Phd in
Educational Science and Psychology

Cycle: XXXII

Coordinator Prof. Simonetta Ulivieri

When the group performs better than teammates? Studying the effectiveness of *collective intelligence* among youngsters and different task types

Academic Discipline MPSI/05

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Years 2016/2019

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Abstract

Humans organise in teams to overcome complex problems and succeed in a large variety of tasks. This emergent property of groups to display higher intelligence than a single has been called collective intelligence. The research identified three factors related to higher collective intelligence in groups: number of females, average social abilities of group members, and variance in the conversational turnover. Previous studies on this topic underpinned that collective intelligence showed in both real and online environments but focused mainly on adult participants. Furthermore, the recent literature about collective intelligence argues that a unique factor, namely the C factor, can explain the variance of the groups' performance on a wide variety of tasks. Firstly, the hereby work is aimed to understand the process that rules the complex dynamics of groups' interactions and shed light on the factors that promote group performance in adolescents enrolled in an online environment task. Secondly, the aim of this work is to verify if it could exist differences in group performance depending on the kind of task that the group has to solve. In particular, the scope is to verify if there is a correlation between the logical-task performance and the moral-task performance of the same group. To test the hypotheses, two studies were carried out. Regarding the first study, 265 high school students took part in the experiment facing a logical task (Raven's advanced progressive matrices) before alone and then in a group in a setting of computer-mediated communication. Results showed that the group can enhance the performance of its members approximately by 30%, and that, in the case of logical tasks, performance in the group is negatively affected by the difficulty of a problem to solve and the total number of communicative exchanges. Moreover, this work provides a comprehensive model of collective intelligence for the youngster engaged in a logical task within an online environment. Taking into account the psychological dimension, indeed, the average perceived cohesion among group members, teammates' average intelligence, neuroticism, and heterogeneity of social abilities predict again in the performance of members in the group condition respect the individual one. For what concerns the second study, 220 university students took part in the experiment. The persons part of the sample carried out logical and moral tasks both in groups and alone. The results of this second study, first of all, show how the group outperforms the individual both in logical and in moral tasks. Secondly, according to the results, there is a weak correlation between logical group performance and the moral one.

Chapter 1

Collective intelligence: a framework for the study of groups performance

1.1 Collective intelligence

In 2009, D. H. J. Polymath proposed an innovative proof of the Hales-Jewett theorem, a particular problem of the combinatorics branch of mathematics. From the moment when the problem was first addressed to the moment when D.H.J. Polymath found the central solution, only about 37 days have passed (Polymath, 2009). At that time, D. H. J. Polymath owned at least two Fields Medals (the equivalent in the mathematics of the Nobel Prize), several professorships in many prestigious universities (e.g., Cambridge University, UCLA, University of British Columbia), and dozens of scientific articles in high-level scientific journals.

Someone might think that the Latin saying *nomen omen* is real; however, D. H. J. Polymath was an acronym formed by *Density Hales-Jewett* (D. H. J.), the topic of the work and Polymath that stands for *many mathematicians*. Indeed, Polymath was an ambitious project launched by Timothy Gowers (the owner of one of the Fields Medals) on his blog to verify the ability of mathematicians to solve problems collectively. In the 37 days that lasted to find the solution, without a direct invitation to participate except the open call of Gowers on his blog, 27 people (university professors, graduates, students) contributed producing approximately 800 comments useful to reach the goal (Gowers & Nielsen, 2009). Even the acronym was chosen by the community to identify itself in the authorship of the paper produced.

The Polymath project represents not only a formidable contribution to show the potentiality of an open and decentralised approach in scientific research that aims to harness the power of the Internet and information and communications technology, but also a tremendous and successful example of the so-called *collective intelligence*.

Collective intelligence is the emergent property of the groups, whether they are humans or non-humans, of living or non-living entities, that activates a process of integration of multiple and diverse sources of information, producing an outcome that encompasses all the individuals one, and can result in creating something better and more efficient, or that is impossible, respect what a single agent can do alone.

1.1.1 Definitions and concept

The construct of Collective intelligence (CI), thanks to its cross applicability among disciplines, has been studied in many fields of research such as computer science, psychology, sociology, and biology.

One of the first scientific contributions that directly addressed the existence of CI is the work of Wechsler (1971). In his paper, the author argued that as well as a person has an individual intelligence, also groups manifest a collective one that results in something different than the sum of the individual abilities of the members. Moreover, in his work, Wechsler pointed out the fact that this collective manifestation of intelligence may be a powerful feature which could enhance persons' abilities, but also something that could bring to their ruin if it mutates in something assumable in the term *collective stupidity.* The concept of CI has attracted particular interest from the explosion of the mass information and communication technologies (ICT) with the diffusion of the Internet and portable devices connected to it (Singh, 2011). The so-called *ICT revolution*, indeed, allowed the possible instantaneous connection between millions of individuals creating the perfect conditions to exploit the full potentiality of CI.

In this regard, Hiltz and Turoff (1978) describing the effects of the new (at the epoch) computer technologies emphasised the role that they would have in connect-ing people and enhancing their ability to solve problems collectively. They identified in the CI one of the crucial phenomena involved in this process defining CI as a collective decision ability of groups that it could produce an outcome at least equal to that of any single member of the groups if not better.

Smith (1994) studied the CI as the process underlying collaboration in groups, in particular in the field of computer-supported cooperative work (CSCW). For the author, a group of human beings displays CI when it acts as an organism facing a task and works as a single mind rather than individuals acting each other independently. According to Smith groups that display CI achieve a degree of collaboration for which the group itself start to act as a single information processing system were, of course, the single elements may be recognised (i.e., member of the group), but the product is carried out as separate entity in a coherent way.

The deep connection between CI and the diffusion of new forms of communication technologies is also highlighted by the work of Pierre Lévy (1997) titled *Collective Intelligence: Mankind's Emerging World in Cyberspace*. In his book, the author stated that the growing innovations in ICT would create a full connected word where all the individual knowledge, efforts and contributions will be collected and validated. Lévy called this virtual assembling of information *knowledge space* and theorised that CI represents the tool to exploit it. Indeed, Lévy defined CI as the ability of human beings to cooperate and act in a synergistic way to create innovative solutions (Lévy, 1997). According to the author, the intelligence of groups is a form of universally distributed intelligence that arises when all the members can work together, releasing the cognitive abilities of individuals and facilitating the effective mobilisation of skills inside teams (Lévy, 1997). For Lévy, the link between CI and ICT lies in the capacity of new technologies to allow real-time connections and constant coordination among people that results in the exploitation of single's knowledge to create an entity (i.e., the group) that surpass all the individualities.

Of similar advice is Francis Heylighen, one of the founders of the cybernetic approach in the study of CI. The author pointed out in his definition of CI the property that it has in allowing groups to obtain results that are better than what individuals can do (Heylighen, 1999).

In the field of computational science Szuba, attempting to propose a formal model of CI, defined this phenomenon that encompasses living and artificial agents. The author described CI as a property of all social structures that agents implement as unconscious, parallel and distributed computational process allowing groups to be able to solve a higher number of complex problems than individuals can do alone. Moreover, for Szuba as well as individual intelligence may be assessed; CI represents a measurable characteristic for groups, in which the agents that compose it communicate and cooperate in a certain way to solve complex tasks (Szuba, 2001b).

Brown and Lauder (2001) addressed the issue of CI from a sociological and economic point of view. Accurately, for the authors, CI represents a tool for social change based on cooperation and the achievement of common goals. They described CI as an empowering process for the communities that derive from the pooling of individual bits of intelligence in an attempt to resolve complex problems in society. According to the view of Brown and Lauder, CI is the constitutive element on which to base the ideological framework to build the culture of the third millennium.

Malone, Laubacher, and Dellarocas (2009) studying CI from an organisational behaviour perspective claimed that: *"...intelligence is not just something that arises inside individual brains — it also arises in groups of individuals. We call this collective intelligence: groups of individuals collaborating in ways that seem intelligent"*.

Woolley, Chabris, Pentland, Hashmi, and Malone in 2010 proposing, for the first time a model of CI based on experimental evidence deriving from groups of humans engaged in the resolution of problems described the phenomenon as *"the general ability of a group to perform a wide variety of tasks"* (Woolley et al., 2010).

Jerome Glenn (2013) defined CI as *"an emergent property from synergies among three elements: data/info/knowledge, software/ hardware, and experts and others with insight that continually learns from feedback to produce just-in-time knowledge for better decisions than any of these elements acting alone"*.

Singh, in his review of the litterateur on the phenomenon, shows how CI has been described manly characterising it as an emergent property of a system of agents, whether they are people, insects or software, that together can be more intelligent than the individual members who are part of it (Singh, 2011).

Analysing the above definitions of CI, produced in the last 50 years or so by the research in the field, it is possible to identify two main aspects that mark this phenomenon: 1) it is configured as a higher-level problem-solving ability and 2) it is an emergent property. The first aspect denotes that CI has been seen as a tool to exploit the potentiality of groups to solve problems in a more efficient way, respect individuals alone, and to face more complex ones with a higher probability of solving them. This aspect emphasised the adaptive role that CI has and had in the society allowing individuals who act and acted in a joined effort to obtain relevant and advantageous results. The second aspect describes how the former is not an effect merely ascribable to the assembling of many entities, but that the result of the combination of the agents in the group in more than the sum of the single member's contribution. Indeed, phenomena of emergence are the results of a process of organisation of single parts of a system at a micro-level that produce effects at a macro-level that cannot be considered only as a mere sum of the individual components but results in something different and novel with own characteristics. (Goldstein, 1999). Emergent properties could arise in both natural and artificial systems and are subject of study for many disciplines such as biology (Blattner et al., 1997; Bhalla & Iyengar, 1999), computer science (Kauffman, 1984) and cognitive science (Courtney, 2004). Indeed, Intelligent behaviour can emerge from interactions that stabilise between individuals who respect standard rules within groups. A system can, therefore, be considered more intelligent than another if, in a defined interval of time, it can solve more problems or find objectively better solutions. A group implements phenomena of CI when it finds more solutions or better solutions than those that could be found by all the members that compose it if they worked individually. All organisations, be they businesses, institutions, or sports teams, are created based on the assumption that the members who will compose them can do more together, working collectively, than they could do on their own. To address a common problem is essential that the subgroups can communicate with each other in order to exchange information. At any time, all the subgroups should know what others are doing and what goals they have achieved so that they can exploit the results reciprocally. This fact creates a massive load of information, which requires communication channels capable of supporting exchanges. The complexity and the size of the communication circuits, in fact, increases with the increase of the members that form the group.

1.1.2 Some examples of collective intelligence

During the last half-century, many attempts have been made to study methods to exploit the potential of groups from the perspective they represent a sort of augmented information processing and problem-solving systems.

This direction could be seen in the work of Doug Engelbart that, at the beginning of the 1960s, developed a framework to boost collaborative decision-making and problem-solving. The author called this framework *H-LAM/T* (Human using Language, Artifacts, Methodology, in which he is Trained) (Engelbart, 1962). According to Engelbart, humans regularly create devices to augment their capabilities; he divided these devices into four primary classes:

1. **Artifacts:** the set of material tools developed to achieve some scopes.
2. **Language:** the set of concepts and their symbolic representation used to communicate them.
3. **Methodology:** the set of methods, procedures, and strategies developed to solve problems.
4. **Training:** the set of the process implemented to learn and apply the points 1, 2, and 3.

For Engelbart, the H-LAM/T represents an integrated computerised system that encompasses all the classes, and that will help individuals in the process of decision-making and problem-solving augmenting human intellect. This system would support individuals by processing the information in a parallel way and interacting simultaneously with the person that uses it (Engelbart, 1962). The H-LAM/T framework may be seen as one ancestor of the modern approach to computer-supported cooperative work that exploits the principles of CI merging humans and artificial systems.

Moreover, an example of an early approach implemented to exploit the capabilities of groups is the Delphi method born as an augmented forecasting tool. The Delphi method (DM) was developed between the 1950s and the 1960s at the RAND

Corporation, a global think-tank active in political and social research (Dalkey & Helmer, 1963). The concept underlying the conceptualisation and creation of the DM is that the output of a group of individuals guided in their reasoning throw specific structured steps is more accurate and useful than the one produced by individuals that face the same problem in an unstructured way. (Rowe & Wright, 2001). The underlying implementation of the DM usually, after the recruitment of the participants, follows 3 phases or rounds (Brady, 2015a). The first phase is characterised by a preliminary survey proposed to participants to gather usually anonymously and independently their opinion about the topic discussed. In the second phase, a facilitator is in charge of collect the individuals' views and summarise them in a single report to be provided to each participant as feedback. The third phase consists of the reanalysis of the problem using confronting all the ideas that emerged intending to reach a consensus. After its original implementation at the RAND corporation, thank to his versatility, the DM has been used in a large variety of contexts. Primarily DM has been implemented in the field of public policy making to understand which measures to implement and to gather opinions regarding the policies already applied (Adler & Ziglio, 1996). Besides the public sector, DM has also been applied in private and organisational to increase decision-making abilities (Loo, 2002). Finally, DM has been successfully used in the field of community-based participatory research and qualitative studies (Brady, 2015b). Nowadays, thank to the opportunities provided by modern ICT the methodology of DM has also been implemented using online tools that allow the real-time interactions of participants (Helms, Gardner, & McInnes, 2017).

Another application of CI may be found in the formation of the so-called *think-tanks*, namely, organisations (manly no-profit) that are active in the research on different domains (e.g., politic, economic, social change, and technology) that recruit scholars from all over the world to work united on global relevant topics. One example of a think-tank that exploited the principles of CI is The Committee for the Future that in early 1970s instituted the SYNCON, a participatory methodology that integrated face-to-face discussions with video tools and computer conferencing (Glenn, 1994). The approach of SYNCON provides a participatory methodology that should be able to accelerate the process of integration of ideas and then produce original ones. During a SYNCON session, multiple groups analyse the problem from different points of view (e.g., environmental, political, physical, economical), and they are reunited in a single group to combine the different aspect analysed; usually, this process is carried out in three-and-one-half-day (Glenn, 1994). Another established example of a think-tank that applied CI process in its action is The Millennium Project, a participatory research and advocacy institution founded by the American Council for the United Nations University in 1997 and become independent in 2009 (*The Millennium Project*, 2019). The Millennium Project, beyond the participatory research method implemented, developed two particular works that demonstrate the CI approach of the organisation. The first project is the Global Futures Intelligence System (GFIS) developed for the International Center for Scholars in Washington, D.C., in 2013 (Glenn, 2013). This educational system consists of an online platform accessible from all the world that allows people sharing research findings and methods, and let discuss them with experts and identify possible participants (Glenn, 2013). The second project, called ISIS (Integrated Synergistic Information System), was developed for the Egyptian Academy of Scientific Research and Technology and represented the first national and public collective intelligence system in the world (Glenn, 2015). The project aims to integrate all the public and government information and be accessible by every user that requests an account. ISIS was designed with the purposes of merge the information about the Country and make them available for public and experts, update this information, connect the academic environment with the civic one and provide a system to receive and give feedback usefully to make better decisions (Glenn, 2015). In this therms, the ISIS system designed by The Millennium Project harness the CI principles providing an online environment that serves as an interactive support system for decision-making and problem-solving, allowing users to interact in real-time and collaboratively giving opinions and ideas. Finally, the TechCast Project is a global think-tank organisation actives in the context of forecasting emerging technologies. The TechCast Project pools the opinions and knowledge of about 130 experts (e.g., managers, CEO, researcher, engineers) in the field of modern technologies in order to develop predictive models about the usage of specific technologies in the future (Halal, 2013).

One of the most successful paradigmatic examples in the use of CI mechanisms can be found in Wikipedia, the largest free encyclopedia in the world active in more than 294 languages, which through the collaboration and coordination of millions of users around the world manages to contribute to the dissemination of knowledge and culture (Kittur, Chi, & Suh, 2008; Doan, Ramakrishnan, & Halevy, 2011). Notably, Wikipedia is comparable in terms of accuracy with the *Encyclopedia Britannica*. Indeed, the findings of a research that made compare fifty articles for each source to a pool of experts showed how the difference in error distribution in both encyclopedias is substantially the same (Giles, 2005). However, due to the collaborative and collective nature of Wikipedia, some issues have been addressed to this project, in particular, the role of administrators that manage the contents has been investigated alongside the "neutrality" of the articles. Greenstein and Zhu (2014) analysed the bias that drives articles towards some opinion instead of providing a neutral point of view, still comparing the contents of Wikipedia with one of the *Encyclopedia Britannica*. In their work, the authors found the articles of Wikipedia significantly more biased and deviating from neutrality respect the articles of the *Encyclopedia Britannica*. However, their findings suggest that this gap is reduced when an article is subjected to a higher number of revisions carried out by more users with different ideologies bringing multiple points of view (Greenstein & Zhu, 2014). Moreover, Das, Lavoie, and Magdon-Ismail (Das, Lavoie, & Magdon-Ismail, 2016) approached the problem of the malicious contribution of users that deliberative provide polarised opinions or fake news. The authors of this study suggest that the conventional method used to elect editors and administrators on the platform reveals the information necessary to identify potential manipulators and that in this process should be given more weight to influential voters in the community (Das et al., 2016).

A further example of the application of CI in the context of scientific research is represented by The Psychological Science Accelerator (PSA) born to improve the quality of the studies in the psychological discipline. The PSA is a distributed network of more than 300 laboratories around the world designed to accelerate the accumulation of reliable and generalisable evidence in psychological science (Moshontz et al., 2018). The PSA follows four different steps to implement a research project:

1) Proposition by a member of the network and consequent evaluation of the project by a committee of 10 referees selected based on methodological and statistical expertise: 2) preparation of all the labs involved managing all the resources required and decision authorship; 3) implementation of the research starting from the hypothesis formulation and the protocol decision to the data collection; 4 data analysis and dissemination of the findings at least one stable, publicly accessible repository (e.g., PsyArXiv,) (Moshontz et al., 2018).

Wolf, Krause, Carney, Bogart, and Kurvers (2015) provided a precious insight on the potentiality that a CI approach could bring to contexts that require high specialised experts such as the field of medical decision-making. In their research, the authors tested if a CI process could bring advantages for a radiologist in the identification of risky conditions related to breast cancer in terms of true-positive rate and false-positive rate. The researchers, using a large data-set of 16,813 interpretations by 101 radiologists of 182 mammograms, evaluated if an individual expert evaluation would be better than one resulted from the implementation of a CI driven approach in groups of increasing size (Wolf et al., 2015). The authors compared three different rules groups conditions distinguish by the rule to decide: majority, based on the number of voters; quorum, based on a threshold resulting than overall interpretation in the data-set; and Weighted quorum, where the vote of each radiologist was weighted on the base of the expertise of the doctor. The findings of this study suggest that in general, a CI approach outperforms decisions taken individually, regardless of the rule applied to decide on the team; moreover, the increase of the group size has also increased the correctness of group decisions (Wolf et al., 2015).

1.1.3 Collective intelligence as a field of study

The study of the effects generated by the aggregation of people and the formation of groups and crowds has been an essential subject of study in many disciplines (Reicher, 2008). Initially, the emphasis in the study of crowd dynamics has been placed on the negative aspects that derive from belonging to large aggregates of people. Indeed, Le Bon (Le Bon, 1896) described the behaviour of crowds as something destructive compared to one of the individuals. For Le Bon (Le Bon, 1896), humans, when packed in crowds, tend to lose their critical think and control and induce impulsive and irrationals behaviours.

In contrast with the view of Le Bon, the sociologist Durkheim argued that the tendency to aggregate in groups had been one of the propulsive forces that allowed humans to succeed. Indeed, the ability to form groups and act as a collective entity enables humans' societies to create environments where logical thinking can flourish. For Durkheim, societies own higher intelligence respect single members because transcend individuals in both time and space (Durkheim, 1915).

Regarding CI as an applied research topic, especially for what concerns humans systems, represents a relativity new field of study (Salminen, 2012).

For instance, one of the first approaches to the study of CI from academic scholars may be identified in the conceptualisation of the Global Brain Hypothesis (GBH) (Russell, 1983). The basic idea behind GBH is that people thank the ICT, and the development of the Internet through self-organisation processes could constitute a network that process information worldwide as well as neurons in the brain represent the fundamental basis of information processing for living entities (Heylighen, 2002). After the formulation of GBI, scholars contributed to this field of study, developing computational algorithms that could drive systems build to harness Web technologies to implement the Global Brain architecture (Bollen, Heylighen, & Apostel, 1996; Heylighen & Bollen, 1996). Subsequently CI has been examined by researcher first theoretically and (Szuba, 2001b, 2001c) conceptually (Luo, Xia, Yoshida, & Wang, 2009) then studied also by means of computational models (Bosse, Jonker, Schut, & Treur, 2006).

The first academic conferences on the topic of CI happened starting from the 2000s (Malone & Bernstein, 2015). One of the first has been the *Computational Collective Intelligence. Semantic Web, Social Networks and Multiagent Systems conference* organised in Poland in the 2009 (Nguyen, Kowalczyk, & Chen, 2009), followed, in the 2010, by the *Symposium on Collective Intelligence (COLLIN 2010)* (Bastiaens, Baumöl, & Krämer, 2010), and then the *Collective Intelligence 2012 conference* in Cambridge, Massachusetts (Malone & von Ahn, 2012).

Instead, the first institute specifically meant to study CI the *Canada Research Chair in Collective Intelligence* was created in 2002 at the University of Ottawa, followed in 2006 by the *Center for Collective Intelligence*, at the Massachusetts Institute of Technology in 2010.

Finally, the first model based on empirical findings about CI (i.e, the *c* factor see 1.4) factor model in humans was proposed by Woolley et al. in the (2010).

1.2 Phenomena related to collective intelligence

In scientific literature, it can be found numerous construct that may be seen as partially related to the phenomenon of CI and that in some aspect overlap it. Indeed, the principles that allow CI to arise as an emergent property in groups are ordinary in many complex adaptive systems (CAS). The term CAS refers to forms of complex systems where a large number of heterogeneous entities (such as artificial agents, insect, bacteria) interact without the existence of an external or internal centralised control unit, and adapt their behaviour in response to environmental feedback to collectively obtain a goal (J. H. Miller & Page, 2009).

Following in this section will be analysed four main phenomena that could be displayed by complex adaptive systems linked to CI: swarm intelligence, the wisdom of crowds, crowdsourcing, and stigmergy.

1.2.1 Swarm intelligence

One of the most notable examples of the phenomenon of the emergent complexity of a natural system in the animal kingdom, deriving from collective behaviour and sociability is the *swarm intelligence*. The term swarm intelligence has been initially used to describe the emergence and implementation of intelligent practices deriving from the self-organisation of simple agents (e.g., ants, bees and birds) who act without supervision and in response to the environmental drives (Karaboga & Akay, 2009). Swarm intelligence has been first studyed in insects and than the findings applied to the research in the field of artificial intelligence and robotic (Bonabeau, Dorigo, & Theraulaz, 1999). Swarm intelligence of social insects has inspired many models and ways to analyse and solve complex problems in real-world such as traffic routing, networking, games, industry, robotics, economics, and generally designing artificial self-organised distributed problem-solving devices (Karaboga & Akay, 2009). For instance, a typical form of application of swarm intelligence may be found in the foraging behaviour of ants. One of the first studies investigating food research and collection actions of ants concerning swarm intelligence is te work of Deneubourg, Aron, Goss, and Pasteels published in 1999. The authors showed that the typical pattern of movement of ants (i.e., walk inline) is caused by the secretion of specific pheromones of every ant and that allows the colony to usually find the shortest path from a resource to the nest and back. Indeed, it happens that the first ant that came back to the nest during a foraging activity results to be the one that found the shortest solution in both ways, and the other ants follow the direction marked by the first conspecific (Deneubourg et al., 1990). However, this mechanism is not free from risk and errors. Indeed, if, for some reason, the shortest direction is not found quickly, the entire colony may be staked in the use of a non-optimal path (Bonabeau et al., 1999).

The other landmark study in the field of swarm intelligence is the one published by Reynolds in 1987 about flocks of birds. The author, trough a computational simulation, showed how birds following a series of rules independently could form complex aggregates that are evolutionary advantageous to avoid collisions with others and perform a more active flight. The three rules identified by Reynolds are (Reynolds, 1987):

1. *the avoidance rule* - birds must avoid flying too close to each other;
2. *the copy rule* - a bird must move in the same direction of the others at average velocity respect the ones that surround it;
3. *the centre rule* - a bird should minimise exposure to the sided of the flock moving toward the centre of it.

