33 (0.41)	-23,26	0.95	0.46 (0.23)	0.44 (0.82)	-4,35	0.95	0.40 (0.20)	0.42 (0.47)	+5,00	0.85	0.36 (0.13)	0.30 (0.52)	-16,67	0.67	0.35 (0.17)	0.45 (0.69)	+28,57
Give Positive Opinion	0.62	0.66 (0.27)	0.39 (0.78)	-40,91	0.79	0.64 (0.23)	0.77 (0.86)	+20,31	**0.03**	0.68 (0.24)	0.29 (0.44)	-57,35	**0.03**	0.71 (0.24)	0.63 (0.88)	-11,27	0.43	0.63 (0.24)	0.90 (0.73)	+42,86	0.67	0.64 (0.27)	0.50 (0.74)	-21,88
Give Proposition	0.75	0.30 (0.17)	0.23 (0.36)	-23,33	0.59	0.28 (0.16)	0.60 (1.03)	+114,29	0.77	0.31 (0.18)	0.24 (0.39)	-22,58	0.77	0.32 (0.18)	0.33 (0.44)	+3,13	0.17	0.34 (0.15)	0.18 (0.26)	-47,06	0.67	0.29 (0.11)	0.36 (0.50)	+24,14
Give Self Information	0.78	0.21 (0.11)	0.17 (0.29)	-19,05	0.92	0.21 (0.11)	0.23 (0.41)	+9,52	0.77	0.21 (0.11)	0.13 (0.27)	-38,10	0.77	0.17 (0.10)	0.29 (0.62)	+70,59	0.17	0.23 (0.13)	0.09 (0.21)	-60,87	0.67	0.24 (0.13)	0.18 (0.40)	-25,00
Give Task Information	0.75	0.21 (0.20)	0.32 (0.55)	+52,38	0.70	0.22 (0.20)	0.41 (0.74)	+86,36	0.77	0.24 (0.21)	0.37 (0.66)	+54,17	0.77	0.22 (0.22)	0.00 (0.00)	-100,00	0.58	0.27 (0.26)	0.16 (0.32)	-40,74	0.67	0.32 (0.23)	0.18 (0.40)	-43,75
Manage Task	0.37	0.28 (0.17)	0.12 (0.27)	-57,14	**0.00**	0.30 (0.15)	0.06 (0.16)	-80,00	0.95	0.27 (0.16)	0.28 (0.40)	+3,70	0.95	0.31 (0.15)	0.21 (0.40)	-32,26	0.85	0.28 (0.15)	0.32 (0.45)	+14,29	0.33	0.28 (0.14)	0.09 (0.30)	-67,86
Relax Atmosphere	0.74	0.24 (0.14)	0.39 (0.57)	+62,50	0.92	0.26 (0.14)	0.29 (0.41)	+11,54	0.77	0.25 (0.15)	0.44 (0.56)	+76,00	0.77	0.26 (0.17)	0.08 (0.29)	-69,23	0.72	0.23 (0.16)	0.33 (0.45)	+43,48	0.67	0.22 (0.13)	0.36 (0.50)	+63,64
Display Reflection	0.78	0.33 (0.26)	0.39 (0.62)	+18,18	0.79	0.30 (0.21)	0.25 (0.33)	-16,67	0.77	0.34 (0.29)	0.53 (0.96)	+55,88	0.77	0.38 (0.29)	0.29 (0.40)	-23,68	0.72	0.37 (0.28)	0.49 (0.66)	+32,43	**0.02**	0.42 (0.35)	0.05 (0.15)	-88,10
Manage Tool	0.78	0.29 (0.23)	0.25 (0.45)	-13,79	**0.00**	0.31 (0.24)	0.03 (0.11)	-90,32	0.95	0.25 (0.21)	0.28 (0.54)	+12,00	0.95	0.23 (0.19)	0.42 (0.63)	+82,61	0.89	0.30 (0.24)	0.28 (0.45)	-6,67	0.67	0.33 (0.23)	0.64 (1.21)	+93,94

Note. p-values are corrected for multiple comparisons with the Benjamini-Hochberg procedure. Significant results are in ***bold*** *on grey background. M-:$\overline{RTU}$ when no-emotion sharing. M+:$\overline{RTU}$ when emotion sharing.*

TABLE 6.4: Comprehensive results for the receiver for each couple of shared emotion and collaborative act

6.2.4 Discussion

6.2.4.1 Does emotion sharing interact with collaborative acts?

The first question that drove this study concerned a potential relationship between emotional sharing and collaborative acts (RQ1). We proposed above that, in collaborative settings, the expression of emotion by collaborators could, at specific points of time, 1) from the emitter's point of view, help to draw the other's attention implicitly and explicitly on socio-relational and socio-cognitive matters and 2) from the receiver point of view, focus on the other's emotional state to make inferences, reduce ambiguity and adapt to the emitter's needs. Drawing on the literature, we proposed that real-time changes of the emitter's collaborative acts occur before the emitter's emotional sharing (H1a) and real-time changes of the receiver's collaborative acts follow the emitter's emotional sharing (H1b).

Some relationships have been found in both directions. First, emotional sharing does relate to how emitters use some collaborative acts just before. Indeed, some significant variations in the use of collaborative acts occur only before some emotional sharing and do not occur without emotion sharing. Accordingly, emotional sharing does has a relationship with how receivers use collaborative acts just after. Indeed, some significant variations in the receiver's collaborative acts occur only after the sharing of some emotions by the emitter. These results confirm that emotional sharing has a relationship with collaborative acts in problem-solving and strongly suggest that emotional sharing is probably a way for the emitter to highlight his/her previous collaborative acts to elicit adaptive changes from the receiver. However, a surprising result is that emotional sharing only induced significant $\overline{\text{RTU}}s$ decreases. In a window of n collaborative acts, decreases in some collaborative acts are compensated by increases in some others. However, in our case, if some decreases reached the significance level, it was not the case for the increases. In other words, if emotional sharing did result in increases in some collaborative acts compensating the decrease in some others, these increases were not consistent enough among the whole sample. How can one explain that emotional sharing only leads to consistent decreases in collaborative acts? We propose two different explanations that can complement each other. First, emotional sharing would put on hold the ongoing dynamic of collaborative problem-solving. In other words, the emitter would stop to share collaborative acts related to the ongoing matter to promote a change from the receiver through emotion sharing. As this message has to be understood by the receiver to adjust his/her subsequent collaborative acts, it would also cut the receiver's collaborative acts dedicated to the ongoing matter. If this process would consistently decrease some collaborative acts, it could also lead to some discrepancies between participants, some of them adjusting collaborative acts more or less rapidly. Second, receivers would react differently and quite inconsistently to emotional sharing. In other words, receivers would implement different ways to answer the emotional message coming from the emitter. Therefore, an increase in a given

collaborative act would be less likely to reach the significance level across the whole sample studied.

6.2.4.2 Are there patterns of collaboration related to some emotion sharings?

The second question that drove this study was whether some patterns of collaborative acts involving specific emotional sharings can be found (RQ2). We proposed that specific triads relate more specifically to dealing with specific epistemic or relational matters (H2a). We also assumed that some triads occur preferentially in specific collaboration phases (H2b). In the discussion below, we will assume the role of emotion sharing in considering both the significant results when available and major $\overline{\text{RTU}}$ variations described in the descriptive results. Appendix B presents examples taken for the conversation for an illustrative purpose.

The sharing of *interested* would primarily occur when participants produce and debate ideas to solve the problem. At the cognitive level, sharing interested could follow the willingness to draw the partner's attention to the fact that a previous contribution could provide a line of thought in a moment of brainstorming, where the emitter mainly generates new ideas. The collaborative partner would respond to this interest by mainly accepting more coordination, reminding more the task rules, and managing less the progress of the task. In the relational space, the emitter would alleviate less the atmosphere before emitting interest. This could be congruent with the assumption that socio-cognitive tensions may emerge from the search of ideas (Andriessen et al., 2011), perhaps starting sometime before the sharing of *interest*. In response, collaborative acts dedicated to alleviating this tension (Andriessen et al., 2011) would be emitted by the receiver since a potential solution has just emerged. All in all, sharing *interest* would mark a pivotal point between the search and discovery of a good idea to solve the problem at the cognitive level, which would go hand in hand with a transition between tension and relaxation at the relational level.

The sharing of *focused* would also primarily occur when participants produce and debate ideas to solve the problem. At the cognitive level, contrary to the sharing of *interest*, *focused* seems to draw the receiver's attention to the fact that previous contributions are still not satisfying, and further thinking is needed. The collaborative partner would start, in turn, to generate new ideas and decrease managing the task and using the collaborative tool. At the relational level, contrary to the sharing of *interest*, the sharing of focused would not lead to alleviating socio-cognitive tension as no good idea has emerged yet. All in all, sharing *focused* would be intended to increase group thinking in the search for a good idea.

The sharing of *amused* would primarily occur when participants produce ideas. Sharing *amused* could be a way to highlight the desire to strengthen group harmony at both relational and cognitive levels. At the cognitive level, the emitter

would agree more on new ideas and share more information about his/her thinking. Instead, he/she would accept less group coordination and manage less the task progress. In return, the emitter would display more reflection and give more task information. At the relational level, both partners would improve the atmosphere when amused is shared. Thus, the sharing of amused could mark quick consensus-building, which refers to a rapid agreement of the other's contribution, aiming at promoting the generation of ideas instead of confronting them (Weinberger & Fischer, 2006), which goes hand in hand with an attempt to improve group atmosphere.

The sharing of *relaxed* would occur in roughly equivalent proportions across phases. At the cognitive level, it would mark a phase mixing the search of new ideas with the task, group, and tool management. Participants could give free rein to their ideas. At the relational level, contributions dedicated to alleviating the atmosphere would also decrease in both sides, possibly marking a phase of socio-cognitive relaxation.

The sharing of *satisfied* would also occur in roughly equivalent proportions across phases. At the cognitive level, the emitter would signal that a satisfactory proposition is found in giving significantly less new ideas just before. He/she would also give more information about his/her own thinking, perhaps for explaining his/her view. The receiver would accept less group coordination and give fewer new ideas. Instead, he/she would mainly give more positive opinions about previous ideas and more information about his/her own thinking. At the relational level, the sharing of satisfied would alleviate tension in the group as collaborative acts dedicated to improving the atmosphere increase.

Finally, the sharing of *delighted* would primarily occur when participants produce ideas and choose the best idea in the end. At the cognitive level, delighted would mark a transition between successful collaborative work and the beginning of a moment dedicated to the management of the collaborative tool. On the one hand, the emitter would decrease the management of the task progress, display more reflection and information about his/her thinking, and produce fewer positive opinions about previous ideas. On the other hand, the receiver would agree with previous ideas and manage the tool more, probably for writing down the solution(s) found. He/she would also decrease reflection, perhaps adapting him/herself to an increase of reflection from the emitter, and decrease the management of the task progress. At the relational level, the sharing of delighted would occur in a relaxation phase as both emitter and receiver would produce more collaborative acts dedicated to relaxing the atmosphere. The sharing of *delighted* and *satisfied* seem to be used in a quite similar fashion. However, *delighted* would mark more definitive solutions.

The preliminary results obtained strongly suggest that emotional sharing intervenes in different aspects and phases of collaborative problem-solving. However, emotional sharing does not appear to relate solely to cognitive and relational matters and relational and cognitive dimensions appear closely intertwined.

6.2.5 Limitations

As with any research involving naturalistic collaboration settings, the present study is not without limitations. First, our research highlights the difficulty of studying quantitatively emotional sharing because it is challenging to make participants share emotions "on-demand". Explicit emotional sharing appears to be a discrete process that responds to specific problem-solving situations. These kinds of situations appear at some specific moments and can hardly be experimentally scheduled. As a consequence, the number of occurrences of each emotion of interest appeared relatively small (about 2 on average for a 20-minute collaborative exchange). Therefore, higher variability in the $\overline{\text{RTU}}s$ of the emotion windows produced less robust changes across participants than in the no-emotion windows. This could also partly explain why collaborative acts increases failed to reach significance. For this reason, we are deeply aware that the results highlighted in this paper, although they confirm the role of emotion sharing and give a first insight of the interrelations that may exist between emotion sharing and collaborative acts, need to be deepened and replicated.

A second related issue that results from the difficulty of manipulating emotional sharing was the very small number of some emotions in the sample, prevented us from including them in the current analysis. Especially, the potential effects of negative emotions on the partner's collaborative acts have been completely overlooked. In a previous analysis conducted on the same sample (Avry et al., 2015), researchers analyzed the difference between the proportion of emotions experienced by problem-solvers versus the proportion of emotions shared. If participants shared more positive emotions as they really experienced (86% vs. 71%), highlighting that the sharing of positive emotions could play an instrumental role in problem-solving regulation, the reverse pattern was found for negative emotions. Indeed, participants experienced twice as many negative emotions as they share (29% vs. 14%). This result strongly suggests that participants refrain themselves to share explicitly negative emotions in collaboration settings, potentially to prevent unwanted negative impact on the group. However, there is a strong likelihood that the sharing of negative affects would also induce similar or even more potent effects on the partner's collaborative acts, but perhaps more implicitly (e.g., through para and non-verbal communication). A way to increase the sharing of some emotions (and especially negative emotions) without affecting the naturalistic characteristics of collaboration could be to design more constrained collaborative situations. For example, a situation where reaching a joint agreement would be impossible could generate specific negative emotions (e.g., frustration, confusion). Furthermore, analyzing larger samples will also increase the overall reliability of the results obtained.

Finally, a third limitation is the absence of control regarding the independence of peers' measures (see Kenny et al., 2006). Therefore, a possible effect of the dyads cannot be excluded in this study.

6.2.6 Conclusion and perspective

This study was conducted as a premise to a more global and deeper comprehension of the dynamics between emotional sharing and communicative exchanges in collaborative problem-solving. First, we examined if real-time adaptive changes in the emitter's collaborative acts influence his/her emotional sharing and if the emitter's emotional sharing induces real-time adaptive changes in the receiver's collaborative acts. Second, we investigated if some specific patterns of emitter's collaborative acts, emitter's emotional sharings and receiver's collaborative acts have privileged relationships in different phases of the collaboration. First, we confirmed that emotional sharing follows and induces a rapid modulation of the emitter and receiver's collaborative acts. This result fits with the idea that emotional sharing regulates collaborative problem-solving in the same way that it regulates social interaction more broadly. As proposed by some researchers (Keltner and Haidt, 1999; Van Doorn et al., 2015; Van Kleef and Fischer, 2016; Van Kleef et al., 2016) regarding social interaction, emitter's emotional expressions may be used to draw the partner's attention and elicit adaptive changes regarding socio-relational and socio-cognitive matters. Meanwhile, the partner needs to infer emitter's beliefs, intentions, and orientations regarding both the cognitive (i.e., how the problem is solved) and the relational space (i.e., how the group interacts) in the context of collaborative problem-solving. In addition, we highlighted that specific patterns of emotion sharings and collaborative acts relate more specifically to dealing with specific matters in different phases of the collaboration. These findings also suggest that emotion sharing would initiate different collaborative socio-cognitive stages. These socio-cognitive changes would also involve concomitant socio-relational changes, especially the modulation of tensions and relaxations in the group. Furthermore, even if this assumption has to be confirmed, our results suggest that receivers would adapt their collaborative acts in different ways for a given emotional sharing. Therefore, other factors have to be explored (e.g., history of the dyadic relationship, beliefs about competence, motivational aspects) to understand more finely the dynamics between emitter and receiver' collaborative acts.

By and large, this work highlights the value of studying collaborative problem-solving with the emotional aspects that pervade it. Based on these preliminary findings, some perspectives can be considered in both educational psychology and computer science fields. First, if emotional sharing leads to the modulation of subsequent collaborative acts, it could be promoted as a way to understand and leverage group reflection, decisions, and actions in collaborative complex learning such as problem-solving. In this way, it could be particularly useful for promoting emotional regulation and strengthen emotional competencies among problem-solvers (Mayer et al., 2011; Mikolajczak et al., 2020) as a socio-metacognitive and meta-relational tool (Hogan, 1999). However, further studies have to assess if explicit

sharing of emotion could have an added value in emotionally impoverished environments (e.g., some collaboration software) and would not disrupt other aspects of the collaboration, such as increasing cognitive load among group members. Second, in combination with natural language processing (semantic analysis of speech utterances; Baets et al., 2019) and process mining (analysis of patterns of collaborative acts; Van der Aalst, 2011) techniques, emotional sharing data could help to gain a better insight into the bottlenecks as well as the facilitators of successful collaborative problem-solving.

