Crowd science projects: how leaders' emotions shape online participation

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Résumé :

Pour résoudre de grands problèmes scientifiques, les scientifiques ont de plus en plus tendance à collaborer avec des communautés en ligne via des plateformes de *crowd-science.* Malheureusement, il n'est pas toujours facile de garantir un niveau de participation élevé. Cette recherche vise à comprendre comment les émotions exprimées par les leaders influencent le niveau de participation dans les projets de *crowd-science*. Cette recherche est réalisée à partir d'un projet de *crowd-science*, Polymath, réunissant des mathématiciens (professionnels ou non) afin de résoudre des grandes conjectures jusqu'ici non-résolues. La théorie EASI (Emotion As a Social Information) est mobilisée pour analyser comment les émotions des leaders du projet Polymath se propagent aux autres membres de la communauté. Le programme d'analyse LIWC est utilisé pour mesurer la dimension affective (ex., % de mots positifs/négatifs) des messages électroniques que s'échangent les participants. A partir d'une analyse quantitative multi-niveaux, nos résultats montrent que les émotions positives des leaders se propagent par contagion aux membres du projet. Ces émotions positives augmentent la participation qualitative et quantitative de la communauté. Par ailleurs, conformément aux prédictions de la théorie EASI, nos résultats montrent que les émotions négatives des leaders ne se propagent pas contagion mais par inférence cognitive. Par ailleurs, nous montrons que les émotions négatives des leaders entraînent une diminution de la participation. Cette étude étend le périmètre d'action de la théorie EASI, nos résultats contribuent une meilleure compréhension de l'impact du leadership et des dynamiques collectives dans les plateformes en ligne.

Mots-clés: Leadership, émotion, crowd science, participation, communauté en ligne

Summary :

To resolve complex scientific challenges, scientists increasingly collaborate with online communities. However, maintaining a high level of participation in crowd-science projects is difficult. This research aims to understand how leaders' expressions of emotions can enhance voluntary participation in crowd-science projects. This research is based on Polymath, a crowd-science project where professional and non-professional mathematicians collaborate to solve very difficult problems. Drawing on Emotion As a Social Information (EASI) Theory, we explore the influence of leaders' emotions on subsequent participation with a multi-level count analysis. We find that (1) leaders' positive emotions have a positive relationship through participants' positive emotions with participation's quantity and quality, and (2) leaders' negative emotions have a negative relationship through participants' cognitive complexity. By examining the role of leaders' affective dimension in crowd-science projects, our research brings theoretical contributions to crowd science and online community leadership literatures. Our research also extends the EASI theory through the exploration of its mechanisms, through its application in text-based communication contexts and highlights the importance of emotional intensity. Limits and future directions are discussed.
Keywords : Leadership, emotion, crowd science, participation, online communities

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1.INTRODUCTION

To tackle complex scientific problems, a growing number of scientists collaborate with online communities of volunteers (Cooper et al., 2010; Franzoni & Sauermann, 2014; Nielsen, 2020; Raddick et al., 2013; Sauermann et al., 2020; Scheliga et al., 2016). Crowd science projects enable professional scientists to access a large pool of professional and non-professional scientists with diverse skills at a low cost (Franzoni et al., 2021). Such diversity of knowledge may increase the speed at which the most complex scientific problems can be solved (Jeppesen & Lakhani, 2010). One emblematic crowd science project is *Polymath* initiated by Prof. Timothy Gowers, a mathematician professor at the University of Cambridge (Gowers & Nielsen, 2009). On 27th January 2009, Timothy Gowers posted an unsolved mathematical problem in his blog and asked his readers to share their ideas and thoughts. Seven weeks later, 40 participants successfully solved the problem (Polymath, 2012a).

However, maintaining a high level of participation in crowd science projects remains difficult (Ali-Khan et al., 2017; Franzoni & Sauermann, 2014; Nov et al., 2011; Sauermann & Franzoni, 2015). The majority of participants in crowd science projects are typically not paid for their work (Lyons & Zhang, 2019; Scheliga et al., 2016). Many of these volunteers do not actively contribute but only follow discussions and provide sporadic contributions (Amichai-Hamburger et al., 2016; Sun et al., 2014). The participation in online communities seems to follow the famous "90-9-1" rule, which states that 90% of the participants only read messages, 9% of the participants edit a few messages and 1% of the participants actively create new content (Arthur, 2006). Sauermann and Franzoni's study (2015) analyze the rate of participation in seven crowd science projects of the Zooniverse platform. Again, their findings indicate that most of the participants do not actively contribute and that the turnover is very high. Few participants produce more than 70% of the total content while most of the other contribute only once and with little effort (Franzoni & Sauermann, 2014; Sauermann & Franzoni, 2015). In a study of crowd science project at NASA, Nov et al. (2011) explain that volunteers' motivations may decrease over time because the projects' outputs are not immediate and because participants do not always receive recognitions for their own contribution.

To maintain voluntary participation in crowd science projects, the role of leaders has been underscored. Empirical studies point out that crowd science projects' leaders are usually the investigators who set-up the scientific objectives, organize the experiments, synthetize the latest results and coordinate the work to keep the projects on track (Franzoni et al., 2021; Franzoni & Sauermann, 2014; Sauermann & Franzoni, 2015). The crucial role of leaders has been also noted in other type of voluntary-based online projects such as open source software communities (Faraj et al., 2015; Li et al., 2012). Leaders in such online communities often provide remarkable technical contributions which inspire and motivate other participants (Fleming & Waguespack, 2007).