In addition to the three rules of Reynolds Flake (1998) added a fourth rule, namely, the view rule. This rule imposes to birds to slightly flight away from the others that block their view.

Therefore, it appears that the swarm behaviour of the birds in flocks that gives them the typical "V" shape is the result of the complex interaction of the relatively simple behaviours of the individual birds.

Individuals can self-organise in complex aggregations when the results of this arrangement come with at least four features: 1) the presence of positive feedback, 2) the presence of negative feedback, 3) fluctuations in agents' behaviour and 4) multiple interactions between the agents' (Bonabeau, Theraulaz, Deneubourg, Aron, & Camazine, 1997). In particular, the first and second features satisfy the need for the swarms to maintain or abolish respectively advantageous and disadvantageous activities already implemented so that it to allow the stabilisation of the common behavioural patterns which keep the swarm alive. The third feature enables the swarm to produce innovative and potentially successfully behaviours, through random mutation in the conduct of the individual agents. Finally, the fourth feature allows the exchange of information between the agents part of the swarm hat could have different skills.

Another vital characteristic of swarms that it allows many species of social insect to increase their ability to face problems through collective activities is the division of labour which permits the implementation of tasks in a simultaneous and paralleled way (Calabi & Traniello, 1989; Robinson, 1992; Waibel, Floreano, Magnenat, & Keller, 2006; Karaboga & Akay, 2009)

Moreover, have also been defined five principles that describe whether a behaviour displayed by a swarm could be classified as intelligent (Millonas, 1994). Indeed, a swarm could be defined to show intelligence if (Millonas, 1994):

1. The agents can implement their behaviour considering time and space variation.

2. The agents can classify qualitatively the features of the environments.

3. The agents divide the resources available.

4. The agents show stability in the behaviour that is not altered by stochastic events

5. The agents identify the right moment to change their behaviour to adapt to the modifications of the environments and increase the resources available.

An artificial swarm intelligence system has been applied to CI in a problem-solving activity. Rosenberg and Willcox (2019) tested if groups moderated by swarming algorithms would heave overcome individual performance and groups voting condition in a problem solving prove using the Raven's Standard Progressive Matrices. The swarming algorithms were developed to assist the group decision-making process by weighting teammates' responses with their score in the test. The findings of the cited article show how the group in swarm supported condition overcame in terms of the correct answer the groups in the voting condition that in turn had overcome individuals

1.2.2 The wisdom of crowds

When it comes to the study of collective behaviours a distinction must be made between the phenomena that occur in large groups and small groups. Indeed, dynamics that rule the interaction in small groups and large groups or crowds are quantitative and qualitative different (Carletti, Fanelli, Guarino, & Guazzini, 2009; Lauro Grotto, Guazzini, & Bagnoli, 2014)

A construct that can help to understand how the phenomenon of Collective Intelligence can have its effects in increasing the capacity of large groups to solve problems and highlight its mechanisms is the Wisdom of Crowds effect. The wisdom of crowd term describes the phenomenon of information aggregation that occurs in large groups of people, and that often leads to a higher ability of groups to make decisions concerning individuals.

The first scientific evidence of this effect is date back in 1907, when Galton, in his statistical studies, observed that the aggregation of judgements even of non-expert persons could produce more accurate estimates (and therefore decisions) than those of individual experts of a given sector (Galton, 1907b, 1907a). Galton used as an experimental condition a country fair where people participated in a contest where the purpose was to guess the correct weight of a dressed ox (Galton, 1907a). The researcher collected 787 esteems, and found that taken alone the estimates were wrong by from $-3.7\% to + 2.4\%$ of the actual weight, instead, using all the forecasts as a single product and averaging them the resulting error was only of the 0.8% (Galton, 1907a).

The *Wisdom of Crowds* (WoC) effect is configured in the first instance as a mere statistical phenomenon of the aggregation of judgements and not a psycho-social effect (Lorenz, Rauhut, Schweitzer, & Helbing, 2011).

Surowiecki (Surowiecki, 2004) describes three factors that allow explaining how the aggregate mass decisions typical of *Wisdom of Crowds* to be able to give rise to an increase in performance at the group level compared to those of the individual:

- Cognition: understood as the capacity that the masses have to process information more quickly and without bias than the individual experts.
- Coordination: understood as the natural distributed optimisation of the problems that one has in the masses of individuals
- Cooperation: understood as the possibility of performing "calculations" in a distributed way in a self-generating network and self-organising.

The same author then describes the essential elements so that the aggregation of judgements obtained through the WoC is effective; they are:

- Diversity in opinions: understood as the heterogeneity of the positions of the individual members of the mass.
- Independence of opinions: understood as the possibility of each member of the mass to have a different opinion concerning that of others and not connected with their.
- Decentralisation: understood as the possibility of creating "pockets of knowledge" at the subgroup level of the mass.
- Aggregation: understood as the existence of mechanisms that can lead the opinions of single individuals to become opinions of the mass.

The study of the phenomenon of the WoC can, therefore, allow the understanding of multiple factors that affect the ability of groups to solve tasks, allowing, on the one hand, to consider groups and masses as alone individuals or systems and then study their functioning as a single organism (Oinas-Kukkonen, 2008).

The WoC is a source of interest in many fields of study, from economics to marketing, including mathematics, the study of decision making, and political predictions (Yu, Chai, & Liu, 2017).

As shown in the literature, numerous models have been proposed in the attempt to exploit better and better the effect of the WoC, widening its potential by overcoming the mere aggregation of judgements and opinions by adding different weights to the contributions of each individual (Du, Hong, Wang, Wang, & Fan, 2017).

A striking example of the effectiveness of the WoC phenomenon could be found in the fall of stock action of Morton Thiokol enterprise followed by the infamous explosion of the shuttle *Challenger* on January 28 of the 1986 (Malone & Bernstein, 2015). It happened that after the tragedy occurred to the shuttle, of the four enterprise involved in its construction as contractors of the NASA, the Morton Thiokol suffered significantly higher loss in terms of share price respect the other such that only after half hour after the disaster the title was suspended at the New York Stock Exchange (Maloney & Mulherin, 2003). Surprisingly, four month later, the official commission delegated to investigate on the explosion officially accused Morton Thiokol of the events occurred pointing the cause of the accident in the failure of an "O-Ring" produced by the company (Malone & Bernstein, 2015). Maloney and Mulherin (2003) investigating in the events occurred that day in the financial market argued that no evidence of insider trading. Summarising, it possible to argue that what happened that day in the stock exchange was proof of the potentiality of WoC in the economic context.

To date, the most effective model proposed in the literature that has proved capable of expanding the effects of the Wisdom of Crowds is the one developed by Prelec, Seung, and McCoy in 2017. The authors identify a way to gather information from the individual members of a group or mass of people to extend the potential of WoC and call the model resulting from their study the title *"Surprisingly Popular" algorithm* (Prelec et al., 2017). The ingredients of the algorithm proposed by the authors are three:

- The actual judgement of a person
- The estimate of the probability made by the same person to have given the correct judgement (degree of reliability perceived)
- The estimate by the person of the percentage of the reference population that gave the same opinion.

The researchers affirm that by weighing judgements, perceptions of correctness and the perception of the sharing of opinion it is possible to increase the reliability of the aggregate responses recovered through the mechanism of the WoC for sizes ranging from 22% up to at 48% The authors in their study showed how, through the use of their algorithm, by using the estimates and opinions of a group of subjects naive in the artistic field it was possible to approximate the aesthetic judgement and the relative market quotation of some works of art to that proposed by experts in the art market sector and by aggregating the judgements of dermatologists experienced in detecting possible skin cancers, a higher level of efficacy has been achieved than simple individual judgement (Prelec et al., 2017). The theoretical assumption underlying the operation of the *Surprisingly Popular algorithm* is that information must be present, at least in some degree above zero, within the population (i.e., group or mass of individuals) from which the attempt is made to obtain an opinion or information, in fact, it is not possible to get a reliable estimate or judgement regarding a sphere of knowledge from a set of individuals who have no minimum experience in that field (e.g., it will never be possible to have a reliable estimate regarding opinions on a particular statement of quantum physics from a group of people who do not know the subject) (McCoy & Prelec, 2017).

The effect of the WoC phenomenon could represent a mechanism that permits a partial explanation of how the CI phenomenon allows groups to gather and structure information from individual members and produce more accurate, effective and efficient judgements, decisions and opinions respect those that individual members could provide independently.

1.2.3 Crowdsourcing

The "digital world" has now become an important, if not fundamental, part of what concerns the lives of people around the world. According to the report published by the agencies We are social and *Hootsuite*, which gathers all global data on the use of the Web, in 2018 more than half of the world population has access to the internet, owns a smart device, and uses daily services connected to the network (Kemp, 2019).

Given the high pervasiveness of these tools and the rapid increase in technologies and possibilities that the Internet offers, the study, and understanding of the social dynamics that develop in virtual environments have become a topic of great interest in the scientific community. One of the emerging phenomena related to the world of the Web that has aroused great attention, both in the world of academic research and in the entrepreneurial world for its application implications, is crowdsourcing (Rouse, 2010).

The term crowdsourcing was coined by Jeff Howe in June 2006, in an article for Wired magazine, to define the action of a company or organisation that decides to delegate functions, once performed by its employees, to an undefined group of people gathered in a network, through free participation (Howe, 2006). With this concept we tend to define a type of action carried out in virtual contexts in which a subject (e.g., an organisation, a company or a single person) proposes to a group of individuals the voluntary participation in some task by requiring knowledge, workforce or, also, money offering in exchange the satisfaction of essential needs for those who have adhered to the request (Estellés-Arolas & González-Ladrón-De-Guevara, 2012). Integrating the above definition, it is, therefore, possible to conclude that crowdsourcing represents a process in which:

- A subject (e.g., company, organisation, individuals) has a task that must be completed;
- There is plenty of people who are potentially interested in committing to completing that task voluntarily;
- There is a virtual environment or platform that allows the necessary exchange of information to work and to support this;
- A mutual benefit both for those who make the request and for those who respond to them (Brabham, 2013).

Summarising, crowdsourcing can be defined as a particular type of *social problem solving* which, by making use of the potential of networks and the Internet, is able to connect a large number of individuals and exploit from each of them resources (e.g., money, knowledge , skills, opinions) to carry out a task in a more effective and efficient way, (Brabham, 2013).

Every action that can be defined as crowdsourcing is primarily based on the idea that through the use of technological tools of the latest generation an organisation can at the same time address a multitude of subjects that is capable of coming together, interacting and communicating virtually by gathering together a large number of useful information for completing a task (Greengard, 2011).

One of the most successful paradigmatic examples in the use of crowdsourcing mechanisms can be found in Waze, the most famous crowdsourced GPS mobile application, which through a permanent open-call, brings users to contribute independently to the increasing of real-time accuracy of traffic information and GPS navigation.(G. Wang et al., 2016; Nakatsu, Grossman, & Iacovou, 2014).

Another example of particular effectiveness in sharing web objectives and the tendency to come together in a collaborative way to achieve them is that represented by GNU/Linux computer operating systems, open-source products, managed by a worldwide community of users, freely downloadable and usable on almost any technological device (Peng, Babar, & Ebert, 2014).

Even in the world of entrepreneurship, forms of crowdsourcing have shown their effectiveness (Gatautis & Vitkauskaite, 2014), emblematic is the first case of the IT company *Threadless.com* which, addressing itself through its network directly to its customers and asking to interact in the creative process of its products (i.e., t-shirts), it has succeeded in significantly increasing its turnover, as it has succeeded in responding in an exact manner to the requests of its reference public with the creation of *ad hoc* products made following the direction of the final buyers (Brabham, 2013).

Even the ITC company *Google* is implementing crowdsourcing to improve the services offered to its users by exploiting their collaboration. Indeed, *Google*, through the voluntary participation of millions of people in some tasks in exchange for credits to be used in its services, is managing to progress in the development of its algorithms systems that make up artificial intelligence that structures every product offered, such as semantic search services on the web and linguistic translation (Davis & Marcus, 2015; Fast & Horvitz, 2016).

Finally, the effective implementation of strategies and processes based on crowdsourcing can also be found in the world of research. It is possible to perform research projects that require numerous samples by recruiting people on the Web and making them interact from remote in online environments (i.e., Amazon's Mechanical Turk).

Researches that have used this recruitment mechanism have proved to be more representative of the population, and have greater validity, compared to similar study carried out through a classic recruitment (Kittur et al., 2008; Rand, 2012).

Summarising, crowdsourcing may be seen as a particular application of CI declined in a distributed and massive form on the Internet and implemented through an open-call available for everyone.

1.2.4 Stigmergy

One of the most exciting processes to study in the context of group interaction is the communication activities that append between the members of the team. In particular, focusing on self-organising agent, it is possible to distinguish between direct and indirect interactions (Bonabeau et al., 1999). Direct communication could be identified when two or more members of the group communicate employing sound, physical contact, or using chemical signals (e.g., the above-explained mechanism used by ants with pheromones) (Bonabeau et al., 1999). Instead, indirect forms of interactions are more subtle to detect and need much more attention. Indeed, it is called an indirect communicative interaction between agents when one modifies the surrounding environment, and the others act in response to this modification (Bonabeau et al., 1999). The mechanism of stigmergy has been initially studied in social insects such as termites and ants and then extended to other lining and artificial entities (Bonabeau et al., 1999). Stigmergy rather than gives some insight and explanation for individuals coordinated activities provides a framework to understand mechanism related to individual approach to mass and group, namely, the interrelation between modification made in the environment that lead to a change in behaviour that than itself bring to others modifications in the environment (Bonabeau et al., 1999). Stigmergy was also applied in the fields of robotics testing the ability of robots to autonomously cluster items (Holland & Melhuish, 1999). Moreover, it has also been studied in the contexts of computer-supported collaboration within groups of people, in particular through the world-wide-web (Bolici, Howison, & Crowston, 2009).

The basics components underling, the phenomenon of stigmergy, are agents, a medium, an action, and a mark or signal (Heylighen, 2016). These elements are linked with a non-linear relationship that assumes more the form of a loop (Heylighen, 2016). Indeed, it is possible to describe a liner flow of events such as an agent that acts that produce a mark or a change in the medium, namely the part of the environment directly involved in the interaction (Heylighen, 2016). However, these components are related to one with the other such as a change in the environments that could stimulate agents to perform an action, and so on (Heylighen, 2016).

Concerning CI, stigmergy represents a supporting mechanism that allows the self-organisation of entities in the group (Heylighen, 2007). In particular, taking into account online environments, it is possible to observe how actions of an individual leaves marks in a shared medium (e.g., Web pages) and that others individuals react to this signal building further activities on the previous ones so that it will create a coherent stream of coordinated activities(Heylighen, 2011). Moreover, this process is increased by the positive feedback that occurs in such a way that the more mark and signals are stored in the environment, the more stimulus agents will receive, and the more activities will be implemented (Heylighen, 2011). The scenario above described could well explain the modern phenomenon of contents generations in the Web.

1.3 Cooperation and competition: two processes underling collective intelligence

In the study of the systems that human activity form and the social interactions of great interest in the field of research regarding those mechanisms that allow the aggregation of individuals in groups, communities, and societies. Cooperation and competition are two of the primary behaviours that can be investigated to understand the functioning of the set of events and conditions that lead people to unite and create highly complex and interconnected social systems forming non-linear dynamics (Avilés, 1999).

1.3.1 Cooperative and collaborative behaviours in nature

In the field of ethology a distinction regarding the relationships between individuals, even belonging to different species, can be made through the following categories:

- *Commensalism*

  It is an asymmetrical relationship that occurs when an animal takes advantage of another animal by feeding on its waste or merely taking advantage of its mere presence in some way, without the latter being influenced both in positive and negative terms. An example is a seagull that feeds on the man's waste near the ports.

- *Inquilinism*

  This too is an asymmetrical relationship where one animal benefits and the other receives no influence. It represents a particular case of commensalism in which an animal lives inside the nest, den, or body of another animal.

- *Mutualism*

  It occurs when two individuals establish a mutual interaction to obtain both advantages. A clear example is that of the hermit crab and sea anemone. In this relationship, the hermit crab for protection uses the shell of the anemone, which in turn uses the hermit crab as a means of locomotion.

- Altruism In its general concept, it indicates that behaviour that causes a cost to the individual who puts it into practice and a benefit to those who are the object of such conduct that the agents involved in the interaction receive as a result of the behaviour. An example is the behaviour of the *suricates Suricata suricatta*, small mammals that live in family groups of about thirty specimens in southern Africa. These animals can be prey to attacks by predators during their hunting practices during the day. To quickly identify the possible predators and limit the losses, in turn, each member of the group plays the role of sentinel, that is, it looks on a raised point and observes the surrounding environment. If the situation is quiet, the watcher suricate emits faint sounds, when instead it finds a possible predator, it emits a scream. At this signal, the other members enter the burrows quickly, but the sentinel continues to launch the alarm and remains on guard until all the others are not put in safety, sometimes losing his life because it becomes an easy target of an attack (Clutton-Brock et al., 1998)

Cooperation can be seen as a kind type of individual behaviour that involves personal costs, to engage in an activity that confers benefits higher than the costs to other members of your group (Bowles & Gintis, 2003). From an ethological point of view, an unexpected event appears because, in nature the altruism should be a losing behaviour destined to become extinct given that the egoists, who receive help by offering nothing in return, can survive and reproduce, while those who collaborate perish. The paradox arises from the observation that altruistic behaviours exist and are consolidated within natural contexts. The altruistic type of behaviour, and its perpetration, could contradict the fundamental principles of the Darwinian evolutionary theory, or the idea that to survive is the most suitable (Spencer, 1851). In fact, according to the concept of natural selection introduced by Darwin (1859), in a natural context characterised by the continuous competition between individuals, only those who have a higher fitness are selected and survive, or rather that their characteristics allow them to have on average more children than all the others with whom they compete for survival (Darwin, 1859). According to this theory then altruism, as behaviour that reduces one's survival and therefore, the possibility of reproducing, should not be an adaptive and handed down attribute. Compared to this problem, a fundamental contribution was made by Haldane's studies (1955), in which he senses that there may be a particular genetic mechanism that promotes altruistic maintenance on a hereditary level. To understand this concept, fitness must be reconsidered in genetic terms; that is: if an individual can spread more copies of his ancestral heritage over time than others cannot, then he will have a higher fitness and his own characteristics will be more frequent in the population. Therefore, considering fitness no longer relative to the individual but relative to its genetic heritage, it is possible to introduce the concept of kinship coefficient (r), namely, the probability that two individuals have relatives and therefore share the genetic heritage. In consideration of the ratio of kinship, altruism can be explained as a behaviour handed down to protect relatives who share a significant portion of the genetic heritage, for an individual in evolutionary terms, and it will, therefore, be convenient to save two or more siblings or children with whom shares fifty percent of the genes even if this results in their death (Haldane, 1955). Net of Haldane's theoretical considerations, it remains to be clarified how altruistic individuals can leave heirs, or how the gene of altruism can be passed on to future generations even if the altruistic subjects tend to perish. To solve this dilemma, it has been introduced the concept of kin selection or parental selection (J. M. Smith, 1964). Hamilton (1964), considering the ideas of Haldane, states that in a population of individuals the gene of altruism can evolve and be handed down because if we consider the fact that who survives is a relative of an altruistic subject who sacrificed himself, he too will be the bearer of the gene dell altruism, regardless of its manifest behaviour, and thus reproducing will cause the altruistic trait to remain as a genetic variant; formally this concept is expressed according to the inequality: $rB > C$, where, r is the coefficient of kinship, B, the tract benefit of the altruistic act and, C, the cost of the altruistic act (W. Hamilton, 1964). To explain the results of this model, the concept of inclusive fitness was introduced, which is defined as the sum of the direct fitness of an individual, that is the contribution to the transmission of genes performed with his reproduction, and of indirect fitness, the contribution genetic brought by more or less close relatives thanks to the altruistic action of the individual. The inclusive fitness of the altruistic individual is, therefore, all the higher, is its coefficient of kinship with the helped individual, or the higher the percentage of genes shared between the two individuals (D. W. Hamilton, 1987). Through the concept of kin selection, it is possible to understand the behaviour of altruism present in the meerkats, described above, since living in relatively small communities all end up being to a certain extent related to each other and therefore the possible direct sacrifice of fitness of an individual in the role sentinel paid off in terms of indirect and inclusive fitness.

The concept of kin selection through the coefficient of kinship is not, however, the only principle that regulates altruism.

Parental bonds are important but do not explain all of the generosity phenomena, mutual help, and cooperation that can be observed in nature. There are such behaviours even among unrelated individuals showing that there must be ecological reasons that are juxtaposed or replace the relations of consanguinity completely. To explain this type of conduct deriving from various variables contextual to the living environment of individuals, such as availability of resources, the number of partners, and dangers, the term reciprocal altruism has been introduced. R. L. Trivers to explain that even unrelated individuals can benefit from implementing altruistic behaviours through the concept of reciprocity, namely, in cases where an animal helps another without having an immediate advantage expecting the favour to be repaid in the future (R. L. Trivers, 1971). If all the members of a group act taking into account reciprocity, it will happen that everyone will offer something to everyone. In return, everyone will receive something from someone. According to this perspective, one can speak of altruism when an individual helps another obtaining only disadvantages. At the same time, more specifically, one speaks of cooperative behaviour when the sacrifices of individuals allow getting all the actors involved a common gain (R. Trivers, 1985). In cases of reciprocal altruism from an evolutionary point of view, considering each help situation as an isolated event, the best choice seems to be helped and to avoid helping with deceptive and opportunistic behaviour, but in a dynamic biological perspective, the balance the best one is created is complex. In fact, in a group of individuals, the continuation of a strategy of deception leads very quickly to the disappearance of altruism because to those who help, not receiving, in turn, any surrender, they prefer to renounce collaboration altogether. To explain how mutual altruism can be explained in interactions in nature Axelrod (1984) shows that the strategy that allows altruistic behaviour to survive and reproduce in a population is that of the tit-for-tat. The tit-for-tat is the strategy for which, in an initial encounter, an individual behaves in an altruistic manner towards the other and then adapts, in subsequent interactions, to the behaviour of others. This strategy leads to the stabilisation of cooperative behaviour within a population when the frequency of meetings between individuals is sufficiently high because it has two main characteristics:

- It is a punitive strategy that prevents constant deceivers from reproducing because they no longer receive anything from the lack of cooperation.
- It is a strategy that allows forgiveness by allowing those who compete to return to cooperate and receive help again, restoring reciprocity. (Axelrod & Hamilton, 1981).

An example of this strategy can be found in vampire bats. Vampire bats live in social collectives of many individuals, not all of them related, and feed exclusively on blood by getting them through small wounds to other animals. Their metabolism is so rapid that if, once the energies are over, an individual fast for more than 24 hours risks death. Under these conditions, mutual aid behaviours take place in the communities of these animals. That is when in difficulty, an individual is rescued by a companion these, noticing the signs of fasting, regurgitate part of the ingested blood to help him. In this species, the use of reciprocity based on the strategy of the tit-for-tat is evident. The individuals remember well who previously helped a companion by returning the favour in case of need, showing instead stingy with those who showed little collaboration (Wilkinson, 1988). A further perspective based on population genetics of how altruism has spread within natural contexts subjected to evolutionary mechanisms is introduced by Richard Dawkins (1976) in his book "The Selfish Gene." The English geneticist starts from the consideration that individuals are nothing more than "containers of genes," simple vehicles that transport genetic material from generation to generation, so all that matters for survival are not what an individual does in his life but only the fate of the genes he carries. Dawkins (1976) supposes that at the origin of life, there are organic molecules of genetic material inserted in the primordial soup. These molecules, through mutations, would be able to produce a barrier that protected them from the surrounding environment giving life to the first forms of single cells. Since this coating produced an advantage in terms of survival, these cells would have reproduced in greater numbers and rewarded by natural selection. Through evolutionary mechanisms and numerous other mutations, these cells would then have given rise to more complex systems and multi-cellular organisms. So according to this author, altruistic behaviour is nothing but the result of an "egoistic behaviour" that genes evolved to survive from generation to generation and to reproduce since natural selection acts at the level of genes, rather than at the level of the individual or species, thus resulting in a product of genetic competition (Dawkins, 1976). From this view it can be seen that cooperative and altruistic behaviour is a means that has been used for evolutionary purposes, formed and adapted as a useful tool for interaction with the context of life and useful insofar as this behavioural trait provides in this environment advantages in terms of reproduction and genetic multiplication.

