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Master Thesis – Data Science and Marketing Analytics

Community Interactions and User Participation on Reddit

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Abstract

On Reddit, users create and join online communities of interest known as subreddits. These subreddits interact with each other through hyperlinks, where users may refer to a community in another. User participation is affected by community interactions, and this study aims to examine the mechanisms behind this relationship. This research hypothesizes that community cohesiveness, the ability of subreddits to retain users, and activity diversity, the tendency of users to explore and disperse themselves across the platform, mediate the relationship between community interactions and user participation. Additionally, the type of community interactions (positive vs. negative) is considered, and the constructs are operationalized at the user level and averaged per community. The results indicate that positive and negative community interactions have a positive and negative effect, respectively, on user participation. Community cohesiveness is found to mediate the relationship between (positive) community interactions and user participation, while activity diversity does not. Activity diversity is further broken down into two sub-constructs, user exploration and user dispersion, which are shown to mediate the effect of negative community interactions on user participation. Finally, actionable recommendations are provided to stakeholders in online communities, and future research directions are suggested.

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1. Introduction

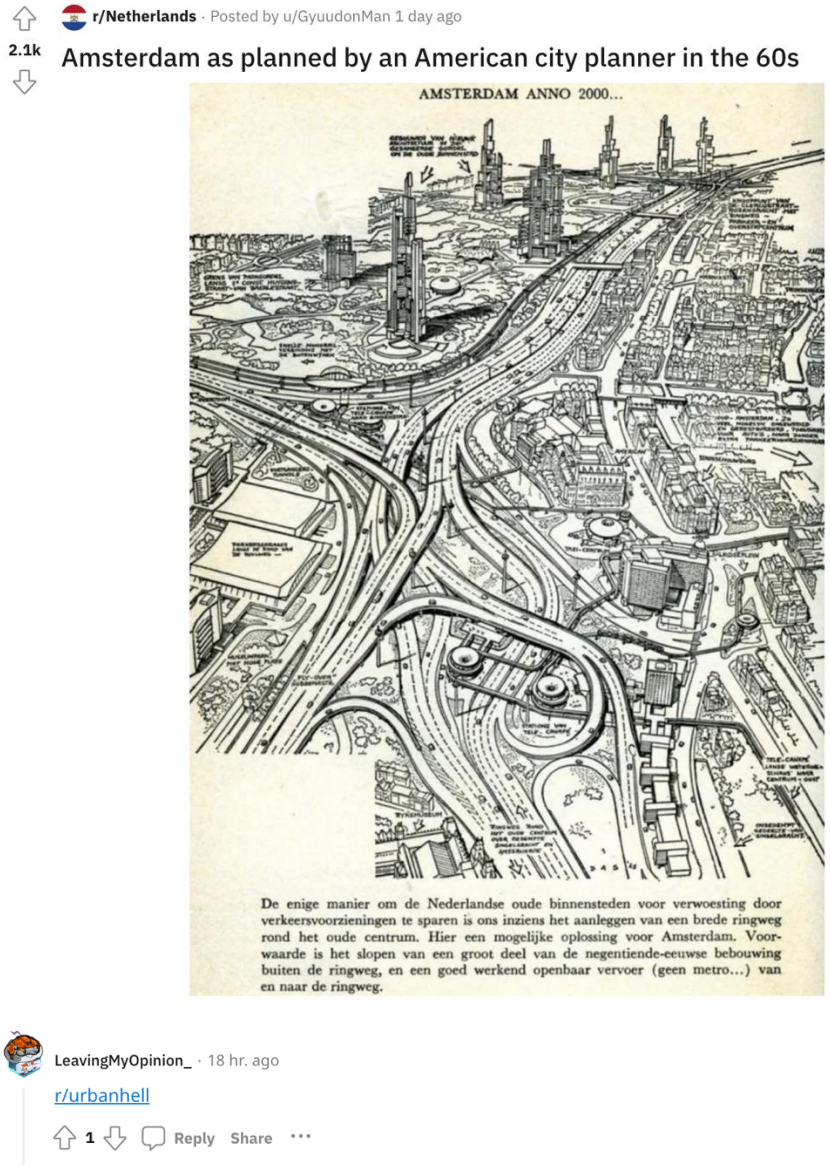

Figure 1: Example of a Reddit post with a subreddit hyperlink comment (Link)

On Reddit, communities are not isolated but frequently interact with each other. According to Krohn & Weninger (2022), community interactions can positively impact the subreddit landscape, such that community hyperlinks (Figure 1) induce the creation of new subreddits and foster participation among them. On the other hand, Kumar et al. (2018) show that negative community interactions generate conflicts between subreddits and can result in long-term adverse effects for targeted communities and their members.