Most prior studies investigating how leaders support participation in online communities revolve around structural, social and technical issues (Ball, 2014; Franzoni & Sauermann, 2014; Sauermann & Franzoni, 2015), however, less is known about how much leaders' emotions could influence the participation of crowd science projects' members. Prior research show that leaders often use affective words in their communication with online communities (Huffaker, 2010; Johnson et al., 2015). Emotions often drive the engagement and involvement of members of online communities (Bateman et al., 2010; Garcia et al., 2016). Still, we know little about how the emotional tone of leaders' messages affect members' participation in crowd science project. In particular, we do not know whether leaders should express positive and/or negative emotions to enhance members' participation in crowd science projects. Prior research remain inconclusive. In a series of laboratory experiments, Venus et al. (2013) find that people are more likely to support and share the visions of leaders who communicate their messages with positive emotions. In contrast, other research emphasizes that participants of online communities tend to react and reply more to leaders' negative messages (Chmiel et al., 2011; Lee & van Dolen, 2015).

To frame our investigation, we leverage theorizing on Emotion As a Social Information (EASI), a theory about the interpersonal effects of emotions (Van Kleef, 2009). This theory holds that the emotional expressions of one person often influence other individuals through two mechanisms. Emotional expressions can lead to affective reactions in others through *emotional contagion*. For instance, a leader who expresses happiness often make their employees happier (Barsade, 2002). Emotional expressions can also be interpreted by others as meaningful information – a second mechanism known as *cognitive inferences*. For instance, when leaders express negative emotions, employees can interpret them as signals that the current situation is not convenient and requires adjustments (Van Kleef, Anastasopoulou, et al., 2010).

Building on EASI theory and leadership literature, this research hypothesizes that (1) leaders' positive emotions have a positive relationship through emotional contagion with participation's quantity and quality, while (2) leaders' negative emotions have a negative relationship through participants' cognitive inferences. We test these hypotheses through an analysis of four successful Polymath projects. Polymath is a relevant empirical setting for this research for several reasons. First, creating and maintaining a high level of participation in Polymath is challenging. In Polymath projects, the participation cannot be easily increased by decomposing problems into smaller ones (Franzoni & Sauermann, 2014; Giuri et al., 2010; Sauermann & Franzoni, 2015). The complexity and non-modularity of Polymath projects require a certain level of expertise in mathematics, which is a major obstacle for participation.

Also, Polymath addresses problems that have never been solved, the chances of success are extremely low, which may easily discourage participants. Second, Polymath leaders play a critical role in supporting participation (Ball, 2014; Cranshaw & Kittur, 2011; Franzoni & Sauermann, 2014; Kloumann et al., 2016). Prior studies show that Polymath leaders extensively communicate with participants (Franzoni et al., 2021). The presence of Polymath leaders is crucial to keep a global focus and head for the resolution of the problem at hand. Finally, solving complicated mathematical problems induces a large spectrum of emotions, from negative emotions of frustration to more positive emotions of “Aha” moments (McLeod, 1988; McLeod & Adams, 2012; Muis et al., 2015). We thus expect that the emotional tone of the leaders may have a significant influence on the participants’ motivation to contribute.

To investigate Polymath leaders’ emotions , the emotional content of the leaders’ posts is measured with the Linguistic Inquiry and Word Count (LIWC) text application (Pennebaker et al., 2015). Based on multilevel count analysis, the effect of leaders’ emotions on subsequent participation (i.e., number of participants per day and participation quality) is analysed. Our findings show that leaders’ positive emotions have a positive relationship through participants’ positive emotions with participation’s quantity and quality, while leaders’ negative emotions have a negative relationship through participants’ cognitive complexity.

This study has three main theoretical implications. First, this work has implications for research in organizational aspects of crowd-science, particularly on the motivational aspects of crowd participation (Franzoni et al., 2021). Our results show that leaders’ emotional expressions represent another important driver of crowd-science participation. Second, this study provides implications for research on the micro-foundations of open innovation in science (Beck et al., 2020). In particular, findings show that the affective dimension of leaders deserves consideration since it significantly influences participation. Third, our research extends our understanding of the contagion-interpretation model of EASI theory (Van Kleef, 2009; van Knippenberg & van Kleef, 2016) explores the medium of text-based communication contexts and emphasizes the importance of emotional intensity. Limits and future directions are discussed.

2.LITERATURE REVIEW

2.1. CROWD SCIENCE: VOLUNTEERS' ONLINE PARTICIPATION

A growing amount of scientific research is done in an open manner (Sauermann and Franzoni, 2015). Crowd science appears as a form of open organizing where '*participation in a project is open to a wide base of potential contributors, intermediate inputs such as data or problem solving algorithms are made openly available' (p.1)* (Franzoni & Sauermann, 2014). For instance, Franzoni & Sauermann (2014) and Scheliga et al (2016) show that most of crowd science projects are compliant with open participation and open access features. There is often no formal restriction in terms of participation. In most of crowd science projects, the intermediate and dinal inputs are openly shared. The success of crowd science projects critically depends on the degree to which participants provide continuous inputs (Sauermann and Franzoni, 2015).

Extant literature demonstrates that participants often join a crowd science project because the topic itself is of interest to them (Brossard et al., 2005). In contrast to crowdsourcing, where monetary prizes are common, crowd science projects heavily depend on volunteers whom do not receive any pecuniary rewards (Friesike & Schildhauer, 2015). Raddick et al (2013) analyze participants' motivation in the crowd science project - Galaxy Zoo, an astronomy project that invites people to assist in the classification of large numbers of galaxies. While the authors note that crowds' motivation is multifaceted, the most common motivation was an intrinsic interest in the topic of astronomy. Brabham (2010) pointed out that some participants have a broader interest in just being part of a community. Prior work also assumes that participants increase their understanding about the process of science. Though, as Sauermann and Franzoni (2015) indicated, the authors often participate only once and their effort is limited. The issue of maintaining motivation online persists (Riesch & Potter, 2014). Additionally, the more complex and ill-structured is the task, the more contributors need to interact and build on each other's inputs, limiting the number of contributors who can work on a given project at the same time (Franzoni & Sauermann, 2014).