1.3.2 Cooperation an competition in human beings

Argyle (2013) defines cooperation within human societies as: "acting together, in a coordinated way at work, leisure, or in social relationships, in the pursuit of shared goals, the enjoyment of the joint activity, or simply furthering relationship". To describe what competitive behaviour is Deutsch (2008) use the following words: "...competition produces conflict(. . .).Competition implies an opposition in the goals of the interdependent parties such that the probability of goal attainment for one decreases as the probability for the other increases.".

Altruistic, collaborative, and mutual-aid behaviours are widely present and easy to observe in humans both individually and socially, between related and unrelated individuals (Warneken & Tomasello, 2009). In people, cooperation has played a significant role for the survival of the species, in it lies one of the abilities that made the proliferation of the human being possible our ancestors were not the strongest predators and were not the apex of the chain food, they found strength in numbers and collective action and since it was human groups that survived the modern human being is the bearer of genes that predispose him to collaborative and mutual aid behaviour (Barrett, Dunbar, & Lycett, 2002). Most human societies represent an enormous anomaly in the animal world; in fact, they are wholly based on a division of labor and cooperation between genetically unrelated individuals in large groups (Boyd & Richerson, 2005). That is true for modern societies formed by an intricate number of individuals, large organisations, and national states. Still, it also applies to our hunter-gatherer ancestors, who generally displayed dense networks of exchange relationships and practiced sophisticated forms of food sharing and cooperative hunting (Hill, 2002). In contrast, most animal species show little division of labour and cooperation is limited to small groups, even in other primate societies, cooperation is far less developed than it is among humans, despite common ancestors (Fehr & Fischbacher, 2004). Only social insects, such as ants and bees, show a degree of altruism and quantity of similar and often higher cooperative behaviours than human beings. However, their cooperation is based on a significant amount of kinship at the genetic level (Ross & Keller, 1995). A contribution in explaining how altruistic behaviours may have been handed down in human communities comes from the work of Bowles (2006), in which he affirms that the phenomenon of the stabilisation of high levels of cooperation in human groups can be the fruit of the particular initial conditions of human societies. His study is based on his empirical assessments based on mathematical analyses within a framework in which the cooperation of an individual is seen as an act that produces a profit for all the members of the group, but that puts, in the single interaction, in a position of disadvantage the altruistic agent compared to the one who is not, in terms of direct gain from an action. Bowles (2006), with the model proposed in his article, he shows how the genetic differences between early human groups, in the earliest communities at the beginning of the evolution of the species, were probably large enough to cause group competition to be lethal for those groups that showed an excessive propensity to competition, thus explaining the evolution of altruism. Fundamental to this process is distinctive human practices such as sharing food beyond the family, monogamy, and other forms of levelling reproductive capacity; that have turned into culturally transmitted norms assuming advanced cognitive and linguistic abilities (Bowles, 2006). The proposed work does not directly imply that a genetic predisposition that favours human altruism exists, or that other possible cultural explanations of human altruism are of minor importance, he suggests that if such an arrangement exists, it may be the result of a process co-evolutionary between gene and culture in which the group conflict played a decisive role. At the biological and ethological level altruistic behaviour, as shown above, can be widely understood through the concepts of kin selection and reciprocal altruism, however, in the study of human cooperative systems these two mechanisms do not seem to be able to fully explain cooperative phenomena due to the high complexity and dynamics to which the factors that intervene in human social systems are subjected (Bowles & Gintis, 2003). In human reality, because many of the altruistic behaviours are carried out by unrelated individuals. The concept of kin selection does not, therefore, seem sufficiently explanatory of the complex world of human social relations, and even in nature it does not always prove to be a reliable predictor of such actions (Silk, 2007). Also, Trivers's concept of direct reciprocity, seems to be of little use in fully explaining human altruism since it presupposes repeated interactions between the actors to allow the manifestation of retaliatory mechanisms against antisocial actions (R. L. Trivers, 1971; Bowles & Gintis, 2003). Principally Bowles and Gintis (2003) affirm, much of the experimental evidence on human behaviour regarding cooperation derives from experiments in the laboratory-based on non-repeated interactions, or the final phase of repeated interaction. The two authors affirm that people can distinguish between situations of repeated iterations and situations of a single action and behave differently. Bowles and Gintis (2003) also states that the conditions in which the first humans found themselves living could have made the mechanism of continuous repetition of competitive behaviour and punishment an ineffective for cooperation. In fact, in many critical situations during human evolution, the repetition of interaction was rather unlikely, such as when groups faced situations of dissolution due to conflict or an adverse environment. Finally, the mechanism involved in the mutual altruism of repetitions and punishments can hardly explain why selfish individuals begin to collaborate in environments where large numbers of people interact. The major critical points exposed by Bowles and Gintis regarding mutual altruism as an explanation for the appearance of cooperative behaviours about punishment in large groups are:

- The number of accidental defections or perceived defections increases as the number of people in the group increases, also increasing the cost of the punishment to be imposed.

- The likelihood that a sufficiently large fraction of a large group of individuals will begin to cooperate, causing the cooperation to become profitable decreases exponentially with the increase in group size,

- The coordination and incentive mechanisms necessary to ensure the punishment of defectors about group members become increasingly complex and cumbersome as the number of its members increases (Bowles & Gintis, 2003).

To understand how behaviours of an altruistic type may have evolved within human social systems, one of the mechanisms that can be taken into consideration is that of *indirect reciprocity.* With the term indirect reciprocity Nowak and Sigmund (1998), it was defined that conditions for which altruistic behaviours are not always and only reciprocal considering a dyad of individuals, but they can also include a third subject. To better understand, find a given individual A, altruist and an individual B who receives the benefits of the action of A, the concept of indirect reciprocity implies that the two subjects can no longer meet and that it is the behaviour of a third subject C a be influenced by the previous interaction (Nowak & Sigmund, 1998). Indirect reciprocity can occur in two different ways: upstream and downstream (Nowak & Sigmund, 2005). By the term upstream reciprocity, we mean the condition that occurs when a subject A performs an act of altruism towards B, which in turn helps C; for downstream reciprocity, on the other hand, a situation is defined whereby an A in helping B increases the probability that an individual C will, in turn, help A (Nowak & Roch, 2007). One of the identified factors on which the evolution of indirect reciprocal behaviour is based is reputation (Nowak & Sigmund, 2005). Through reputation, or information about past behaviours and the degree of trust to accord to an individual, one can understand how those who cooperate more are more inclined to be themselves targets of cooperative behaviour by favouring a mechanism that allows consolidation. of collaborative attitudes within social groups (Milinski, Semmann, & Krambeck, 2002; Mohtashemi & Mui, 2003; Engelmann & Fischbacher, 2009). The mechanism of indirect reciprocity is an effective stabiliser, in groups, of cooperative behaviours in the collectively employed in collaborative actions. Scientific evidence demonstrates how the exclusion of *free-riders* (those who benefit from altruistic acts without performing them) by altruistic members, refusing collaboration in interaction with them, is an evolutionary stable strategy in contexts of groups that are engaged in collective actions (Panchanathan & Boyd, 2004). If, from the perspective of direct altruism, the mechanics of repetitions-punishments, as previously stated, has critical aspects in explaining the cooperative behaviours, with the introduction of indirect reciprocity, the punitive mechanisms assume fundamental importance in describing the collaborative attitudes in the large human groups and the evolution of these. People tend to punish those who recognise as non-cooperative people, to reward those who are recognised as altruistic individuals and in proportion to donate all the more as they were themselves the object of a help even when there is no apparent benefit to be put into effect such behaviour dynamics (Fehr & Fischbacher, 2003). This set of behaviours, where punishing the one who violates altruistic behaviour can also damage the executor of the punishment, is known by the term of *strong reciprocity* (Gintis, 2000). A person who is willing to sacrifice resources to help those who have been generous *positive reciprocity* and sacrifice their resources to punish those who have been unfair *negative reciprocity* behaves following robust reciprocity mechanisms (Bowles & Gintis, 2004). Evidence suggests that strong reciprocity mechanisms are also functional in large groups in the stabilisation of cooperative behaviour, in human societies, this leads to the formation of moral rules, values, and social norms (Bowles, 2006; Fehr & Fischbacher, 2004).

One of the factors that have been determined to be important for the development of cooperative dynamics within human social groups is the construct of *social value orientation* (SVO), implicated both on a motivational level and in the development of strategies and behavioural choices (McClintock & Allison, 1989). The SVO is a trait that identifies the degree to which an individual evaluates the outcomes and gains of action and how he prefers that they are assigned in relation if and other people (Messick & McClintock, 1968). The SVO is a construct of a continuous type that can be described based on the altruism that a person shows about the gains that can be obtained by oneself and others (Griesinger & Livingston, 1973). Four main types of guidelines can be described, namely:

- Individualistic Identify those who are interested only in their earnings, making decisions based only on what they think maybe the outcome of an action for them without considering others. These types of people tend not to get involved with others by avoiding both helping them and interfering in their actions. Their way of acting can hurt other members of the group, but such damage is not an objective that individualists aim to achieve.

- Competitive Even these types of people tend to maximise their earnings, but at the same time, they try to minimise the gains of others. Such individuals see situations of conflict and disagreement as potentially favourable and tend to impose their ideas on others. For competitors, each individual should seek in all situations the most advantageous strategy for himself at the expense of the gain of others. Competitors are a little interested in maintaining strong interpersonal relationships.

- Cooperative Cooperators tend to maximise both their earnings and those of other group members. They prefer strategies that allow everyone to gain an advantage.

- Altruistic People with an altruistic orientation are motivated to help others who need it even though this can lead to their loss. They are little interested in their own needs and preferences to be able to act in such a way as to make others gain money.

Individualistic and competitive orientations are seen as ego-centered, while cooperative and altruistic ones are considered pro-social (Forsyth, 2006). The impact of SVO on collaboration levels is relevant in many situations: it is a predictor of the level of cooperation in social dilemmas (De Cremer & Van Lange, 2001; Smeesters, Warlop, Van Avermaet, Corneille, & Yzerbyt, 2003) especially in the prisoner's dilemma without payment for choice, pro-social individuals cooperate more than ego-centred individuals (Balliet, Parks, & Joireman, 2009); shows itself capable of predicting the implementation of voluntary donations for beneficial purposes by pro-social individuals (Van Lange, Bekkers, Schuyt, & Vugt, 2007); pro-social people tend to make fewer requests and make more concessions in social negotiations, showing higher levels of conscientiousness and equity than others (de Dreu & van Lange, 1995). McClintock and Allison (1989), demonstrate with their work how the SVO is positively linked to rescue and help behaviours. In their study, they asked a sample of university students how many hours they were willing, hypothetically, to spend to help another person in need of help. The results show that psycho-social subjects were more generous in terms of hours than those who were classified as individualists or competitors (McClintock & Allison, 1989). In an attempt to analyse which factors could affect a person to make them more or less prone to pro-social behaviour, Gärling (1999) investigated the effect of collectivist values such as justice and equity and the priorities assigned to them using the prisoner game paradigm. The results show that the priority given to universal values, but those of benevolence, can successfully discriminate between participants whose SVOs have been classified as pro-social. The priority given to these values accurately explains the predispositions to altruistic behaviour in this type of social dilemmas (Gärling, 1999).

A level of analysis to be taken into consideration when analysing cooperative behaviours and understanding their evolution in human beings is that of the selection that is carried out at the group level (Bowles, Choi, & Hopfensitz, 2003). An important assessment of the reasons that lead people to conduct cooperative behaviours can be made based on social norms. Social norms define that set of cultural products (values, beliefs, and traditions) that individuals use as a source of information to guide their behaviour within social life contexts and imagine the behaviour of other people (Cialdini, 2003). Generally, in the social aggregates, the norms can be distinguished in constitutive norms that carry out the function of generating new behaviours (e.i. in the games), and regulatory norms that regulate the already existing behaviours (e.i. laws of the state). Social norms, as tools that individuals possess to understand which modes of behaviour are preferable to adopt based on the expectations of others' behaviour, can be subdivided into a further categorisation: injunctions and descriptive norms (Cialdini, Kallgren, & Reno, 1991). The injunctions describe what people believe would be appropriate or inappropriate to do in certain situations and are based on beliefs about behaviours that can be morally approved or disapproved; the descriptive norms refer to what most people do or think they will do in a given situation (regardless of their degree of perceived morality) (Cialdini et al., 1991). Social norms can have the utility of bringing a certain degree of understanding and order to those situations, in which the absence of such norms, would cause a perception of ambiguity and uncertainty, thus bringing a sort of sense by indicating schemes and possible behaviours by put in place (B. H. Raven & Rubin, 1976). The rules can become, if internalised, real repeated behavioural patterns through which an individual interacts with the members of his group, forming expectations in others about how he will behave, thus becoming useful for forming expectations and action plans for future interactions with each member of the collective (Bettenhausen & Murnighan, 1991). Finally, social norms can be distinguished between "explicit" and "implicit". The explicit rules are those formally communicated between members of the same group; the implicit norms instead are those that can be perceived, evinced and learned from the behaviour of the other people in the group making part of it (Birenbaum & Sagarin, 1976; Bettenhausen & Murnighan, 1991). Social norms therefore play an active, fundamental role in understanding the mechanics that animate group processes such as those relating to cooperative and competitive behaviour. Social norms can play an important role in explaining the strong human propensity to engage in cooperative behaviour through the punitive actions that they predispose. The social norms in fact and the sanctions connected to them remove the advantages of competitive behaviour within the groups and favour the selection of those behaviours respectful of the norm inside and of mutual well-being in the groups (Fehr & Fischbacher, 2004). A further factor to consider in the evolution of cooperation in human groups, in relation to social norms, are the forces that push to *conformism* (Andrés Guzmán, Rodríguez-Sickert, & Rowthorn, 2007). The term conformism was generally defined as the tendency that people have to ignore their free subjective expression and adapt to the behaviour, ideas, norms and value of a majority of people in a group of which they are a part of the people (Mucchi Faina, 1998). One of the most famous studies in the field of conformism is that of Asch (1951), who studied the way in which people tend to submit or challenge the positions of a majority of individuals and the effects on beliefs and opinions. The original experiment was based on a task of visual perception with a low degree of ambiguity in which a group of eight subjects, of which seven were collaborators of the experimenter without the experimental subject, given an initial stimulus based on a vertical segment was asked to choose which of three other stimuli, different in length, was more similar to the initial stimulus. The task involved a low degree of ambiguity; in fact, only the answer was evident since of the three incentives, one was precisely identical to the initial stimulus. Subjects had to repeat this task eighteen times. The experimental subject was always in the penultimate position in making his choice, thus feeling the decisions that the other members of the group made. The investigator's collaborators were required to choose the manifestly opposite alternative for twelve of the eighteen repetitions. The results of the experiment showed that 25% of the participants did not comply with the majority, but 75% complied at least once, choosing the wrong answer, to the position expressed by the group, and 5% of the subjects adapted to every single repetition of the task (Asch, 1951). Andrés Guzmán et al. (2007) show in their model how cooperative behaviours can derive from learning rules based on conformism. In their study, using computational simulations and a model that attempts to replicate the initial conditions of human groups, the authors show how conformist behaviours evolve when individuals are engaged in dealing with a task of cooperative social dilemma, in which pro-social behaviour always has a cost for the subject (Andrés Guzmán et al., 2007). A further phenomenon linked to the groups that can help to understand the evolution of cooperative events within social aggregates is that of the inter-group bias inserted within the theoretical framework of social identity. The theory of social status deals with all aspects of interactions between groups from the perspective of understanding the conditions in which people feel motivated, individually or collectively, to maintain or change their group membership (Tajfel, 1974). The inter-group bias is relative to the fact of positively evaluating and having more benevolent attitudes for the members of the own group than for the other individuals. A very clear example of the extent of intergroup bias is shown in Tajfel's experiments (1970), using the minimal groups' paradigm. In the first place, subjects were shown twelve paintings equally divided between works by Klee and Kandinsky, but without showing them the author's signature. After exposure to the paintings they were asked for their preferences or which of the paintings they preferred most and which they had hated. In the second instance, after the expression of preferences, the participants were divided into two groups giving them the impression that they had been divided according to the author of the picture they had preferred, labeling the groups randomly with the names of the two painters. The last phase of the experiment involved the task of assigning rewards by each participant to the members of his group and to that of others through matrices. The results of the experiment showed that the simple division into groups without the possibility of interaction among the members, led to conditions of favouritism for their in-group, in fact the participants tended to assign more points to the hypothesised members being of their own group and to maximise the score difference between their peers and others (Tajfel, 1970). Ruffle and Sosis (2006), show how belonging to a group can also influence cooperative and altruistic behaviours. In their study, the authors observe cooperative behaviour in a resource distribution game by comparing samples of different individuals from kibbutzim (voluntary Israeli associations of workers, based on rigidly egalitarian rules and the concept of common ownership) and city citizens Israeli. The results of their experiment show that kibbutzim members, when informed that they are playing against a citizen of a city, tend to cooperate significantly less than the situation in which they are engaged in dealing with members of other kibbutzim (Ruffle & Sosis, 2006).

Studies about altruistic behaviour in humans suggest that it could be driven not only by the phenomena described above (e.g., reciprocity) that it could exist a form of pure altruism, not evolutionary selected to bring advantage to the individual in terms of fitness, but by empathy.

Finally, Rand et al. (2014), as a multi-level explanation of cooperative mechanisms in humans, they introduce the concept of social heuristics hypothesis (SHH) to explain cooperative behaviours in terms of intuitions and results from dual-process theories. With the term SHH the authors define the assumption that people tend to internalise, and act intuitively, those behaviours that resulted successful in every day social context also in environments that not coincide with the one where the behaviours have been learned, such as research laboratories. However, these intuitive mechanisms may be overcome by the deliberative process, bringing people to change the automatic behaviour according to the given context (Rand et al., 2014). SHH proposes that instead of evaluating options (cooperating or not cooperating) according to a single utility function, people have two preferences that conflict or an intuition or a more reflective part is enough on the specific context. Evidence for the SHH has been proved in different researches. Rand et al. (2014) in a work comprehending 15 different studies for a total of 5,832 unique participants, conducted employing tools of the game theory (i.e., public goods game and prisoner's dilemma), found that including time constrains to prompt participants to intuitive process in their actions to bring in an increasing toward cooperative behaviours. Moreover, the authors found that this effect is reduced by the experiences of participants in previous experiments, o that they found the research setting more familiar. Indeed, the participants recruited through Amazon's Mechanical Turk (i.e., a platform for recruiting experimental subjects paying them for online researches) who had high experience in being experimental subjects showed a lower level of cooperation respect to lesser experience subjects (2014). Moreover, intuition has been proved to affect women and men differently. In a two study Rand, Brescoll, Everett, Capraro, and Barcelo (2016) conducted a two-study meta-analysis to identify the role played by gender and intuition in promoting cooperation. The first meta-analysis was held on 22 experiments ($N = 4,366$) that used game theory technique of the dictator game (i.,e. a game where participants unilaterally decide how to divide actual money between themselves and an anonymous recipient). In this study they found that intuition affect the cooperative behaviour of women significantly, increasing it, respect men that not showed significant differences, In the second study the authors conducted a meta-analysis on four ($N = 1,831$) experiments in which was asked to participants the sex-role identification (i.e., feminine or masculine). The findings showed that women that perceived themselves as masculine acted less cooperative and altruistic in the situation where time constraint was not introduced. Intuition has also been proved to act differently in the context where cooperation has or not effect self-interest. (Rand, 2016) conducted a meta-analysis on 67 studies in the field of economic cooperation games ($N = 17,647$) founding that pure cooperation (i.e., cooperative behaviours implemented when few consequences could be found in the future so that it result to be against own interest) is effected by intuition incensing cooperation respect strategic cooperation context (i.e., cooperation lead to increasing in personal gain). SHH is a theory that emphasises the role of own experiences and explains that insights can predict in laboratory experiments that those who cooperate more will be those who have more skills of cooperative behaviour in everyday life and who have had little experience of previous laboratory experiments (Rand et al., 2014).

Cooperation has also been studied in relation between the size of the group and the difficulty of the problem that the team has to solve. Guazzini, Vilone, Donati, Nardi, and Levnajić (2015) proposed a simulation in which they tested the effectiveness of the group in solving problems of increasing difficulty in groups of increasing size. This study shows how a population of agents reaches adequate levels of cooperation when it is divided into groups of equal size and faces tasks of intermediate difficulty (Guazzini et al., 2015). The authors suggested that huge groups in terms of dimensions are affected by the increasing number of selfish agents that slow the cooperative benefit of collaboration. However, this effect is mediated by the increasing difficulty of the problems faced by the group (Guazzini et al., 2015). These two concurring factors bring in an optimal state in the condition of medium size groups that meet issues of medium difficulty. Subsequently, Guazzini et al. (2015) implemented empirical research to test the finding of the above simulations. In this experiment, the authors recruited 216 participants who faced an economic game based on the functioning of the simulation in groups of increasing size ($N = 1, 3, 6, and 12$) whit problems of increasing complexity. The findings showed that people significantly cooperate less in small groups for simple issues (i.e., displaying levels of cooperation not effective in the game) respect when they face issues in large groups (i.e., reaching quasi-optimal levels of cooperation in the game) (Guazzini et al., 2019).

The dynamics that modulate the cooperative behaviour for the human being, and the groups that form, are still far from being fully understood. Many fundamental elements may be involved that bring the social systems that people create to stabilise in an iteration that involves cooperative attitudes, and how these elements influence each other is undoubtedly complicated and not merely described except through complex and multi-factor models. The manifestation of CI, in social groups, is possible thanks to the ability that members possess to conduct cooperative behaviours towards other members of their group. These behaviours are possible thanks to the knowledge, which some organisations have, to culturally spread certain types of behaviour, to feel empathy, to understand the mental states of others, and to imitate their behaviour (Bandura, 1989). These abilities make cooperative and competitive behaviours possible, fundamental for the manifestation of forms of CI (Lévy, 1997). For Bandura (2002) would be the capacity for symbolisation to allow the human species to give meaning to the experiences he lived, or to those he observed living to others (modeling), and to organise them into cognitive structures capable of guiding it in action.

1.4 Models and factors of collective intelligence

The phenomenon of the CI is the basis of numerous researches and objects of study in many disciplines: philosophy, anthropology, ethology, biology, social sciences, economics, engineering, computer science, and psychology (Leimeister, 2010). Following the systems theory approach, CI phenomenon can be defined as an emergent property of group interaction where the set of elements of the system produces a result that goes beyond the arithmetic sum of the characteristics of the individual (Von Bertalanffy, 1968). The underlying concept of CI can be found in all the aggregates of agents that constitute complex adaptive systems (e.g., people, insects, robots, software) that together can be more performing than the individual members that are part of the group (Mataric, 1993; Millonas, 1994; Blum & Li, 2008).

Some attempts in the years have been made in the research to describe the process that brings groups to display CI and to identify models and factors that predict CI, and that could be useful to exploit such phenomenon to increase performances in teams.

A conceptual model of collective intelligence

Luo et al. (2009) developed a conceptual model of CI for online communities basing on the assumption that CI may emerge from the knowledge exchange activities on the Web. The authors focused their work on the online environments for three main reasons: 1) the Internet reached a great pervasiveness such as it allows to reach millions of people; 2) the Web is become a container of all kind of information and assumed a distributed form accessible from all the world; 3) finally, the Internet reached a computational power that encompasses all the devices connected to it providing power to process problems never existed before (Luo et al., 2009). Luo et al., in their paper, described the structure of CI achieved through the Internet and the interactions that occur in it. The structure described by the authors is composed of three networks: the human network, the knowledge network, and the media network (Luo et al., 2009). The human network is described as the set including the individuals communicating. The media network is represented by the hardware and software devices that interconnected allows humans to communicate and connect to the Internet. The third network is the knowledge network that contains all the knowledge information. The set of three networks together form a "supernetwork" fully connected (Luo et al., 2009). Knowledge transmission in the networks could happen in two ways direct and indirect. The first way is the one that involves the direct link between two people, the information seeker and the people who have the requested knowledge through a direct connection. The indirect transmission occurs instead when an acknowledged member externalise its information and let it accessible in the network (e.g., a post on a Web page),. Then another member reaches this content and internalise it. The model proposed by Luo et al. is built on three assumptions needed to display CI formulated using as a reference to the human brain. The first assumption is that the community of involved owns a system to store memories and knowledge, such as the human brain. The second assumption states that the community should be able to exploit such stored intelligence in a strategic way to solve problems in the same way that humans use knowledge in their problem-solving activities. Finally, the third assumption the knowledge system must be able to evolve and to improve, such as the cognitive system develops and changes throughout the life of individuals.