6.2.7 Appendices

Appendix A

Collaborative process	Collaborative act	Number of acts	Percentage relative to the total number of acts
Relationship management	Display solidarity	23	0.44
	Relax atmosphere	**232**	**4.51**
	Use social convention	38	0.74
Interaction management	Check reception	69	1.34
	Check comprehension	16	0.31
	Display active listening	122	2.37
	Display reflection	**448**	**8.71**
	Coordinate teamwork	102	1.98
	Accept coordination	**425**	**8.27**
	Refuse coordination	12	0.23
Information management	**Give Task Information**	**219**	**4.26**
	Give Explanation	18	0.35
	Elicit Task Information	87	1.69
	Give Self Information	**215**	**4.18**
	Elicit Partner Information	60	1.17
	Give recall	153	2.98
	Elicit recall	16	0.31
Argumentation management	**Give proposition**	**295**	**5.74**
	Give positive opinion	**619**	**12.04**
	Give negative opinion	62	1.21
	Elicit proposition	30	0.58
	Elicit opinion	132	2.56
	Agree	**495**	**9.63**
	Incorporate	38	0.74
Task management	**Manage task**	**310**	**6.03**
Tool management	**Manage tool**	**309**	**6.01**
Other	Other	561	10.91
Outside activity	Outside activity	34	0.61

TABLE 6.5: Number of collaborative acts and percentage for each category for the whole sample

Emotion	Number of sharing	Percentage relative to the total number of emotions	Number of participants where the sharing occurred at least once
Focused	**50**	**21.01**	**21**
Interested	**37**	**15.61**	**19**
Satisfied	**35**	**14.77**	**16**
Amused	**33**	**13.92**	**18**
Confident	16	6.75	9
Relaxed	**17**	**7.17**	**12**
Delighted	**12**	**5.06**	**11**
Confused	9	3.79	6
Empathic	5	2.11	4
Stressed	4	1.69	2
Annoyed	4	1.69	1
Anxious	2	0.84	2
Relieved	2	0.84	2
Dissatisfied	2	0.84	2
Bored	2	0.84	1
Frustrated	2	0.84	2
Grateful	1	0.42	1
Disappointed	1	0.42	1
Surprised	1	0.42	1
Envious	0	0	0

TABLE 6.6: Number of emotions, percentage for each category and number of participants where the sharing occurred at least once for the whole sample, not including emotions removed due to overlap or absence of at least five consecutive collaborative acts before or after

Appendix B

Interested

P1	Wait, let's write one slogan	Manage task
P1	We can create some messages for the agressors and some other for the victims	Give proposition
P2	*Without violence you're stronger*	Give proposition
P1	I was thinking, maybe it is not adapted to victims	Give negative opinion
P1	An eye for an eye, a tooth for a tooth ?	Give proposition
P1	For me it's the right message, but we should make it more attractive	Give proposition
P1	**Interested**	
P2	Yes, why not?	Give positive opinion
P2	It could be a way to involve victims	Give positive opinion
P1	Yes because at some point maybe the victim is too submissive	Give positive opinion
P2	Ok, let's think about that idea	Accept coordination
P1	And it is like a vicious circle	Give positive opinion
P1	Do you want to be part of a vicious circle ?	Give proposition
P2	(Chuckles)	Relax atmosphere
P2	Hit him, do not hit you ?	Give proposition

Focused

P2	We can speak together now right?	Elicit task information
P1	Yes	Give task information
P1	*You could be the victim*	Give proposition
P1	*Strike with your arguments*	Give proposition
P2	You ruin your life and everyone else's ?	Give proposition
P1	It could be fun to have a slogan in english	Give proposition
P2	I'm not very good in English but we can try yes	Agree
P1	Ok, no problem	Accept coordination
P1	**Focused**	
P2	Hmm	Show reflection
P2	Do unto others as you would have others do unto you ?	Give proposition
P2	Punches are for cowards, be clever ?	Give proposition
P2	Hmm	Show reflection
P1	It could be nice to make a pun	Give proposition
P2	Oh, we could look for our slogan with a word battle	Manage task
P1	Yes why not ?	Manage task
P2	How can we do that ?	Coordinate teamwork

Amused

P1	(Chuckles)	Relax atmosphere
P1	It is not easy !	Give self information
P1	Can we start to make links between ideas at this step?	Elicit task information
P2	Yes I think so	Give task information
P1	This one is very funny (Chuckles)	Relax atmosphere
P1	*Violence, addiction of feeble-minded*, well done!	Show solidarity
P2	(Chuckles) yes, thank you	Relax atmosphere
P1	**Amused**	
P2	Hmm	Display reflection
P1	We could say that violence is like an addiction ?	Give proposition
P2	Yes, exactly	Agree
P2	(Chuckles)	Relax atmosphere
P2	They do not have the power of ideas but the power of muscles	Give explanation
P1	(Chuckles) True !	Relax atmosphere
P2	(Chuckles)	Relax atmosphere

Relaxed

P1	We could add another slogan	Manage task
P1	*You are not a punchball*	Give proposition
P2	(Chuckles)	Relax atmosphere
P1	I don’t know, I am not convinced by this one	Give negative opinion
P2	Let’s put our random ideas here	Coordinate teamwork
P1	Ok	Accept coordination
P1	I think we should add the idea that cool people are not violent	Give proposition
P1	**Relaxed**	
P2	Ok let’s write down this idea	Tool discourse
P2	May we add something else	Tool discourse
P1	Is that cool to pull fly wings out ?	Give proposition
P1	It has just come to my mind	Give self information
P2	I have some difficulty to imagine the message that would make a difference	Give self information
P1	Hmm	Show reflection
P2	Otherwise I have another idea	Give self information
P2	Remember those who died before hitting	Give proposition

Satisfied

P1	Phase n°2 is done, isn't it?	Manage task
P2	Yes	Manage task
P1	For me, this one is among the finalists	Manage task
P2	Yes, I'm ok with you	Manage task
P1	It's a good mix between both our ideas	Give positive opinion
P2	Yes exactly !	Agree
P1	A beautiful mixed-breed (Chuckles)	Relax atmosphere
P2	I'm quite satisfied !	Give self information
P1	Me too !	Give self information
P1	**Satisfied**	
P2	We can now submit it to the city of Geneva (Chuckles)	Relax atmosphere
P1	(Chuckles) I don't know if they wish to use it to be honest	Relax atmosphere
P1	We never know, we never know	Relax atmosphere
P2	It is good yes !	Give positive opinion
P2	But I don't think so (Chuckles)	Relax atmosphere
P1	(Chuckles)	Relax atmosphere
P2	Hmm	Show reflection
P2	So, how long is expected to last Phase n°3 ?	Elicit task information

Delighted

P1	I find it original	Give self information
P1	I've tried to make words rhyme	Give self information
P1	*You are the boss of your classroom but if it were you the scapegoat?*	Give recall
P2	But uh…	Display reflection
P2	Ok, it works !	Give positive opinion
P1	Ok	Agree
P2	Uh…	Display reflection
P1	So, we have to write in the tool now	Give task information
P1	**Delighted**	
P2	Original according to the rhyme, right?	Elicit opinion
P1	Yes	Agree
P2	Ok, I write rhyme	Manage Tool
P2	And I move that below	Manage Tool
P1	Ok	Manage Tool
P2	Do I link it with appropriate also?	Manage Tool
P1	Yes, I think so	Manage Tool

Chapter 7

STUDY 3: Emotional regulation dispositions and collaborative problem-solving [1]

7.1 Introduction

7.1.1 Emotions in interpersonal interactions and collaboration

Literature reports that the perception of others' emotions is a useful source of information (Van Kleef & Fischer, 2016) allowing individuals to gain evidence regarding each other's interpretation of the current situation (Van Kleef et al., 2016). In this way, emotions can help people infer the causes and consequences of a given emotional state and adapt accordingly, considering the context that led to its emergence (Van Kleef et al., 2010). Emotions could allow group members to gain a deeper understanding of cognitive (e.g., disequilibrium, stuck), motivational (e.g., beliefs about self-ability, attitudes towards problem-solving, mastery or performance goals, intrinsic or extrinsic values) and relational (e.g., receptivity, dominance, affection, trust; Hale et al., 2005) aspects of the collaboration. Therefore, it could promote a better mutual adaptation and foster the achievement of the common goal.

However, during collaborative problem-solving, group members' resources are primarily mobilized by the cognitive activities required to solve the problem. In such a context, some emotional cues related to essential aspects of the collaboration can be more easily overlook than in casual interactions. This phenomenon could be even accentuated in computer-supported collaboration settings where the possibility to access nonverbal cues conveying emotional information is limited (Stewart et al., 2019; Walther et al., 2015). This aspect can impair the quality of collaboration in reducing the possibility of using nonverbal cues to build mental models of the collaboration (Avry, 2020; Molinari et al., 2009; Sangin et al., 2011) and undermine the

[1] The study presented in this section is adapted from *Avry, S. & Molinari, M. (2020). Impact of explicit emotion sharing and interpersonal emotion regulation dispositions on relational dimensions of collaboration. Manuscript submitted in the International Conference of the Learning Sciences (ICLS).*

mutual adaptation of group members. However, individuals may compensate for this limitation by sharing more emotional information through verbal rather than non-verbal communication (Walther et al., 2015). Building on this idea, some authors have studied how the explicit sharing of emotions between group members impacts the different afore-mentioned dimensions of collaboration. For example, (Eligio et al., 2012) investigated whether group members can improve their mutual understanding of emotions by the explicit sharing of emotional labels. Results showed a positive effect of emotion sharing on the mutual understanding of each other's emotions, group affect and group performance, especially when participants collaborate remotely. Molinari et al. (2013) showed that the explicit sharing of emotions stimulates group members to engage in mutual modeling of emotions. This mutual modeling also correlates with more positive feelings in group members. Other studies have also demonstrated that the explicit sharing of emotions influences the kind of intentional exchanges (i.e., collaborative acts; Avry, 2020) used by the group members (Avry & Molinari, 2018; Avry et al., 2020b). For example, Avry and Molinari (2018) reported a positive impact of the sharing of emotions on the number of collaborative acts dedicated to greetings or courtesy and sharing information about one's own and partner knowledge or thinking. Moreover, some other findings showed that the explicit sharing of positive emotions contribute to regulating each other's collaborative acts throughout the collaboration. It also suggests that the sharing of specific emotions could be associated with particular patterns corresponding to different collaboration phases (Avry et al., 2020b). Overall, these studies suggest that the explicit sharing of emotions stimulates the mutual understanding of emotions, fostering mutual adaptation in the cognitive, motivational, and relational dimensions of collaboration. Ultimately, it might benefit various collaborative outcomes such as group implication, performance or relational climate.

7.1.2 Emotions and interpersonal emotional regulation

However, along with the understanding of emotions, the regulation of emotions is also crucial to task achievement as it allows individuals to harness the beneficial or detrimental effects of both positive and negative emotions on collaborative outcomes (Koole, 2009). For example, alleviate frustration due to cognitive difficulties may lead to implementing surface cognitive strategies that may impair problem-solving. Thus, emotion regulation allows group members to find good reasons to tolerate a certain degree of frustration. However, this reflective regulation of emotions (i.e., monitor and manage emotions to achieve intended goals) is the highest level of a hierarchy of emotional competencies (Fernández-Berrocal & Extremera, 2006) that also include the perception and expression of emotions (i.e., identify emotions through physical and psychological states, express emotions accurately as well as the needs related to them, discriminate between accurate and inaccurate feelings according to the context), the understanding and analysis of emotions (i.e., comprehend, recognize and describe emotions using language) and the assimilation of

emotions in thought (i.e., harness emotions to promote thinking in various cognitive activities) (Mayer et al., 2011). People with higher emotional competencies would have better problem-solving abilities (Lam & Kirby, 2002), especially when confronted with frustrating problems (Schutte et al., 2001).

When group members interact together, the perception, assimilation, understanding, and regulation of other's emotions is also an integral part of emotional competencies. In recent years, a growing interest in the role of emotion regulation in interpersonal contexts has emerged. Interpersonal emotional regulation refers to the attempt to initiate, maintain, modulate, or change emotions in self and others in interpersonal contexts (Fischer, Manstead, et al., 2016; Niven et al., 2011; Zaki & Williams, 2013). According to Niven et al. (2011), the regulation of emotions in interpersonal settings can be directed toward oneself or others (intrinsic vs. extrinsic regulation) and is dedicated to improving or worsening emotions. Hence, it is possible to distinguish four main categories of interpersonal emotion regulation. Intrinsic affect-improving refers to the intentional improvement of one's own feelings. Intrinsic affect-worsening refers to the intentional worsening of one's own feelings. Extrinsic affect-improving refers to the intentional improvement of another person's feelings. Finally, extrinsic affect-worsening refers to the intentional worsening of another person's feelings. Literature reports that individuals differ in the extent they regulate emotions. Some modes of interpersonal emotion regulation would be more closely associated with specific personality traits (Mikolajczak et al., 2008; Niven et al., 2011). For example, a lack of interpersonal control is correlated with a greater tendency to worsen one's own and other's feelings (Niven et al., 2011). The regulation of emotions in interpersonal settings is also a resource-consuming process that can compete with other cognitive tasks. Some forms of interpersonal emotion regulation appear more depleting than others. For example, worsening other's emotions is more resource-consuming than improving other's emotions (Niven, 2016, 2017).

The underlying intention of interpersonal emotion regulation is to alter self and other's behavior to promote goal accomplishment. Different motives for self-regulating emotions have been uncovered in the literature. Some of these motives are related to increasing other's performance, such as coaching motives (i.e., try to regulate other's emotions to help them perform better) or instrumentality motives (i.e., try to improve team members' emotions to make them work harder). Some others are related to relational concerns, such as compassion motives (i.e., try to regulate other's emotions to help them feel better) or conformity motives (i.e., try to regulate other's emotions to promote the smooth running of social situations) (Niven, 2016). In collaboration, the interpersonal regulation of emotions could serve cognitive, motivational and relational motives leading to promote better collaborative outcomes. For example, improve one's own and partner's emotions when the problem to be solved generates intense confusion could help group members to maintain an emotional state that could be more conducive to stimulate divergent thinking and find

novel solutions. Worsening one's own and partner's emotion could also help to keep a cool head and avoid distractions so as to promote careful processing of information and stimulate convergent thinking. Similarly, interpersonal regulation could encourage affiliation or generate social distancing (Fischer, Manstead, et al., 2016). For example, collaborative work can sometimes benefit from maintaining an relational distance to promote more task-oriented exchanges. All in all, the ability to perceive and regulate emotions properly according to the context appears to be an essential aspect of successful collaborative problem-solving.

7.2 Hypotheses

The first goal of this study is to explore further how the mutual sharing of emotion can impact group members' accuracy to assess their partner's emotions throughout the collaboration. We assume that the explicit sharing of emotions during a collaborative task increases the attention dedicated to the modeling of partner's emotions. Therefore, when participants share emotions throughout the collaboration, they should increase their accuracy of their partner's emotional state (**H1**).

Second, higher interpersonal emotional regulation competencies are related to a higher ability to regulate one's own and partner's emotion in interpersonal contexts. These competencies allow the group members to regulate emotions to promote behaviors that benefit the attainment of the common goal, i.e., better cognitive, motivational, and relational quality. People also diverge in their disposition to regulate other's emotions. As part of this study, we examine more particularly the relationship between these dispositions and the relational dimensions of the collaboration (Hale et al., 2005). We assume that groups with higher tendencies to regulate self and other's emotions have a better relational quality (**H2**).

Third, the capacity to regulate emotions in self and others is closely tied to comprehending emotions. As these emotional competencies are hierarchically structured, the capacity to regulate emotions depends on perceiving emotions accurately. From this perspective emerges the idea that lower dispositions to regulate emotions could be due, at least in part, to difficulties in comprehending other's emotion. Therefore, we hypothesize that the sharing of explicit emotions induces a positive effect on the relational quality of group members with lower dispositions to regulate emotions (**H3**), in improving each other's emotional accuracy.

Finally, we also assume that an improvement of the relational quality of collaboration is reflected on collaboration more globally. Indeed, we hypothesize positive correlations between the relational quality and the perception of difficulty, effort, and the participants' motivation (**H4**), as well as the attention to the other's information (**H5**) and group performance (**H6**).