However, community interactions alone hardly explain activity among subreddits. Cunha et al. (2019) investigated the success of Reddit communities through multiple lenses and operationalized it as the growth and retention of their members, long-term survival of the community, and volume of activities

generated by their users. According to the authors, these success measures can be predicted early through factors such as the volume and distribution of activities, composition of users, and social network structures among their members, among others. For example, Waller & Anderson (2019) proposed a principled measure of how generalist or specialist a user is and studied their behavior on online platforms through this lens. Their result showed that activity diversity is a critical phenomenon of user behavior and that specialists tend to stay in communities while generalists engage with more diverse sets of users. Finally, Kim et al. (2022) explored the differences between passive and active community participation from the community cohesiveness and community attachment perspectives and found that both dimensions were influencing the participation of community members.

While there is a substantive amount of literature on web communities (Romm et al., 1997; Kumar et al., 1999; Reddy, 2001; Fortunato, 2010; Datta et al., 2017), including their coexistence (Hessel et al., 2016; Kumar et al., 2018; Krohn & Weninger, 2022) as well as the activity of their users (Hamilton et al., 2017; Horne et al., 2017; Zhang et al., 2017; Kumar et al., 2018; Thukral et al., 2018; Waller & Anderson, 2019; Krohn & Weninger, 2022; Tenorio-Fornés et al., 2022), little research combined these aspects and investigated the relationship between them, such that it remains unclear how community interactions relate to user participation. Therefore, the purpose of this study is to understand the effects of community interactions on the participation of users on Reddit. With this topic, I would like to answer the following research question:

RQ: *How community interactions relate to user participation on Reddit?*

Accordingly, this research investigates the relationship between online community interactions and user participation through subreddit hyperlinks and user comments. Although recent literature investigated the relationship between subreddit hyperlinks and the participation of users, past research has not 1. investigated the causality of several success measures (e.g., community cohesiveness and activity diversity on user participation) (Cunha et al., 2019) nor 2. filtered for factors impacting the effectiveness of subreddit hyperlinks on the participation of users (i.e., hyperlink sign and community size) (Krohn & Weninger, 2022). I believe that examining the relationships between several community factors would help to understand the “how” behind the activity of online communities driven by community interactions. I also think that filtering for the type of interactions and community size is vital to understand the impact of community interactions on the activity of subreddits at the user level. As a result, this research focuses on investigating factors mediating the relationship between subreddit hyperlinks and user participation. Ultimately, understanding how online phenomena like subreddit hyperlinks induce user participation would benefit both the use and design of online platforms and their communities.

Additionally, this study would contribute to the literature on online communities and their users on Reddit by investigating the relationships between constructs based on social networks of communities and users. Therefore, the unique aspect of this research is that it combines networks of communities connected through subreddit hyperlinks and networks of users connected through user comment replies.

Hence, I study four relevant constructs: community interactions, community cohesiveness, activity diversity, and user participation. Community interactions on Reddit take place when a community references or is referenced by another community, encouraging users to visit the community. Community cohesiveness, on the other hand, can be seen as the retention of users in the community, and activity diversity reflects the tendency of users to spread their activity across the platform. Finally, user participation represents the engagement of users in a community. Studying the implications of these phenomena is crucial for platform developers because they all lead to different outcomes. As such, understanding how they relate to each other could enable online platforms to engineer mechanisms that would benefit different strategies, such as preventing communities from dying, diversifying portfolios of users, or promoting new communities.

In summary, analyzing the relationship between community interactions and user participation through the lenses of community cohesiveness and activity diversity would provide valuable insights into the optimization of community-based platforms through their policy and design. By studying how community interactions relate to user participation, platform developers can better understand how stimulating or restraining those interactions can influence user participation, ensuring sustained activity on the platform.