A formal model of collective intelligence and its measurement

Whit the aim to develop a formal definition of CI, Szuba (2001a) proposed a computational model of interactions among agents in social structure and a theory-based measure applicable to the phenomena of CI. The Szuba's model of CI is grounded in the assumption that collective actions that bring to displaying intelligent behaviours are more easily observable respect the processes underling individual intelligence (i.e., humans intelligence). For this reason, CI represents a phenomenon for which a statistical evaluation and measure is possible (Szuba, 2001b). To develop a formalisation of the phenomenon of CI Szuba utilise the mechanism of the molecular quasi-chaotic model. The author identified seven basic assumptions of that permit to identify intelligent behaviours in all kind of social aggregates (Szuba, 2001c):

- In social structures, it is difficult to differentiate between living and non-living agents.

- Agents in social structures usually cooperate in a chaotic and non-continuous way. Inferences are implemented randomly when an encounter among agents, it is possible or the resource needed (e.g., time) are available.

- Single agent's inference is usually accidental and chaotic.

- Resources to implement inferences are distributed among the agents in the social structure.

- The organisation of a social structure influence the level of intelligence behaviours.

- Facts and rules in the social structure can create incoherent systems.

- To quantify the intelligence of the social structure (IQS) must be used a probability function regarding the problems solution

From this assumptions is possible to observe that in the model of Szuba the phenomenon of CI is assumed to be present in aggregates of both living (e.g., ants, human beings) and artificial agents, instead, no assumptions are made about actual voluntary form of cooperation or about the system of communication involved. According to Szuba CI emerges from the chaotic molecular-like interaction of knowledge transported and gathered by agents in social structures that results in a higher knowledge than the same agents outside the aggregate; this phenomenon leads groups to display higher skill in problem-solving (Szuba, 2001c). Indeed synergy and coexistence of agents in the same environment leads to an exchange of information that allows social structures to solve problems in an effective way. In this regard, (Szuba, 2001c) also proposed a formal method to measure CI as IQS. IQS is measured as the probability that after a certain time, a problem is solved as a result of the interactions and inferences occurred among the members of the group (Szuba, 2001c). Moreover, this definition of CI measure permit also to compare group that exhibit intelligent behaviours classifying them from lower to higher. The author explained that the above measure definition requires four conditions to be applicable (Szuba, 2001c):

- As inferences must be considered, any processes involved in problem-solving in the social structures taken into account, including technologies applied. This condition is required due to the fact that some inferences may be observed only by the product produced.
- In the case of simulations, to model, the phenomenon of CI mus be considered the division of resources needed to implement.
- Inferences may work in parallel, such as if an inference needs a component, another inference could produce that component to resolve a problem.
- Inferences are multi-directional: they could go forward, through improvement, backward, retrieving specific information from a general situation; and generalisation, combine two or more inferences.

The model proposed by (Szuba, 2001c) in addition to allowing a conceptualisation of a method for measuring CI it permits to describe CI as the phenomenon that encompass all social structure (i.e., living and non-living beings) and emerges in all kind of groups beyond the form of communication used by the members to share knowledge.

The source of collective intelligence: collective mental maps

Since it allows the resolution of complex problems in collective mode, CI can be described as a particular form of social intelligence and social problem-solving. Social problem-solving can be defined as the ability to solve tasks an ecological context within a social environment (D'Zurilla & Nezu, 1982). The ability to solve complex problems in groups is the basis of the evolutionary success of social species, including the human one, for which the possibility of implementing winning social problem-solving strategies has determined survival as a species modeling social and cultural behaviour human (Moleon et al., 2014). The result of this modeling is the innate ability of human beings to coordinate and synchronise their activities with others to face and overcome challenges in social environments (Dumas, Lachat, Martinerie, Nadel, & George, 2011). The application of problem-solving allows finding a sequence of actions that will transform the current state, through a series of intermediate states, into a final state called objective (Heylighen, 1988). The aggregation of the individual desires of the members of a group entails the birth of a shared goal, reachable only through cooperation (Heylighen, 1999).The perception of the problem then becomes shared among all members of the group. For the solution of this social problem, the application of collective problem-solving is necessary. It should be emphasised, however, that what is preferable for a single member is not necessarily what is preferable for the whole group (Heylighen & Campbell, 1995). Indeed, a collective has emergent properties that cannot in any way be reduced to a simple sum of the properties belonging to the single agents that compose it. The effectiveness of the application of mental problem-solving depends on the way in which the problem is represented within the cognitive system of the agent that implements it (Heylighen, 1988, 1999). The representations generally consist of the following sub-components:

- A set of states of the problem
- A series of possible actions to be implemented in order to solve the problem
- A fitness criterion for deciding which action should be preferred and implemented among all possible ones

The fitness criterion varies depending on the specific objectives or preferences of the agent. However, representations of a problem are not unique. There are several ways in which the same problem can theoretically be broken down or solved. Changing the representation of a problem, considering it from different angles and giving importance to different characteristics of the situation, can make an unsolvable problem a trivial problem, or vice versa (Heylighen, 1988, 1990). Actions can be represented as transitions that map the path a state has taken to transform itself into another. A final state can be achieved through the implementation of a single action or after passing a series of intermediate states determined by different actions. A set of actions produces a topological structure that determines a space of the problem. The simplest model of this space is a network, in which the states correspond to the nodes of the network, and the actions to the links that connect these nodes (links). Through the selection criterion, it is possible to represent a preference function that assigns a specific weight to each link. This method of representation produces a real mental map for the problem space agent, useful to guide him in the solution.

To solve a problem, a method is needed to select the sequence of actions that will lead to the goal as quickly as possible, this means that the application of a general heuristic is required. If we assume that the agent has only local awareness of the mind map, that he can only evaluate actions and states directly connected to the current one, the only heuristic it can use works as follows:

- Starting from the current state, the agent will have to choose the link connected with the greater weight to reach the next status.
- If all the possible links have already been tried and none of them has led to a subsequent state acceptable to the agent, he will have to go back to a previously visited state and attempt an alternative, unexplored path.
- The agent will have to repeat this procedure until he reaches the status he has chosen as a goal or until he has exhausted all the available link sequences:
- The enlargement of the mind map through the addition of states and actions.
- The improvement of the preference function, so that the total increase in options is counterbalanced by greater selectivity in the options that must be explored to solve a given problem.

With regard to the coordination of individual solutions, it is possible to apply the following conceptual framework of collective problem-solving. If a group of individuals tries to solve a problem, theoretically, each member explores his mental map to identify a sequence of actions that he believes will solve the problem in question. It may be sufficient to combine all the partial solutions proposed by the members into one *Collective Mental Map* (CMM) and the most advantageous solution for the problem to implement the phenomenon of CI. One criticism of this model could be the observation that if we assume that individuals are similar (for example, all human beings or all ants), and that they all live in the same environment, then we should expect their mind maps to be similar and that, as such, produce similar results. However, mind maps are not objective reflexes of the real world; they are individual constructions, which are determined by preferences and subjective experiences (Heylighen, 1990). It is precisely individual diversity that guarantees the power of the application of Collective Intelligence, given that it is precisely from the integration of the variety of solutions found by the members of a group that the best and most innovative solutions arise. Because it is evident that a CMM cannot be developed through the mere registration and modification of the individual contributions of group agents, it will be necessary to study different methods of CMM development. The simplest method to reach collective decisions avoiding conflicts is certainly voting. This method assumes that all options are known to all participants and that the issue is to determine the preference of the majority. The average, the feedback, and the division of labour are three other basic examples of how a CMM can be developed, or give us the idea of how a number of individuals can reach a shared solution to a problem. A CMM is essentially the superposition of individual mental maps of members belonging to the same group. Plus, these mind maps they are different the bigger the CMM will be. The best way to encourage the expansion and improvement of the collective mind map is to use positive feedback that encourages members to use paths discovered by others, but which is not so strong as to discourage the exploration of new roads (Heylighen, 1999).

According to Heylighen CI, therefore, allows a group and its members to make intelligent behaviours emerge through simple and coordinated interactions, exhibiting in collective way an intelligence that allows to find solutions to a problem in greater number and better than those that could be found by individual group members if they worked individually (Heylighen, 1999).

The collective intelligence genome

Malone et al. (2009), proposed a framework to study CI and to highlight the underling element that allow it exploitation in teams. The authors in their work identified the building blocks that make possible CI rise in groups, and labelled these as "genes"; also describing the condition for each gene to be useful in the processes of CI and the combination that these genes may have. To identify the genes of CI, the author analysed 250 Web sites that use CI to improve their performance (e.g., Wikipedia, Amazon, YouTube). Whit the purpose to classify the structural properties of the genes that allow harnessing of CI, the authors developed two pairs of question that guided their research (Malone et al., 2009):

- *Who* is doing the task? *Why* are they doing it?

- *What* kind of action the task implemented involves? *How* this task is being fulfilled?

The first pair of questions represent respectively, the agents that undertake the activity (Who), and the incentives expected to gain in carrying out the activity (Why). The second pair of questions represents respectively the structure of agents involved and the processes implemented (How), and the goal for what the actions are conducted (What).

Thanks to the first question (i.e., Who) the authors identified two genes:

- *Hierarchy.* A group in which people possess different degrees of authority regarding decisions in the process of task accomplishment.

- *Crowd*: A group where anyone at any moment could undertake all kinds of activity, without the need of an authority.

Malone et al. stated that the Crowd genome is the one on which the Web implementation of CI is based.

From the second questions (i.e., Why) the authors derived three genes about the motivation that drive people in CI activities (Malone et al., 2009):

- *Money.* The perspectives to obtain an immediate gain or to increase the possibility of a future one represent strong motivations that for people.

- *Love.* Represents the motivation in such case where there is no possibility of an immediate gain. Love drives people to act to obtain self enjoyment, or for the opportunity to reach gratification in doing something in a social way, or finally to join an important cause.

- *Glory.* The recognition of the effort made in a task and the resulted obtained represent important motivators that could bring people to act in CI systems.

The third question (i.e., What), regarding the objective behind the implementation of actions by individuals, it was used by the authors to identify two genes of CI:

- *Create.* This gene is used when individuals are involved in the generation of something new.

- *Decide.* Implementing this gene means to be involved in the process of decision-making toward the action to fulfill.

The authors suggest that these genes may be implemented simultaneously during problem-solving activities, creating possible ideas, and evaluating them deciding which apply.

Finally, regarding the fourth question (i.e., How), the authors studied in deep the modality in which Creation and Decision are implemented in the crowds depending on the presence or absence of the possibility of single individuals to act independently one from the other (Malone et al., 2009). The combination of these conditions generate four possible genes in the manifestation of CI behaviours:

- *Collection.* Is the gene used when all the contributions in the team by members are completely independent. CI, in this case, rises from the aggregation of the single contributions to create a unique product.

- *Collaboration.* This gene is displayed when the crowd's members must work together to create something. In this case, all the contributions are deeply dependent on one from the other.

- *Group Decisions.* Group Decisions represent the gene that is activated when a super-ordinate objective shared among all group members is preferred to individual objectives creating a situation of dependency inside the team. Mostly group decisions may occur by voting; consensus, when all, or essentially all, group members agree on the final decision and averaging when all single decisions are pooled, resulting in the average contribution of the group.

- *Individual Decisions.* This gene occurs when single members of the crowd make decisions alone without taking into account the other teammates' decisions, resulting in an application of CI from independent reasoning.

The authors in their paper affirmed that Crowds are the best gene to implement in that situation where *the resources and skills needed to perform an activity are distributed widely or reside in places that are not known in advance* (Malone et al., 2009). Whit this statement, they emphasise the possibilities that Crowd have to decentralise task resolution and divide assignments to multiple members. Moreover, to increase the abilities of CI systems the researcher describe also combination of genes that results particularly effective in increasing motivation and participation in teams. The first combination described in the paper is *Love and Glory*. This combination according to the authors allows the possibility to reduce cost of the work teams appealing to the accreditation deriving from the resolution of task and the sense of appurtenance to the group. The second combination that the authors highlighted is *Money and Glory*, illustrated as capable to accelerate the workflow in groups. Indeed, providing monetary incentives alongside the opportunity to achieve prestige in the team could result in increasing mobilisation trow the goal.

Malone et al. suggested that the framework created could be an essential tool to manage groups and teams with the purpose to harness their CI taking into account all the area involved in the process. From these conclusions, the authors affirmed that different initial conditions and different final objectives require different genes to be applied to group dynamics to improve performance in teams and make them exploit CI (Malone et al., 2009).

The *c* factor

For many years research in social and organisational psychology tried to clarify the reason why some group performed better than others and tried to find predictive factors of team performances (Hackman, 1987; Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Larson, 2013). One of the factors that mostly has been noted as important predictor of group performance is individual members' ability. Still, apart from this also groups with the the same capabilities of the members have been found to perform differently (Woolley, Aggarwal, & Malone, 2015).

Starting from the above findings Woolley et al. (2010), using parallelism with individual intelligence, proposed a definition of CI of groups as *"the general ability of the group to perform a wide variety of tasks"*. Moreover, supporting their claiming the authors bring two empirical evidence according to which a single factor occurs in deeming CI of teams. Woolley et al. in their paper of 2010, to determine if - and how - CI in groups has predictive power on the performances of groups beyond the knowledge of single members' abilities, examined trow two studies the relations between individuals intelligence (i.e., IQ) and group performances in a large variety of tasks. In the first study, the researchers they recruited 120 participants assigning them randomly in 40 groups of three-person each. Each group worked tougher for about five hours to solve together six different tasks Woolley et al.. The selection of the task was conducted on the base of the quadrants of the *McGrath Task Circumplex* (McGrath, 1984), a taxonomy of group problems-solving activities categorised on the base of the coordination required to be solved. The final problems selected were: visual puzzles (using the even-numbered Raven's Advanced Progressive Matrices), brainstorming, making collective moral judgements, negotiating over limited resource, and a criterion task represented by collaborative video checkers against a virtual opponent. (Woolley et al., 2010). Moreover, the IQ of all the members was assessed using the odd-numbered Raven's Advanced Progressive Matrices (J. C. Raven & Court, 1962). The findings of this experiment supported the conclusion of low correlation between individual IQ and the capacity of groups to well perform in a large variety of problems. First of all, the average inter-item correlation for group scores on different tasks was found positive ($r = 0.28$). Secondly, a confirmatory factor analysis supported the existence of a single factor responsible for more than 43% of the variance in groups score; labelled c factor. Moreover, the authors showed was possible to predict the performance of groups on the criterion task with the variables that loaded on the single general factor of CI ($r = 0.52, P = 0.01$) (Woolley et al., 2010). As of the last result, the data of the experiment suggested that the average and maximum IQ scores of teammates not significantly correlate with c not predicting performances of the groups.

In the second study, Woolley et al. (2010) replicating the structure of the previous experiment tested 152 groups of variable size (from two to five). For this second study, the authors changed the individual IQ measure and the criterion task accomplished by groups. For the first was used the Wonderlic Personnel Test (Wonderlic, 1992), and for the criterion task, an architectural design task. The findings of study 2 strongly supported the results o the first study, showing how c factor predicted much better than IQ group performance in the criterion problems (Woolley et al., 2010). Combining the data gathered in the two studies, the authors identified three variables that predicted groups' performance in a wide variety of problems, thus constituting the c factor (Woolley et al., 2010). The three main results obtained were Woolley et al.:

1. A significant correlation between c and the average social sensitivity of group members, measured with the *Reading the mind in the eyes* (RME) test (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) ($r = 0.26, P = 0.002$).

2. Results showed that c was negatively correlated with the variance in the number of speaking turns by group members ($r = -0.41, P = 0.01$), namely, the more was the presence of equality in the number of interventions during task resolution the higher was group performance.

3. Finally, the authors find the proportion of females in the groups was significantly correlated with c ($r = 0.23, P = 0.007$). However, this last result appears to be largely caused by the first one (i.e., RME). Indeed, the authors found men significantly score worst respect women ($1(441) = 3.42, P = 0.001$). Supporting this view Woolley et al. showed in a regression analysis on the groups for which all three variables (social sensitivity, equality in the number of interventions, and number of female) were available, that all the three of them had ad similar predictive power for c, but that only social sensitivity reached statistical significance (Woolley et al., 2010).

The authors concluded that the model proposed not only emphasised the roles of composition of groups but also it pointed out the importance of the phenomena that emerge among the interaction of teammates. (Michaelsen, Watson, & Black, 1989).

After the findings of the c factor model, many kinds of research have been carried out using the experimental framework provided by Woolley et al. to better understand the mechanisms that predict CI.

Woolley (2011), analysing previous studies on group performance whit the view of CI, pointed pout that CI systems are characterised by the ability to promote behavioural patterns of convergence and divergence inside teams and engage members in learning activities.

To verify the predictive power of the c factor at the vary media used to communicate by teammates Engel, Woolley, Jing, Chabris, and Malone (2014) implemented a research comparing teams working face-to-face and groups working online. The authors used an experimental protocol similar to the one proposed by Woolley et al. in 2010. For the study conducted, the researchers recruited a total of 272 participants randomly assigning them to 68 groups of four people. Of the total teams 32 completed the experiment in a face-to-face condition, the remaining 36 collaborated via chat on an online platform. All the groups faced a battery of seven tests: typing, detection, memory, judgement, brainstorming, matrix solving, and unscramble words. In addition each participant completed a measure for individual personality traits (using the Five-Factor Inventory Test; McCrae and Costa, 1987) and social sensitivity (using the RME; Baron-Cohen et al., 2001) (Engel et al., 2014). The results of the analysis of the data obtained whit this study showed two major findings. The first result was that in both online and face-to-face conditions the factor analysis replicated the single factor structure of CI in groups showed by Woolley et al. in 2010, respectively explaining the 49% and 41% of variance in groups outcomes (Engel et al., 2014). The second finding reported regarded the power of social sensitivity scores in predicting CI in both online and face-to-face interactions. Indeed, the researchers showed that the average RME scores of groups members positively correlate significantly with CI of teams in both conditions with $r = 5.47, p < 0.01$ for face-to-face and $r = 5.48, p < 0.01$ for online groups (Engel et al., 2014). No effect of personality traits has been found in this experiment. The authors in their work suggested that these latter findings could be caused by the fact that RME does not simply evaluate social sensitivity with the individual capacity to recognise emotion and mental state from facial expressions but it may capture a deeper aspect of social abilities related to social reasoning and CI.

Starting from the findings of the above-described paper Engel et al. in 2015 proposed a work aimed to investigate the relation of the emergence of CI and type of communication, group context, and culture diversity. Whit this purpose, the authors recruited three different samples of participants in different three different countries: United States (68 four-people groups), Germany (116 groups from two to five people), and Japan (25 groups of four people). The experimental setup replicated the one of Engel et al. (2014), indeed, the groups in the United States and Germany were divided completing the tasks online or face-to-face with Japanese groups that used only online condition. Moreover, the groups where also distinguished between those where people have worked for long time together previously and those who does not. The results of this study showed that controlling for both communication condition (i.e., online or face-to-face) and previous knowledge among members, and culture, a single general factor of CI is presented and it explains around the 40% of variance in group performance. Moreover, the authors provided evidence that indicated a stronger predictive power of CI for complex tasks respects simple ones (Engel et al., 2015).

Regarding the occurrence of CI processes in online environments Kim et al. (2017) provided some evidence supporting the hypothesis that a single factor model could is accountable for the groups' performances. The authors in this work compared the performance of 248 teams involved in playing a Massively Multiplayer Online Game (MMO), namely *League of legends*, and their score regarding the *c* factor model of CI as measured by Woolley et al. in 2010; using a digitised version of the battery. First of all, findings obtained trow factor analysis. The study showed how even in this kind of interactions, a single factor model fit well the data collected and that this factor resulted in responsible for the 38.38% of variance in team performance. Secondly, controlling results for the time spent by participants in the game, the authors found that CI is a significant predictor of teams' ability in the game and their chance of a win. Finally, data about the impact of communication in playing teams (allowed by an in-game chat) showed a negative but not significant correlation with CI quotient (Kim et al., 2017). In other words, besides the statistical significance not reached, it appeared that groups where more emerged a leader concerning communication performed well respect those teams where equality in conversation was reached (Kim et al., 2017).

Whit the aim to describe and identify the underlying factors that allow CI to emerge in humans groups Woolley et al. (2015) provided a classification of some variables according to their research in literature that could predict CI in teams. The authors identified two kinds of process involved in CI process: bottom-up and top-down. The bottom-up processes included all the characteristics of teammates that contribute in the task resolution (e.g., social sensitivity). Instead, top-down processes include all those features deriving from interaction among groups members such as norms, and coordination in the work. The researchers concluded that relying on this classification should permit to approach toward the study of CI in a more efficient way. Moreover, Woolley et al. (2015) suggested that albeit increasing individual intelligence seems a very complex challenge improving CI in teams look less difficulty thanks to the possibility to focus on specific variables that could be enriched in individuals.

In this regard, Chikersal, Tomprou, Kim, Woolley, and Dabbish (2017) investigated the role of physiological synchrony among group members and satisfaction in relation to group performance. In their experiment, the authors recruited 116 participants and divided them into dyads, resulting in 18 dyads of the only male, 20 dyads of only females, and 20 dyads of mixed gender (Chikersal et al., 2017). Each dyad completed the test for CI developed by Woolley et al. in 2010. Moreover, each participant's physiological synchrony was measured, gathering data about galvanic skin response of individuals, heart rate, and facial expressions. Group satisfaction, instead, was measured with the Team Diagnostic Survey, a Likert-type scale administrated to participant requesting their opinions on the interactions that occurred during the teamwork. The results of this work showed a correlation between CI and facial expression synchronism, but neither between CI and galvanic skin response or heart rate. Furthermore, the results of a series of mediation models showed that the average social perceptiveness had a positive indirect effect on CI via synchrony in facial expressions and that ethnic diversity indirectly increased CI increasing synchrony in facial expressions (Chikersal et al., 2017). Age and sex diversity between members of the dyads were found to influence CI negatively. Finally, no direct or indirect effect of satisfaction was found to influence the degree of CI expressed by groups.

Finally, Aggarwal, Woolley, Chabris, and Malone (2019) in a recently published paper exterminate the impact of the encoding type of information implemented by teammates has in the learning process unlocked by CI. In this experiment, the authors recruited 337 participants dividing them into 97 groups from two to five members. The group to assess CI completed the same battery of test described by (Woolley et al., 2010) in their work in 2010. Subsequently, the teams played the Minimum Effort Tacit Coordination Game, a task where the maximum results are obtained coordinating with the other but not involving verbal communication and where for each round, participants do not know the decisions of their teammates (Van Huyck, Battalio, & Beil, 1990). The game was repeated for ten rounds. Furthermore, individuals measure of the cognitive style, reflecting modalities used to manage information, was obtained administrating the OSIVQ questionnaire that investigates the object, spatial, and verbal styles (Blazhenkova & Kozhevnikov, 2009). Finally, the learning score was calculated as the rate of change in the gain obtained for each group across the ten rounds of the game (Aggarwal et al., 2019). Firstly, the results of this experiment showed that CI is positively related with the learning scores of groups ($\beta = 0.29, t = 2.74, p = 0.007, R^2 = 0.34$). Secondly, the relation between CI and cognitive styles diversity in groups obtained in the experiment resulted in an inverted U-shaped relationship ($\beta = -0.91, t = -2.19, p = 0.03, R^2 = 0.40$). In other words, high an low levels of cognitive diversity among group members decreased CI displayed by teams contrariwise medium levels increase the ability of groups in a wide range of tasks.