7.3 Method

7.3.1 Participants

One hundred and twenty-four students from the University of Geneva (86 women and 38 men; *M* = 23.24 years, *SD* = 4.37 years, 2.62 years of postgraduate education on average), grouped in same-sex pairs, took part voluntarily to the experiment. The study was designed to uncovered effects with an effect Cohen's d = 0.32 (between small and medium effect size) with a 80% power. Each pair received 40 CHF as inconvenience allowance. They were not acquainted with each other.

7.3.2 Experimental design

During the registration phase, participants had to fill the EROS (Emotion Regulation of Others and Self) questionnaire measuring their disposition to regulate one's own and other's emotions (Niven et al., 2011). Participants were automatically assigned with a partner of the same gender and with a similar EROS score (average scores difference was equal to 0.44 out of a maximum of 8 points). The motive was to have similar pairs in terms of emotion regulation dispositions. Pairs were then assigned to one of the two experimental conditions (i.e., explicit emotion sharing vs. no emotion sharing). The scores of the EROS questionnaire in the two conditions were the closest possible (mean difference was equal to 0.08).

7.3.3 Collaborative problem-solving task

A collaborative problem-solving task inspired by a report stating the food and agriculture challenges in 2050 (FAO) was designed for the purpose of the experiment. Each participant was invited to read a statement describing the problem and the requirements for solving it. The meaningful information was divided equally into the two statements, as in the Jigsaw technique (Aronson et al., 1978). Therefore, each participant only had a part of the necessary information to solve the problem (see Appendix A for a complete description of the statements). Besides, participants also had a statistic table in which numeric information related to the data was presented for each crop (i.e., energy intake, production costs, ecological costs, yield, robustness, water need, and technology need). Each participant had a different set of food plants in their table (see Appendix B for a complete description of the statistic table). The information required to solve the problem were split over the participants for two reasons. On the first hand, to stimulate the interdependence between participants, and so doing, promote collaboration. On the other hand, to evaluate which information was eventually exchanged and memorized. The problem participants had to deal with was an optimization problem. In other words, participants had to find the optimal set of food plants according to the given criteria. The procedure to solve the problem optimally was the following:

1. Calculate the productivity (yield times energy intake) of each crop

2. Select the nine most productive crops
3. Sum production and ecological costs
4. Sum production and ecological costs
5. Sum others characteristics according to the remaining criteria (i.e., robustness, water need and technology need)
6. Distribute crops in the different zones according to the gathered criteria
7. Check if the production and ecological costs are distributed fairly in each zone

These steps should lead participants to select the rye, oat, and sunflower in the Mediterranean zone, almond tree, palm tree, and soya in the tropical zone, and peanut, barley, and rape in the semi-arid zone. At the end of the experiment, a computer program coded in Python© returned the performance according to the response given from 0 (no correct answer) to 9 (optimal answers).

7.3.4 Collaborative software

The computer of each participant was connected to a network and they collaborated remotely without seeing each other. A collaborative application developed with the software ClickTeam Fusion© (Version 2.5) was used for the experiment's purpose. This software allowed participants to collaborate by communicating through a chat, exchanging information in a shared notepad, and submitting joint answers (Figure 1). Chat exchanges, shared notes, and joint answers were stored throughout the collaboration. Depending on the experimental condition (emotion sharing vs. no emotion sharing), the software was also displaying either emotions or life habits to be assessed at different times of the experiment. At the end of the task, participants also completed computerized questionnaires in the application.

7.3.5 Questionnaires

7.3.5.1 Pre-task questionnaire

The affect regulation dispositions of the participants were assessed by a questionnaire adapted from the EROS questionnaire (see Appendix C). They were divided into four types depending on the target of the regulation (self or other's affect) and the regulatory motive (worsening or improving affect), namely intrinsic affect-improving, intrinsic affect-worsening, extrinsic affect-improving and extrinsic affect-worsening (see Appendix C). Participants were asked to answer the questions through 8-point Likert scales from 1 to 8 (i.e., *never*, *very rarely*, *rarely*, *sometimes*, *quite often*, *often*, *very often*, *systematically*). The different items (initially available in English), were translated in French for the experiment. The forward-backward procedure was applied to obtain the translation ("Process of translation and adaptation of instruments"). In step 1, two bilingual translators carried out a forward translation

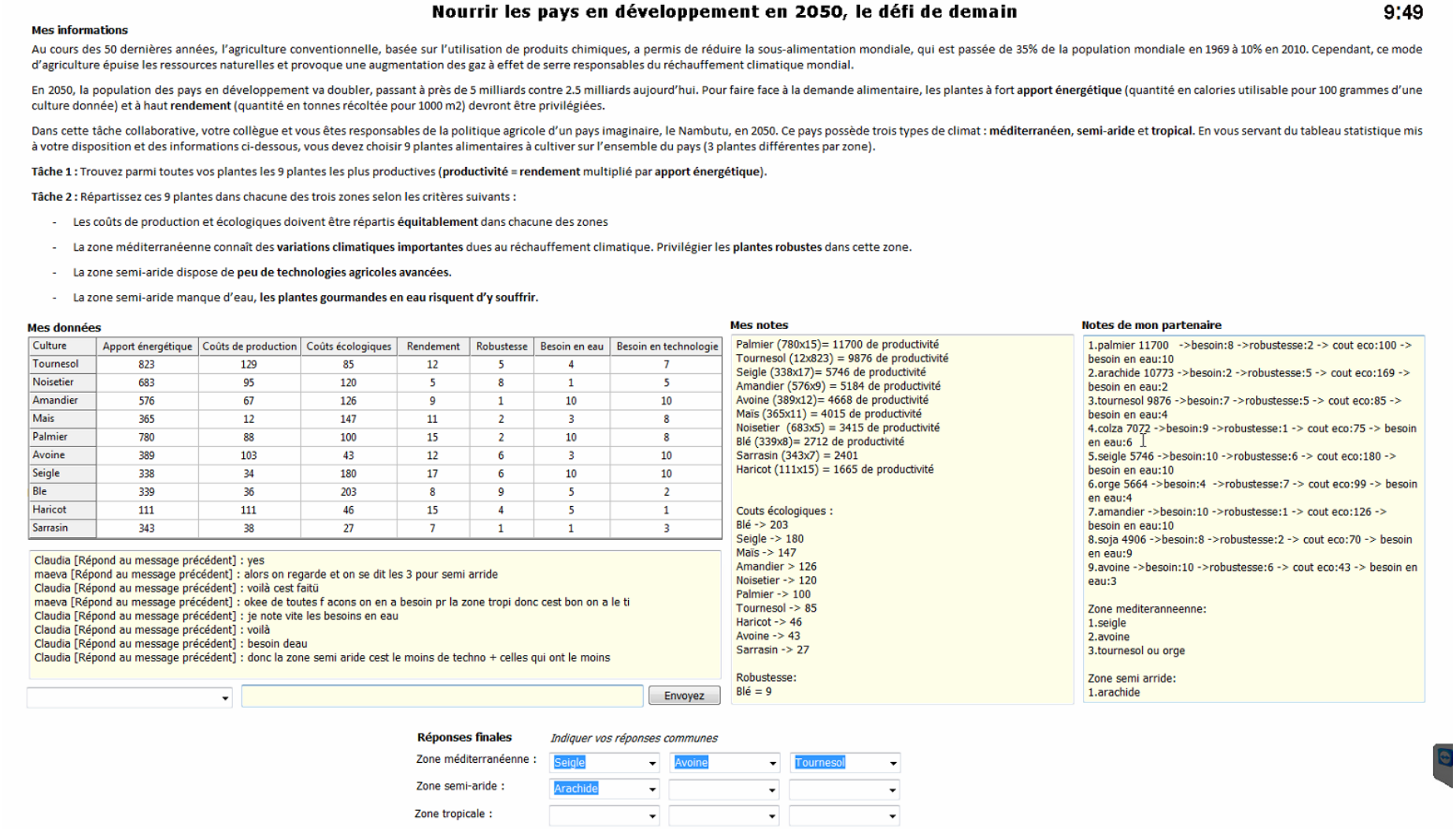

FIGURE 7.1: The collaborative software used in the experiment

from English to French. The experimenters then selected the best phrases from both translations. In step 2, two other bilingual translators performed a backward translation from French to English and the experimenters selected the best sentences from both translations again. In step 3, seven bilingual English native speakers compared the original and translated English versions and make comments. These comments were eventually used to refine the final French version. The scores at this questionnaire were introduced in the following statistical analyses as an independent variable.

7.3.5.2 Peri-task questionnaires

Depending on the experimental condition, participants filled a questionnaire on either their emotions or life habits several times during the task. The variant on emotions assessed the intensity of both participants' own emotions and partner's perceived emotions (*frustration*, *interest*, *boredom*, *enjoyment*, *confusion*) through verbal labels. It was asked to the participants to focus on the last 10 minutes of collaboration. The variant on life habits assessed the frequency of both participants' own life habits as well as Swiss people's life habits (five different sets of life habits were presented for each display of the questionnaire). The life habits questionnaire was a dummy questionnaire used to involve participants in a task of the same time and difficulty but with no connection with emotions in the no emotion sharing condition. Both variants of the questionnaire (emotions and life habits) used 7-point scales from 0 to 6 (i.e., *not at all*, *very slightly*, *slightly*, *moderately*, *rather strongly*, *strongly* and *very strongly* for emotions and *never*, *once every 10 years*, *once a year*, *once a month*, *once a week*, *once a day* and *even more*). Immediately after the submission, a graph was displayed allowing the participants to contrast their own estimation of their partner's emotions and the actual partner's emotions regarding the last 10 minutes (Figure 7.2). In the life habits variant, the graph displayed their own life habits compared to the Swiss people's life habits.

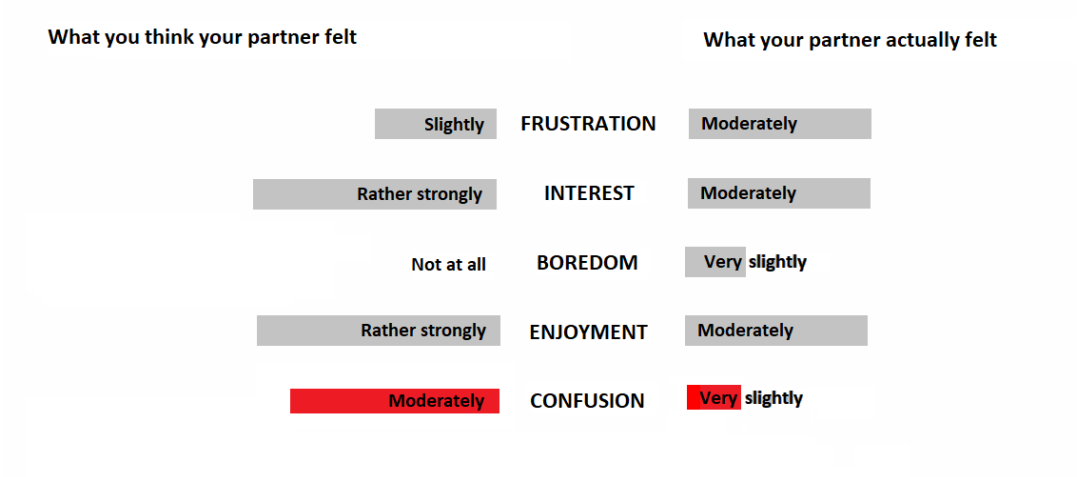

FIGURE 7.2: Feedback about the participant's estimation of their partner's emotions (left) and the actual partner's emotions (right) in the emotion sharing condition. Differences greater than 2 points were highlighted in red. Translated from French.

7.3.5.3 Post-task questionnaires

Participants completed several questionnaires immediately after the task. First, they responded to several questions concerning both their own (10 questions) and their partner's information (10 questions). On one side, this questionnaire allowed the assessment of the information memorized by the participants. On the other side, it was also a marker of information exchange between participants. Second, participants completed a questionnaire assessing their perception of motivation, perceived difficulty, and perceived effort, designed from Huang (2017) (see Appendix E). Finally, the perception of collaboration was assessed through seven questions covering seven relational themes (see Appendix D), namely equality, affection, receptivity, depth, dominance, implication and productivity. This questionnaire was adapted from the relational communication scale (Hale et al., 2005). Equality refers to the degree to which participants perceived their partner as treating them as equal. Affection is about the degree to which participants perceived their partner as friendly. Receptivity concerns the degree to which participants perceived their partner as attentive, accessible, open, and interested in the collaboration. Depth focuses on the degree to which participants perceived their partner as trying to create a sense of familiarity between them. Dominance reflects the degree to which participants perceived their partner as influential during the collaboration. Implication evaluates the degree to which participants perceived their partner as involved in the collaboration. Finally, productivity assesses the degree to which participants perceived their partner as contributing equitably to the collaboration. Each question used a 7-point Likert scales from 0 to 6 (i.e., *no agreement*, *very little agreement*, *little agreement*, *somewhat agreement*, *quite agreement*, *strong agreement*, *total agreement*).

7.3.6 Procedure

Participants introduced each other briefly and then seated in front of a computer screen. They were each placed in the corner of the experimentation room, separated from each other by an office divider. They received oral instructions from the experimenter presenting the problem to be solved and the functioning of the collaborative software. This information was also available at any time by the participant in a written form. It was notified to the participants that they did not have all the required information in their own statement and that the relevant information was dispatched between them and their partner. The problem-solving task per se lasted sixty minutes, interspersed with five breaks of about two minutes dedicated to the per-task questionnaires. At the end of the task, participants completed the post-task questionnaires (about ten minutes) and then received feedback on their answers, the optimal solutions, and the computed group performance. In the end, they were explained about the research question of the study and received their monetary compensation.

7.4 Results

7.4.1 Unit of analysis

In order to assess the (non-)independence of peers' measures and confirm the possibility to use the individual as unit of analysis (see Kenny et al., 2006 for further discussion), intraclass correlation was performed between subject A and subject B's data (A and B being of the same pair). We computed the ICC for all the dependent variables of interest. No evidence of a dyad effect was supported by these analyses (cf. Appendix F). Therefore, individual-level measures were used as unit of analysis with standard inferential statistical methods.

7.4.2 Age and level of education

No difference of age ($t(116.26) = -0.76$, $p = 0.44$) or level of education ($t(120.98) = 0.13$, $p = 0.89$) were found in emotion sharing and no emotion sharing conditions.

7.4.3 Emotion regulation dispositions

The average global score of emotion regulation dispositions across participants was 4.79 ± 0.66 out of 8 ranging from 3.26 to 5.63. The average intrinsic improving score was 5.52 ± 1.24 ranging from 1.66 to 7. The average intrinsic worsening score was 3.22 ± 1.37 ranging from 1.25 to 5.75. The average extrinsic improving score was 6.11 ± 1.14 ranging from 1.66 to 7.5. Finally, the average extrinsic worsening score was 2.81 ± 1.20 ranging from 1.16 to 6.4. No difference was found on these scores between emotion sharing and no emotion sharing conditions.

7.4.4 Global Emotional intensity

Table 7.1 describes the global mean intensities of the explicitly shared emotions. No differences of intensity were found between self and partner emotions. The intensity of frustration, boredom and confusion were significantly lower than interest and enjoyment. The intensity of interest was significantly more intense than enjoyment.

	Frustration	Interest	Boredom	Enjoyment	Confusion
Mean (self)	1.88 (1.34)	4.53 (0.82)	0.93 (0.81)	3.89 (0.91)	1.90 (1.17)
Mean (other)	1.97 (1.21)	4.34 (0.80)	1.05 (0.82)	3.76 (0.81)	1.98 (1.07)

TABLE 7.1: Mean intensity and standard deviation of emotion (out of 6) for each emotion shared during the collaborative problem-solving.

7.4.5 Emotional accuracy (H1)

A series of one-way repeated measures ANOVAs was conducted for each emotion (frustration, interest, boredom, enjoyment and confusion) to compare the effect of repeated explicit sharing of emotions on participants' emotions accuracy. For each participant and each estimation, a group inaccuracy score was computed as the mean of the absolute differences between **each participants' estimations of their partner's emotions** and **what their partner actually reported**.

7.4.5.1 Frustration

On average, the group inaccuracy score for frustration was 1.20 $\pm$ 0.77 (out of a possible 6).

No overall significant effect of repeated estimation of partner's frustration on group inaccuracy for frustration was found ($F(4, 155) = 1.80$, $p = 0.13$). However, paired t-tests indicate marginally significant differences between Estimation 1 ($M = 1.5$, $SD = 0.92$) and Estimation 2 ($M = 1.12$, $SD = 0.71$) and between Estimation 1 and Estimation 3 ($M = 1.12$, $SD = 0.79$), as well as a significant difference between Estimation 1 and Estimation 4 ($M = 1.03$, $SD = 0.77$) (Figure 7.3).