Prior work on online communities and open science indicated the importance of leadership and coordination in managing online participation and maintaining the engagement levels (Faraj et al., 2015; Li et al., 2012). Leaders' role in supporting participation in online communities revolves around structural, social and technical issues (Franzoni & Sauermann, 2014; Kokshagina, 2019; Scheliga et al., 2016), however, less is known about how much leaders' emotions contribute to supporting online participation.

2.2. Theoretical background: the Emotion As a Social Information Theory (EASI) theory

Human motivation and behaviour are influenced by primary drivers such as emotions, which influence social interactions (Van Kleef, 2009; van Knippenberg & van Kleef, 2016). Prior research has shown that leaders can use their emotional expressions as a powerful mean of influence to enhance the performance of followers to the best of their abilities (Van Kleef, 2016). For instance, prior studies demonstrated that leaders' expressions of emotions can trigger analytical performance, creative performance and creative task engagement of their followers (Van Kleef, Anastasopoulou, et al., 2010; Visser et al., 2013). Leaders' emotional expressions can also affect followers' perceptions of the leader, which would in turn influence their motivation to accomplish the task and their engagement to attain a particular goal.

The EASI (Emotion As a Social Information Theory) (Van Kleef, 2009) provides theoretical arguments about how leaders' emotional expressions could enhance participation in crowd science project. The EASI theory aims at better predicting how emotions expressed by one person can have an influence on the behaviour of others. This theory has been applied to explain the social effects of emotions in several social activities such as group dynamics (Dezecache et al., 2013), conflict and negotiation (Sinaceur et al., 2013) or consumer behaviour (Cheshin et al., 2018). Recently, the domain of leadership has received some attention (Van Kleef, 2016). Following the EASI theory (Van Kleef, 2009), the contagion-interpretation model predicts that leaders' emotional expressions influence followers through two paths: affective reactions (contagion) and/or cognitive inferences (interpretation) (Van Kleef, 2009; van Knippenberg & van Kleef, 2016). On one hand, participants may feel the emotions that leaders express, through *emotional contagion*, and such emotions can influence their behaviour. For instance, Visser et al. (2013) show that leaders' expression of happiness increases the followers' feelings of happiness, which triggers their cognitive flexibility, and in turn, increase employees' creativity. Similarly, these authors showed that followers could also experience the sadness of leaders, which positively impact their analytical performance. On the other hand, leaders do not always influence followers' own emotions, in contrast, followers can consider leaders' emotions as information. For instance, leaders' emotions may be interpreted as a signal for a change: when leaders give feedback on followers' ideas with anger, the followers may interpret such negative emotional expression as a signal that their creative performance is not satisfactory and need to be improved (Van Kleef, Anastasopoulou, et al., 2010).

2.3. Hypotheses Development

Prior literature has already explored the effect of positive and negative emotions on team performance (Van Kleef, 2009, 2016). Findings show that these effects are very context dependant.

Prior studies show that followers often appreciate and are motivated by leaders who display positive emotions (Johnson, 2009; Rubin et al., 2005). For instance, the overall quality of leader-member exchanges tends to increase with the rise of leaders' positive emotions (Day & Crain, 1992). Also, leaders who express positive emotions are usually perceived as more charismatic (Awamleh & Gardner, 1999; Bono & Ilies, 2006; Damen et al., 2008). Moreover, prior research shows that transformational leaders tend to express positive emotions, which enhance goal commitment (Chi et al., 2011). Transformational leaders are found to be particularly good at inspiring others and motivating collaborative behaviours (Van Kleef, 2016). Transformational leaders allow for self-direction and for volunteers to challenge and stimulate each other's perspectives (Li et al., 2012). Volunteers will then be more motivated to adopt a pro-social behaviour, which will increase collaboration (George & Bettenhausen, 1990). Furthermore, leaders' positive emotional expressions enable volunteers to adopt better group coordination in their exchanges to resolve the problem at hand (Sy et al., 2005), which leads to better team performance (Chi et al., 2011; Gaddis et al., 2004; George, 1995). To summarize, prior research suggest that leaders who express positive emotions would be more likely to energize their followers. In the context of our research, we thus hypothesize (see Figure 1):

Hypothesis 1a: Online participation in crowd science projects increases with the rise of leaders' expression of positive emotions.

When leaders express positive emotions, participants can experience positive affective reactions trough emotional contagion (Van Kleef, 2016; van Knippenberg & van Kleef, 2016). Barsade (2002) showed that when people work together, their emotions tend to converge over time. Positive emotional expressions are also contagious even when people express emotions through text-based communication (Cheshin et al., 2011; Van Kleef et al., 2015). Participants can then experience the leaders' positive emotions, which broaden their thought-action repertoire, enhance their creativity (Baas et al., 2008; Visser et al., 2013) and allow for exploration (Fredrickson & Branigan, 2005). Furthermore, prior research shows that people who are confronted to leaders expressing positive emotions will tend to react positively and like the leader (Van Kleef, 2009). When leaders express positive emotions, participants tend to like them more (Van Kleef et al., 2009), their relationship with the leaders is better (Day & Crain, 1992), and leaders are seen as more charismatic (Bono & Ilies, 2006). Therefore, leaders' expression of positive emotions make participants more engaged to create favourable outcomes (Staw et al., 1994)

Hypothesis 1b: The effect of leaders' expression of emotions on online participation is mediated by participants' emotional contagion.