Summarising what described above it is possible to observe how in the last decades many attempt have been made to produce descriptive and explanatory model of CI with the aim to harness its potential. Conceptualisation of cognitive process in groups provided (i.e., Heylighen, (1999) remarkable insights about the dynamics the underling the emergence of CI in distributed and coordinated systems of agents. Moreover, formalisation of processes behind the manifestation of intelligent behaviours inside groups (e.e., Szuba, (2001b) allowed to identify basics variables related to CI and to crate an underpinning theory underlying quantification of CI in teams and its comparison. Regarding humans being, (Woolley et al., 2010) in Woolley et al. developed a framework to study CI in groups. This framework allowed the identification of a single factor c responsible for the performance of groups in a large variety of tasks. The predicting variable of this unique factor have been showed to be: social sensibility of group members, equity in turn-talking during task accomplishment, and number of the females in group (reported to be directly correlated with the first variable). Concluding, CI in humans has been found useful in both face-to-face interactions and online and to be influenced by both individual characteristics of people composing groups (e.g., cognitive styles used to approach the problems) and by process activated by interaction among individuals (e.g., communication exchanges).

1.5 First criticisms of the single factor structure of collective intelligence.

After the experimental evidence supporting the single factor structure of CI provided by (Woolley et al., 2010) in (Woolley et al., 2010) many research followed this framework bringing findings in sustain this interpretation of the underlying cause of CI behaviours in groups (Engel et al., 2014, 2015; Kim et al., 2017; Aggarwal et al., 2019).

However, recent works started to raise some criticisms against the single factor interpretation of CI.

Bates and Gupta in a paper published in 2017 conducted a rigorous replication study of the work presented by (Woolley et al., 2010) in 2010. The authors replicated both studies 1 and 2 of the original paper and a novel experiment investigating the role of leadership in groups and their CI. Among the three studies, the authors recruited 312 participants divided into groups of different sizes. The first study of Bates and Gupta (2017) represented a replication of study 1 of Woolley et al. (2017), they recruited 72 participants and formed 26 groups. The groups completed four tests to asses CI: brainstorming, group Ravens, plan shopping trip, and architectural design. These tasks have been chosen among the ones used by Woolley et al. (2010) according to their factor ladings on the c factor (Bates & Gupta, 2017). To measure individual intelligence and social sensitivity also Bates and Gupta (2017) used here the same instruments used by Woolley et al. (2010) in their first study, namely, Raven's Advanced Progressive Matrices (J. C. Raven & Court, 1962) and the Reading the Mind in the Eyes (Baron-Cohen et al., 2001). Results of the first replication study described a significantly different scenario than the one obtained originally by Woolley et al. (2010). The model obtained by Bates and Gupta (2017), indeed, albeit finding a single factor accountable for the 58% of variance in group performance, showed a strong predictive power of individual IQ on the teams outcome ($\beta = 0.76[0.4, 1.12], t = 4.37, p < 0.001$) failing to find the same effect of the other variables described by Woolley et al. (2010) (i.e., social sensitivity, number of females, and equity in turn-talking). The second replication study whilst attempt to replicate the study 2 of Woolley et al. (2010). Bates and Gupta (2017) recruited 40 teams of four participants, each one involved in the resolution of five different tasks retrieved by the protocol of study 2 in Woolley et al. (2010) (uses of brick, matrix reasoning, word fluency, missing letters, and group typing). Individual intelligence also was measured with the Wonderlic Inventory Test (Wonderlic, 1992) as used by Woolley et al. (2010). The findings of the second replication study suggest once again a single factor model accountable for about the 50% the groups' performance. The authors also in this case found individual IQ ($\beta = 0.74[0.54, 0.94], F(1, 34) = 57, p = 8.6x10 - 09$) and, this time, RME ($\beta = 0.3[0.11, 0.5], F(1, 34) = 9.80, p = 0.003$) to strongly predict CI, but not the number of females and the communication patterns. The third study presented by Bates and Gupta (2017) regarded the manipulation of leadership in teams. They recruited 40 for teams of three people. Groups were involved in the same experimental procedures described above for the second replication study. Besides, after the main study was completed, three group conditions have been randomly created, manipulating the emerging leadership in groups during a problem-solving task (i.e., Set E of the Raven's Standard Progressive Matrices; J. Raven and Court, 1988). In a first condition involving 14 groups, participants have been instructed on the importance of emotions, asking them to ensure that each person in the group received an equal amount of talking-time. For the second condition, in 12 groups, the authors decided the leader on the base of their score in the individual intelligence test, asking the other members to let him decide the problem-solving response ultimately. Finally, 14 control groups completed the task without any intervention of researchers. Results also provided in this case, evidence for a single factor accountable for group performance. Specifically, the effect of individual IQ was found large and highly significant ($\beta = 0.67[0.42, 0.92], t = 5.52, p < 0.001$). Moreover, adding individual intelligence in the model authors found to render the effect of RME non-significant ($\beta = 0.15[-0.10, 0.41], t = 1.22, p = 0.23$). Finally, Bates and Gupta (2017) joining the results of the second replication study, and the third study performed a series of structural equation models to investigate the structure of CI and test the hypothesis of Woolley et al. (2010). In particular, they compare the following four models:

- Social sensitivity drives CI directly.
- Individual IQ explains CI directly
- Social sensitivity and Individual IQ drive CI
- No effect of Social sensitivity on CI but a direct effect of individual IQ

Of the four model, the one that showed the best fitting parameters was the last. In other words, Bates and Gupta (2017), relying on the evidence of their data, argued that the cause of the group ability to resolve a wide variety of task could be identified in individual intelligence of teammates, arguing that ultimately to create efficient teams must be grouped, intelligent people. Moreover, even social sensibility was found directly correlated to the IQ of group members.

Alongside empirical evidence of replication study that failed to confirm the findings of Woolley et al. (2010), Credé and Howardson (2017) have re-examined six previous published studies in the field of CI. The authors extracted 6 different samples from 3 papers who analysed the CI in groups of humans with the framework proposed by Woolley et al. (2010). The Sample 1 and 2 were gathered from from Woolley et al. (2010), sample 3 from Engel et al. (2014), sample 4 and Sample 5 from Engel et al., and the sixth sample from J. Barlow and Dennis (2014). The authors used the data gathered from the six works to simulate a sample of 500 subject assigned to 125 teams of four individuals in 20 different group tasks. The researcher carried out firstly a one-level confirmatory factor analysis that showed a low or negative intraclass correlation coefficient among the scores, indicating weak evidence for a single structure explaining CI in a wide variety of tasks. Secondly, the authors conducted a two-level confirmatory analysis that produced fitting the data better than a unique factor model. The authors concluded their work stating that two primary artifacts have occurred in the research about CI: the influence of low effort responding and the nested nature of data. The first artifact, according to Credé and Howardson (2017) was caused by the low motivation of individuals during the group and individual phases of problem-solving. This phenomenon suggested the authors could have bee caused by the usually little time given to each group in the experiments in many tasks (e.g., 10 minutes for the brick task) that lowly engaged participants. This poor engagement could have resulted in general low scores that statistically increased correlation among different tasks. Secondly, Credé and Howardson (2017) claimed that the nested nature of the data otherwise could have caused an untrue high correlations among group performance scores because each individual before interact with other performed the group task "individually" because any group discussion required that group members foreshadow a possible solution or opinion regarding the problem and it resolution before the proper group reasoning started; therefore resulting in a simple aggregation of individual inputs.

In response to the study of Credé and Howardson (2017), Woolley, Kim, and Malone (2018) produced a paper where analysed the critics to the model of CI proposed by Woolley et al. (2010). In this work the authors bring elements to argue with the conclusion of Credé and Howardson (2017). First of all, they noted that four tasks of the simulated data of Credé and Howardson (2017) appeared to have a common general factor in common, arguing that even if a *c* factor is not accountable for all the tasks used it does not mean that it does not exist. Secondly, the authors does not agree on the acceptable threshold indicated by Credé and Howardson (2017) (i.e., 0.70) regarding factor loadings in the data analysis. Indeed they affirmed that a threshold of 0.40 is accepted in literature, especially in the context of social science. Moreover, they showed how the inclusion of sample 6 in the study of Credé and Howardson (2017) significantly decreased the evidence toward a single factor interpretation of CI, mostly caused by the use of only 3 tasks in the experiment that generated that data. Finally, Woolley et al. (2018) moved a critique about the hypnotised low motivation of experimental subject claimed by Credé and Howardson (2017) in the experiments. The authors explained that the measure of motivation was obtained in some studies used by Credé and Howardson (2017) (e.g., Woolley et al., 2010), but empirically it was not found a correlation accountable for the hypnotised effect.

Finally, in a recent proceeding paper presented at the Collective intelligence conference of 2019, Graf and Barlow proposed preliminary results of their meta-analysis on 745 teams in 13 studies from 6 scientific papers regarding CI: (Woolley et al., 2010), (Engel et al., 2014), (Engel et al., 2015), (J. B. Barlow & Dennis, 2016b), (J. B. Barlow & Dennis, 2016a), and (Bates & Gupta, 2017). The analysis implemented by the authors was a meta-analytic structural equation modeling that was used to synthesise respective correlation coefficients to a single pooled correlation matrix. The findings of this work suggested that rather than a single factor CI is composed by a multi-factors structure. In particular, the authors detected three of them: a factor that involves the idea generation, one that concerns conflict resolution, and a final one accountable for the execution of tasks.

Concluding and summarising, it is possible to affirm that, beyond some evidence that has undermined the interpretation of the CI as a phenomenon linked to a single factor characterising the groups, it is still very difficult to affirm that this emerging property does not exist except as a simple sum of individual skills.

Thus, future research should, therefore, analyse the individual factors of the individual members, but above all, the characteristics of the different tasks that could cause the ideal conditions for some groups to show intelligent behaviours beyond those that can be obtained individually from the individual members of the teams.

Chapter 2

Investigating the role of interaction with peers, and the task type in group problem solving on collective intelligence effectiveness

2.1 Theoretical background

In the past few years, collective intelligence (CI) has been of particular interest in scientific research, as individual intelligence did in the last decades. The individual intelligence was defined as the ability of human beings to solve a wide variety of tasks (Gardner, 1983), much like CI was defined as a general factor able to explain the "group's performance on a wide variety of tasks" (Woolley et al., 2010). According to the most up-to-date lines of study, CI is an emergent property of groups that results from both bottom-up and top-down processes (Woolley et al., 2015). The bottom-up processes involve the member characteristics that contribute to enhancing group collaboration; the top-down processes, instead, include the group structure and the norms that regulate collective behaviour to improve the quality of members' coordination. In particular, the most recent model of collective intelligence in the literature shows how three different variables can explain about 43% of the variance of group performance. The first is a top-down factor and is represented by the variance of the conversation's turnover. The second and the third are two bottom-factors: the proportion of women in the group and the average of members' abilities in the theory of mind (Woolley et al., 2010). Other studies indicate that also the average of group members' intelligence is a fundamental bottom-up factor in explaining the variance of CI (Bates & Gupta, 2017). Despite both individuals' characteristics and groups' structure are sure drivers of groups' performance, there are other factors that the empirical research could take in more account. The cognitive processes behind the social problem-solving that the groups implement solving a task could be of interest in the field of the study of CI. In this regard, Heylighen (1999) proposes an attractive formal model of social problem-solving founded on the assumption that to solve a task the group's members have to merge their representations of the problem (i.e. a set of problem states, a set of possible steps for the solution of the task, and a preference fitness" criterion for selecting the preferred actions) in a single collective mental map. The effectiveness of social problem-solving depends on the cognitive representation that the group has of the task (Heylighen, 1988). According to Heylighen, there are three ways in which a Collective Mental Map (CMM) can be developed. First of all, when all the group's members know the possible solutions of the task, the CMM result from the average of members' preferences. Johnson and colleagues (1998), simulating this scenario, demonstrate that this kind of CMM is not particularly different from the single members' mental maps. However, there is a series of studies in the field of the wisdom of the crowd that shows how the average of the group's members' opinion is the best solution for a wide variety of problems (Prelec et al., 2017). The second way of building the CMM is characteristic of the groups organised on the division of labour. In these groups, each agent can solve only a specific part of the problem. Therefore, the CMM will result from the sum of members' mental maps. The third system of CMM development is group discussion. Expressing their preferences and explaining the reasoning behind their chooses, each agent can play a role in the modification of other group members' Mental Maps, contributing, in this way, to the extension of the CMM. The most crucial obstacle to the effectiveness of the discussion in contributing to the expansion of CMM is too much diversity in the group's members' knowledge. When the expertise of agents is also different, indeed, they can't understand each other in communications, and this inhibits the expansion of CMM (Heylighen, 1999). Then, with Heylighen, we could consider the members' expertise as another bottom-up factor in explaining the variance of the group performance. Although the empirical evidence about the effectiveness of CI are many, there are studies that tried to resize the magnitude of the construct (Bates & Gupta, 2017; Credé & Howardson, 2017). In particular, a recent re-analysis of the four main empirical studies in the field of CI (J. B. Barlow & Dennis, 2016b; Engel et al., 2015, 2014; Woolley et al., 2010) does not support the hypothesis of a general factor able to explain the performance variation across a wide variety of group-based tasks (Credé & Howardson, 2017). while a meta-analysis conducted on 13 CI studies showed supporting evidence for a three-factorial model (Graf & Barlow, 2019).

Studies about CI conducted in an online environment suggest that CI manifests itself differently depending on context (J. B. Barlow & Dennis, 2016b). Furthermore, the literature suggests that it is possible to suppose the existence of different models of CI to explain the variance of group performance, for each kind of task that the group can solve (Credé & Howardson, 2017; Wildman et al., 2012).

For what concerns the structure of problems, Laughlin (1980) argued that group tasks might be placed on a continuum between intellectual and judgemental tasks. Intellectual tasks are problems characterised by a correct solution that is demonstrable and are tested (e.g., geometrical problems). Otherwise, judgemental tasks are problems that not have an acceptable answer that is demonstrable and universally recognised (e.g., aesthetic judgement or juries deciding on guilt or innocence in criminal cases). Laughlin and Ellis (1986) identified four conditions to distinguish an intellectual task from a pure judgemental one when faced in a group. The first condition concerns the agreement among group members about the solution that must lie on a demonstrable claim (e.g., mathematical, logical, scientific). Secondly, the information available to the group members must be sufficient to solve the problem. The third condition is that enough information must be available for group members who do not know the correct answer to recognise it. Finally, the fourth condition provides that the group members that do know the right answer own sufficient ability, motivation, and time to demonstrate the correct answer to the others. In this regard, Lam (1997) shows how the structure of task affect the quality of group communications and decisions. In his studies, the author takes into account conjunctive, disjunctive, and additional tasks. Steiner (1972) identified and described these three types of task structures. In the additive task, group performance is determined by the aggregation of individual effort (Lam, 1997). Each group member has the same responsibilities and information, and he has to maximise his or her own personal performance to increase the overall group achievement (Zaccaro & Lowe, 1988). In a disjunctive task, a group selects one optimal solution from an array of solutions proposed by individual group members (Steiner, 1972; Littlepage, 1991). The achievement of this kind of task is influenced by the performance of the members who make the most significant contribution. In a conjunctive task, no member of the group has enough information to solve the problem alone. Therefore, the successful decision can only be achieved when all the group members maximise their efforts (Lam, 1997). In this kind of task, a group solves a problem only when all of the information held by individuals are merged in a single CMM.

Summarising what exposed above, there are a lot of factors involved in the explanation of the variance of group performance. In addition to top-down and bottom-up group's factors (Woolley et al., 2015; Bates & Gupta, 2017), also the context in which the group work, the structure of the task that it has to solve (Credé & Howardson, 2017; Lam, 1997) and the cognitive processes underlying the social problem-solving reasoning (Heylighen, 1999), appear as drivers of groups' performance. So, of particular interest would be to find the models of collective intelligence useful to predict the group performance in all the variety of group-based tasks.

2.2 Study 1: General problem-solving ability in adolescents

2.2.1 Introduction to study 1

The ability to solve problems has been generally considered as a proxy to evaluate the intelligence of an individual (Gardner, 1983). A problem can be typically described as a situation where there is a gap between an initial state and a desirable state of a given condition. Therefore, the act to solve a problem consists of finding a way to fill the existing gap and is usually defined with the term problem-solving.

Problem-solving has been defined as a behavioural and cognitive process that makes available many possible solutions for a particular problem and increases the probability of selecting the most effective solution among all the alternatives produced (D'Zurilla & Goldfried, 1971).

The process that leads to the resolution of a problem consists mainly in two phases: understanding the nature of the problem and find the correct strategy to resolve it (Hayes, 2013).

During the first phase, the problem solver creates an internal representation of the problem, identifying the goal to obtain, the initial state, the tools, or operators, to use, and the possible obstacles (Hayes, 2013). The internal representation of a problem is the medium by which reasoning takes place. It is subjective and not an identical reproduction of the external problem situation due to the active role that the problem solver has in the process of its creation (Hayes, 2013). Representations of problems can also be externalised (e.g., by means of drawn or written schemes), and in such case, they are called external representation (Hayes, 2013).

The second phase consists of the active process carried out to reach the desired state. During this step, the problem solver examines the space of the problem (i.e., the set of all the possible patch available to solve the problem) accessible to him and implements strategies to reach the goal (Hayes, 2013). Hayes (2013) identified four major strategies that can be achieved by individuals to resolve a problem: 1) trial and error, 2) proximity methods, 3) fractionation methods, and 4) knowledge-based methods. The first strategy involves the evaluation of the posterior effects of the action performed to solve the problem in a recursive way exploring all the solutions identified until the problem is solved. The proximity strategy involves the systematic approach to the resolution of the problem, progressing step by step in activities that allow getting closer and closer to the goal. The splitting strategy is the method that involves the subdivision of the objective into sub-goals and approaching their resolution to reach the final desired state. Finally, the knowledge-based methods are strategies used when the problem solver exploits the information and knowledge stored in his memory to guide the resolution of the problem. The strategies are not mutually exclusive, indeed, to solve a problem an agent could first lie on a strategy and after change, the strategy adopted (Hayes, 2013)

Once the strategy is executed and the outcome of the attempt to resolve a problem is evaluated as successful or not, an important step that may occur is the process of consolidation. During the consolidation process, the problem solver is engaged in reflecting on the method used to solve the problem. The consolidation process plays a fundamental role in the learning process activated during and by problem-solving activities because it allows the creation of schemes that could drive the representation of future problems (Hayes, 2013).

People can implement problem-solving processes as individuals as well as in teams. In the latter case, we talk about group problem-solving (D'Zurilla & Goldfried, 1971). Analysing the processes that are implemented during group problem-solving can be found four fundamental factors that determine the outcome: 1) group task, 2) group structure, 3) group process, and d) group product (Laughlin, 2011). The group task is the kind of assignment that is to be executed. Group structure represents the internal organisation of the team and is composed of roles, norms, and individual characteristics of the members (including psychological ones). The group process describes the interaction that occurs among the members that influence each other. Group product is the output generated collectively by the effort made.

Research in the field of group problem-solving in small teams produced two significant approaches to study the processes underlying the interaction among members: the social communication approach and the social combination approach (Baron & Kerr, 2003). According to the first approach, the communication that occurs within the group can be studied to understand the influence that each member has on the outcome of the group. The social combination approach, instead, assumes that the process generating the result of a group is a combination of the individual members' responses that collectively are reassembled in one single solution.

Many studies have been conducted with the aim of analysing and comparing group and individual problem-solving. The findings in this topic have led to conflicting conclusions. Indeed, on the one hand, some researchers argued that groups hinder individuals' performance, also causing a failure in effective judgements production; on the other many scholars found in their work that group usually outperform individuals in a large variety of tasks.

Steiner (1972) theorised that groups that produce less than expected are characterised by members that can not find the correct solution and fails in the process to recognise the correct answer given by others. Latane, Williams, and Harkins (1979) shed light on the effect that groups have on individual efforts. In their experiment, the authors asked university students to clap and produce noise as teams and as individuals. They found that in-group condition, participants reduce their effort in the task from 28% to 68%. This effect of loss of individual effort in a group situation was called "social loafing." These results supported the classical finding of Ringelmann that showed how the effort in teams is reduced with the increasing of the group size (Moede, 1927). In his experiment, Ringelmann observed that, when participants were asked to take part in a rope pulling task, the individual performance dropped significantly with the increasing number of partners engaged. Later, reproducing the original experiment with college students, the Ringelmann effect was confirmed, observing that it is a curvilinear effect and not a linear one (Ingham, Levinger, Graves, & Peckham, 1974). Moreover, groups have also been found to fail to provide correct judgement (Hackman, 1987). Indeed, Kerr, MacCoun, and Kramer (1996) in their review of the literature regarding group judgement effectiveness concluded that individuals are less affected by bias in judgemental task and tend to fail less frequently than the group in this kind of problems.

Conversely, a large amount of research produced opposite results. In an early study, (Shaw, 1932) compared the performance of college students assembled in teams and individually, on problems of intellectual nature (i.e., mathematical puzzles), finding that groups performed better than individuals. The author hypothesise that the result of his research should be addressed to the tendency of group members to recognise and to correct the incorrect answers. Lorge and Solomon (Lorge & Solomon, 1955), starting from the evidence of Shaw, proposed a mathematical model in which they identified as principal factors for the better performance of groups the ability of their members to recognise the correct answer given by one of them. Thanks to the diversity of members' knowledge and abilities studies performed using adults and college students have showed how groups to express a greater efficiency and higher quality in the solution of problems respect individuals (McGrath, 1984; Laughlin, 1999; Mesmer-Magnus, 2009). In particular, in an experiment that involved university students, Laughlin and Bonner (Laughlin & Bonner, 1999) found that groups are able to solve problems effectively in tasks where is required to process an high amount of information. Solving problems and working in teams has also proved to produce beneficial effects in members involved, such as an increase in the commitment to the tasks (Hackman, 2002) and improving the understanding of problem situations, providing more accurate judgements (Sniezek, 1992; Sniezek & Henry, 1989). Furthermore, Straus and Olivera, in their review about the effectiveness of virtual work teams, have pointed out that group problem-solving can be a powerful learning tool to increase members' skills and knowledge through interaction with others (Straus & Olivera, 2000). The advantage of group problem-solving compared to individual performance has also been verified in children, in particular with a task involving mathematical and logical problems (S. A. Miller & Brownell, 1975; Perret-Clermont, 1980; Doise & Mugny, 1984).

In cognitive sciences, such emergent property of groups, namely to go beyond the single members' capabilities and to integrate them in something more significant than the simple sum of the individuals' abilities, has been labelled as collective intelligence (CI) (Heylighen, 1999). Recent research on CI not only showed how the group could boost the performance of the single individuals but also how one of the effects deriving by interacting in collective environments is the promotion of the increase of knowledge among group members (Woolley et al., 2010; Aggarwal et al., 2019; Gadeceau & Training, 2015).

Given this latter property, understanding how to exploit the full potential of the collective intelligence in educational environments would be of great interest also in the light of the massive spread of online educational learning platforms. Indeed, the effectiveness of the processes activated in the group by the phenomenon of collective intelligence has been proven to retain also in online environments (Engel et al., 2015; Kim et al., 2017). However, much of the research in the field of CI focused mainly on adults and lack of works investigating groups of youngster peers.

Thus, the first work hereby proposed aims to investigate the phenomenon of collective intelligence in a sample of adolescents engaged in performing a logical-mathematical task, comparing computer-mediated interaction with face-to-face interaction, and isolate the main factors that explain the ability of online groups in solving a logical-mathematical problems.

2.2.2 Hypothesis

- *H1: No significance difference will be found between the performance of the groups involved in the CMC task condition and groups involved in the FtF task condition.*

  According to the literature about collective intelligence, the phenomenon should not be affected by the type of communication used to interact during problem-solving and decision-making activities (Kim et al., 2017).

- *H2: Groups will perform better than single individuals.*

  According to the most relevant literature on collective intelligence, groups can harness individuals' intelligence, resulting in displaying a greater ability in complex task resolution (Heylighen, 1999; Woolley et al., 2010; Engel et al., 2014, 2015).

- *H3: Individual intelligence is a factor that explains the ability of groups to solve logical-mathematical tasks.*

  According to some recent evidence (Bates & Gupta, 2017), individuals' IQ is a determining factor also in a group task, resulting in a parameter to be evaluated to understand the phenomenon of CI.