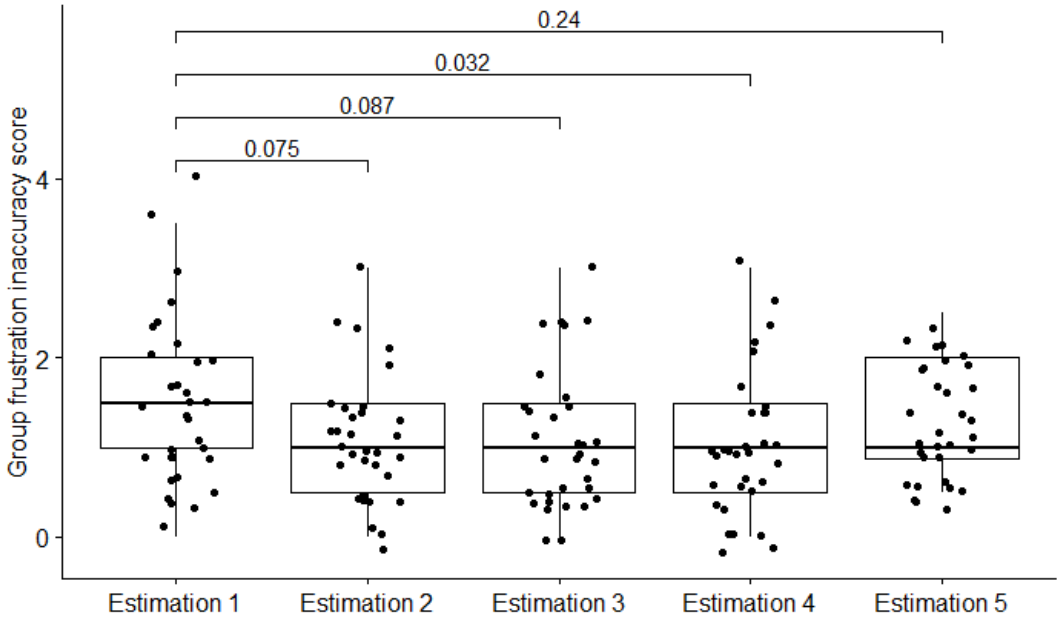

FIGURE 7.3: Group inaccuracy scores for frustration for each emotion estimation of partner's frustration. Numbers above boxplots indicate p-values for each paired t-test.

7.4.5.2 Interest

On average, the group inaccuracy score for interest was 0.97 ± 0.78 (out of a possible 6).

No overall significant effect of repeated estimation of partner's interest on group inaccuracy for interest was found ($F(4, 155) = 0.72$, $p = .57$). Paired t-tests indicate no significant differences between the different estimations (Figure 7.4).

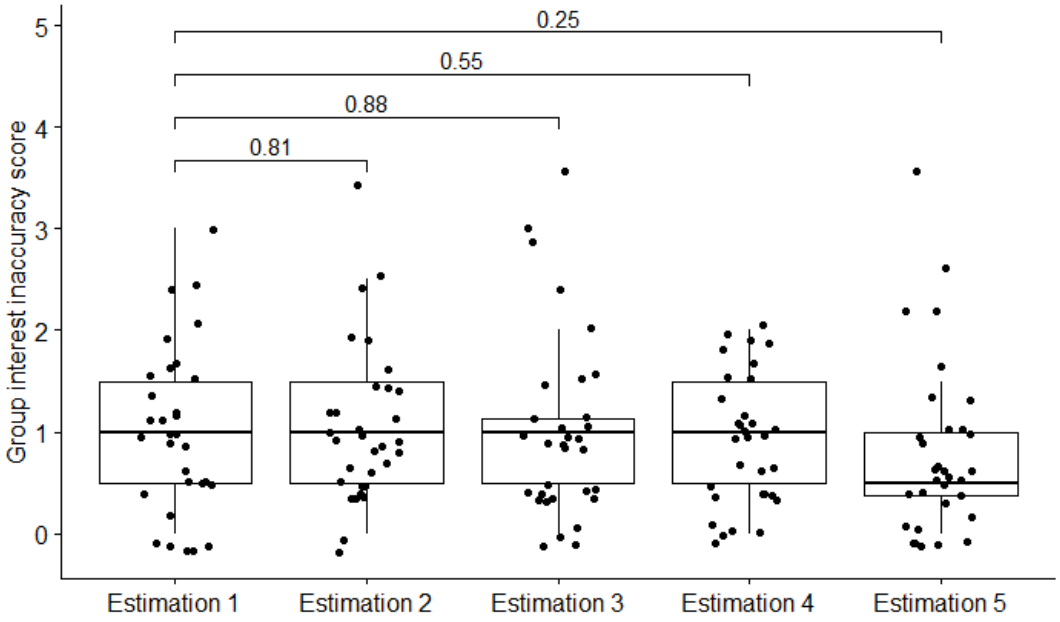

FIGURE 7.4: Group inaccuracy scores for interest for each emotion estimation of partner's interest. Numbers above boxplots indicate p-values for each paired t-test.

7.4.5.3 Boredom

On average, the group inaccuracy score for boredom was 0.8 ± 0.75 (out of a possible 6).

No overall significant effect of repeated estimation of partner's boredom on group inaccuracy for boredom was found ($F(4, 155) = 1.65$, $p = .16$). However, paired t-tests indicate marginally significant differences between Estimation 1 ($M = 1.08$, $SD = 0.92$) and Estimation 2 and between Estimation 1 and Estimation 5 ($M = 0.79$, $SD = 0.71$), as well as a significant difference between Estimations 1 and 4 ($M = 0.65$, $SD = 0.53$) (Figure 7.5).

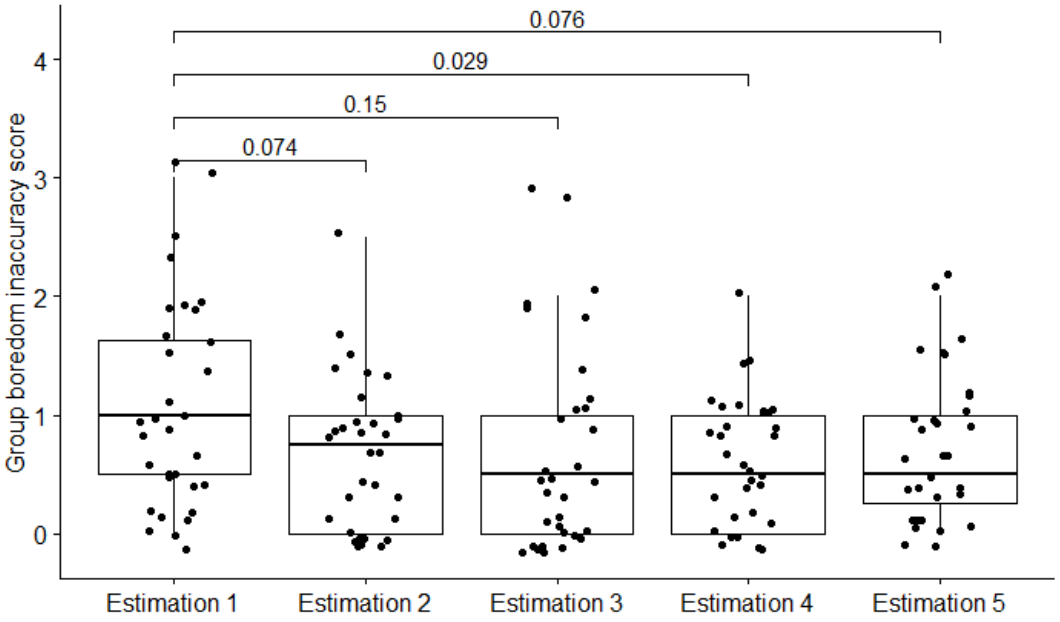

FIGURE 7.5: Group inaccuracy scores for boredom for each emotion estimation of partner's boredom. Numbers above boxplots indicate p-values for each paired t-test.

7.4.5.4 Enjoyment

On average, the group inaccuracy score for enjoyment was 0.91 $\pm$ 0.79 (out of a possible 6).

No overall significant effect of repeated estimation of partner's enjoyment on group inaccuracy for enjoyment was found ($F(4, 155) = 0.72$, $p = .57$). Paired t-tests indicate no significant differences between the different estimations (Figure 7.6).

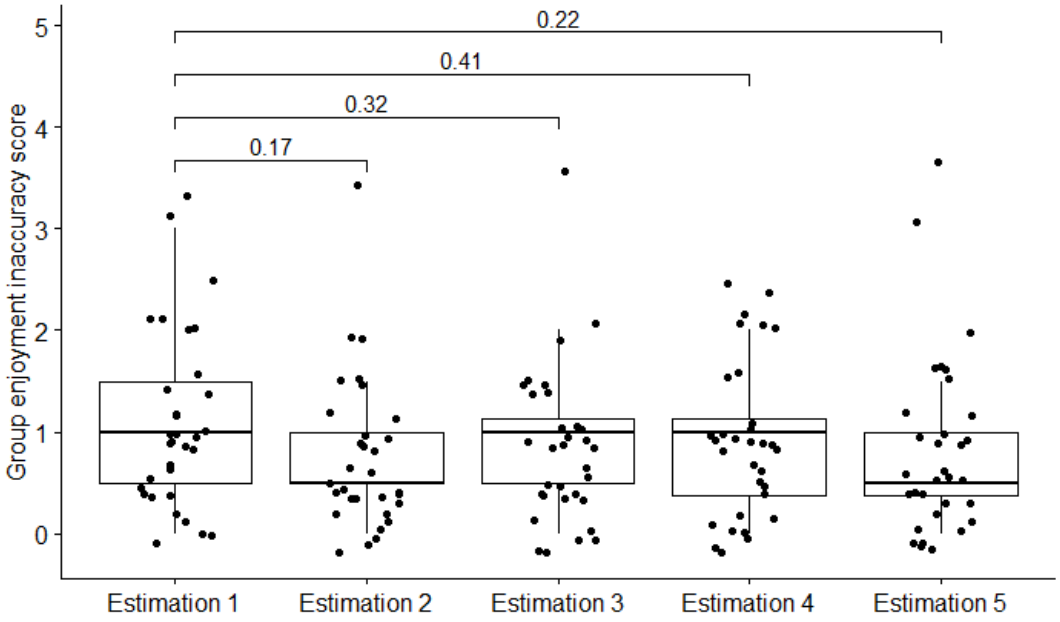

FIGURE 7.6: Group inaccuracy scores for enjoyment for each emotion estimation of partner's enjoyment. Numbers above boxplots indicate p-values for each paired t-test.

7.4.5.5 Confusion

On average, the group inaccuracy score for confusion was 1.14 $\pm$ 0.89 (out of a possible 6).

There was an overall significant effect of repeated estimation of partner's confusion on group inaccuracy for confusion ($F(4, 155) = 2.66$, $p = .03$). Paired t-tests indicate significant differences between Estimations 1 ($M = 1.55$, $SD = 1.02$) and 3 ($M = 1.06$, $SD = 0.94$), between Estimations 1 and 4 ($M = 0.89$, $SD = 0.69$), and between Estimations 1 and 5 ($M = 1$, $SD = 0.78$) (Figure 7.7).

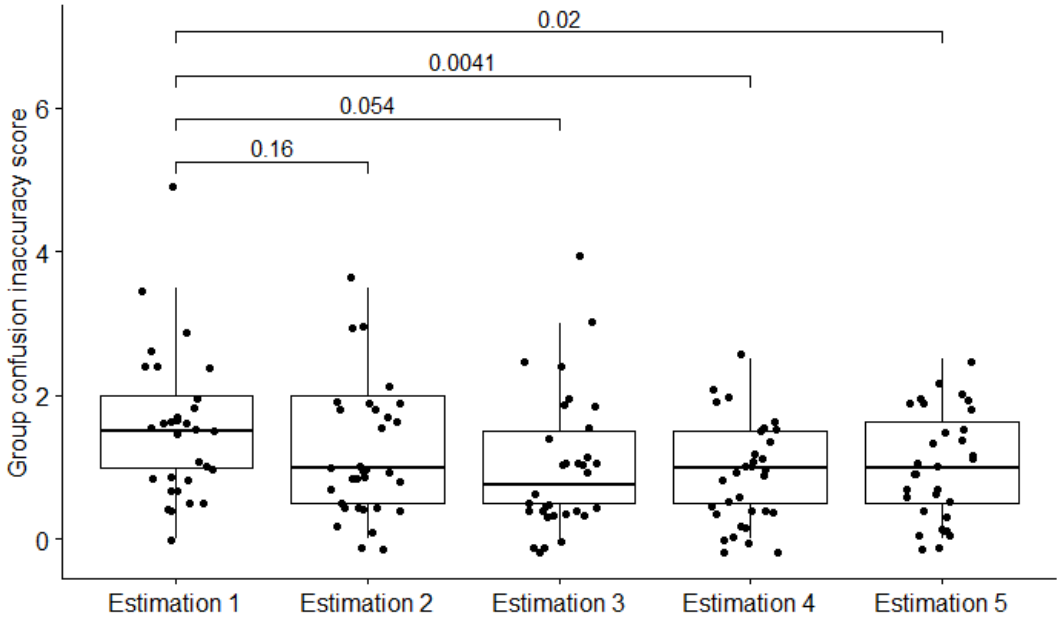

FIGURE 7.7: Group inaccuracy scores for confusion for each emotion estimation of partner's confusion. Numbers above boxplots indicate p-values for each paired t-test.

7.4.6 Perception of relational quality (H2 and H3)

Several multiple linear regressions were calculated to predict the different relational measures based on emotion sharing and emotion regulation dispositions. P-values are reported in Table 7.2 and significant results are described in detail in the following sections.

	[1]	[2]	[3]	[4]
Equality	**p < .05 (0.07)**	n.s. (0.01)	**p < .05 (0.07)**	n.s. (.0.00)
Affection	n.s. (0.06)	n.s. (0.00)	n.s. (0.03)	n.s. (0.00)
Receptivity	**p = .05 (0.07)**	n.s. (0.02)	n.s. (0.03)	n.s. (0.00)
Depth	n.s. (0.04)	n.s. (0.03)	n.s. (0.03)	n.s. (0.00)
Dominance	n.s. (0.02)	n.s. (0.02)	n.s. (0.01)	n.s. (0.00)
Implication	n.s. (0.02)	n.s. (0.02)	n.s. (0.06)	n.s. (0.01)
Productivity	n.s. (0.05)	**p < .05 (0.08)**	n.s. (0.05)	n.s. (0.04)

TABLE 7.2: P-values (effect size f^2) for the different multiple linear regressions with emotion sharing and emotion regulation disposition as independent variables and the different measures of relational quality as dependent variable. [1] Extrinsic worsening x emotion sharing; [2] Extrinsic improving x emotion sharing; [3] Intrinsic worsening x emotion sharing; [4] Intrinsic improving x emotion sharing.

7.4.6.1 Equality

On average, participants *strongly agreed* that their partner treated them as equal during the collaboration (M = 5.36, SD = 0.85).

Extrinsic worsening regulation dispositions x emotion sharing A significant regression equation was found ($F(3, 120) = 2.94$, $p < .05$), with a R^2 of .07. Both emotion sharing and extrinsic worsening regulation dispositions explained a significant proportion of variance in equality scores. There is a significant positive association between equality and extrinsic worsening regulation dispositions in the non emotion sharing condition, ($r(58) = .25$, $p = .05$). There is also a significant negative association between equality and extrinsic worsening regulation dispositions in the emotion sharing condition ($r(62) = -.27$, $p = .03$) (Figure 7.8).