In contrast, empirical evidence suggests that leaders' negative emotions, but expressed with low intensity only, can also be beneficial. Research shows that leaders' expressions of negative emotions may give signals of honesty and credibility to volunteers, as well as clues of trustworthiness (Bucy, 2000). For instance, leaders expressing negative emotions such as anger may appear as decisive and competent leaders (Anderson & Kilduff, 2009; Lord et al., 1986; Tiedens, 2001; Van Kleef, 2016). When they express negative emotions and behave assertively, leaders express dominance, are perceived as more competent and obtain higher levels of influence in groups (Anderson & Kilduff, 2009). Leaders' negative emotional expressions may then trigger volunteers' motivation to work on the problem at hand, and to provide more effort and persistence in the task (Sy et al., 2005). Also, leaders' feedback formulated with an angry tone are found to enhance individual creativity and team's analytical performance (Van Kleef et al., 2009; Van Kleef, Anastasopoulou, et al., 2010), since they signal to participants that they have to correct their behaviour to increase their performance.

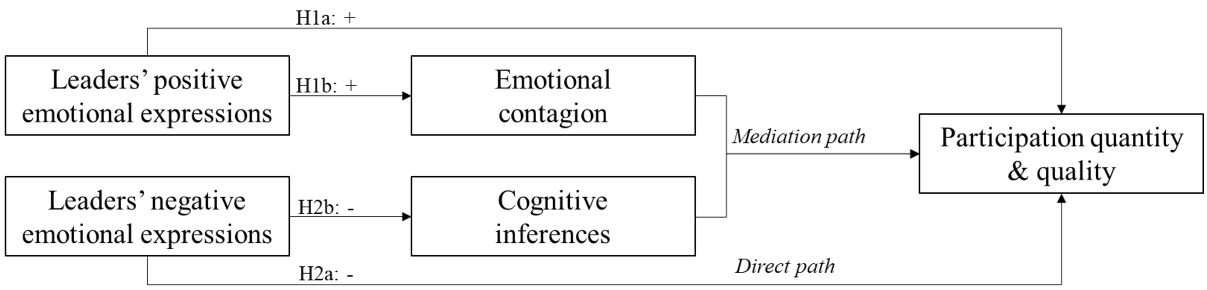
However, expressing too much negative emotions can also be perceived as inappropriate by the followers (Van Kleef et al., 2012). When negative emotions are perceived as inappropriate, followers can become unwilling to perform organizational citizenship behaviour (Koning & Van Kleef, 2015). Moreover, in text-based communication such as in crowd science project, participants often perceive the intensity of negative emotions higher than it is in reality (negativity bias) (Parkinson, 2008), and negative emotions are more quickly judged as inappropriate. The reason is that contrary to face-to-face interactions, text-based communication does not allow for non-verbal cues (face, tone of voice, gestures), which offers nuances of negative emotions (Ekman, 2009; Ekman et al., 1976; Parkinson, 2008). Text-based communication is quite restrictive and requires leaders to express negative emotions in a more explicit manner (Parkinson, 2008). Contrary to face-to-face interactions. In summary, according to prior studies, it may be expected that volunteers in crowd science projects should be more motivated to participate if leaders express moderately negative emotions. We thus hypothesize:

Hypothesis 2a: Online participation in crowd-science projects is higher with intermediate levels of leaders' expressing negative emotions (i.e., inverted U-shape relationship).

When leaders express too much negative emotional expressions, participants can cognitively infer such emotional expressions as a signal of inappropriateness, and as a result provide less effort (Van Kleef et al., 2012) In their recent review, Van Kleef & Côté (2021) showed that negative emotional intensity can have curvilinear effects on perceived appropriateness across diverse domains: excessive emotional intensity will be seen as inappropriate and then will be detrimental to outcomes. For instance, the Dual Threshold Model of anger (Geddes & Callister, 2007) suggests that there is a threshold of intensity of anger, after which excessive expressions of anger will be perceived as inappropriate by volunteers, and therefore reduce their willingness to cooperate. In cooperative settings such as a crowd-science project, such excess of leaders' negative emotional expressions can be inferred as inappropriate, which will reduce cooperativeness among participants and increase tendencies to move against the teammates (Van Kleef, De Dreu, et al., 2010). In other words, participants would reduce theirs effort in elaborating posts to solve the scientific problem at hand, i.e. reduce the cognitive complexity of their posts, and in the end, reduce the quality and quantity of participation.

Hypothesis 2b: The inverted U-shape effect of leaders' negative emotional expressions on online participation is mediated by participants' cognitive inferences.

Figure 1. Conceptual model



3. METHOD

3.1. SAMPLE

This research is based on the empirical analysis of Polymath, a crowd science project initiated by mathematicians, which aims at solving extremely difficult mathematics problems (Ball, 2014). Our sample includes 345 individuals involved in four successful Polymath projects (Polymath 1, Polymath 4, Polymath 5 and Polymath 8) (see Appendix A for more details). These projects were judged as successful and resulted in peer-reviewed publications (Castryck et al., 2014; Polymath, 2010, 2012a, 2012b, 2014; Tao, 2017). Polymath 1 aimed at finding a new combinatorial proof to the density version of the Hales–Jewett theorem. Polymath 4 was related to deterministic methods to find primes. Polymath 5 aimed at solving the Erdős discrepancy problem. Polymath 8 was about improving the bounds for small gaps between primes. These four projects lasted from 20 months to 70 months. They comprised between 600 and 2600 online posts and attracted between 44 and 110 participants (see appendix A).