This paper is structured as follows. First, I review the theory about online communities and their users. Then, I describe the methods and data used to conduct my research. Next, I analyze the data, present the results, and answer the hypotheses. Finally, I discuss the main findings, answer the research question, provide managerial implications, and suggest further research directions.

2. Literature

In this section, I define online communities and stress their importance in society and on the internet, but more specifically on Reddit. Following this, I describe user participation in online communities and enumerate its most influential factors so I can explain their implications on business and research. Finally, I discuss the current literature about the primary constructs of my approach, which ultimately draw the conceptual framework of this research.

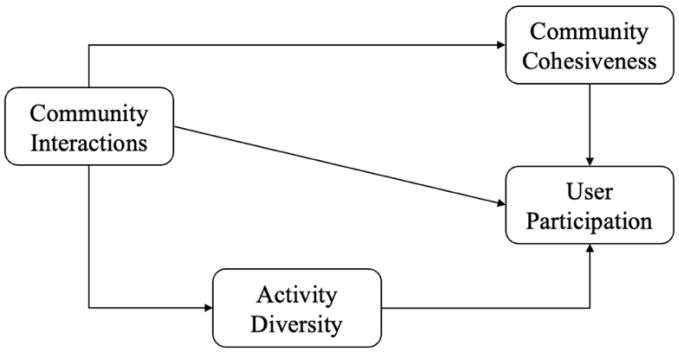

Figure 2: Conceptual Framework

2.1 Online communities

Robert Plant (2004) defines an *online community* as "a collective group of entities, individuals or organizations that come together either temporarily or permanently through an electronic medium to interact in a common problem or interest space" (Robert Plant, 2004, p54). From the author, online communities find their emergence from the human desire for connection, knowledge, and information and operate at multiple levels, such as business-to-business commerce, governmental functions, not-for-profit organizations, professional communities, and non-commercial levels, as communities of interest (Plant, 2004). Moreover, the development of online communities among suppliers or customers became essential for the success of businesses (Hagel, 1999). Early on, McKinsey & Company demonstrated the importance of online communities in business by showing that online community websites could convert 60% of their visitors into members compared to 2% for transaction websites (Agrawal et al., 2001). Academic research showed the growing prevalence of online communities on the web by identifying that 84% of American internet users contacted online groups (Pidgeon, 2004). With the web 2.0 era, virtual communities changed the relationship between marketers and their customers as more and more consumers started expressing themselves and sharing their knowledge, experiences, and opinions about different products and services online (De Valck et al., 2009). According to the authors, participants commonly rely on online communities to learn, get suggestions, or look over an expert user's viewpoint before purchasing a product or service. Therefore, online communities constitute an important social space that connects consumers and allows them to interact with and influence each other (De Valck et al., 2009). Furthermore, online communities exist in various forms and present critical societal implications. The rest of this section covers the position of online communities in society, their presence on the web, and current research on the social media platform Reddit.

Romm et al. (1997) conceptualized the significant stages of online communities' life cycle to better understand their position in society. They found that community membership is affected by technological, motivational, task-related, and system-related variables such as their structure,

environment, culture, and politics. In addition, the authors demonstrated that community membership influences the linguistic, performance, social, and political aspects of its immediate environment, affecting production systems, national identities, community integration/fragmentation, and personal relationships in society. Finally, this model suggests that community members are primarily concerned with survival issues, such as belonging to the community in the early stages and gaining interest in the nature of the community, such as language, relationships, and politics in later stages (Romm et al., 1997).

Research about online communities supports the idea that they constitute a hyperlinked environment, where some online communities are pointing towards many communities (hubs) and others are pointed to by many communities (authorities) (Gibson et al., 1998). According to the authors, this notion implies a mutually reinforcing relationship between the two types of communities, where good authorities find good hubs and vice-versa. The web has thousands of explicitly defined communities, where users share a common interest on web pages most popular among them, but also many implicitly defined communities that emerge from the chaotic nature of content creation on the internet (Kumar et al., 1999; Reddy & Kitsuregawa, 2001). This research holds a similar idea with the difference that it focuses on the social media platform Reddit, where communities are explicitly defined, created, and managed by its users, but where these new communities also emerge from the chaotic nature of content creation on the internet.