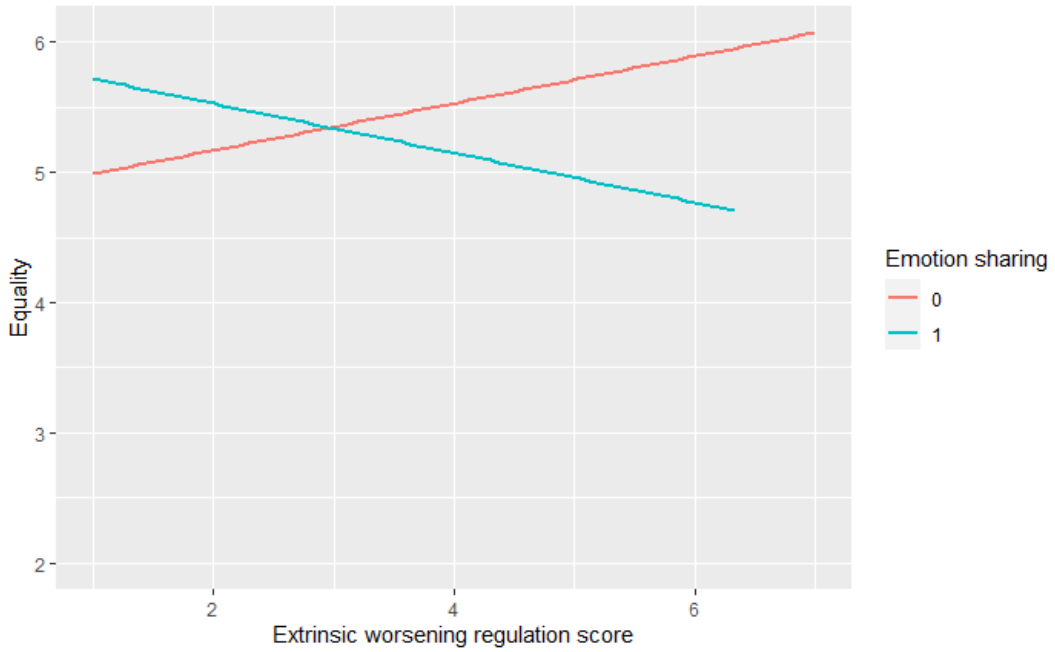

FIGURE 7.8: Interaction between emotion sharing and extrinsic worsening regulation dispositions in the perception of equality during the collaboration

Intrinsic worsening regulation dispositions x emotion sharing A significant regression equation was found ($F(3, 120) = 2.81$, $p < .05$), with a R^2 of .07. Both emotion sharing and intrinsic worsening regulation dispositions explained a significant proportion of variance in equality scores. There is a significant negative association between equality and intrinsic worsening regulation dispositions in the emotion sharing condition, ($r(62) = -.27$, $p = .02$), which is also marginally found in the no emotion sharing condition ($r(58) = .23$, $p = .07$) (Figure 7.9).

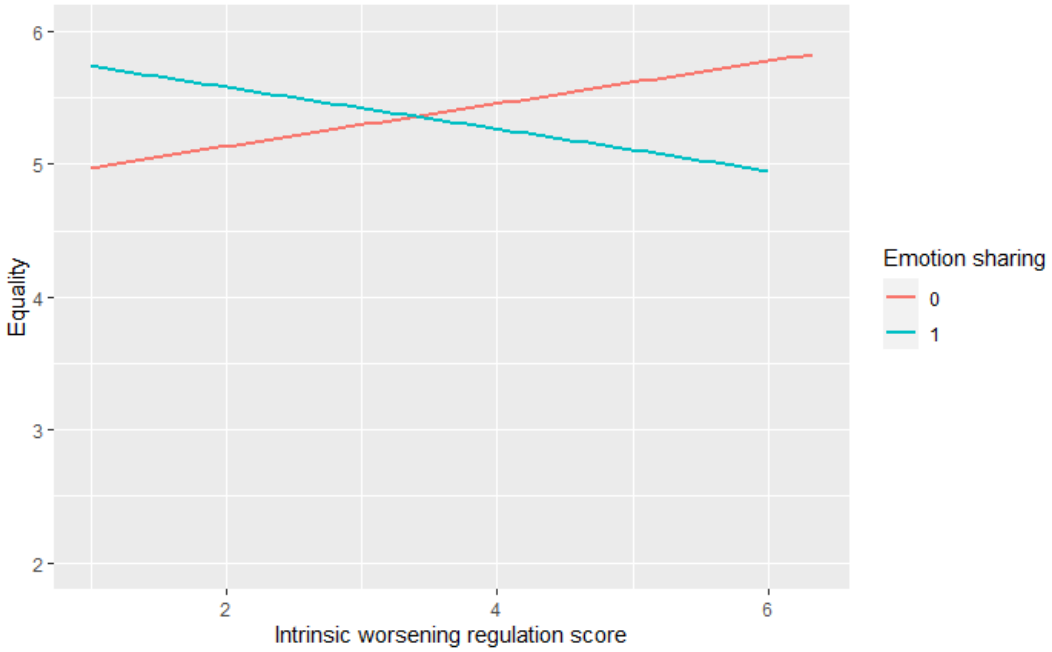

FIGURE 7.9: Interaction between emotion sharing and intrinsic worsening regulation dispositions in the perception of equality during the collaboration

7.4.6.2 Affection

On average, participants *totally agreed* that their partner was friendly during the collaboration (M = 5.58, SD = 0.67). No significant regression equations was found.

7.4.6.3 Receptivity

On average, participants *totally agreed* that their partner was attentive, accessible, open and interested during the collaboration (M = 5.53, SD = 0.72).

Extrinsic worsening regulation dispositions x emotion sharing A significant regression equation was found ($F(3, 120) = 2.60$, $p = .05$), with a R^2 of .06. Both emotion sharing and extrinsic worsening regulation dispositions explained a significant proportion of variance in receptivity scores. There is a significant positive association between receptivity and extrinsic worsening regulation dispositions in the no emotion sharing condition, ($r(58) = .38$, $p = .00$), which is not found in the emotion sharing condition ($r(62) = -.13$, $p = .28$) (Figure 7.10).

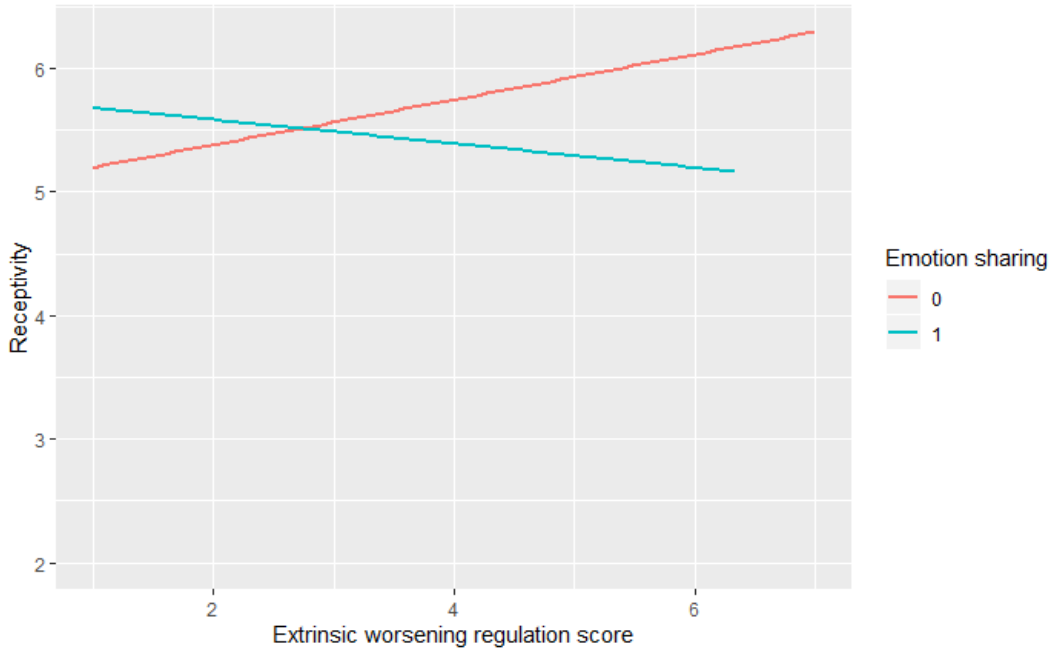

FIGURE 7.10: Interaction between emotion sharing and extrinsic worsening regulation dispositions in the perception of receptivity during the collaboration

7.4.6.4 Depth

On average, participants *quite agreed* that their partner tried to create a sense of familiarity between them during the collaboration (M = 4.41, SD = 1.38). No significant regression equations was found.

7.4.6.5 Dominance

On average, participants *little agreed* that their partner was influential during the collaboration (M = 2.36, SD = 1.53). No significant regression equations was found.

7.4.6.6 Implication

On average, participants *strongly agreed* that their partner was involved in the task (M = 5.37, SD = 0.84). No significant regression equations was found.

7.4.6.7 Productivity

On average, participants *strongly agreed* that their partner contributed equitably to the task (M = 5.16, SD = 0.95).

Extrinsic improving regulation dispositions x emotion sharing A significant regression equation was found ($F(3, 120) = 3.46$, $p < .05$), with a R^2 of .08. Both emotion sharing and intrinsic improving regulation dispositions explained a significant proportion of variance in productivity scores. There is a significant positive association between productivity and intrinsic improving regulation dispositions in the non

emotion sharing condition, ($r(58) = .39$, $p = .00$), which is not found in the emotion sharing condition ($r(62) = .02$, $p = .83$) (Figure 7.11).

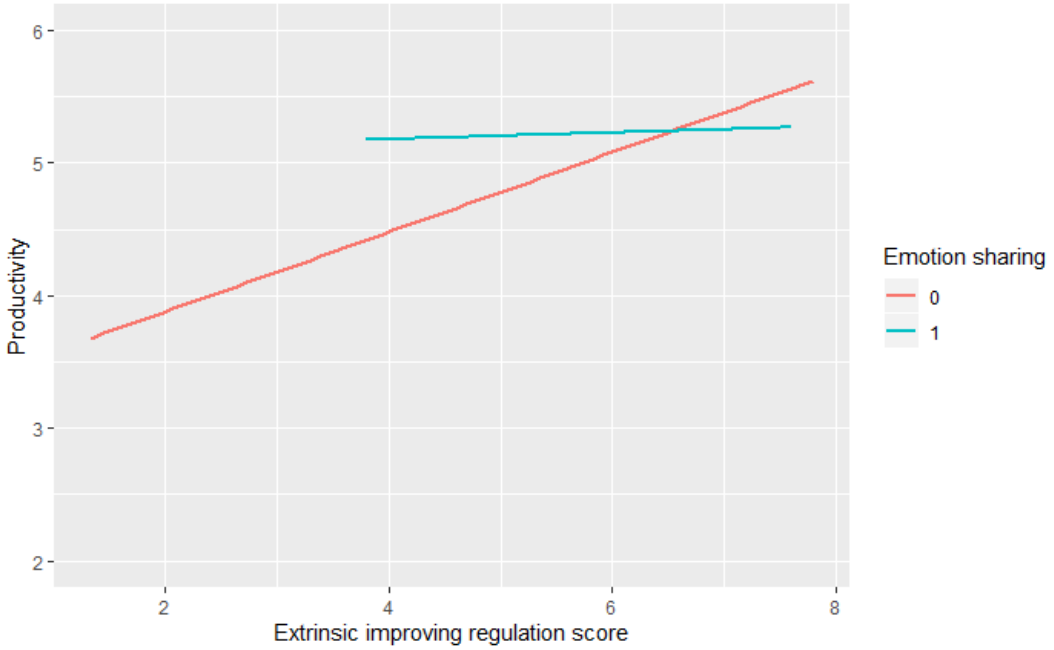

FIGURE 7.11: Interaction between emotion sharing and extrinsic improving regulation dispositions in the perception of productivity during the collaboration

7.4.7 Relationships between relational quality and difficulty, effort, motivation (H4), retention of partner's information (H5) and group performance (H6)

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The different relational measures were correlated with the participants' perception of several cognitive and motivational aspects of the collaboration as well as group performance. P-values are reported in Table 7.3 and significant results are described in detail in the following sections.

	[1]	[2]	[3]	[4]	[5]
Equality	n.s. (-0.13)	n.s. (0.05)	n.s. (0.15)	n.s. (-0.03)	n.s. (0.19)
Affection	n.s. (-0.18)	**p<.01 (0.36)**	n.s. (0.20)	n.s. (-0.10)	n.s. (0.04)
Receptivity	n.s. (-0.03)	n.s. (0.13)	**p<.05 (0.26)**	n.s. (-0.05)	n.s. (0.06)
Depth	n.s. (-0.04)	n.s. (0.18)	n.s. (0.10)	n.s. (-0.04)	n.s. (0.18)
Dominance	n.s. (0.11)	n.s. (0.09)	n.s. (0.04)	n.s. (-0.03)	n.s. (-0.11)
Implication	**p<.05 (-0.25)**	n.s. (0.08)	n.s. (0.03)	n.s. (-0.05)	n.s. (0.04)
Productivity	**p<.05 (-0.25)**	n.s. (0.02)	n.s. (0.19)	n.s. (-0.02)	n.s. (0.12)

TABLE 7.3: P-values (effect size r) for the correlations analyses between the different relational measures and the participants' perception of cognitive and motivational aspects of the collaboration as well as group performance. [1] Difficulty; [2] Effort; [3] Motivation; [4] Retention of partner's information; [5] Group performance.

7.4.7.1 Difficulty, effort and motivation

Difficulty On average, participants *somewhat agreed* that the task was difficult (M = 2.50, SD = 1.31).

Among the dyads, the perception of implication ($r(60)$ = -0.25, $p < .05$) and productivity ($r(60)$ = -0.25, $p = .05$) were negatively correlated to the perception of difficulty.

Effort On average, participants *strongly agreed* that the task was effortful (M = 4.81, SD = 0.80).

Among the dyads, the perception of affection was positively correlated to the perception of effort ($r(60)$ = 0.36, $p < .01$).

Motivation On average, participants *somewhat agreed* that the task was motivating (M = 4.39, SD = 1.10).

Among the dyads, the perception of receptivity was positively correlated to the perception of motivation ($r(60)$ = 0.26, $p < .05$).

7.4.7.2 Retention of partner's information

On average, participants memorized 2.80 $\pm$ 1.06 of their partner's information (out of a possible 10). No correlation was found between the retention of the partner's information and the different relational dimensions studied.

7.4.7.3 Group performance

On average, participants had a performance score of 5.24 $\pm$ 1.74 (out of a possible 9). No correlation was found between the group performance and the different relational dimensions studied.

7.5 Discussion

7.5.1 Does mutual sharing of emotion improve emotional accuracy?

Previous results have reported that the mutual sharing of emotions is positively correlated with more perceived modeling of emotions (Molinari et al., 2013). The first question that drove this study was if mutual emotion sharing positively affects mutual emotional accuracy during collaboration. We assumed that problem solvers increase each other's emotional states' accuracy through mutual sharing (**H1**). To test this hypothesis, we computed a dyadic score reflecting the accuracy between the participant's prediction of their partner's emotions and what their partner reported. This score was computed for the five different emotions studied (frustration, interest, boredom, enjoyment, and confusion) at five different times of the collaboration.

Results showed that dyads tend to become more accurate (i.e., they know more precisely the intensity of their partner's emotions) over the collaboration. However, this is especially true for negative emotions, namely frustration, boredom, and confusion. No real improvement of accuracy has been found for enjoyment and interest, perhaps because the accuracy for positive emotions was already better than for negative emotions. Concerning negative emotions, dyads became globally more accurate at their second estimation and then kept a similar accuracy throughout the collaboration. This result suggests that the first estimation (without any previous estimate) serves as a benchmark and allow participants to refine the understanding of their partner's negative emotions thereafter. Gaining a more accurate mutual understanding of negative emotions during the collaboration, especially in terms of intensity, could be useful to orient group members to important emotional events that would be costly to overlook.

Nevertheless, in the case of frustration, group estimation appears less accurate for the last estimation. This may reflect that in the later stages of the collaborative task, frustration does not reflect only epistemic matters (i.e., related to the learner's cognitive processing of information; D'Mello and Graesser, 2012) but also achievement matters (i.e., associated with the achievement of activity and outcomes; Pekrun, 2006). In this case, participants could have more difficulty to assess the intensity of their partner's frustration as it also depends on his/her judgment of achievement regarding the task, which could be more prone to individual subjectivity.

7.5.2 Does mutual sharing of emotion and emotion regulation dispositions interact with each other regarding group relational quality?

The second question that drove this study was about the relationship between emotion regulation dispositions and relational quality. We assumed that groups with higher emotion regulation dispositions have better relational quality (**H2**). However, we also assumed that the sharing of explicit emotions induces a positive effect on the relational quality of group members with lower dispositions to regulate emotions (**H3**). Results showed effects that point toward these hypotheses.

Equality When participants do not share their emotions explicitly, the perception of equality (i.e., the degree to which participants perceived their partner as treating them as equal) is positively correlated with the disposition to worsen both one's own (Figure 7.9) and other's emotions (Figure 7.8). Counter-intuitively though, the tendency to worsen one's own (e.g., in thinking about one's own shortcomings or looking for the problems of the current situation) and other's emotions (e.g., in telling someone about their shortcomings) predict more perceived equality in the group. As reported in Rimé (2009), the exchange of some negative emotions in potentially distressing situations, such as complex problem-solving, could promote affiliation. Therefore, the mutual tendency to worsen emotion could reinforce the feeling of equality in fostering social integration (Yang & Kelly, 2016).