To identify leaders in each Polymath project, we followed the definition of Cranshaw & Kittur, (2011), i.e., we considered their academic reputation and the number of posts published (see Appendices A & B). Besides, in their theory of leadership in self-managing virtual teams, Eseryel et al. (2021) showed that individuals perceived as online leaders are the ones who contribute the most to the task at hand. Based on the quantity of posts written, we identified then two leaders for each Polymath project, these leaders having contributed significantly more than the Top 3 contributor and the rest of the participants (see Appendix C). For instance, Terrence Tao and Timothy Gowers are two well-known mathematicians with a strong academic reputation, as they have won both a medal fields (e.g. the equivalent of the Noble Prize for mathematical disciplines).

3.2. STATISTICAL APPROACH

Following Cranshaw & Kittur (2011), we structured the data per day so that we could explore the impact of emotional tone expressed by leaders during the previous active (i.e., day D-1), on other members' participation the next day (i.e., Day D). To explore this relationship, models in table 3 explore the link between the control variables, the emotional tone (i.e., positive or negative) from leaders and participants and online participation from volunteers.

3.3. VARIABLES DEFINITION

3.3.1. Independent variable

This research uses the Linguistic Inquiry and Word Count (LIWC) text analysis application (Pennebaker et al., 2007) to investigate the emotional tone of the online messages exchanged by the leaders and the other participants. LIWC consists of dictionaries of over 2,300 words categorized by independent judges into 68 psychological and cognitive dimensions. We use then the following variables as independent variables: *Positive Leaders Day D-1* and *Negative Leaders Day D-1*, i.e., the average daily scores of positive and negative emotional tone respectively, for Day D-1 from the leaders.

3.3.2. Dependent variable

The variable to measure the quantity of participation, named *Participation Quantity*[1], is the number of participants on Day D, while the one to measure the quality of participation, named *Participation Quality*, is the average number of cognitive words (e.g., cause, know, ought) written on Day D by volunteers. Such words are recognized using LIWC and represent true markers of cognitive activity and processes (Pennebaker et al., 2015).

3.3.3. Mediators

This research considers also mediating variables, the first being *Emotional contagion Day D*, i.e., the score of positive emotional tone for Day D from the participants. The second mediating variable is *Cognitive Inferences Day D*, measured through the cognitive complexity of participants' posts. Participants provide less cognitive effort and complexity in the problem at hand when they have cognitive inferences about the leaders. Cognitive complexity was measured as the average number of differentiation words (but, without, exclude) for Day D, since people using differentiation words tend to express complex thoughts, differentiate between multiple competing solutions, and are attempting to establish distinctions (Pennebaker et al., 2015; Tausczik & Pennebaker, 2010).

3.3.4. Control variables

To control for alternative explanations, we used *Positive Participants Day D-1* and *Negative Participants Day D-1*, i.e., the average daily scores of positive and negative emotional tone respectively, for Day D-1 from the volunteers. We also considered variables linked to the amount of participants' activity from the previous active day. Indeed, prior research shows that in open-science platform, comments from leaders and contributors spur activity on the next day (Cranshaw & Kittur, 2011). We considered then the number of posts on the previous active day *Number posts Leaders Day D-1* and *Number posts Participants Day D-1*, respectively from the leaders and the participants. Also, online participation might

[1] Leaders were not counted in this variable, only the volunteers.

be influenced by participants anonymity (Spears et al., 2007; Spears & Lea, 1994). The variable *Number anonymous Day D-1* controls this aspect: a value of 1 is assigned when the participant is anonymous, 0 otherwise. Furthermore, the fact that day D may be a weekend day may explain a decline of participation. The dummy variable *Weekend* controls for such effect with 1 when day D is a weekend, and with 0 otherwise. Also, the variables *Timeline* and *Timeline²* control for the possibility that the participation increases at the beginning of the project and decreases naturally with time. Tables 1 & 2 report how the different variables were coded and provide descriptive statistics for the variables.

Table 1 - Variables of the models

	Variable name	**Definition**		**Coding of the variable**
Dependent	*Participation Quantity*	Number of unique participants on Day D		Number of contributors who published at least one post on day D
	Participation Quality	Score of cognitive words on Day D	from the participants	
Mediators	*Emotional contagion Day D*	Score of positive emotional tone on Day D	from the participants	
	Cognitive Inferences Day D	Score of cognitive complexity on Day D		Aggregation per active day (average) of the scores given by LIWC on each post
Independent	*Positive Leaders Day D-1*	Score of positive emotional tone on Day D-1	from the leaders	
	Negative Leaders Day D-1	Score of negative emotional tone on Day D-1		
Control	*Positive Participants Day D-1*	Score of positive emotional tone on Day D-1	from the participants	
	Negative Participants Day D-1	Score of negative emotional tone on Day D-1		
	Number posts Leaders Day D-1	Number of posts on Day D-1	from the leaders	Aggregation per active day of the

Number posts Participants Day D-1	from the participants	number of posts published
Number Anonymous Day D-1	Number of anonymous contributors on Day D-1	Aggregation per active day of the number of anonymous contributors
Weekend	Score informing if Day D is a weekend or not.	Dummy variable: 1 if Day D is a weekend day, 0 otherwise.
Timeline	Chronology of active days	Number of active days since the beginning of the project