- *H4: Top-down and bottom-up process explain the groups' performance in CMC condition.* According to the most recent findings in the field of collective intelligence (i.e., Graf and Barlow (2019), a single factor view of processes underling group performance is not consistent. Indeed, this work aimed to identify a more comprehensive model of collective intelligence including bot individual characteristics such as personality traits; characteristics deriving from the context, such as group cohesion that could predict performance of groups in the way that higher cohesive groups perform better (Evans & Dion, 1991; Chang & Bordia, 2001); and characteristics peculiar of the task such as difficulty of the problem to solve.

2.2.3 Sample

The sample of this study consisted of 563 high school students from the first to the fifth year of courses (460 females, and 103 males, see Fig.2.1). The sample belongs to Human Science High School "Licei Giovanni da San Giovanni," which offers a humanistic formation to all its students. The average age of participants was of 15.78 for years ($SD = 1.50$ years).

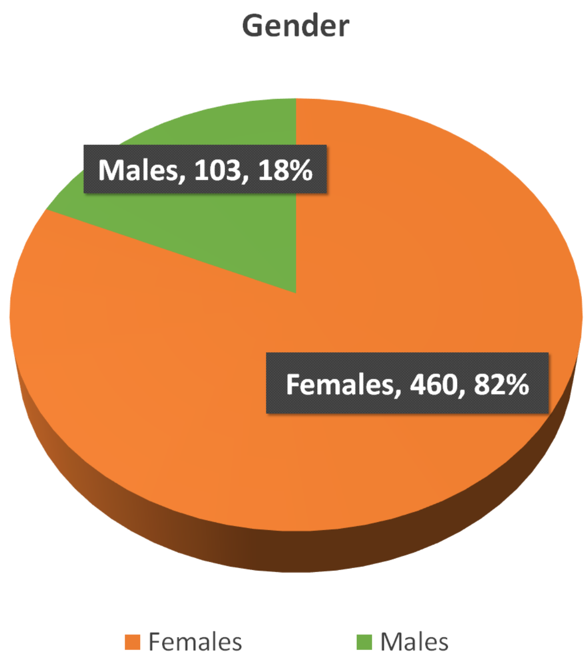

Figure 2.1: Gender distribution of the initially recruited sample.

The inclusion's criteria for this study were: understand the Italian language correctly, do not have high developmental disorder, can give the voluntary participation in the study and have signed consensus form (by legal tutors if the participants did not have the legal adult age at the moment in which the experiment was carried out). Only 13 students (the 2.63% of the initial sample) do not fulfill the previous criteria. Thus, the final sample of the research was composed of 550 participants (Age $M = 15.62$ years $SD = 1.48$ years; 449 Females, and 101 males) as showed in the figure 2.2.

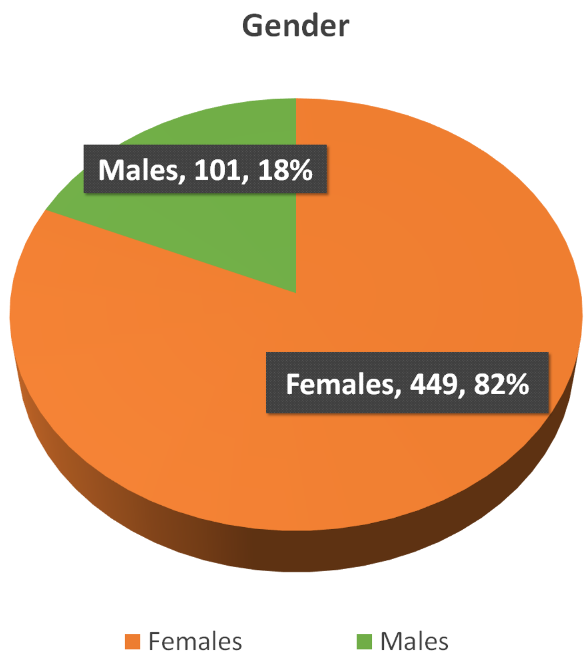

Figure 2.2: Gender distribution of the final sample involved in the experiment.

The experiment was carried out following the guidelines of the Italian Psychological Association (AIP) in a matter of ethical and privacy issues.

2.2.4 Materials and methods

The psycho-social survey

To gather data to control the possible effect of individual characteristics it was administrated a psycho-social questionnaire to all the participants. The self-report survey was composed of two sections: a demographics section and a psychological one. The first data about gender and age of participants were collected, while the second section was devoted to assessing a series of psychological dimensions.

- *Personality traits*

  The I-TIPI inventory test ($\alpha = 0.59$) (Chiorri, Bracco, Piccinno, Modafferi, & Battini, 2015) has been used to obtain measures of personality dimensions on the base of the big five model (Costa & McCrae, 1992) (the OCEAN model). This test is composed of ten items on a seven-point Likert scale (1 = strongly disagree, 7 = strongly agree). The I-TIPI is formed of five sub-scales: Extroversion, Agreeableness, Conscientiousness Neuroticism, and Openness,

- *Cohesion among group members*

  The Sense of Community (SOC) has been measured using the Classroom and School Community Inventory (CSCI) ($\alpha = 0.93$) (Rovai, 2002; Rovai, Wighting, & Lucking, 2004), which assigns two separate scores: one for the *Learning Community* ($\alpha = 0.87$) and one for the *Social community* ($\alpha = 0.92$). The scale was composed of a total of 20 items, 10 for each sub-scale, on a five-point scale (1 = strongly agree, 5 = strongly disagree). The literature defined generalised sense of community as a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to being together (McMillan & Chavis, 1986). In this regard, it could be considered as an adequate proxy for study cohesion among specific groups.

- *Social sensitivity* Finally, the Italian version of the Reading the Mind in the Eyes test (RME) ($\alpha = 0.605$) (Vellante et al., 2013) has been administered to measure participants' social sensitivity. RME is composed of 36 images of displaying the eyes and the part around. The images show different emotions. Each participant is asked to guess the correct emotion among four different options for every image.

Stimuli

The experiment was carried out using a digitised version of the Raven's Advanced Progressive Matrices (RAPM) set II test, expressly developed for this study.

The full test consists of the resolution of 36 matrix puzzles asking the subject to identify a missing element in a grid to complete a pattern between 8 different options.

The individual task was represented by the assessment of each participant intelligence using the 18 odd-numbered (RAPM).

Instead, the group task consisted of the resolution of the remaining 18, even-numbered matrices from the RAPM test.

The Raven's Advanced Progressive Matrices were chosen as stimuli in this research for three main reasons. First of all, the same test and same partition of matrices in individual and group condition was used by Woolley et al. (2010) in their seminal work in the field of collective intelligence. Moreover, it became part of the *collective intelligence test battery online tool* (Engel et al., 2015) a canonical research instrument to study CI. Secondly, RAPM is one of the most widely-used intelligent test, and it has been found to resist well to cultural effects in its implementation in different environments and cultures (J. Raven, 2000; Rushton, Skuy, & Bons, 2004; Brouwers, Van de Vijver, & Van Hemert, 2009). Finally, the design of Raven's Progressive Matrices was found to maintain its validity as a well-established intelligence test also in its transposition from paper form to digital form (Arce-Ferrer & Guzmán, 2009).

Procedures

The experiment took part within the school places during the class hours and was composed of two phases that lasted over two weeks. During the first phase, participants were asked to fill a self-report survey. In the second phase, that occurred one week after the first, participants completed two trials: an intelligence assessment task, carried out individually, followed by a group task.

In Fig.2.3 is showed the user interface used by participants to complete the individual task.

In both individual and group, phases were introduced a time constraint, giving to the participants, for each part of the trials (i.e., individual and group), 15 minutes.

Two conditions for group task were implemented in the experiment: computer-mediated-communication (CMC) and face-to-face (FtF).

Before the beginning of the experiment, the participants of each class were randomly divided into groups of five members, and each group randomly assigned to one of the two experimental group conditions. At the end of the experiment 57 groups completed the task in FtF condition (230 females, and 55 males, see Fig. 2.4) and 53 groups completed the task in the CMC condition (219 females, and 46 males, see Fig. 2.5).

In the CMC condition, 5 participants for each group were seated at PC stations equipped with a tablet and a pair of earphones. Using the tablet, participants could see the matrices and evaluate the possible answers. To communicate with the other teammate, each member of the group could use a voice chat to reach an agreement

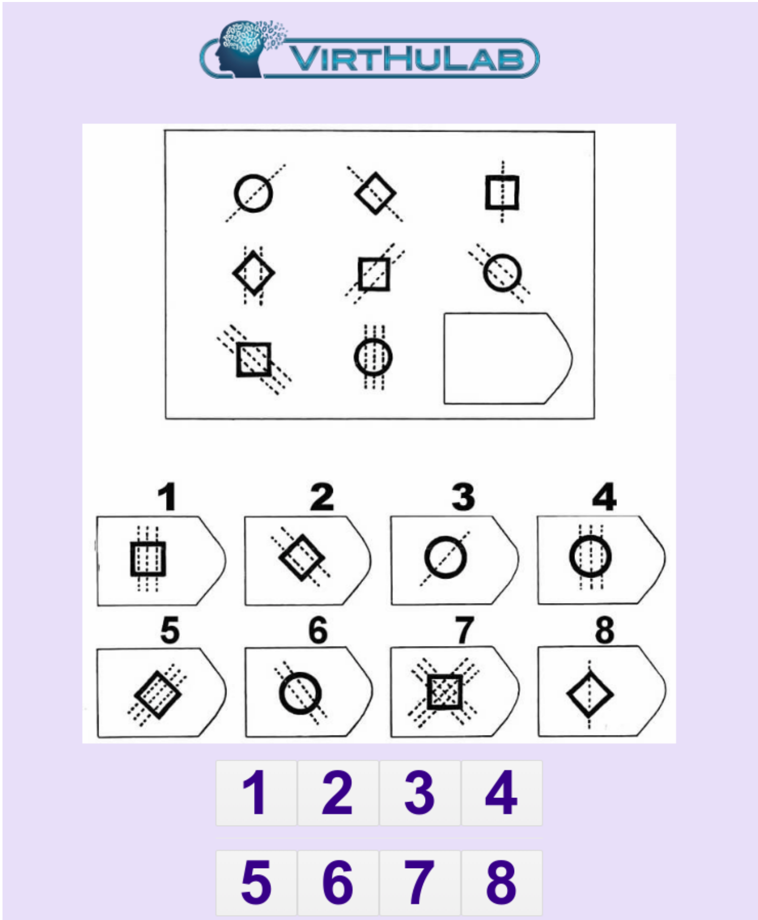

Figure 2.3: User interface of the software used by participants in the individual task.

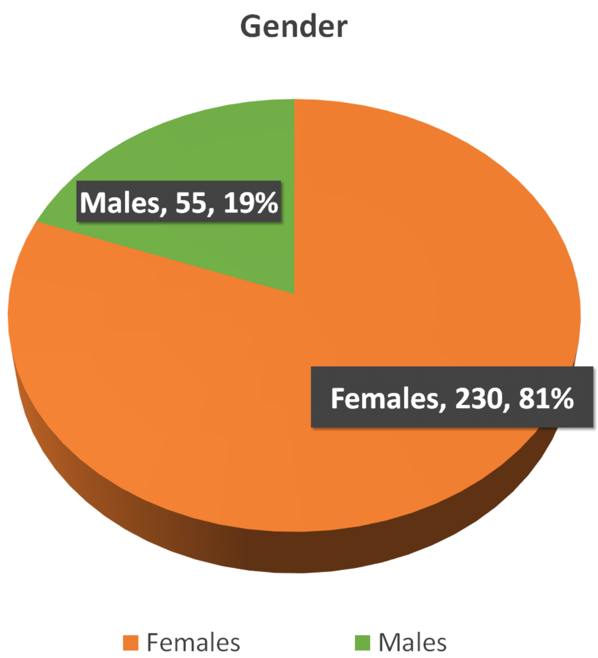

Figure 2.4: Gender distribution of groups in the face-to-face condition.

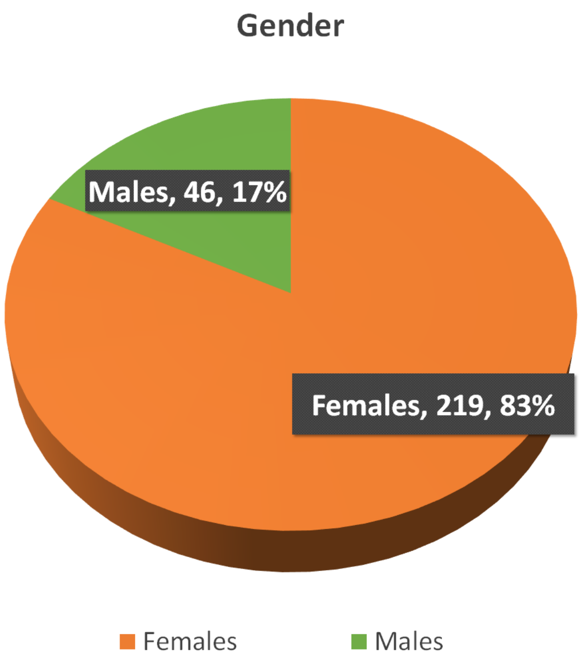

Figure 2.5: Gender distribution of groups in the Computer-mediated-communication condition.

about the response to be given. Each group member used the tablet to select the chosen solution. The group could advance to the next matrix only if at list three out of five members picked the same answer. Otherwise, the system again showed the same matrix to the participants asking them to find a majority agreement. In Fig.2.6 is showed the user interface used by participants to complete the individual task.

In the FtF condition, a group of 5 participants took place around an interactive whiteboard where each matrix were projected to them. Each member of the group could speak with the others to find the correct answer and reach the majority agreement. Once the approval was obtained (i.e., $\frac{3}{5}$ of the team agreed), the group should communicate the choice to the researcher, which annotated it trough a special panel in the software, together with the percentage of agreement in the group (see Fig. 2.7).

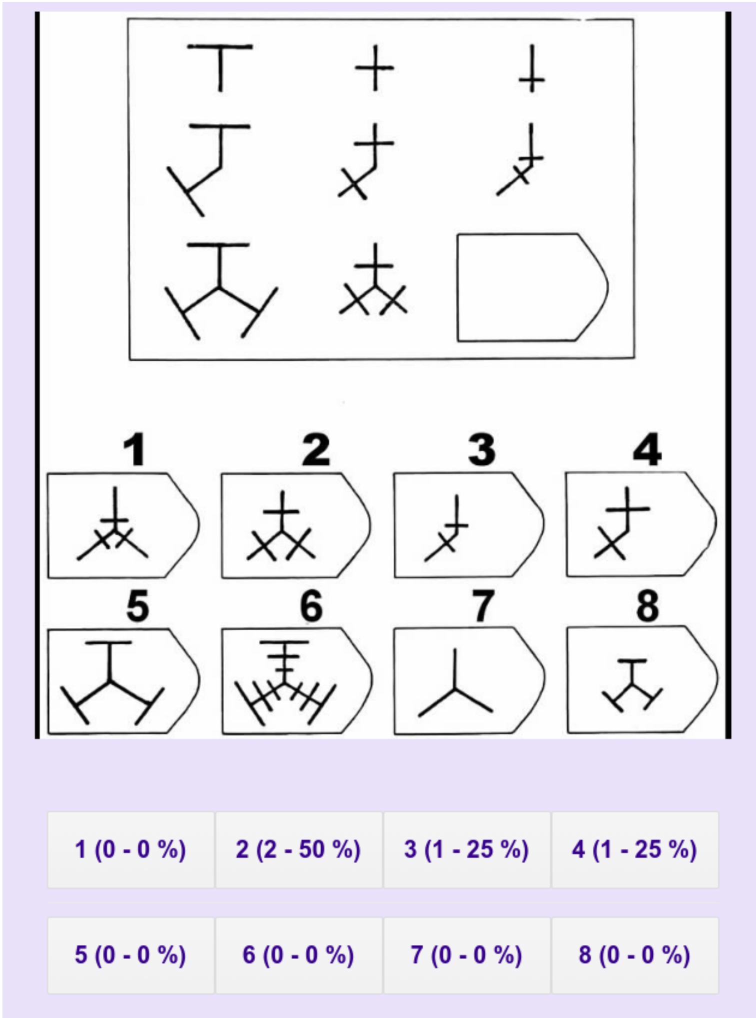

Figure 2.6: User interface of the software used by participants in the CMC group task.

2.2.5 Analysis

After scoring the data obtained from the preliminary surveys, administered to all participants, the analysis of these data was performed. Initially, a first study was performed to describe the statistical characteristics of the sample through the calculation of descriptive statistics and to verify the preconditions necessary for subsequent analyses. In particular, it was observed if the sample had a Gaussian distribution of continuous variables through an asymmetry index (skewness), and the shape of this distribution with respect to the normal by the kurtosis coefficient, which, taking into consideration the 'thickness' of the queues, measures the degree of flattening of the function. The achieved sample size adequate to obtain robust statistical analyses was verified, and the equinumerosity of the subsamples subjected

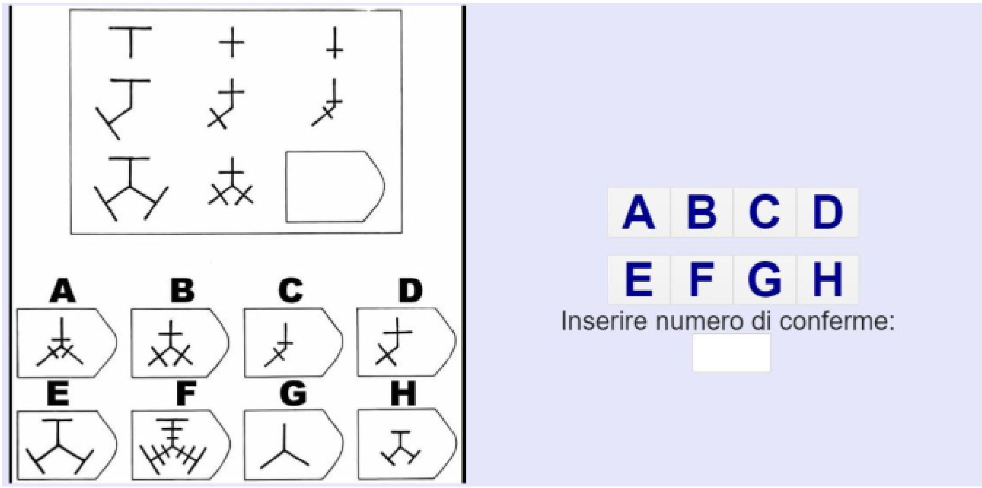

Figure 2.7: User interface of the panel used by the researcher to save the data during the face-to-face group condition.

to comparison for the analyses based on the techniques of Student's t-test. The ratio between the correct answers and the number of matrices faced during the 15 minutes of each task has been used as order parameter, to evaluate and compare the performance of participants and groups during their respectively tasks. This decision has been made according to the theory of measure of CI exposed by Szuba (2001b) (see 1.4), for whom CI must be parametrisied as a probability function overtime to solve problems. To verify the impact of the difficulty of the task in the effectiveness of group problem-solving, it has been taken advantage of the RAPM test design to compute a new variable called: Difficulty of the task. Indeed, the RAPM test was developed to present to subjects more complex problems with the progression of it, namely, the first matrices are significantly easier to solve respect the last. So in this work, every four matrices have been customised to form a level of the variable For the comparison between discrete factors and continuous variables, it was used the Student's t-test and the GLMM. The first was used for two-level factors, such as group condition, while the second for those that include at least three, such as the difficulty of the task. To perform these procedures were used Jamovi (R Core Team, 2018; The jamovi project, 2019), and MatLab (The Mathworks, 2018) statistical analysis software.

2.2.6 Results

As showed in Fig. 2.8, the t-test analysis found no significant difference between the performance achieved by groups that complete the task in CMC and FtF conditions ($t_{(109)} = 1.39, p = 0.166, d = 0.266$), supporting H1.

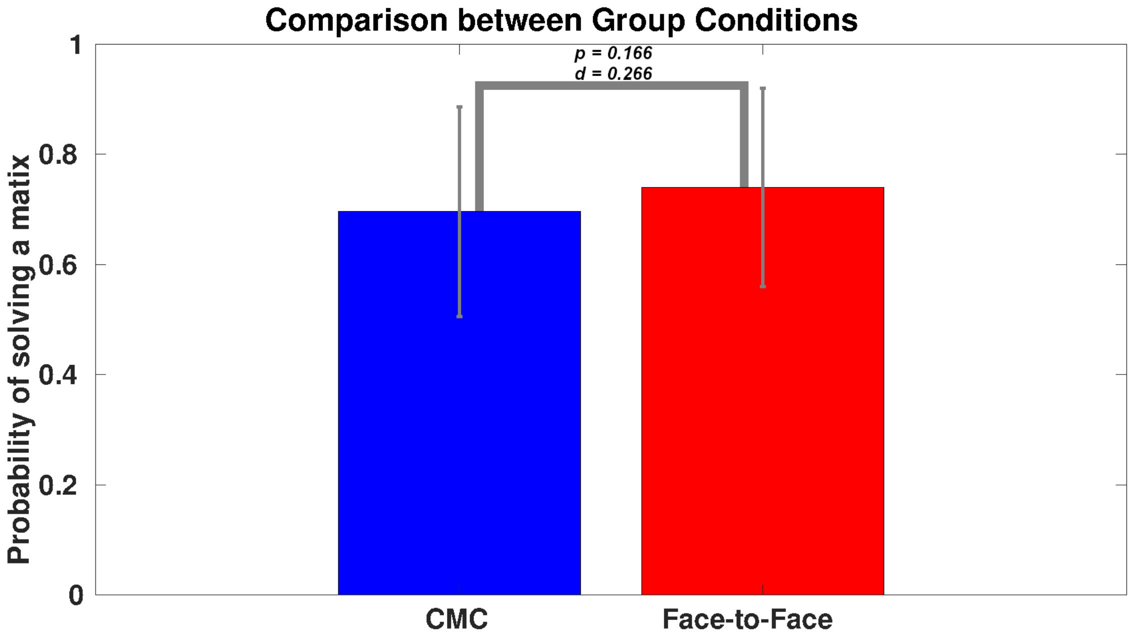

Figure 2.8: Comparison between groups conditions in the experiment

Hypothesis 2, predicting a better performance of groups respect individuals, was also supported. Indeed, as shown in Fig. 2.9 and Fig. 2.10, the groups outperformed its own members whether they completed the task individually in both CMC ($t_{(52)} = 13.184, p < 0.001, d = 1.81$) and FtF condition ($t_{(56)} = 14.674, p < 0.001, d = 1.91$). In detail, results highlight that there is a significant difference between the group probability to choice the correct answer in both CMC ($M = 0.696, SD = 0.19$) and FtF ($M = 0.74, SD = 0.18$), and the average performance of the respective members of these groups in the individual task, namely ($M = 0.392, SD = 0.096$) for those who completed the group task in CMC condition and ($M = 0.41, SD = 0.11$) for those who completed the group task in FtF condition.

Thus, a gain of around 30% in the group outcome was observed, compared to the average members' performance.

For what concerns the second aim of this work, namely, understanding the factors underlying groups' performance in an online environment, the best multivariate model explaining the *collective intelligence* of the groups in the CMC condition is

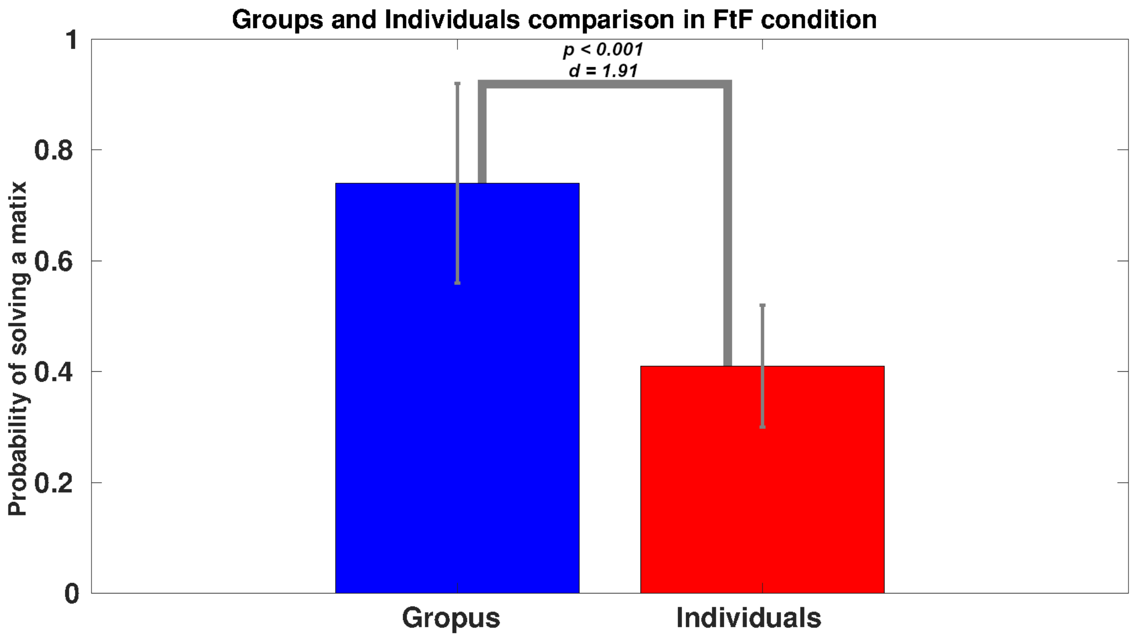

Figure 2.9: Comparison between the performance of groups in facet-to-face condition and the members' performance in the individual task.