However, a reverse effect is found in the emotion sharing condition, which could be explained by a tendency to share mainly positive emotions explicitly, as found in this study (stronger intensities for positive emotions; Table 7.1) and other previous studies (e.g., Avry et al., 2020b). This latter tendency could conflict with the tendency to worsen emotions and thus disrupt the behavior of individuals who naturally worsen emotions to increase a feeling of equality in the group. Participants with lower dispositions to worsen emotions, however, seem to rely more on the explicit sharing of emotions (mainly positive emotions in this case) as a way to judge equality.

Receptivity The perception of receptivity (i.e., the degree to which participants perceived their partner as attentive, accessible, open, and interested in the collaboration) also seems to be related to the disposition to worsen the other's emotions. However, the disturbing effect of explicit emotional sharing in participants with higher dispositions for worsening emotions does not appear significant in this case (Figure 7.10).

Productivity Finally, a different pattern is found for the perception of productivity (i.e., the degree to which participants perceived their partner as contributing equitably to the collaboration), which depends on the disposition to improve other's emotions. Indeed, when participants do not share emotions explicitly, the more the

participants have the disposition to improve other's emotions, the more they find their partner as contributing equitably to the collaborative task. In this case, the effect of emotion sharing does not seem to have any disturbing effect on participants with higher emotion regulation dispositions (Figure 7.11).

7.5.3 Does relational quality improve other dimensions of collaboration and performance?

Perception of difficulty, effort and motivation We also proposed that an improvement of the relational quality of collaboration could bring some benefits regarding the perception of difficulty, effort and motivation (**H4**). Results show that some relational themes differently affect these different aspects. First, the perception of difficulty decreases when the perception of implication (i.e., the perception that the partner was involved in the task) and productivity (i.e., perception that the partner was contributing equitably to the task) increase. The perception of perceived effort appears to be positively related to the dimension of affection (i.e., the perception that the partner was friendly). This result suggests that participants could be more prone to invest effort in the task when they find their collaborative partner more friendly. Finally, the degree of motivation appears to be substantially related to the perception of receptivity (i.e., the perception that the partner was attentive, accessible, open, and interested). All in all, these results suggest that the relational, socio-cognitive (perceived difficulty and effort), and socio-motivational (motivation) of collaboration are interconnect and affect each other.

Attention to partner's information At the beginning of the collaborative task, participants were advised that they had not all the necessary information to solve the problem in their own statements. In fact, each participant had only half of the necessary information. Therefore, they must exchange information at some points during the task. In this experiment, some questions about the partner's information were asked at the end of the task to assess the attention to that information. In general, people memorized little information from their partner (less than one third on average). This result could suggest that people exchange little information during the task. However, this low retention score can also be explained by the fact that participants were not explicitly asked to memorize that information. Although we proposed that an increase in the relational quality of the collaboration could enhance the attention to the other's information (**H5**), no relationships between relational dimensions and attention to partner's dimensions were found in this experiment.

Group performance Finally, we also assumed that an improvement of relational dimensions could have some benefits on group performance (**H6**). Although the impact of a better relationship of the collaboration on group performance has been demonstrated or suggested in other studies (Andriessen et al., 2011; Barron, 2003),

this result was not found in this study. One of the possible reasons explaining this absence of relationships could be that the scores on the different relational dimensions studied were high. Indeed, on average, participants reported strong to total agreement regarding the relational dimensions of equality, affection, receptivity, depth, implication, and productivity, as well as little agreement for dominance. This ceiling effect could explain why we failed to uncover any impact on group performance. It is, in fact, possible that all dyads had more or less equally benefited from high relational quality.

7.6 Limitations

The present study has limitations that restrict the confidence placed in some of the results obtained. First, we demonstrated an increase in the emotional accuracy of negative emotions in the emotion sharing condition. However, we cannot guarantee that the improvement of mutual accuracy is solely due to the mutual display of emotions, as participants did not report their emotions in the no emotion sharing condition.

Second, the results uncovered regarding the beneficial effect of explicit emotion sharing in participants with lower emotion regulation dispositions occurred in an environment where the exchange of emotions was otherwise very restricted (chat). For this reason, one can question the robustness of such an effect in an emotionally richer environment (e.g., with the possibility to share non-verbal cues of emotions).

Finally, another drawback of this study is that we failed to generate enough intergroup variability regarding the different relational dimensions studied. This ceiling effect might somewhat reduce or prevent some of the effects studied. This can be done by manipulating more finely some events that significantly affect the relational dimensions of the collaboration (e.g., lack of friendliness, dominance behaviors, task difficulty), as it can be the case in more ecological settings. Therefore, the perception of the different relational dimensions could be more volatile and intense outside the laboratory conditions. In the same way, there was also little dispersion regarding the emotion regulation dispositions scores, that could be related to a social desirability effect, especially regarding the emotional worsening dispositions. A good way to prevent this effect should be to use more implicit assessment of the interpersonal emotion regulation dispositions.

7.7 Conclusion

In recent years, numerous studies have highlighted the impact of emotions in interpersonal interactions. However, cognitive resources are limited and high cognitive load can lead to overlooking extra-cognitive activities in collaborative problem-solving. This phenomenon could be further accentuated in computer-supported collaboration settings where emotional cues, an essential source of information regarding the different dimensions of collaboration, can be very limited or impoverished (Stewart et al., 2019; Walther et al., 2015). Therefore, some authors have put forward the idea that explicit sharing of emotions during collaboration could positively affect group outcomes in improving the mutual modeling of emotions. Besides, literature reports that interpersonal emotion regulation dispositions, that are part of the general emotional dispositions, and depend on lower-level emotional abilities, such as the perception, assimilation, and understanding of emotions, differ from individual to individual. In this study, we tested different hypotheses regarding the effect of explicit emotion sharing and emotion regulation dispositions in relation to the relational quality of the collaboration.

Results show that if participants have a good general accuracy of positive emotions, explicit sharing of emotions seems to give them the possibility to increase their accuracy of negative emotions. It also appears that higher emotion regulation dispositions are related to better relational quality, especially in terms of perceived equality, receptivity, and productivity. In more detail, some emotion regulation dispositions seem to relate more to the improvement of some relational dimensions. The perception of equality could be more preferentially related to the tendency to worsen self and other's emotions, the perception of receptivity to the tendency to worsen other's emotions, the perception of productivity to the tendency to improve other's emotion. Also, the explicit sharing of emotions seems to help the group members with lower emotion regulation to improve their perception of relational quality, possibly by promoting a better understanding of negative emotions during collaboration. However, explicit sharing of emotions could have disrupting effects on some relational dimensions, such as equality. In addition, some of the relational dimensions studied here also influence the perception of other dimensions of the collaboration, such as perceived difficulty, effort, and motivation.

All in all, this study supports the idea that relational dimensions of the collaboration are impacted by interpersonal emotion regulation dispositions and could benefit from explicit emotion sharing in group members with lower emotion regulation dispositions, especially in situations where emotional information is hardly perceived or accessible. These results intend to improve the comprehension of emotions in collaborative problem solving and provide useful knowledge for the development of emotion-based collaborative environments.

7.8 Appendices

Appendix A

Problem statements (translated from French)

Participant 1

During the past 50 years, conventional agriculture, based on chemical products, has allowed for the reduction of malnutrition at a global level, from 35% of the world population in 1969 to 10% in 2010. However, such a form of agriculture depletes natural resources and provokes an increase of greenhouse gases responsible for global warming. In 2050, the population of developing countries will double, rising to 5 billion against 2.5 billion today. To meet the food needs, plants with **high-energy intake** (quantity of calories usable in 100 grams of a given crop) and with **high yield** (quantity in tons harvested in 1000 square meters) should be preferred.

In this collaborative task, you and your colleague are responsible for the agriculture policy of an imaginary country, Nambutu, in 2050. This country has three climate zones: mediterranean, semi-arid and tropical. Using the statistic table at your disposal and the information below, you have to choose nine food plants to cultivate over the whole country (3 plants for each zone).

Task 1: Find out among your plants the 9 most productive ones (**productivity** = **yield** times **energy intake**).

Task 2: Distribute these 9 plants in each of the 3 zones according to the following criteria:

- Production and ecological costs should be distributed **fairly** in each zone.
- The mediterranean zone has **significant climatic fluctuations** due to global warming. Prioritize **resilient plants** in that zone.
- The semi-arid zone has **few advanced agricultural technologies**.
- The semi-arid zone has water scarcity, plants with high water need have **a risk of suffering from the lack of water**.

Participant 2

During the past 50 years, conventional agriculture, based on chemical products, has increased the global production of food plants up to 25% and decreased their prices down to 40%. However, such a form of agriculture depletes natural resources and provokes an increase of greenhouse gases responsible for global warming. In 2050, the population of developing countries will double, rising to 5 billion against 2.5 billion today. To meet the food needs, the **production costs** (quantity of money in euros needed to grow a given crop to term) and the **ecological costs** (quantity of

money in euros needed to clean up 1000 square meters of a given crop) should be controlled.

In this collaborative task, you and your colleague are responsible for the agriculture policy of an imaginary country, Nambutu, in 2050. This country has three climate zones: **mediterranean**, **semi-arid** and **tropical**. Using the statistic table at your disposal and the information below, you should choose nine food plants to cultivate over the whole country (3 plants for each zone).

Task 1: Find out among your plants the 9 most productive ones (**productivity** = **yield** times **energy intake**).

Task 2: Distribute these 9 plants in each of the 3 zones according to the following criteria:

- Production and ecological costs have the **same importance**
- The mediterranean zone has **advanced agricultural technologies**. Prioritize plants with **high technological need** in that zone.
- The semi-arid zone suffers from **few climatic fluctuations** due to global warming.
- The tropical zone has plenty of water available. Prioritize plants with **high water need** in this zone.

Appendix B

Participant 1

Crop	Energy intake	Production costs	Ecological costs	Yield	Robustness	Water need	Technology need
Sunflower	823	129	85	12	5	4	7
Hazel tree	683	95	120	5	8	1	5
Almond tree	576	67	126	9	1	10	10
Corn	365	12	147	11	2	3	8
Palm tree	780	88	100	15	2	10	8
Oat	389	103	43	12	6	3	10
Rye	338	34	180	17	6	10	10
Wheat	339	36	203	8	9	5	2
Bean	111	111	46	15	4	5	1
Buckwheat	343	38	27	7	1	1	3

Participant 2

Crop	Energy intake	Production costs	Ecological costs	Yield	Robustness	Water need	Technology need
Peanut	567	11	169	19	5	2	2
Banana Tree	89	128	29	18	10	7	8
Sugar cane	396	30	167	9	4	1	7
Chicory	311	138	212	14	2	10	5
Rape	884	84	75	8	1	6	9
Barley	354	23	99	16	7	4	4
Chickpea	364	103	207	7	6	1	1
Quinoa	120	73	187	17	4	1	9
Sesame	573	78	114	5	4	1	6
Soya	446	62	70	11	2	9	8

Appendix C

Assessment of the interpersonal emotional regulation dispositions (adapted from the EROS questionnaire, Niven et al., 2011 and translated from French)

Interpersonal emotion regulation dispositions	Items
Extrinsic affect-improving	I gave someone helpful advice to try to improve how they felt
	I did something nice with someone to try to make them feel better
	I discussed someone's positive characteristics to try to improve how they felt
	I made someone laugh to try to make them feel better
	I listened to someone's problems to try to improve how they felt
	I spent time with someone to try to improve how they felt
Extrinsic affect-worsening	I told someone about their shortcomings to try to make them feel worse
	I acted annoyed towards someone to try to make them feel worse
	I explained to someone how they had hurt myself or others, to try to make the person feel worse
Intrinsic affect-improving	I thought about my positive characteristics to make myself feel better
	I did something I enjoy to try to improve how I felt
	I sought support from others to try to make myself feel better
	I thought about something nice to try to make myself feel better
	I thought of positive aspects of my situation to try to improve how I felt
Intrinsic affect-worsening	I looked for problems in my current situation to make myself feel worse
	I think about my shortcomings to make myself feel worse
	I thought about negative experiences to try to make myself feel worse

Appendix D

Assessment of the relational dimensions of collaboration (adapted from the relational communication scale, Hale et al., 2005 and translated from French)

Socio-relational dimensions	Items
Equality	Your partner treated you as equal
Affection	Your partner was friendly with you
Receptivity	Your partner was attentive, accessible, open and interested in the collaboration
Depth	Your partner created a sense of familiarity between you
Dominance	Your partner took the control of the discussion
Implication	Your partner was involved in the task
Productivity	Your partner contributed equitably to the task

Appendix E

Assessment of perceived difficulty, perceived effort and motivation (adapted from the Huang, 2017 and translated from French)

Perceived difficulty, Perceived effort and Motivation	Items
Perceived difficulty	I had difficulties to understand the subject
	To understand the subject, I had to make a serious effort
	Working of the subject was difficult
Perceived effort	I paid special attention to the available information to solve the task
	I accomplished my task the best as I could
	I tried my best to take into consideration the information on the subject
Motivation	I liked to learn more about this subject
	I liked to work on this subject
	I found this subject interesting
	I found what I learnt useful

Appendix F

Dependent Variables	ICC	p-Value
q6_infos_other	-0,189885969261279	0,139818511727063
q5_infos_other	-0,154150197628458	0,19086403638992
q8_infos_self	-0,153764581124072	0,191468051509292
enjoyment2_other	-0,150829328786235	0,196102257706216
enjoyment1_self	-0,134626038781163	0,222828502747097
q8_infos_other	-0,132743362831858	0,226057029949133
q1_infos_other	-0,118072289156627	0,252060872409168
q3_infos_self	-0,110814419225634	0,265459644379228
ec_q19	-0,101838249890817	0,282493975881672
q3_infos_other	-0,0893617021276596	0,306971106031465
receptivite	-0,0873786407766991	0,310942408100725
interest2_other	-0,0843039830577503	0,317141474482315
q5_infos_self	-0,0726256983240224	0,341125347446195
q10_infos_self	-0,0268378063010501	0,440379140139274
difficulte1	-0,0208887200911507	0,45368734597009
q2_infos_other	-0,0158730158730159	0,464947394983734
infos_self	-0,0147511240829849	0,467470045086293
confusion1_other	-0,0137810866466023	0,469652270251624
q1_infos_self	-0,00313479623824451	0,493647303779778
q6_infos_self	-0,00313479623824451	0,493647303779778
q7_infos_self	-0,00313479623824451	0,493647303779778
q4_infos_other	5,72458747072346e-17	0,500721005115956
q10_infos_other	0	0,500721005115957
q2_infos_self	0,00507614213197969	0,51217444639224
motivation4	0,0193146417445482	0,544224362648397
frustration1_self	0,0196595480235478	0,544998191088727
boredom1_self	0,0376719542427532	0,585122804655507
effort1	0,0413835701050031	0,593300987592692
ec_q16	0,0477643827254692	0,607269135063469
difficulte2	0,0649750096116878	0,644253693073867
q4_infos_self	0,0670553935860058	0,648645677348611
q9_infos_self	0,0751445086705202	0,665540198156414
interest2_self	0,0802395209580838	0,676022835594459
interest1_other	0,0837764299491753	0,683223231984141
effort3	0,0981053199509651	0,711703358746512
similarite	0,100065402223676	0,715508162050862
q7_infos_other	0,102803738317757	0,720785164864567
q9_infos_other	0,107296137339056	0,729343109494405
infos_other	0,110271327224298	0,734941371262501
ec_q17	0,110338835794961	0,735067746769422
ec_q14	0,110817069136619	0,73596216166428
ec_q11	0,11773885902549	0,748741587385706
boredom1_other	0,119316207093586	0,751609613178922
ec_q8	0,132321041214751	0,774608691614512
enjoyment1_other	0,140294286598029	0,788120458934933
ec_q4	0,152709359605911	0,80823385947793
motivation1	0,15743280307186	0,81558358116992
ec_q12	0,160954035697362	0,820952551197271
productivite	0,166175024582104	0,828738845030116