Table 2 – Variable descriptive statistics

Variable	Descriptive statistics				Correlation															
	Mean	S.D.	Min	Max	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Participation Quantity	2.27	2.14	0.00	12.00	1.00															
2. Participation Quality	14.07	6.77	0.00	36.36	0.34***	1.00														
3. Emotional contagion Day D	2.77	3.11	0.00	37.69	0.11**	0.23***	1.00													
4. Cognitive inferences Day D	3.49	2.38	0.00	14.29	0.30***	0.75***	0.09*	1.00												
5. Positive Leaders Day D-1	2.31	2.53	0.00	25.00	0.08*	0.03	0.08*	0.00	1.00											
6. Positive Participants Day D-1	2.77	3.11	0.00	37.69	0.04	0.06	0.13***	0.06	0.10**	1.00										
7. Negative Leaders Day D-1	0.90	1.24	0.00	12.50	0.11**	-0.01	0.04	0.00	0.19***	0.05	1.00									
8. Negative Leaders Day D-1²	2.34	8.95	0.00	156.25	-0.03	-0.01	0.05	-0.07	0.13***	0.03	0.83***	1.00								
9. Negative Participants Day D-1	1.09	1.63	0.00	25.00	0.04	0.00	-0.03	0.01	-0.06	-0.02	0.04	0.02	1.00							
10. Negative Participants Day D-1²	3.83	25.76	0.00	625.00	-0.05	-0.08*	-0.04	-0.05	-0.06	-0.05	-0.02	-0.00	0.81***	1.00						
11. Number Posts Leaders Day D-1	3.92	5.47	0.00	39.00	0.55***	0.13***	0.03	0.14***	0.17***	0.03	0.20***	-0.01	0.04	-0.05	1.00					
12. Number Posts Participants Day D-1	5.11	6.15	0.00	44.00	0.63***	0.17***	0.06	0.16***	0.09*	0.07	0.11**	-0.03	0.08*	-0.04	0.67***	1.00				
13. Number Anonymous Day D	0.86	1.64	0.00	19.00	0.35***	0.06	0.09*	0.06	0.07	0.11**	0.05	-0.00	0.04	-0.03	0.35***	0.56***	1.00			
14. Weekend	0.28	0.45	0.00	1.00	-0.05	-0.01	-0.02	0.02	0.02	-0.06	0.04	0.06	0.04	0.01	0.00	-0.02	-0.09*	1.00		
15. Timeline	382.50	220.69	1.00	764.00	-0.23***	-0.10**	0.16***	-0.08*	0.24***	0.16***	0.01	0.05	-0.04	0.05	-0.20***	-0.25***	0.01	0.02	1.00	
16. Timeline²	114.81	80.31	1.00	301.00	-0.36***	-0.10**	-0.01	-0.08*	0.09*	-0.01	-0.06	-0.01	0.00	0.08*	-0.27***	-0.36***	-0.18***	-0.00	0.72***	1.00

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4. ESTIMATION & RESULTS

Because of the limited nature of the variable (it is a count variable) and the fact that we examined four different Polymath projects, a non-linear estimator was employed, i.e. multilevel count analysis. Since the data had a nested nature, we used multilevel structural equation modelling in Mplus 8 (Muthén & Muthén, 2017). The level corresponding to the Polymath projects explains 15% of the variance in the results that will follow. To check on a potential multicollinearity issue, we calculated the variance inflation factor (VIF) in each model and found a maximum of 2.16, and we checked from the correlation matrix that for every independent variable, each correlation factor with the dependant variables is strictly inferior to 0.7, demonstrating no issues on that side.

Table 3 Control variables, positive and negative emotional tones from leaders and participants

	Controls only: Model 1	**Main effects Added: Model 2**
	Estimate	Estimate
Participation Quantity		
Negative participants Day D-1	.069	.054
Negative participants Day D-1^2	-.008*	-.006*
Positive participants Day D-1	.010	.000
Number posts Participants Day D-1	.043***	.038***
Number posts Leaders Day D-1	.025***	.020***
Anonymous Day D-1	-.008	-.007
Weekend	-.092**	-.106***
Timeline	-.022	-.034
Timeline^2	.000	.000
Participation Quality		
Negative participants Day D-1	.576***	.383***
Negative participants Day D-1^2	-.046***	-.028***
Positive participants Day D-1	.087	-.031
Number posts Participants Day D-1	.171*	.062
Number posts Leaders Day D-1	.039*	.026
Anonymous Day D-1	-.157	-.112**
Weekend	-.199	-.526
Timeline	.282	.084
Timeline^2	-.011	-.004
Emotional contagion Day D		
Negative participants Day D-1	-.051	-.045
Negative participants Day D-1^2	.000	.000

Positive participants Day D-1	.122***	.115***
Number posts Participants Day D-1	.015	.017
Number posts Leaders Day D-1	-.002	-.005
Anonymous Day D-1	.128*	.122*
Weekend	-.036	-.071
Timeline	.063	.065
Timeline²	-.002	-.002
Cognitive inferences Day D		
Negative participants Day D-1	.125*	.123*
Negative participants Day D-1²	-.010***	-.010***
Positive participants Day D-1	.037	.039
Number posts Participants Day D-1	.052**	.050**
Number posts Leaders Day D-1	.028	.022
Anonymous Day D-1	-.053	-.047
Weekend	.129	.156
Timeline	.089*	.085*
Timeline²	-.003*	-.003*
	Controls only: Model 1	**Main effects Added: Model 2**
		Estimate
Participation Quality		
Emotional contagion Day D H1b)		.027*
Positive Leaders Day D-1 (H1a)		.020***
Cognitive inferences Day D (H2b)		.102***
Negative Leaders Day D-1 (H2a)		.070
Negative Leaders Day D-1² (H2a)		-.010
Participation Quality		
Emotional contagion Day D (H1b)		.330*
Positive Leaders Day D-1 (H1a)		.078
Cognitive inferences Day D (H2b)		2.082***
Negative Leaders Day D-1 (H2a)		-1.128***
Negative Leaders Day D-1² (H2a)		.151***
Emotional contagion Day D		
Positive Leaders Day D-1 (H1b)		.080***
Negative Leaders Day D-1		-.112
Negative Leaders Day D-1²		.028**
Cognitive inferences Day D		
Positive Leaders Day D-1		-.017
Negative Leaders Day D-1 (H2b)		.185
Negative Leaders Day D-1² (H2b)		-.038*