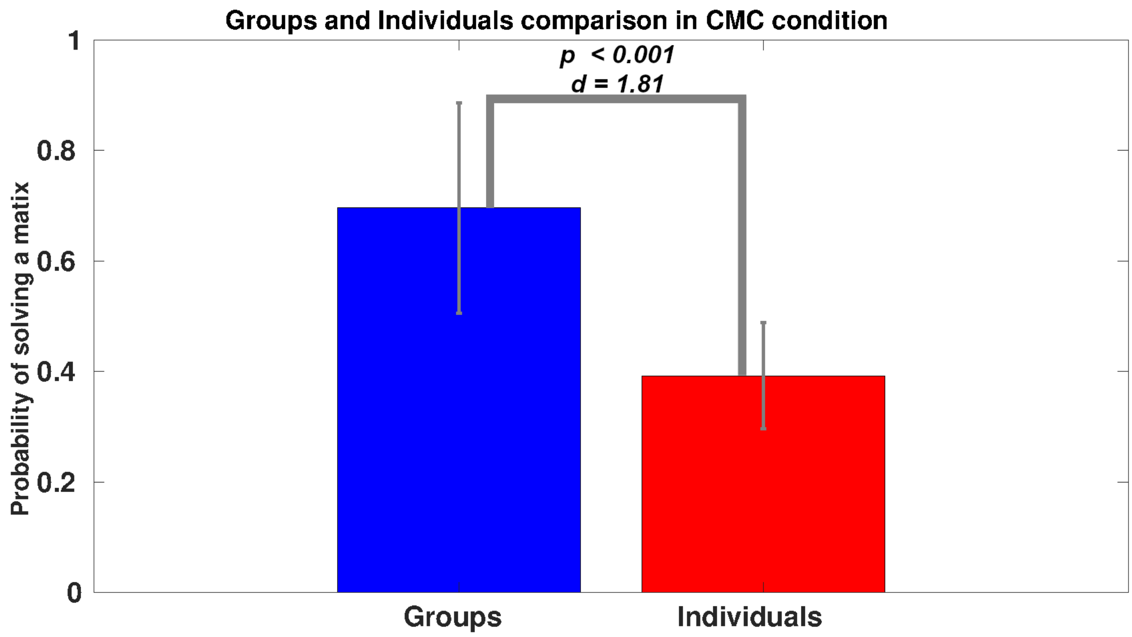

Figure 2.10: Comparison between the performance of groups in computer-mediated-communication condition and the members' performance in the individual task.

presented in Table 2.1.The hypothesis H3 to H4 are supported. First of all, as shown in Table 2.1, it was found that the more a matrix was challenging to be solved, the more the probability of a correct answer was reduced. Secondly, the assumption that cohesion among group members and some participants' personality features would influence the performance of the group was supported. As reported in Table 2.1, the correctness of an individual during the group task appears to be influenced by group, individual, and task features. In particular, the probability to chose the correct answer was higher when the group had a width heterogeneity for what concern social abilities (i.e., group RME standard deviation), as well as when the average members' intelligence and the average members' neuroticism were higher. Finally, the performance was worse in those groups characterised by a large number of communicative exchanges.

Table 2.1: *Generalised Linear Mixed Model. Effect of groups, members, and tasks characteristics on Collective Intelligence*

	Akaike	F	Df-1(2)	Model Precision
Best Model	17,453.795	100.412***	7(3,662)	76.4%
		Fixed Effects		
Factors	**F**	**Df-1(2)**	**Coefficient (β)**	**Student t**
Social abilities heterogeneity of the group	26.761	1(3,662)	0.206	5.173***
Total Conversational Turnover	8.639	1(3,662)	-0.003	-2.939**
Average group members neuroticism	19.356	1(3,662)	0.175	4.400***
Average group members social community perception (SOC)	19.656	1(3,662)	0.091	4.434***
Average group members intelligence	103.351	1(3,662)	4.942	10.166***
Difficulty of the task	262.929	2(3,662)	-2.838	-22.697***
		2(3,662)	-1.220	-13.252***

*** = p. <0.001, ** = p. <0.05

2.2.7 Discussion

The group has the potential to boost and enhance individual abilities. The results of this study confirm the presence of a 30% magnitude of *collective intelligence* factor even within groups of adolescents facing a logical task in computer-mediated communication. In the light of the results reported here, this work suggests a brand new model of *collective intelligence* in online environments within adolescents, taking into account even different dimensions from those previously described in the literature. First of all, the more a task is, the more the group's performance decrease. In particular, for logical tasks (i.e., RAPM), it appears that the number of communicative exchanges reduces the performance of groups. Neuroticism of the members, group cohesion, and average intelligence of group mates enhance the ability of a team to drive their members to the correct solution of a problem in an online environment. Social skills of group' members play a significant role in determining the outcome of a team; indeed, the more a group is characterised by heterogeneity on this dimension, the more it is probable that group achieves excellent performance. Finally, the findings of this research provide an insight addressed to the study of groups' performance in teams of peers who know each other with a previous story of interactions (i.e., classmates), suggesting that the strongest in the social bound perceived by group members' the higher will be the group performance.

2.3 Study 2: moral reasoning

2.3.1 Introduction to study 2

The moral norms namely shared notions about rightness and wrongness (Ruse, 2008), are useful to regulate human social interactions (Lindström, Jangard, Selbing, & Olsson, 2018). Indeed, as well as the other kinds of norms, it is possible to consider the moral rules as schemes of behaviour commonly adopted by a specific society, or group of people, both to decide how to behave and to predict the others intentions. According to Levine e Moreland (1990), all the group norms are shared expectations about how the members' should behave.

The recent literature has shown how moral norms actually rule all the altruistic human behaviours (Lindström et al., 2018). Specifically, it is well-known how people often are willing to implement prosocial behaviours, even though it means to pay a cost to benefit others (i.e., altruistic actions) (Tappin & Capraro, 2018). The evolutionary theories use to explain the selfless behaviours invoking the reciprocity. According to such an assumption, people tend to help their conspecifics because they think paying a cost to benefit them, they will receive help in turn when shall need it (Nowak & Sigmund, 2005; Rand & Nowak, 2013). However, the appeal to reciprocity does not seem enough to explain altruistic behaviours, since it is possible to observe them also in situations in which the opportunities of reciprocity are absent. An example of such cases is the anonymous non-cooperative one-shot games. When people are involved in these kinds of games, they usually cooperate and help the other players more than would be convenient (Camerer, 2008; Capraro, Jordan, & Rand, 2014). Starting from the latter evidence, an alternative explanation to the altruistic behaviour was proposed. According to such interpretation, people help others because they derive utility from performing actions they consider as morally right (DellaVigna, List, & Malmendier, 2012; Krupka & Weber, 2013). This perspective, born in the economic field, is in accordance with some experimental results proposed by the social psychology research, according to which people draw utility from to look at themselves as moral persons (Aquino, Reed, & others, 2002; Dunning, 2007). Starting from this evidence, a recent line of studies advanced the hypothesis that a generalised morality preference drives prosocial behaviour. According to this view, in anonymous, one-shot interactions, people may choose how to behave, evaluating what they perceive as moral rather than aiming to maximise their gain (Capraro & Rand, 2018). At the same time, some authors claim that human beings usually judge others' prosocial behaviours in moral terms (Weber, Kopelman, & Messick, 2004). Thus, morality is involved both in deciding how to behave and in judging others' social actions.

The culture theorists argue that individual morality is a reflection of the norms that regulate the reference social context (Nucci, 2002). Consequently, when people are required to make a moral judgement, of course, the reason also taking into account the moral norms shared in the social context in which they are living. For example, a person can use his morality, and the norms learned in his cultural background, to choose a side in a conflict among other people (Greene & Baron, 2001). Surely, internalised morality is not the only driver of moral judgement. Evidence from studies indicates how several factors can influence this kind of decision. First of all, the individual characteristics seem to play a role in determining moral reasoning outcomes. According to the research, the crucial subjective features affecting moral judgement are: ethnic and cultural background, socio-economical status, educational background, level of religiosity (Hauser, Cushman, Young, Kang-Xing Jin, & Mikhail, 2007), gender (Y. Wang & Chiew, 2010), thinking style (Lombrozo, 2009), need for cognition (Bartels, 2008; Cacioppo, Petty, & Feng Kao, 1984), political orientation (Graham, Haidt, & Nosek, 2009), and sensitivity to reward and punishment (A. B. Moore, Lee, Clark, Conway, & others, 2011; A. B. Moore, Stevens, & Conway, 2011). Secondly, some group phenomena can influence moral reasoning, such as the in-group effect. In more detail, according to a review, in moral dilemmas experiments, when it is necessary to decide who sacrifice, people usually show more difficulty in killing an individual belongs to their in-group rather than a person part of their out-group (Petrinovich, O'Neill, & Jorgensen, 1993).

Although the moral judgement is influenced by some personal features, since the moral norms are group shared notions about rightness and wrongness, of course, a very similar morality will characterise a particular cultural context. In this regard, it is interesting to note how, despite some differences characterises the morality of different cultures, a lot of cross-cultural studies have found some universals in societies moral systems: all the cultures provides punishments for who harm the other members; all the communities show similar values regarding reciprocity and fairness; all the social systems are organised according to hierarchy requirements and the persons decide how to behave by basing on their social status (Haidt & Joseph, 2004; Joyce, 2007). The existence of universal moral rules leaves the space for the hypothesis that they are fundamental to guarantee the evolutive survival of all human societies.

For several years, the research about moral reasoning has been aimed at trying to explain how and where people learn what it is moral and what it isn't. During this period, the cognitive theories of Kohlberg had influenced the psychological research about the development of morality and, generally, all the studies in this field. According to the author's theory about the cognitive-development of moral thought, the social experience would help children construct an increasingly right understanding of justice. In more detail, the theory proposed by Kohlberg is stadial, and it consists of four-level organised in six-stage. Despite expose in-depth Kohlberg's theory fall-outside our purpose, it could be of interest to underling how, during the first stage, the morality is external from the individual. The society has the role in regulating the children behaviour through reinforcement and punishment. In other words, the social group in which the child is inserted to teach him what is moral and what it is not. The development of morality ends with the acquisition of universal moral norms. During this last period, morality is wholly formed, and moral reasoning is based on abstract thinking using universal moral principles (Kohlberg, 1984). The most critical limitation of Kohlberg's theory regards the fact that it assumes that underling adult moral judgements, there is always deliberate and systematic reasoning. However, at the beginning of the twenty-one century, with the introduction of the fMRI in the study of moral reasoning, Greene and colleagues have demonstrated that often people, in moral judgement, use the heuristics rather than the systematic reasoning (Greene & Baron, 2001). The heuristic is a kind of intuitive reasoning that uses few cognitive resources, faster than systematic. The limit of heuristic is that, by using it, people can make a biased or wrong decision (Gigerenzer & Todd, 1999; Simon, 1991; Stanovich & West, 2007; Tversky & Kahneman, 1974)..

Thereby, it could be possible that group moral reasoning results in better decisions respect the individual one because of the group discussion that, triggering the externalisation of the reasoning for sharing the opinion among the members, promote the use of systematic reasoning. In this regard, psychological research has confirmed that individuals can progress to higher levels of cognition result of peer interaction (Azmitia & Montgomery, 1993; Dimant & Bearison, 1991; Kruger & others, 1992), and several empirical studies on general decision-making have shown that groups make better decisions (in terms of performance) than individuals (Keixey & Thibaut, 1954; Lorge & Solomon, 1955; Holloman & Hendrick, 1971). Geil (1998) shows that high levels of understanding of a task are facilitated by social interaction and, therefore, by collaborative reasoning that occurs in group conditions.He suggests that such a phenomenon not happen because of conformity but thanks to the facilitation in understanding the logical aspects of the task provided by the group discussion.

Regarding group effects closely related to moral judgement, Dukerich (1990), in his two studies, investigated the variation of moral reasoning scores in individuals and groups through the assignment of leaders with better or worse moral reasoning. It shows that leadership activity is a critical variable in group performance: groups that had leaders with better moral reasoning improved (study 1) or maintained the same scores (study 2). In addition, according to Dukerich's study (1990), subjects with the lowest pre-scores seem to benefit most from the group experience: individuals tend to have higher reasoning scores after group discussion. Results of a Nichols and Day experiment (1982) also show that the level of development of moral judgement measured by DIT is higher in the interacting group than in the simple average of the group members. There is evidence in the data that individuals with the highest score moved less and, therefore, presumably, influenced group decisions more. Moreover, an important variable to consider is the reasoning level of the individual who has assumed a leadership role in the group (Nichols & Day, 1982). Abdolmohammadi and colleagues (1997) reported results generally consistent with Nichols and Day's, but with a gender effect: group reasoning marginally improves moral reasoning scores, but while for male it improves significantly, for female it decreases, even if not to statistically significant levels. Thus, the group reasoning process significantly improves male students' moral reasoning scores at the expense of female students.

From the studies considered, it can, therefore, be observed that the moral performance of a group is significantly more evident than that of individuals alone and that in groups, there is a higher propensity to morality. As an explanation of that, in the O'Leary study (2007), it is observed that individuals are better prepared to make extreme decisions to act unethically/ethically, while groups tend to opt for the neutral option. Furthermore, according to Mercier (2011) groups are able to converge towards better moral judgements and reasoning can also lead to superior results when the person being judged is not part of the discussion.

2.3.2 Hypothesis

- *H1: Groups will perform better than individuals in logical tasks.*

  According to the most relevant literature on collective intelligence, groups can harness individuals' intelligence, resulting in displaying a greater ability in complex task resolution (Heylighen, 1999; Woolley et al., 2010; Engel et al., 2014, 2015).

- *H2: Groups will outperform individuals in moral reasoning tasks.*

  According to the literature on collective intelligence, that includes the moral problems among the experimental tasks, groups outperform individuals also in these kinds of task (Heylighen, 1999; Woolley et al., 2010; Engel et al., 2014, 2015).

- *H3: There is a weak correlation between the logical-task group performance and the moral reasoning group performance.*

  The literature suggests the existence of different models of CI able to explain the variance of group performance for other type of tasks (Credé & Howardson, 2017; Wildman et al., 2012). Furthermore, Lam (1997) shown how the structure of the task affected the quality of group decisions. In light of the literature, it is possible to suppose that exists a weak correlation between the logical and the moral reasoning performance of the same group.

- *H4: The individuals result more satisfied after taking a moral group decision rather than when they make the same decision alone.*

  According to the most critical findings in the field of moral reasoning and moral decision taking, people morally behave because they derive utility from performing actions they consider as morally right (DellaVigna et al., 2012; Krupka & Weber, 2013). In other words, people draw utility from to look at themselves as moral persons (Aquino et al., 2002; Dunning, 2007). Another line of studies suggests that people, when they are in a group, tend to take more dangerous and difficult decisions rather than they would take alone (Risky Shift phenomenon) (Moscovici & Zavalloni, 1969). In light of the literature, the present work hypothesises that the group promotes satisfaction in difficult moral choices. Indeed, although people prefer to behave morally, to look at themselves as correct persons, the moral dilemma provides only amoral alternatives. Indeed, to kill someone to save more people is a decision not according to the shared norm "don't kill". So, we argue that in the in-group conditions, because of the risky shift phenomenon, people will tend to take more moral but even difficult decisions, and thus they will feel more satisfied.

2.3.3 Sample

For this study, were recruited 245 students from the college level of the University of Psychology in Florence. For technical problems during the experimental phase, 25 subjects were excluded from the study (10.2% of the original sample). The final sample of the research resulted of 220 students (192 Females and 28 Males, see Fig. 2.11). The age of the sample was between 20 and 49 ($M = 21.96$ $SD = 2.55$), and the 95.45% of them had a high-school degree, while the other 4.55% also had a bachelor or a master degree. The participation in this study was completely volunteered, and anyone who wanted to be involved as an experimental subject had to sign an informed consent statement. Furthermore, the study was conducted according to the ethical norms of the Italian Psychological Association (AIP) and received approval from the ethical commission from the University of Florence. The criterion for inclusion in this study was: to have the ability to give consent to participate in the experiment, to have the ability to understand and fluently speak Italian language correctly, and to have a normal or corrected-to-normal vision. All the participants reached the legal age at the time the research was carried out.

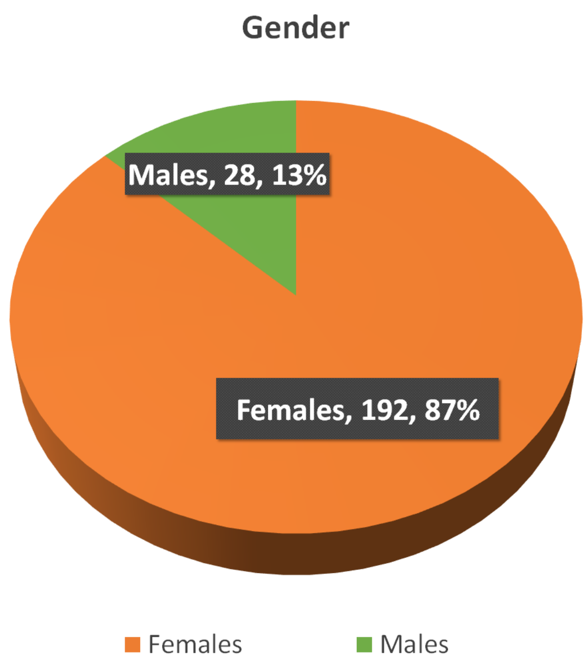

Figure 2.11: Gender distribution in the sample.

2.3.4 Material and methods

Moral stimuli

For the present study were selected as stimuli 36 dilemmas from the 60 non-filler moral dilemmas of the original set developed by (Lotto, Manfrinati, & Sarlo, 2014).

All the stimuli consist of a presentation of a scenario describing a risky situation where lives (i.e., in many cases also the participant life is involved) are in danger. The scenario is followed, after participants complete the reading, by a resolution. After reading the proposed resolution, the participant is asked whether he/she would accept (i.e., *Yes/No*) it.

This specific set of moral dilemmas was chosen because it provides established normative values for five dimensions related to moral judgement: moral acceptability, decision times, emotional salience, and percentages of choices in dilemmas. Moreover, a second reason that has made our selection fall on this particular set of dilemmas is the fact that the validation study of normative values was carried out on a sample of Italian university students (Lotto et al., 2014), namely the same population of the sample used in our research.

The items composing the set used in the experiment presented here for the individual condition were the following original dilemmas: 45, 3, 54, 34, 22, 6, 58, 31, 17, 7, 60, 38, 25, 12, 46, 39, 26, 5; the set used in the group condition resulted in the following original dilemmas: 35, 1, 56, 43, 24, 2, 49, 37, 30, 13, 57, 41, 21, 11, 55, 44, 28, 14.

The above 36 dilemmas were expressly selected to create two sets of 18 different dilemmas that were not dissimilar on the base of the normative values presented by Lotto et al. in their original paper.

Logical stimuli

For the assessments of individual intelligence and ability of the groups in the logical task, it has been used the same experimental procedures described for study 1 (see 2.2.4).

It has been used the Raven's Advanced Progressive Matrices (RAPM) set II test, dividing between odds and even numbers the matrices to create two parallels form of the test to be administrated at individual and group level.

Procedures

The experiment took place in the computer laboratory of the School of Psychology at the University of Florence. To every subject in the group have been assigned a different computer, and all the PC-stations were separated by cardboard walls, in order to guarantee physical isolation. The experiment was divided in the *individual* and *group* conditions. Each experimental session involved five randomly assigned participants, and every condition had a duration of 20 minutes. Firstly, it has been asked several socio-demographic questions to the subjects. Then, in the alone condition, the subjects had to answer first to complete the 18 RAPM and then the set of 18 items that have been selected from the Moral Dilemmas of Lotto et al. (2014). Finally, in the group phase, participants had to complete the other set of 18 RAPM and then the remaining 18 chosen dilemmas, with the difference that they were able to communicate with each other through a headphone and a microphone. Before the beginning of the group phase, it has been explained to participants that they had to respond to the items individually, but they also should try to reach an agreement. At the end of each dilemma, in both alone and group conditions, the subjects had to answer individually to a questionnaire investigating their satisfaction, on a 5-point Likert scale, regarding the choice they just made in a dilemma.

2.3.5 Analysis

Initially, a first study was performed to describe the statistical characteristics of the sample through the calculation of descriptive statistics and to verify the preconditions necessary for subsequent analyses. In particular, it was observed if the sample had a Gaussian distribution of continuous variables through an asymmetry index (skewness), and the shape of this distribution with respect to the normal by the kurtosis coefficient, which, taking into consideration the 'thickness' of the queues, measures the degree of flattening of the function. The achieved sample size adequate to obtain robust statistical analyses was verified, and the equinumerosity of the subsamples subjected to comparison for the analyses based on the techniques of Student's t-test. The ratio between the correct answers and the number of matrices faced during the 20 minutes of each task has been used as order parameter for the scoring of logical tasks in both individual and group condition. For the moral dilemmas, correctness was scored following normative values of the original scale of Lotto et al. (2014) regarding the decision of subjects and groups. In more detail, a decision has been considered correct if it was the same answer expressed by the normative group. Then it has been computed the ratio between the right moral choices and the number of dilemmas faced during the 20 minutes. This decision has been made according to the theory of measure of CI exposed by Szuba (2001b) (see 1.4), for whom CI must be parametrised as a probability function overtime to solve problems. For the comparison between two-level factors, such as group condition, it was used the Student's test. To perform these procedures were used Jamovi (R Core Team, 2018; The jamovi project, 2019) and MatLab (The Mathworks, 2018) statistical analysis software.

2.3.6 Results

First of all, below are presented the results of the analysis implemented to compare the two parallel forms of the test administrated in the individual and group conditions.

Table 2.2: Comparison between individual and group version of the test. No significant difference was found for any dimension.