dominance	0,178071688709987	0,845696528539687
ec_q5	0,196312192020347	0,869565709126789
ec_q9	0,20578463943717	0,88094542322806
motivation3	0,211924821775761	0,887954414808208
interest3_self	0,2141715162755	0,890447344258778
difficulte	0,222562585850272	0,899421799062417
effort	0,223044121483409	0,89992083333643
confusion1_self	0,228426395939086	0,905381858694944
effort2	0,235130628126737	0,911887255743898
boredom2_other	0,253045444598439	0,927699650747945
interest1_self	0,253068795198299	0,927718807974494
ec_q13	0,258058435438266	0,931727990505951
ec_extrinsic_worsening	0,258163587223165	0,931810684355511
motivation	0,259157082409082	0,932588363186594
ec_q7	0,263012436665131	0,93554448172655
boredom3_other	0,265275006166058	0,93723405768842
enjoyment5_self	0,272244109694863	0,942231824068768
ec_q6	0,276704338315713	0,94527022112024
frustration1_other	0,280898876404494	0,948016379410392
interest4_self	0,281535557374584	0,948423932932271
enjoyment3_other	0,290711366627416	0,954032453936689
interest3_other	0,291630904036587	0,954567692168825
interest4_other	0,295008605851979	0,956492884987586
ec_intrinsic_worsening	0,299517431686935	0,958964332840545
confusion2_other	0,303668125709091	0,96114231314344
ec_extrinsic_improving	0,305754819934522	0,962202839746791
affection	0,313089005235602	0,965752777860728
ec_q15	0,318278653600341	0,968102969783287
ec_intrinsic_improving	0,329306423161272	0,972675415144892
confusion2_self	0,335496430889033	0,975003997479725
profondeur	0,36497720568517	0,98401464666858
boredom2_self	0,367231638418079	0,984576682491243
ec_q10	0,369027058146229	0,985012637878226
ec_q18	0,373303556090019	0,986010523762453
ec_q2	0,374149659863946	0,986201341329321
implication	0,378902953586498	0,987233999215963
interest5_other	0,382125363810606	0,987897185773837
ec_q3	0,387345318701845	0,988910982983448
confusion3_self	0,412473463767284	0,992859577605223
frustration2_other	0,416603708153231	0,993378665522731
enjoyment2_self	0,427478445104905	0,994595757980349
motivation2	0,428213166144201	0,994670655716709
boredom5_other	0,430393016837466	0,994887718478572
boredom5_self	0,439050646215388	0,995677388243608
enjoyment3_self	0,440544158221105	0,995802521372934
ec_q1	0,455576559546314	0,996899538240058
interest5_self	0,463284239215892	0,997359510273606
frustration4_self	0,466249674224655	0,99752013751914
boredom4_other	0,46861507804716	0,997642160313273
difficulte3	0,477419234292339	0,998051989552986

boredom3_self	0,482277807344332	0,998250577523479
boredom4_self	0,48238386493454	0,998254709101752
confusion4_other	0,500179937208119	0,998838889870583
ec_global_score	0,502876358353546	0,998910513022101
confusion4_self	0,518169474207816	0,999248279600451
confusion5_other	0,560181163717254	0,999753246936253
enjoyment4_self	0,584407151119138	0,999879026563352
enjoyment5_other	0,595903533170816	0,999915465902543
frustration4_other	0,597461672376032	0,999919559166259
enjoyment4_other	0,602377175328519	0,999931334668396
confusion5_self	0,625183016105417	0,999968198712793
frustration5_other	0,625678683166507	0,999968747488452
confusion3_other	0,635754336369338	0,999978205643121
frustration5_self	0,656498024192737	0,999990049445611
frustration3_self	0,674297454589218	0,999995165960482
frustration3_other	0,678515141811241	0,999995955364448
frustration2_self	0,690576914136953	0,999997610286179

Chapter 8

GENERAL DISCUSSION

The purpose of this research work was to improve the general understanding of how collaborative problem-solving works in providing four main contributions.

The **first contribution** was to review various theories and findings from different domains of research related to individual and group learning and problem-solving. The main idea is that collaborative problem-solving mobilizes a large variety of individual and group processes in three main areas (i.e., cognitive, motivational and relational). These areas have been extensively studied in different fields of research, but no real attempt to integrate them has been made so far. As part of this thesis, we highlighted some research contributions regarding the cognitive dimension, i.e., the self and socio-cognitive resolution of the problem, the motivational dimension, i.e., the processes that modulate personal and interpersonal commitment to achieve the task, and the relational dimension, i.e., the nature of bonds collaborators create between them during the task. We proposed that these dimensions possess a certain degree of independence but interact with each other during collaborative problem-solving.

The **second contribution** was to integrate these various research contributions into a model of collaborative problem-solving that describe these different dimensions in an cognitive-interactional perspective. We outlined that collaborative problem-solving can be understood as a dynamic process of building and updating cognitive, motivational and relational models about self and others through the mobilization of collaborative acts. We believe that the three-level model of collaborative problem-solving can be useful to derive and test further research hypotheses in this domain.

The **third contribution** of this work was to highlight the crucial role of emotional processes in the functioning of collaborative problem-solving. We first presented various research contributions showing that emotional processes occur at both the personal and interpersonal processes occurring in collaboration and should be studied as a pervasive phenomenon instead of being assimilated only to the socio-relational aspects of collaboration. We also outlined how emotions are clues that

group members use to make real-time inferences regarding themselves and their collaboration partners. For example, confusion can indicate a difficulty in understanding an aspect of the problem, boredom can indicate low involvement, contempt can indicate little liking for another partner, and so one. In this way, group members can enrich their cognitive, motivational and relational models through their own and others' emotions and use them to co-modulate and co-regulate collaboration. These emotional aspects of collaborative problem-solving have also been integrated into the three-level model of collaborative problem-solving.

Finally, **the fourth contribution** was to gather empirical evidence regarding the impact of emotions (i.e., subjective feeling, sharing of emotions, emotion regulation dispositions) on the different dimensions of collaborative problem-solving. The following sections will summarize the results found across the four studies described in this thesis, in connection with the three-level model of collaborative problem-solving.

8.1 Summary of the main contributions

8.1.1 Role of self-experienced emotions

The three-level model of collaborative problem-solving we described in section 3.4 underlines the role of self-experienced emotions in collaboration. More specifically, we have proposed that self-experienced emotions have significant effects on collaboration because they modulate individual processes (cognitive and motivational), influence the building of collaboration models (on the cognitive, motivational and relational levels), and modulate collaborative acts. Research has described several types of emotions occurring in individual learning, depending on which aspect of learning they relate (e.g., epistemic, achievement, topic, social concerns). Thus, depending on their appraisals, a similar subjective feeling (e.g., frustration) can refer to different aspects of the collaboration, with different behavioral implications.

The first study of this thesis was dedicated to exploring the impact of self-experienced emotions on collaboration and especially a specific kind of self-experienced emotion called achievement emotions. These emotions involve both cognitive (e.g., perceived success or failure) and motivational (e.g., intrinsic or extrinsic value) appraisals of the collaborative situation.

A first result highlighted in this thesis was that **the appraisal of the collaborative situation shapes group members' emotions**. We showed that different configurations of perceived value and control modulate the intensity of shame, hopelessness, sadness, joy, gratitude, relief and contentment that collaborators experience during the task.

A second result was that **in both successful or unsuccessful situations, collaborators experienced various positive and negative emotions**. This view can contrast

with the idea that difficult situations generate exclusively negative emotions or successful situations only positive emotions. Our study demonstrates that collaborators may, at the same time, strongly enjoy the task and be deeply frustrated by their poor performance. Although some emotions appear more or less prototypical of some collaborative situations as we have seen before, we assume that collaborative behaviors are influenced by concomitant emotions influencing a number of different aspects of the collaboration. Thus, we argue that the impact of self-experienced emotions on collaborative behaviors should be considered as the result of an emotional profile (i.e., a dynamic representation of the nature and intensity of different emotions experienced by the group members at a given time of the collaboration) corresponding to a given collaborative situation.

Interestingly, we also demonstrated that self-experienced emotions influence the perception of socio-cognitive processes. A third result shows that **group members seem to use emotional information, and especially their level of arousal, as a way to assess and monitor how they collaborate** (especially regarding transactivity and task management). If more research has to be done to reproduce and deepen this result, some recent findings appear to support this idea (see, for example, Malmberg et al., 2019).

Finally, a fourth result concerns the influence of the perception of the partner's emotions on collective achievement goals. Especially, **the perception of the partner's gratitude in relation to high arousal could have a beneficial effect on group perseverance and promote mastery goal in difficult collaborative task**. The beneficial effect of gratitude on social relationships has been outlined in the literature, especially its role in group commitment to adopt behaviors that support the partnership even if it could be costly to oneself (Bartlett et al., 2012).

8.1.2 Role of explicit emotion sharing

The three-level model of collaborative problem-solving also outlines the role of the communication of emotions in collaborative problem-solving. Throughout the collaboration, collaborators do not only experience emotions but also share emotions (implicitly or explicitly, verbally or non-verbally) in relation to collaborative events regarding the cognitive, motivational and relational concerns. As we have seen earlier, emotional expression is a valuable source of information allowing the collaborators to interpret in real-time the nature, the causes and the consequences of the emotional message. In this way, collaborators can convey messages to their collaboration partners using emotional expressions. This leads to influence the course of collaboration in a more reactive (collaborative co-modulation) or proactive (collaborative co-regulation) way.

In this thesis, we explored the idea that the explicit sharing of emotions play a role in each of the different dimensions of collaboration. In a first study, we examined

if the sharing of verbal labels of emotions changes the proportion of different types of collaborative acts used during collaborative problem-solving. The rationale behind this hypothesis is that explicit emotion sharing induces changes in the kind of collaborative processes group members mobilized.

A first result showed that the **explicit sharing of emotions seems to be mainly oriented towards positive emotions**. In an analysis we conducted (Avry et al., 2015) on the data from Molinari and colleagues' experiment (cf. sections 6.1 and 6.2), we observed that 86% of the emotions shared were positive emotions. We also observed that collaborators actually refrain from sharing negative emotions, potentially because they try to prevent unwanted negative impacts of these emotions on the group.

A second result highlighted that **the sharing of explicit emotions impacts both relational and cognitive aspects of the collaboration**. It seems to globally promote the use of acts dedicated to improving the group relationship (e.g., greetings, displaying courtesy) and bolster mutual knowledge modeling, i.e., establishing and updating a mental model of each other's knowledge. Men and women may also differ regarding how the sharing of emotion influences their use of collaborative acts. Results suggest that the explicit sharing of positive emotions improves the use of collaborative acts dedicated to improving group atmosphere, probably for reducing socio-cognitive conflict. However, this tendency is not found among women. This result is in line with some research indicating that men have a greater tendency than women to compete in negotiations and bargaining situations (Small et al., 2007). Therefore, the explicit sharing of positive emotions could inhibit their willingness to generate socio-cognitive conflict.

However, as collaboration is a dynamic process that continually evolves depending on emerging collaborative events, we also assumed that explicit sharing of emotions produces not only general collaborative tendencies as we have just seen, but also provokes real-time changes in the use of collaborative acts. The general idea here is that group members have explicit or implicit motives to share their emotions during collaborative problem-solving. These motives are related to the current state of collaboration and are intended to provoke changes in the following partner's behaviors through the use of collaborative acts.

A third result thus concerned the fact that **the sharing of positive emotions interacts with collaborative acts in real-time and vice versa**. Significant variations in the use of collaborative acts occur only before and/or after the sharing of emotions, which strongly indicates that some collaborative acts elicit emotional sharing and, at the same time, emotional sharing produces changes in the use of collaborative acts. However, our study only revealed a decrease of some collaborative acts around the sharing of emotions. Further studies have to be performed to understand these findings more finely.

A fourth result also indicated that **some positive emotions could have closer relationships with the use of some types of collaborative acts**. Preliminary results suggest that the motive to share *interest* would be to signal new possible ideas to solve the problem, the sharing of *focused* would intend to promote the search of new ideas, the sharing of *amused* and *relaxed* would promote brainstorming, the sharing of *delighted* and *satisfied* would reflect different levels of agreement around a common idea. The changes induced by the sharing of emotions at the cognitive level also seem to be closely intertwined with socio-relational adjustments.

8.1.3 Interaction between explicit emotion sharing and emotion regulation dispositions

Finally, the three-level model of collaborative problem-solving also highlights the role of interpersonal emotion regulation in collaborative problem-solving. Especially, based on what they understand about the nature, causes and consequences of emotions, group members are thought to regulate their own and partner's emotions for different motives. For example, they may want to induce more interest in their partner to bolster their persistence or decrease the intensity of pride to refocus the group on the task after a success. The general idea is that better personal and interpersonal emotion regulation dispositions have a beneficial effect on the different facets of collaboration (i.e., cognitive, motivational and relational dimensions) because it could allow collaborators to mobilize and induce more adaptive behaviors. However, if emotions may be used to promote adaptive behaviors, the emotional functionality of emotions is not guaranteed because it strongly relies on the access to emotional information as well as interpersonal emotion regulation competencies. Indeed, emotions can lead to collaborative dysfunctionality when individuals have unreliable access to emotional information or misjudge the nature, the causes or the consequences of emotional states. People can also fail to stimulate functional emotional states or refrain non-functional emotional states appropriately. Therefore, emotions can induce detrimental behavioral tendencies both at the personal and interpersonal levels. Moreover, literature also reports individual differences regarding emotional regulation dispositions. It raises the question of whether people with lower emotional dispositions could take advantage of explicit sharing of emotions. Therefore, the fourth study of this thesis was specifically dedicated to studying the interaction between the explicit sharing of emotions and the interpersonal emotion regulation dispositions.

A first result showed that **group members tend to become more accurate at judging each other's negative emotions throughout the collaboration**. This result may suggest that the understanding of negative emotions has a critical role throughout the collaboration as it can alert group members regarding important events that would be costly to overlook.

A second result revealed that **better emotion regulation dispositions are related to the perceived relational quality of the collaboration**, especially for equality, receptivity and productivity. Interestingly, the improvement of some relational dimensions seems to be related to a greater tendency to worsen emotions in self and others. This result suggests that the sharing of some negative emotions could improve the relational quality in decreasing the social distance between collaborators. This effect is supported by the dynamic model of emotion sharing (presented in Rimé, 2009, see Figure 3.4).

A third result was that **group members with lower emotion regulation dispositions seem to rely more strongly on explicit emotional sharing**. This could be explained by the fact that explicit emotion sharing helps these group members to gain a better understanding of emotions in the group, which could facilitate the relational quality of the collaboration. This effect could be more significant in environments with poor emotional cues.

Finally, a fourth result highlighted that **better relational quality is also correlated with other cognitive and motivational dimensions of the collaboration**. For example, when collaborators perceive their partners as more involved and productive, they perceive less difficulty in dealing with the problem-solving task. These results are congruent with the idea that, although conceptually independent, cognitive, motivational and relational dimensions of the collaboration interact with and influence each other.

8.2 Main challenges of this thesis research

This section describes some of the main challenges that have emerged during the conception and the analysis of the different studies presented in this thesis.

A **first challenge** was to gain a conceptual understanding of the various processes that play a role in collaborative problem-solving. This phenomenon is complex in nature as it involves diverse dimensions of collaboration (cognitive, motivational, relational) and different levels of processing (personal and interpersonal) interacting with each other in a highly dynamic way. To disentangle this complexity, we opted to explore and bring together a vast and sometimes unrelated research literature that can account for different aspects of collaborative problem-solving. This work has resulted in a new model that allows us to reconsider the role of emotional processes in collaborative problem-solving.

A **second challenge** was to translate this complexity into experimental studies allowing us to obtain rigorous data while keeping collaborative problem-solving as natural as possible. For this purpose, the use of collaborative software gave us the possibility to gain better experimental control and a better way to record the data

of interest (for example, the explicit sharing of emotions). However, it has also undoubtedly interfere with how collaboration goes in naturalistic settings and hence the confidence in the results obtained (e.g., sharing discrete labels of emotions is an oversimplification of emotional sharing in collaborative problem-solving). We believe that promising avenues of research have to be explored regarding how computer technologies can be used in non-invasive ways to record meaningful data of the development of collaborative problem-solving (e.g., natural language processing, physiological data, eye tracking).