N=760

Two-tailed p-value - *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$

Table 4 - Direct and indirect effects – mediation tests

Variable			Direct effect		Mediated effect	
Independent	Mediator	Dependent	Estimate	p-value	Estimate	p-value
Positive Leaders Day D-1	Emotional contagion Day D	Participation Quantity	.020	.000***	.002	.000***
		Participation Quality	.078	.306	.026	.002**
Negative Leaders Day D-1	Cognitive Inferences Day D	Participation Quantity	-.010	.135	-.004	.006**
(min)			-.001	.135	.000	.006**
(max)			-.130	.135	-.049	.006**
Negative Leaders Day D-1		Participation Quality	-.977	.000***	.306	.215
(min)			-1.113	.000***	.378	.160
(max)			.758	.000***	-.614	.000***

Results from Table 3 & 4 support H1a and H1b: leaders' positive emotions have a direct effect ($p < .001$) and a partial mediated effect ($p < .001$) on participation quantity, as well as a full mediated effect ($p < .01$) on participation quality, both through emotional contagion. These results then strongly suggest that leaders' positive emotions are contagious and influence participation, both in terms of quantity and quality of participations, through the emotions of volunteers.

Moreover, these results partially support H2a and H2b. Leaders' negative emotions have a full mediated effect ($p < .01$) on participation quantity, through participants' cognitive complexity. However, even if our p-value shows a significant inverted U-shape relationship within our data sample, more refined analysis shows that while leaders' negative emotions increase, our estimate goes from significantly null ($p < .01$) to significantly negative ($p < .01$). Then, results show a full mediated decreasing effect on participation quantity, and strongly suggest that leaders' negative emotions decrease participation's quantity, not through participants' emotions this time, but through participants' cognitive complexity. Concerning participation quality, results show also a partially mediated decreasing effect, the estimate going from non-significant ($p > .05$) to significantly negative ($p < .000$) as leaders' negative emotions increase, similarly to participation quantity. However, contrary to our expectations, the direct effect (H2a) complementing our indirect is significant ($p < .001$) and U-shaped. As leaders' negative emotions increase, our estimate goes from being significantly negative ($p < .001$) to significantly positive ($p < .001$). In other words, not only leaders' negative emotions partially decrease participation quality through participants' cognitive complexity, they also increase participation quality at high levels of negative emotions. These results reveal that the effect of leaders' negative emotions is part of a much more complex phenomenon than hypothesized.

5. DISCUSSION

Prior works on crowd science project emphasized the importance of leaders in coordinating and managing online participation and in maintaining engagement levels (Faraj et al., 2015; Li et al., 2012). Yet, prior work mainly focused on structural, social and technical issues that leaders deal with (Franzoni & Sauermann, 2014; Kokshagina, 2019; Scheliga et al., 2016). This research examines how leaders' emotions influence online participation in crowd science projects.By exploring the role of leaders on participants' behaviour in four Polymath projects, we show that leaders' positive emotions increase online participation's quantity and quality through participants' emotional contagion, while leaders' negative emotions decrease online participation's quantity and quality through participants' cognitive inferences.

5.1. Theoretical and practical implications

This study has two theoretical implications. First, this work provides theoretical implications for research on the organizational aspects of crowd-science (Franzoni & Sauermann, 2014; Sauermann & Franzoni, 2015). In their recent and integrative framework, Franzoni et al. (2021) propose that crowd-science volunteers mostly participate because they are intrinsically motivated by the topic, they are curious to learn more and they desire to contribute to scientific progress. Our results show that leaders' emotional expressions, external stimulus impacting emotional and cognitive internal mechanisms, may be another important driver of crowd-science participation. Future research should explore how leaders' emotions drive participation in another empirical setting than Polymath. Results might be different as Polymath represents an extreme crowd-science case, the majority of volunteers having contributed for a short period of time contrary to other crowd-science projects (Sauermann & Franzoni, 2015).

Second, this work provides broader implications for research on the micro-foundations of open innovation in science (Franzoni et al., 2021). Prior studies has focused on factors related to leaders' behaviors such as sociability, knowledge contribution and use of network (Dong & Götz, 2020; Faraj et al., 2015; Fleming & Waguespack, 2007; Sutanto et al., 2011). Our research underscores the role of leaders' emotion in crowd science projects. Here, the results show that the emotional component of leaders' messages influences online participation and is a factor that deserves more attention. Our results particularly suggest that to be efficient, leaders should express positive emotions at high intensity. Then, we suggest that the emotions expressed by leaders in an online context are an important yet underestimated driver that deserves more attention and that can be used to influence online behaviour.