	M		Student t	Sig.
	Alone	Group		
Affirmative responses %	45.60	46.58	-0.118	0.907
Decision Time (ms)	9276.11	9628.22	-0.911	0.369
Moral acceptability $(0-7)$	2.49	2.59	-0.828	0.413
Valence $(1-9)$	5.43	5.49	-0.601	0.552
Arousal $(1-9)$	2.75	2.80	-0.669	0.508

Regarding the normative values for each of the variables characterising the items

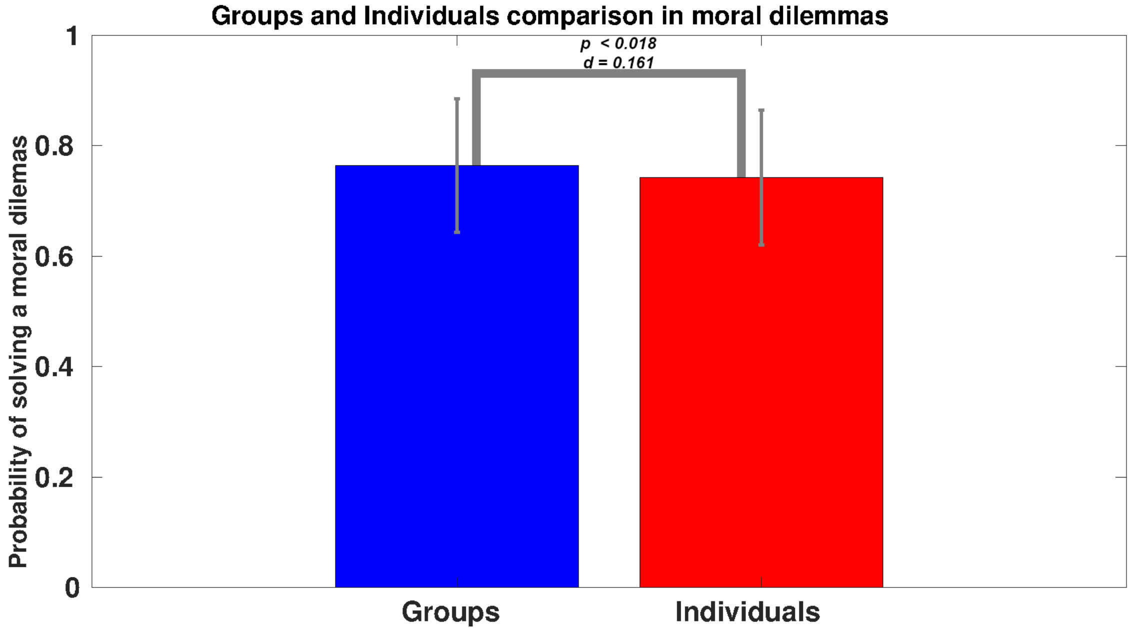

Figure 2.12: Paired-Samples t-Test results for the comparison of morality scores of individuals and groups.

of the original scale, table 2.2 shows that no significant difference has been found in the two parallel forms of the test used in this study. Thus, the items that composed the tasks for the individual and group condition do not differ significantly in the percentage of an affirmative response, decision time, moral acceptability, valence, and arousal.

In Fig. 2.12 it is showed the comparison between individual choices and group choices during the resolution of moral dilemmas. The paired-sample t-test analysis shows how groups significantly performed better than the teammates whether they completed the task individually ($t_{(219)} = 2.39, p = 0.018$). In detail, results highlight that there is a significant difference between the groups probability to choose the correct answer in terms of moral choice ($M = 0.764, SD = 0.121$), and the average performance of the respective members of these groups in the individual task, namely ($M = 0.740, SD = 0.122$). However, as indicated by the effect size analysis ($d = 0.161$), these effects appear to be small in the sample considered here.

To evaluate the degree of improvement or deterioration of moral reasoning of individuals in groups, it has been computed a delta between scores of groups and individuals. Correlations presented in Table 2.3 show a negative and significantly ($r = -0630, p < 0.01$) correlation between the scores of groups and those of team-

Table 2.3: Correlation between the difference among the performance in moral choices in the two conditions and the performance of the individuals and the groups

Variable	M	SD	1
1. Delta moral Ratio groups-individuals	0.025	0.15	
2. Ratio moral scores individuals	0.74	0.12	-0.630**

*** = p <0.001; ** = p <0.01; * = p <0.05

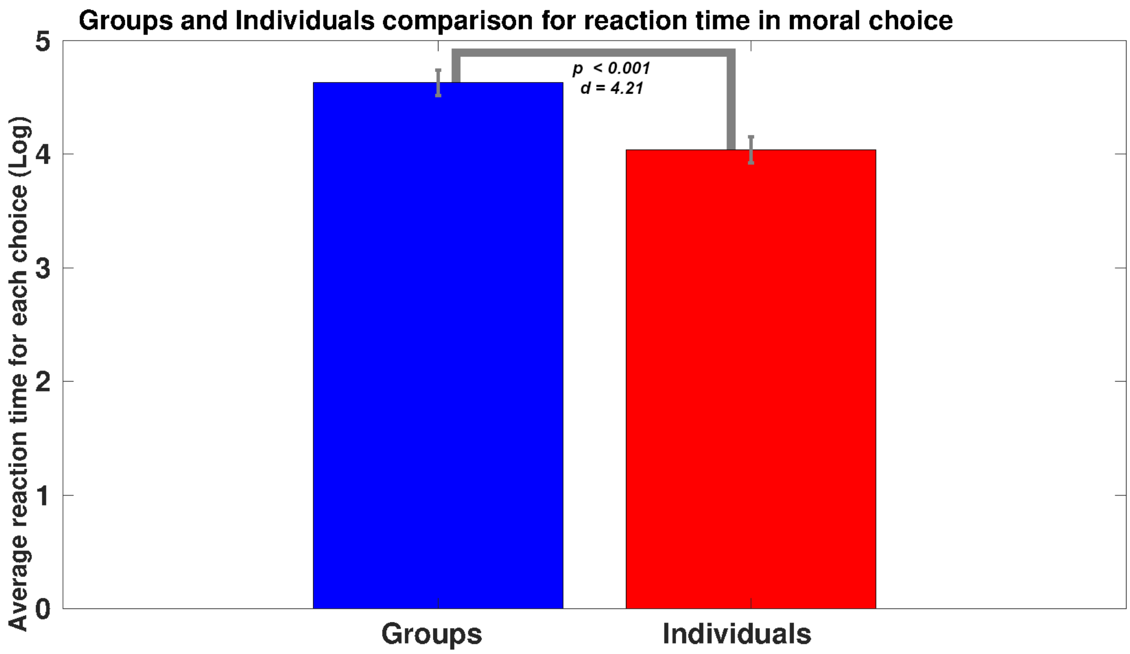

Figure 2.13: Paired-Samples t-Test results for the comparison of the reaction time for choices of individuals and groups

mates in the individual task. In sum, the more a group performed well, the less its members obtained high score in moral task in individual condition.

To verify if groups used more time than single individuals to reach the decision during the resolution of moral dilemmas, a paired-sample t-test analysis has been conducted between reaction times (on logarithmic base) observed for each choice in the two conditions (Fig. 2.13). The analysis found that groups ($M = 4.63, SD = 0.111$) took significantly ($t_{(219)} = 62.05, p < 0.001$) more time respect individuals ($M = 4.04, SD = 0.115$). Effect size analysis shows that this effect is considerably large ($d = 4.21$).

Whit the aim to verify if moral choices in groups where perceived by subject causing more satisfaction respect the ones taken individually a paired-sample t-test

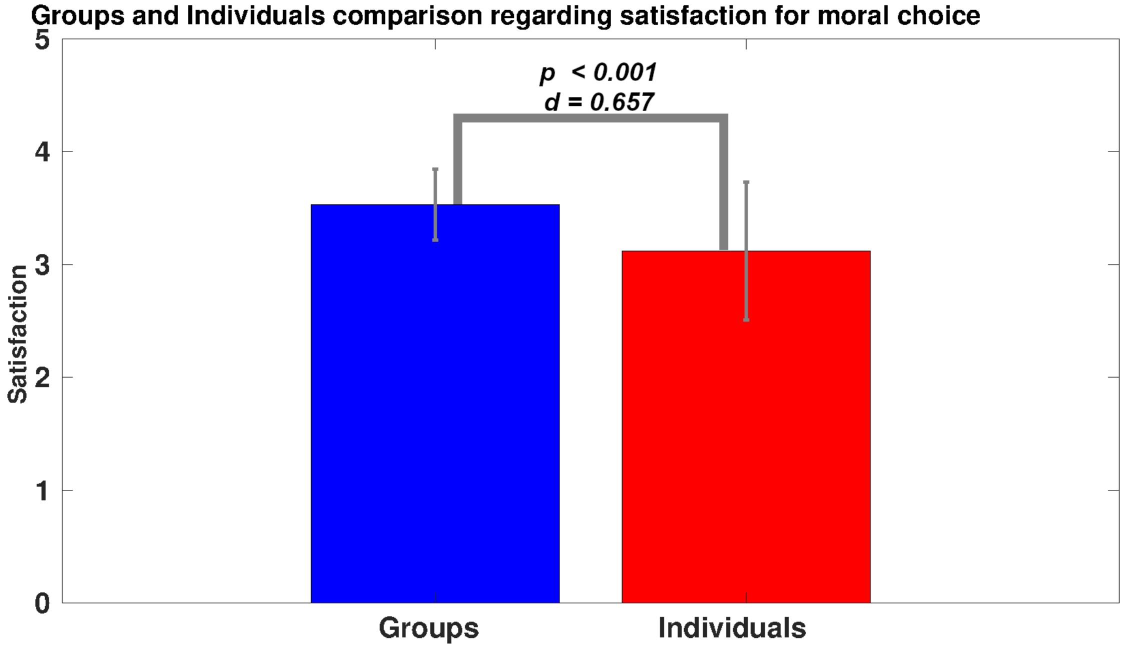

Figure 2.14: Paired-Samples t-Test results for the comparison of subject in the individual and group condition

was conducted. In Fig. 2.14 are reported the results of this analysis. Participants in groups ($M = 3.53, SD = 0.315$) significantly ($t_{(219)} = 9.74, p < 0.001$) perceived more satisfyingly the process occurred that lead to the choice respect the one experienced individually ($M = 3.4, SD = 0.613$). Effect size analysis shows that this effect is medium to large ($d = 0.657$).

In Fig. 2.15 it is showed the comparison between groups ability in logical task and individuals ones. The paired-sample t-test analysis shows how groups significantly performed better than the teammates whether they completed the task individually ($t_{(219)} = 16.1, p < 0.001$). In detail, results highlight that there is a significant difference between the groups probability to choose the correct answer to complete the patterns in the matrices ($M = 0.865, SD = 0.114$), and the average performance of the respective members of these groups in the individual task ($M = 0.654, SD = 0.168$). Effect size analysis shows these effects to be large ($d = 1.09$).

To investigate if participants in groups scored better or worst respect the individual condition in the resolution of logical tasks, it has been computed a delta score between the performance of groups and individuals. Correlation presented in Fig. 2.4 show a negative and significantly ($r = -0809, p < 0.001$) correlation between the scores of groups and those of teammates in the individual task. In sum, the

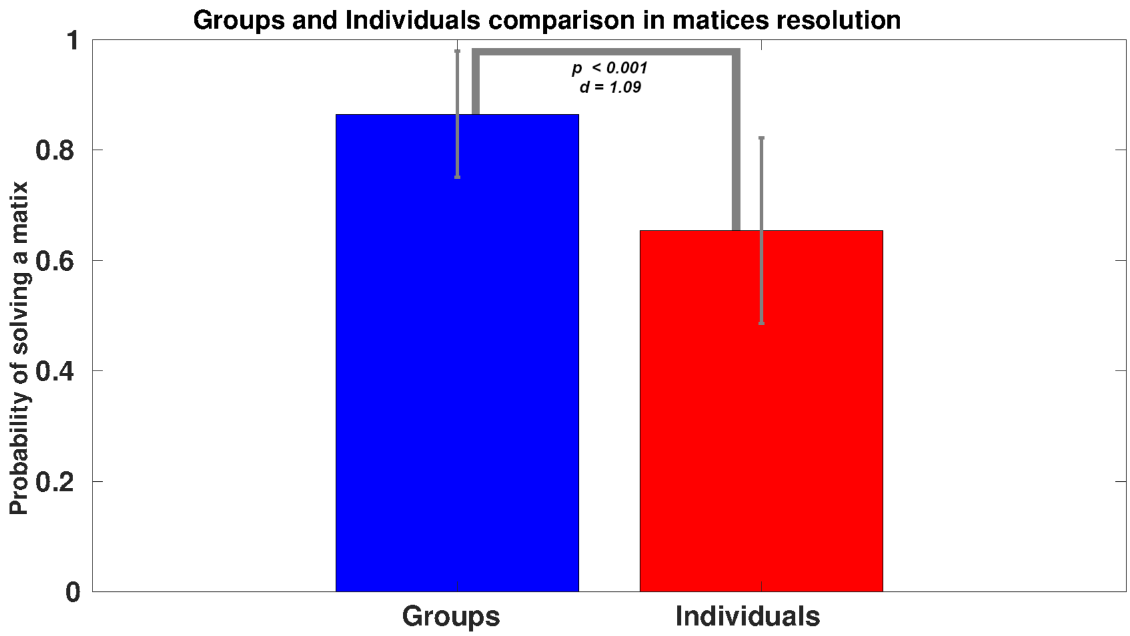

Figure 2.15: Paired-Samples t-Test results for the comparison of matrices resolution scores of individuals and groups.

more a group performed well, the less its members obtained good results in terms of moral score in the individual condition.

Table 2.4: Correlation between the difference among the performance in logical task in the two conditions and the performance of the individuals and the groups

Variable	**M**	**SD**	**1**
1. Delta Ratio Raven groups-individuals	0.211	0.193	
2. Ratio Raven individuals	0.654	0.168	-0.809***

*** = p <0.001; ** = p <0.01; * = p <0.05

To evaluate the degree of the relationship between logical and moral task Correlation presented in Fig. 2.5 shows a positive but weak relationship between the scores of groups in the moral task and the scores of the same groups in logical tasks ($r = 0.228, p < 0.001$). Moreover, a significant but also weak correlation ($r = 0.214, p < 0.001$) was found between moral scores in groups and individual conditions. No other significant relationships between condition and tasks have been found.

Table 2.5: Correlation among experimental tasks (logical and moral) and conditions (individuals and groups)

Correlation Matrix **Pearson correlations**				
	Ratio scores Raven individuals	Ratio scores Raven groups	Ratio scores Moral individuals	Ratio scores Moral groups
Ratio scores Raven individuals	-			
Ratio scores Raven groups		-		
Ratio scores Moral individuals			-	
Ratio scores Moral groups		0.228***	0.214***	-

*** = p <0.001; ** = p <0.01; * = p <0.05

2.3.7 Discussion

The present study aimed to verify if collective intelligence could emerge during the resolution of moral dilemmas, implying that groups reached better decisions than individuals taken alone. The results obtained supported this claim. Indeed, groups appear to produce better decisions in moral decision-making compared to the ones showed by individuals alone. Indeed, computing scoring as a higher adherence to social norms available in the culture, groups have been found to make decisions more similar to the normative population. However, the effect of simple choices appears to be quite small. Nevertheless, group moral decisions have been found able to significantly increase the satisfaction of teammates that found themselves to be engaged in the resolutions of moral dilemmas. Analysing the difference of reaction time occurred to perform moral choices in groups and alone conditions it emerged that groups significantly took more time to decide the answer to give. The second aim of this study was to analyse the relationship between the opposite kind of task from pure decision-making to certain problem-solving tasks, according to the continuum proposed by Laughlin (1980). The results comparing the same groups resolving puzzle matrices and deciding upon moral dilemmas showed that a significant correlation exists between the two tasks, but it is quite small.

Chapter 3

Conclusions and implications

3.1 Conclusions

The study of group dynamics has always been at the centre of numerous fields of research in many different disciplines to understand the processes that regulate social interaction that brings to the achievement of important objectives.

Cooperative and collaborative actions have been investigated in both natural and artificial systems. Social insects, like ants that are able to communicate with their conspecifics and find the shortest path during foraging activities, have been one of the first subject studied by scholars regarding their abilities to coordinate themselves and show intelligent behaviours that go beyond the single capabilities of single agents (Bonabeau et al., 1997, 1999; Karaboga & Akay, 2009). The study of natural environments allowed the isolation of some components that permit simple agents to achieve results impossible alone and commute them in an artificial system that also improves the ability of human beings (Rosenberg & Willcox, 2019). The tendency to act in groups and appeal to collaborative efforts has been observed to have been a successfully evolutive mechanism developed by many species to survive, including human beings.

Human beings are one of the species that display cooperative and collaborative behaviours on a broader way (Boyd & Richerson, 2005; Hill, 2002). Groups have been usually found to display higher abilities to respect single teammates working alone (Shaw, 1932; McGrath, 1984; Laughlin, 1999; Mesmer-Magnus, 2009). This emergent property of groups to be able to show higher intelligence of their members has been called collective intelligence (Heylighen, 1999). It has been argued that this property of groups derives from the interaction that occurs among the different representations of the problems in each member and (Heylighen, 1999).

Recent research on collective intelligence, not only showed how the group could boost the performance of the single individuals but also how one of the effects deriving by interacting in collective environments is the promotion of the increase of knowledge among group members (Gadeceau & Training, 2015; Aggarwal et al., 2019). Nowadays, the principles of collective intelligence have been applied to diverse areas within the educational context, and a common characteristic of all the applications is that their success depends on the capacity to activate the intelligence of all members of the working group. The educational models of collective intelligence are based on the proof of the efficacy of peer learning and start from the evidence that the students can create useful knowledge for the students themselves. The creation of knowledge by the students is the result of active methodologies where the students participate in their own process of learning. The collective intelligence is an emergent property of groups, not reducible to the simple sum of its members' intelligence. The general factor able to explain the group's performance seems to be the result of the complex interaction among many factors, such as the member characteristics, the group structure that regulate collective behaviour (Woolley et al., 2015), the context in which the group work (J. B. Barlow & Dennis, 2016b), the average of members' individual intelligence (Bates & Gupta, 2017) and the structure (Credé & Howardson, 2017; Lam, 1997), and the complexity of the problem that it has to solve (Guazzini et al., 2019, 2015; C. Moore & Tenbrunsel, 2014).

Recent studies had proven empirical measurability of collective intelligence starting from the evidence that three variables can explain the 43% of the variance of the group performance: the numerosity of females who are part of the group, the variance in the conversation turnover, and the group members social sensitivity (Woolley et al., 2010). In this study, the Social Abilities were measured by the Reading the Mind in the Eyes Test, a survey built to measure people skills in the Theory of Mind. The same researchers have found a negligible relationship between collective intelligence and group members' individual intelligence (IQ). More recent research in the field, replicating the experiments that discovered the results exposed above, not found any relationship between collective intelligence and the three variables part of the model of collective intelligence but found a strong link between group performance and the average of the group members' IQ (Bates & Gupta, 2017). Both of the studies exposed above found a significant and robust correlation between members' IQ and their social sensitivity. A very recent meta-analysis analysing 13 different steadies about collective intelligence while found no support for a single factor model underling the phenomenon suggesting instead a three-factorial multilevel interpretation involving idea generation, conflict resolution, and execution of tasks (Graf & Barlow, 2019)

Although the literature results in the field of the models of collective intelligence are still elusive, it is clear how the predisposition to form groups has been one of the factors that lead human beings to successfully compete in the struggle for survival during their evolution (Perc et al., 2017). This attitude allowed humans to overcome complex problems, otherwise impossible for a single individual (Forsyth, 2006).

So, finding a model of collective intelligence useful to predict the group performance in all the variety of group-based tasks would be of particular interest in the educational and organisational context. Indeed, that model could be used to divide the class groups and working groups group into small effectiveness teams during the activities of peer learning.

The aim of this work was to deeply investigate the relationship between bottom-up processes, namely, individual characteristics, and top-down processes, namely contextual and task-related characteristics could influence the emergence of collective intelligence in groups of people. To do this has been presented two studies exploring the collective intelligence phenomenon in young high school and university students.

The first study, conducted with 550 high-school students, aimed to verify the emergence of collective intelligence in adolescents groups of peers involved in the resolution of logical problems (Raven's Advanced Progressive Matrices). The findings support the hypothesis that collective intelligent behaviours also emerge in youngsters that work with known people, regardless of the type of communication used (i.e., computer-mediated-communication end face-to-face). Indeed, groups outperformed individual teammates' performance by 30%. The aim of this study was also to find the characteristics that better allow young student to perform well in online environments. The model obtained, analysing interaction in computer-mediated-communication, in this experiment, showed how group performance was predicted by six variables. The first was the social sensitivity heterogeneity of groups, namely the more was higher the diversity in social ability, the more groups performed well. The second variables were the total conversational turnover, namely the more the teammates discussed during group activity, the less they performed. These findings could be related to the fact that people who know well, like schoolmates, could engage in relational conversation rather than conversation oriented to problem-solving, and this could have undermined the performance in logical tasks. The third variable was the average group members' social community perception, namely the more members perceived to be part of the groups, the more they performed. This could be seen as a proxy of motivation acting in collective intelligence; indeed, the more teammates perceived the importance of the group, the more they were engaged in solving the problem. The fourth variables were the average group members neuroticism, namely the more this personality trait was high among group members better the groups performed. This could be explained by the role of computer-mediated-communication that reduced the amount of social information to elaborate and permitted the participant to spent their cognitive resources in problem-solving. The fifth variable in the model was the average members' intelligence, namely the higher was individual scores of teammates in the single task, the more the groups performed well. This finding could have been found due to the logical kind of task used in the experiment that could be particularly susceptible to individuals characteristics. Finally, the last variable was the difficulty of the task; namely, the more a problem was complex, the less it could be solved by groups.

The second study presented in this essay was conducted on 220 university students involved in the resolution of logical tasks and moral dilemmas in groups of 5 individuals. The aim of this study was to verify the emergence of collective intelligence in task of different typology and the relation among them. The findings of this study showed how collective intelligence emerges in logical tasks as well as in moral tasks. From the results of this research, it is possible to argue that collective intelligence emerges in groups but with different forms and effects. Indeed, while in logical tasks, collective intelligence seems to increase the accuracy and ability of groups to find better solutions, in moral dilemmas, it looks to help to guide individuals to more satisfying choices leading them to behave in a more moral and normative way. This latter results could be caused by the inevitable, group discussion that necessitate collaborative decision-making. Taken this last finding, it is possible to assume that this discussion that occurs in groups leads members to activate deliberative and systematic reasoning respect the intuitive one that could be implemented alone (Greene & Baron, 2001). Finally, the findings exposed here failed to provide substantial evidence for the existence of a single variable accountable for the performance of groups in tasks of different domains because the correlation between logical and moral tasks was found very weak.

Some limitations could be found in this work. First of all, it has not been possible to gather data about speaking variance in the first study, namely the actual number of speaking turns of each participant. This variables, could have represented a precious source of information given the school peers context involved, moreover it represent nowadays a parameters evaluated in the vast majority of experiments in collective intelligence (e.g., Woolley et al., 2010; Engel et al., 2015; Aggarwal et al., 2019). Secondly, participants involved in both studies represent convenient samples, and both of them are heavily unbalanced in favour of the females' numbers. Future works may try to take into consideration these limits to improve the presented researches.

3.2 Implications and future perspectives

The resolution of many issues in modern society is related to the implementation of collective decisions, and social collective actions such as reducing social inequalities (Ariely, Bracha, & Meier, 2009; Gneezy, Keenan, & Gneezy, 2014), and contrasting anthropogenic climate change (Markowitz & Shariff, 2012; Milinski, Semmann, Krambeck, & Marotzke, 2006; Woods, Coen, & Fernández, 2018). At the same time we live in a society increasingly permeated by the use of new technologies connected to the Internet in various areas of everyday life. These rapid changes allow the exploitation of ways of working and participating among people that have never been possible before. The challenge for Social Sciences, from a positivist point of view, is to integrate these technologies and structural changes in human relationships and communications to achieve goals that until now were impossible. The construct of collective intelligence presents itself as one of the most important allies to researchers in the Social Sciences since it allows the exploitation of the incredible potential made available by modern ICT in terms of the connection between people both in terms of speed and number.

Collective intelligence could prove to be an effective factor around which to structure more modern and effective forms of online education and collaborative learning platforms (MOOCs) based on sharing ideas and objectives between users. Finally, collective intelligence, by exploiting its effectiveness online, is a powerful factor to be used to foster school inclusion and access to education even for the most disadvantaged people (both in economic or health terms).

The research described in this essay provides some possible perspectives in the direction of exploiting collective intelligence especially in the field of educational online. The findings from the first study suggest that collective intelligence principles could also be harnessed in online educational contexts. Indeed, the results presented indicate that small working groups could obtain better results than individuals working alone and also through computer-mediated-communication. This could guide the design of the future implementation of e-learning platforms and school laboratories, even considering literature findings that link collective intelligence with increasing learning abilities.

Instead, the second study described here shade light on the importance of improving research in both bottom-up processes and top-down processes to design and understand the phenomenon of collective intelligence. Indeed, it appears that not only individual characteristics my affect the emergence of collective intelligent behaviour but also the one related to specific features of the tasks. Moreover, the findings of this study suggest that also dimensions such as moral reasoning took advantage of the processes triggered by collective intelligence. Thus, might be useful testing and implementing group decision-making mechanisms guided by collective intelligence even in community contexts where individuals are called to make decisions, not about facts or problems with a secure outcome but where the component of uncertainty is predominant. Collective intelligence would, therefore, seems to be one of the main aspects that should be applied to modern group decision-making contexts taking place at the societal and organisational level, such as processes of participatory democracy and active citizenship.

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