A **third challenge** was the conception of collaborative tasks. Three main elements had to be considered. The first element was to use tasks that really involve collaboration. As highlighted by Burtis and Turman (2005), the question as to whether working in group is the best way to solve the problem in question should be systemically assessed. For example, tasks that can be solved effectively alone, do not require to interact with each other about complex information or have a clear path to solution (well-defined problems) do not necessitate group work. The second element was to use tasks that constrain real collaboration. If a task necessitates group work but allows people to work on fixed and independent sub-tasks and then assemble their work into a final output, without any co-construction of knowledge, it is not, in our view, a collaborative task. Finally, the third and most challenging element was to use collaborative situations that integrate enough motivational incentives to guarantee a suitable involvement of the participants into the task. This aspect is especially crucial in the study of emotional processes. Indeed, if participants do not have enough incentives to succeed, collaborative events could be not appraised as important enough to trigger emotional reactions. In our view, particular attention still needs to be given to the conception of collaborative tasks maximizing the occurrence of emotional reactions similar to what can be observed in naturalistic collaboration settings.

Finally, a **fourth challenge** was related to the type of data and hypotheses and the statistical methods to address them. First, dyadic data required to assess the non-(independence) of peer's measures when using the individual as unit of analysis. This approach was preferred to the more complex multilevel analyses as part of this thesis. However, multilevel modeling would have made it possible to take better account of the possible variations between dyads. Second, as collaborative problem-solving is a dynamic process, the study of how emotional processes impact it cannot not be fully understood through static analyses. Especially, to take into account the temporality in the exchanges of collaborative acts (see Study 2b in section 6.2), specific statistical analyses (in this case, randomization test) had to be used to deal with data that broke the assumptions of classical parametric tests classically used in the psychology and education fields. Again, more suitable methods of analysis coming from the computer science field would allow a more in-depth insight into the dynamic, temporal and incremental aspects of collaborative problem-solving.

These considerations will be discussed in the next section.

8.3 Further research

Although bringing different aspects of collaborative problem-solving into light, the work described in this thesis is preliminary in our understanding of collaborative problem-solving. In this section, we identify several lines of inquiry that could be investigated in the future to gain a better understanding of collaborative problem-solving.

8.3.1 Regarding the cognitive, motivational and relational dimensions of collaborative problem-solving

First, many processes involved in collaborative problem-solving remain mostly unknown. In this thesis, we have endorsed the idea that collaborative problem-solving is a dynamic process that involves interactions between different dimensions, at the personal and interpersonal levels. A first idea is that group members generate collaborative acts based on discrepancies between their own assessment of the situation and what they think the group needs to achieve the task. For example, the lack of knowledge about how to compute a given part of the problem can trigger cognitive acts dedicated to obtaining the necessary information from others. Discrepancies can also occur in the motivational dimension. For example, group members can trigger motivational acts dedicated to getting motivational incentives (e.g., a good reason to persevere in the task). Besides, group members share relational acts to promote a smooth relationship between them. In addition, collaborative acts can also be generated by what group members perceive from their partner (e.g., lack of understanding, lack of interest, social discomfort). Until now, the different motives that trigger collaborative acts are yet to be explored. An exciting strand of research is then to uncover these different motives, i.e., what drives the decision to mobilize a collaborative act.

Second, we proposed that the different dimensions described in section 2.4 (i.e., cognitive, motivational and relational) should be considered separately as they relate to complementary aspects of the collaboration (i.e., the cognitive dimension deals with the processes related to solving the problem, the motivational dimension deals with the processes related to task commitment, the relational dimension deals with the processes related to the relationship between group members). These different dimensions have a certain degree of independence. For example, collaboration partners can solve the task even if they have little incentive to do it. They can also like each other while being poorly motivated to achieve the task. The nature of the different processes intervening in these three dimensions still has to be studied. Especially, one crucial aspect of future research is to understand how group members translate their intentions into speech. For now, the categorization is based on a holistic human

mutual understanding of group members' intentions using coding schemes. However, we think that more knowledge has to be gained regarding the semantics behind collaborative acts. Understanding more deeply how speech utterances refer to specific collaborative intentions could allow researchers to systematize and generalize the study of collaborative problem-solving. In recent years, this domain of research has started to be explored in the computer science field. For example, some authors (see, e.g., Stewart et al., 2019) have addressed the automatic detection of collaborative problem-solving processes using natural language processing techniques and supervised machine learning algorithms. Results show that Random Forest classifiers can provide similar accuracy as human categorization for three categories of collaborative acts (construction of shared knowledge, negotiation/coordination and maintaining team function), despite non-perfect automated speech transcription. In the same vein, Favre (2020) used different supervised machine learning algorithms to predict eight broad categories of collaborative acts from the Molinari and colleagues' data (Molinari et al., 2013), including cognitive and relational dimensions of collaborative problem-solving such as relationship management, interaction management, information management, argumentation management, task management and tool management. Results showed that recurrent neural networks algorithms such as Long Short-Term Memory also provide similar accuracy as human categorization. These preliminary results offer promising perspectives for further research towards the development of computer interfaces capable of automatically and non-invasively assessing and scaffolding collaborative problem-solving.

Third, although cognitive, motivational and relational dimensions can be thought of as conceptually independent for the reasons afore-mentioned, they continuously interact with each other throughout collaborative problem-solving. For example, poor motivation or different achievement goals may impact the way collaborators mobilize cognitive processes and cognitive acts. Poor receptivity to the other partners can also drastically reduce their cognitive acts or dampen their self-efficacy. Thus, another line of research is to study the reciprocal effects of these dimensions, i.e., the different ways in which these dimensions interact. Moreover, we assume that collaborative functionality is highly dependent on smooth and congruent interactions between each of these dimensions during the collaboration, mainly because they may profoundly influence each other.

Fourth, collaborative functionality requires to appraise, monitor and control the different processes in each of these dimensions at the personal and interpersonal levels. In section 2.4, we proposed a distinction between two different types of collaborative development. Collaborative co-modulation reflects a more automatic and reactive process, where collaborators share collaborative acts in response to those of their partner (i.e., socio-cognitive, socio-motivational and socio-relational acts). Collaborative co-regulation, however, reflects an intentional and proactive

attempt to shape the course of collaboration to maximize task success (i.e., socio-meta-cognitive, socio-meta-motivational and socio-meta-relational acts). For example, a collaborator can explain a notion because he/she considers it is crucial to solving the problem (socio-meta-cognitive act). He/She can also give their partner some good reasons to persevere in the task when perceiving less involvement (socio-meta-motivational acts). Also, he/she can also be more sympathetic regarding their partner's difficulty to increase their feeling of receptivity (socio-meta-relational acts). As raised by Livingston (2003) concerning cognitive and meta-cognitive processes, finding a clear dividing line between *socio* and *socio-meta* acts can sometimes be difficult. Especially, it requires having some access to collaborators' thoughts. This aspect of collaborative problem-solving may bring new promising avenues of research in the future. One assumption is that collaborative functionality is highly dependent on the ability collaborators have to gradually increase their use of *socio-meta* acts as the path to solution become clearer.

Fifth, collaborative problem-solving is a dynamic process, which involves collaborators have to deal with emerging events regarding cognitive, motivational and relational matters. Thus, a deeper understanding of the functioning of collaborative problem-solving may be achieved in studying how collaborative acts emerge and interact with each other throughout the collaboration rather than globally. This kind of research requires improving the way researchers analyze data in this domain. Especially, some data analysis methods should be more suited to the study of the dynamics of collaborative acts than classical statistical analyses on population parameters (e.g., means, sums, proportions). In this aspect of collaborative problem-solving, too, some techniques coming from the computer science field could help to comprehend how collaborative acts combine each other to build more or less efficient patterns of collaboration. For example, repetitive patterns of acts conveying only new information without taking into account previous contributions can indicate a lack of transactivity. Process mining algorithms (Van der Aalst, 2011) can be applied to collaborative acts logs to determine typical patterns of collaborative acts as well as discovering possible bottlenecks. Therefore, these techniques, combined with natural language processing, could provide valuable insights into the real-time development of collaborative problem-solving. Preliminary works have already confirmed that such techniques are suited to enhance the understanding of collaborative creative problem-solving (Ning et al., 2020). They could be applied on large datasets to uncover prototypical paths of collaboration. However, they could also provide useful feedback on case studies to identify bottlenecks limiting the collaborative functionality of some groups.

8.3.2 Regarding the role of emotions in collaborative problem-solving

As we have seen throughout this dissertation, emotions are a valuable source of information regarding the cognitive, motivational and relational dimensions of collaborative problem-solving. Indeed, emotional reactions emerge following personal and interpersonal meaningful events and emotional expressions allow other group members to be informed about the significance of these events. For example, confusion at the personal level informs people about cognitive difficulty (emotional process) and an expression of confusion at the interpersonal level informs the other collaborators about the importance of this cognitive difficulty for the collaborative resolution of the problem (socio-emotional process). However, emotions are not limited to a mere informative role but are also a way to induce behavioral changes for different motives related to cognitive, motivational and relational dimensions, to maximize goal achievement. For example, collaborators can share negative emotions to elicit help or compassion as well as positive emotions to improve relational quality (socio-meta-emotional process). Therefore, several lines of investigation can be considered to deepen the understanding of the role of emotional, socio-emotional and socio-meta-emotional processes in collaborative problem-solving.

First, at the personal level, our work explored different academic emotions. Depending on the events that cause them, other broad categories of self-experienced emotions can be distinguished (i.e., epistemic, social and topic emotions, see section 3.2.2 and Pekrun & Linnenbrink-Garcia, 2012). Therefore, another exciting area of investigation is to explore the differences existing between each of these emotions categories. In addition, as the same emotion (e.g., frustration) can arise from different appraisals (e.g., cognitive issues such as being stuck or social issues such as partner's unreceptiveness), further research on collaborative problem-solving could benefit from considering emotional labels, not only in themselves but also with the emotional category they relate (i.e., achievement, social, topic or epistemic matters). Our work also suggests that collaborative acts arising from emotions could be more the result of concomitant emotions rather than a specific emotion. Therefore, another avenue of exploration is to study the impact of an emotional profile resulting from achievement, social, topic and epistemic collaborative events on the use of specific collaborative acts.

Second, at the interpersonal level, we highlighted a distinction between socio-emotional processes and socio-meta-cognitive processes (see section 3.3). This distinction is similar to that raised earlier regarding *socio* and *socio-meta* acts. Socio-emotional processes cover the more automatic and reactive aspects of emotional expression, whereas socio-meta-emotional processes cover their more intentional and proactive ones. Therefore, we believe that two lines of research need to be addressed more systematically to provide a better understanding of the relationships between the expression of emotions and its impact on collaborative problem-solving. The first one concerns how the perception of the collaborators' emotional expressions is

a significant driver of collaborative co-modulation, i.e., how it leads the receiver to modulate these collaborative acts through real-time inferences regarding the nature, causes and consequences of the perceived emotional expression. In this domain, due to statistical constraints, the study described in this thesis (see section 6.2) was limited to explore the impact of some positive emotions when explicitly shared by collaborators. Therefore, the following studies should consider the differential impact of the implicit and explicit expression of both positive and negative emotions regarding each of the cognitive, motivation and relational dimensions of collaboration. The second line of research is related to how collaborators use emotional expressions as a way to induce desired collaborative behaviors from their collaborative partners, which we assume to be an important driver of collaborative co-regulation. An exciting line of research in this domain is to deepen the underlying motives leading collaborators to use emotional expressions to provoke cognitive, motivational and relational changes. However, as we have seen, the use of emotional expressions in collaborative co-regulation purposes could be dependent on the emotional availability of the collaborative environment (i.e., the possibility collaborators have to share emotional expressions) as well as interpersonal differences regarding emotional regulation dispositions. If greater emotion regulation dispositions seem to have a positive impact on some relational dimensions of the collaboration, as we uncovered it in chapter 6, similar effects still have to be addressed regarding the other dimensions of collaborative problem-solving. Thus, a promising field of investigation is the examination of how and why better emotion regulation dispositions bring an added value to collaborative problem-solving.

Finally, a last line of inquiry concerns the conditions in which emotions could create unwanted effects affecting collaborative functionality. If our work suggests that explicit emotional sharing can contribute to improving collaborative problem-solving in some ways, we claim that explicit emotional sharing can also generate detrimental effects. First, as outlined by Fischer, Manstead, et al. (2016), although emotions have social functions, the sharing of emotions is not always functional, especially when group members share emotions that are inappropriate to the situation (e.g., deactivating emotions during brainstorming). Therefore, an exciting path of research could be to explore how emotions sometimes generate disruptive effects on collaborative problem-solving. Explicit emotion sharing could also conflict with the cognitive processing of task information. This aspect has essential implications in collaborative problem-solving, and especially in the design of emotion awareness tools in collaborative software (Lavoué et al., 2020). For example, in changing the mode of communication of emotion (e.g., from non-verbal to verbal; Walther et al., 2015), emotion awareness tools could provoke an increase of cognitive load or even detrimental side effects by interfering with how emotions are naturally shared in face-to-face settings. There is still research to be carried out to assess how emotion sharing and computer tools can be integrated to each other more optimally. We suggest

that computer tools should strive to mimic how emotions are conveyed in face-to-face collaboration (Makhkamova et al., 2019). That is, the transmission of emotions should be the most unobtrusive as possible (non-verbal sharing of emotions through technologies) and at the same time gives the possibility of explicit sharing of emotions when wanted by the teammates (for regulating others' behaviors for example), as it is the case in face to face collaboration.

8.4 Conclusion

Today's world requires people to be able to deal with the new scientific, environmental, technological and societal challenges that have been arising in the last decades. Therefore, industry, academia and government have an increasing offer of job requiring non-routine skills and competencies such as critical thinking, problem-solving, persistence, collaboration and curiosity (World Economic Forum, 2015).

However, a striking finding is that students have clear deficiencies in collaborative problem-solving (OCDE, 2017). In the 2015 international assessment of collaborative problem solving conducted as part of the Programme for International Student Assessment (PISA), less than 30% of students succeeded at solving the lowest complexity test and less than 10% scored at the highest level (Fiore et al., 2018). Therefore, a clear gap between the employers' needs and the current graduates' competencies is evident in this domain.

If several reasons can explain why people fail to solve complex problems together efficiently, one of them is undoubtedly that the understanding of collaborative problem solving still has many grey areas due to the lack of substantial theoretical contributions and empirical evidence. Although in the last decades, the interest in how people solve problems together has risen up in the fields of problem-solving, collaborative and cooperative problem-solving, computer-supported cooperative work and computer-supported collaborative learning, a comprehensive understanding of collaborative problem-solving is still in an immature stage. Notably, if the research has described the cognitive aspects of collaborative problem-solving in some detail (e.g., Decuyper et al., 2010) and converges around the idea that collaboration mobilizes two main spaces, socio-cognitive and social/relational (e.g., Janssen et al., 2012), a comprehensive understanding of the complexity of collaborative problem-solving is yet to be achieved.

The present thesis aimed at making scientific contributions in this domain by providing a theoretical framework to stimulate future research. An extensive review of various fields of research has led us to propose a first version of an integrative model of collaborative problem-solving, the three-level model of collaborative problem-solving. This thesis has also highlighted that what is commonly known as the *socio-emotional sphere of collaboration* is confusing because it suggests that cognitive aspects

of collaborative problem-solving has nothing to do with emotional processes. Instead, you have showed in this thesis that emotional processes have a pervasive influence on the cognitive, motivational and relational dimensions of the collaboration. Therefore, we propose to look at collaborative problem-solving as a highly dynamic process involving the interplay of the three dimensions afore-mentioned. In this dynamic process, emotions appear to be a valuable source of information as well as a way to initiate collaborative changes for cognitive, motivational and relational motives, to maximize task achievement.

We hope that this thesis work will stimulate new exciting research in the domain of collaborative problem-solving to deepen the understanding of its great complexity. Many aspects still have to be investigated, especially how collaborators build and update cognitive, motivational and relational models of the collaboration through collaborative acts, how collaborative functionality leads to improve collaborative outcomes such as group performance, or how cognitive and emotional abilities moderate these aspects. To this end, we firmly believe that computer science techniques (natural language processing, semantic and sentiment analysis, data mining, machine learning) as a complement to the classical statistical analyses used in psychological and educational research, will provide an essential tool to gain a deeper understanding of the dynamic of collaborative problem-solving.

The next decades will see an increasing need for collaborative problem solving to tackle the future challenges of a more globalized and complex world. We are convinced that learning to solve problems together more efficiently is a critical skill in this domain, which could and should be trained more thoroughly. We hope that this thesis and the following research will provide valuable theoretical insights for the development of training programs for students and adults dedicated to instilling functional collaborative routines that can allow collaborators to 1) build more accurate real-time mental models of the collaborative situation and each other's challenges and 2) build efficient collaborative patterns to improve collaborative functionality. These collaborative routines include the appropriate use of emotional sharing as a way to foster mutual understanding and behaviors that benefit collaboration.

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