Third, this work extends the EASI theory (Van Kleef, 2009) by moving forward the contagion-interpretation model proposed by Van Knippenberg & Van Kleef (2016). We adopted a contingent perspective and showed that the mediation path of the leaders' emotions effect depends on the valence of said emotions: leaders' positive emotions tend to be contagious with participants' emotions, while leaders' negative emotions tend to be cognitively interpreted by participants. While prior empirical work have identified moderators such as participants' epistemic motivation or task criterion (Van Kleef, 2016; van Kleef & Côté, 2021; van Knippenberg & van Kleef, 2016), this research puts an emphasis on the valence of emotional expressions as another possible moderator, extending the boundary conditions of the EASI theory (Van Kleef, 2009).

Moreover, this works extends the EASI theory (Van Kleef, 2009) by focusing on the medium of text-based communication, since prior studies on leadership using this theory mainly focused on the expression of emotions in face-to-face interactions. People seem to perceive emotional expressions differently between an online and an offline setting, and such difference of perception seems to enhance different effects. For instance, in an online setting, people consider negative emotions as more negative than they truly are (*negativity bias*), and are unaware of this bias (Byron, 2008). On the contrary, people can fail to recognize positive emotions and consider them as neutral (*neutrality bias*) (Byron, 2008). These biases could explain how leaders' negative emotional expressions only have a decreasing effect on online participation. Then, we suggest that the emotions expressed by leaders in an online context are an important, yet underestimated, driver that deserves more attention and that can be used to influence online behaviour.

Finally, this work extends the EASI theory (Van Kleef, 2009) by emphasizing the role of leaders' emotional intensity. Prior studies about leadership using this theory focused on the effect of the valence (positive *vs* negative) rather than on the intensity of emotional expressions and Van Kleef (2016) points out that "it is currently unknown exactly how intensity moderates the effects of emotional expressions" (p232). Rare studies approaching the effect of negative emotional intensity in negotiation (Adam & Brett, 2018) or in sports management (Staw et al, 2019) showed that such effect is strongly correlated with the perceived inappropriateness of an emotional expression. This resonates with the dual threshold model of anger (Geddes & Callister, 2007), in which leaders' negative emotions have a decreasing effect after a certain level of intensity, and explains partially our results. It is then possible that a leader's expression of negative emotions has an effect on participation not through emotional contagion, but through the perception of inappropriateness that participants make from leaders' negative emotional expressions, impacting participants' cognitive complexity as well. However, results also show that the effect of leaders' negative emotional expressions is multiple, and a part follows a U-shaped relationship. This shows that leaders' negative emotional expressions send signals that can be interpreted in multiple ways, and these different cognitive inferences can trigger competing effects. Future research should then examine the competing mechanisms of the effect of leaders' negative emotional expressions. Therefore, with the consideration of valence, text-based communication emotional intensity, we derive additional predictions of the EASI theory with greater specificity.

5.2. LIMITS AND FUTURE RESEARCH DIRECTIONS

Our findings and contributions reflect limitations and boundary conditions. First, we have explored the role of leaders' emotions in a special case of crowd science projects – Polymath. We assume that observing other types of organizations online might demonstrate different results, especially in non-scientific contexts. We suggest, then, the following future research directions. First, future research should investigate how leaders' tones of emotions vary in different contexts of online, physical and blended environments. Second, future work can explore in detail how leaders can balance their emotions to ensure constant flux of participation and how emotions can appear as a parameter to consider when designing better online engagement. Third, the notion of leadership online deserves more focus. For example, future work can explore the role of clearly appointed and emerging leaders during online projects.

6. CONCLUSION

To conclude, this research analyses the effect of leaders' emotional expressions on participation's quantity and quality in crowd-science projects. Our research brings theoretical contributions to crowd science and online community leadership literatures, by showing that leaders' affective dimension is a driver of participation that deserves more attention. Our research also explores the mechanisms of the EASI theory (Van Kleef, 2009), its application in text-based communication contexts and the role of emotional intensity.

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APPENDIX A - Participation in the Polymath projects

Polymath #		1	4	5	8
Period		2009-2011	2009-2011	2009-2015	2013-2014
Number of participants		44	82	110	157
Number of posts	Total	1494	599	2637	2138
	Leaders	612 (40,96%)	203 (33,89%)	1311 (49,72%)	858 (40,13%)
	Leader 1	Tim Gowers (22,56%°)	Terrence Tao (20,7%)	Tim Gowers (34,17%)	Eytan Paldi (21,38%)
	Leader 2	Terrence Tao (18, 41%)	Ernie Croot (13,19%)	Alec Egdington (15,55%)	Terrence Tao (18,76%)
	Participants	882 (59,04%)	396 (66,11%)	1326 (50,28%)	1280 (59,87%)
	Participants Top 1	12,45%	8,18%	5,38%	10,48%
	Participants Top 2	7,9%	6,68%	5,27%	8,92%
	Participants Top 3	7,43%	5,01%	4,93%	5,99%
	Participants Top 4	5,89%	4,84%	4,66%	5,29%
Number of days		1006	2011	2135	608
Number of active days	Total	109	108	246	309
	Leader	72 (66,06%)	67 (62,04%)	183 (74,39%)	238 (77,02%)
	Participants	105 (96,33%)	83 (76,85%)	220 (89,43%)	270 (87,38%)

APPENDIX B
Leaders and affiliations

Leaders	Affiliation
Timothy Gowers	University of Cambridge
Terrence Tao	Université de Californie à Los Angeles
Eytan Paldi	Israel Institute of Technology
Ernie Croot	Georgia Institute of Technology
Alec Egdington	Cambridge Quantum Computing

APPENDIX C - Leaders' and participants' quantity of posts per Polymath project