Quoted initially as “the front page of the internet”, Reddit is a social media platform where users create or join interest-based communities to post, vote, and comment on the content. Communities, named subreddits, are hosted by the platform and allow users to post links to external websites or submit content related to the topic of the subreddit. Most subreddits are moderated by volunteers, and the platform ranks submissions based on the votes and comments of users. With these features, users can create and join spaces of interest, and the platform can promote the best part of its content (Singer et al., 2014). Main research topics from the perspective of posts include popularity predictions, generative models for discussion trees, study of memes, and leading research directions from the perceptive of users include activity patterns, community loyalty, trolling and hate speech, inherent networks of communities, and their external influence on the web, among others (Medvedev et al., 2017). For this research, I am particularly interested in the coexistence of communities in the form of inherent networks, where communities interact via subreddit hyperlinks, and user participation as social networks, where users interact via their comment replies on community posts. Accordingly, my research focuses on the relationship between community interactions and user participation and considers the retention (i.e., community cohesiveness) and activity of users (i.e., activity diversity) to enhance the understanding of this relationship. I further discuss these aspects in the following sections.

2.2 User participation

User participation on Reddit occurs when users comment on the social media platform. According to Bishop (2007), user participation is driven by their desire consonant with their goals, values, and beliefs, which depend on their interpretation of their environment (in the present work, their community). In his research, the author explains that users who have participated for a long time do so more regularly because they believe that their contribution will have a positive impact on their environment. On the other hand, passive users avoid doing so because they do not believe in the positive impact of their contribution (Bishop, 2007). Several factors influence user participation in communities. These factors are explained in the remainder of this section.

Malinen (2015) points out that psychological, social, and technical factors influence the participation of users. According to Bateman et al. (2011), community members have psychological ties to a particular online community based on their need, affect, and obligation commitment, such that each commitment has a different implication on user participation. While need-based commitment predicts thread reading (i.e., reading a post), reply posting (i.e., commenting on a post) and moderating behaviors are predicted by affect-based commitment, which according to the authors, represents the emotional attachment and identification of users to the community. Following this, Lampe et al. (2010) found that a feeling of belonging is essential to all types of users on online platforms, where a sense of familiarity, perceived similarity, and trust among members all positively influence this feeling of belonging (Zhao et al., 2012). Finally, Zhou (2011) showed that the social identity and group norms of communities significantly affected user participation.

Accordingly, Backstrom et al. (2008) found that different types of groups produce different degrees of engagement among communities with the highest engagement levels. For example, members of small groups are more active than members of large groups, and those that belong to more groups are less involved with these groups (Backstrom et al., 2008). Furthermore, the authors demonstrated that established members were generally less engaged with newcomers than their peers. While Hsieh et al. (2013) found that social identity predicts users' integration into the community, Casaló et al. (2013) showed that both perceived similarity between users positively influences their satisfaction and intention to participate in community activities. Finally, Bisgin et al. (2010) demonstrated that homophily (the tendency of similar users to associate with each other's) positively influences online participation but cannot explain the creation of new ties.

Consequently, relationships between community members and with the community have important implications for businesses relying on them. Among brand communities, the degree to which an individual perceives his relational bonds with other users has an influence on his relationship with the brand (Carlson et al., 2008). In their research, the authors found that individuals will be more dedicated

to a brand if they feel more a part of the community among other brand users. When firms combine the interaction of users with the brand with the interaction among users, the relationship with the brand is amplified, and the effectiveness of customer interactions is improved (Luo et al., 2016). Furthermore, companies relying on innovative communities to increase their capacity and adapt to the changing business environment benefit from the participation of community members. For companies involving their users in the development process of their product via collaborative communities, Guo et al. (2017) identified that users who collaborate with one another have good relationships and submit the best solutions.

However, Tan & Lee (2015) mentioned that most research about online communities focused too much on their intra-aspect rather than on their inter-aspect, although recent research showed that several factors influence user participation among multiple communities. Therefore, the following sections introduce three main aspects of online communities that influence user participation in an intercommunity landscape: community interactions, community cohesiveness, and activity diversity.

2.3 Community interactions

Community interactions on Reddit occur when users from a subreddit (the source subreddit) post about another subreddit (the target subreddit) while providing the link (subreddit hyperlink) to the target subreddit. According to information behavior theory, hyperlinks constitute a significant factor in user navigation and attention such that they represent a sign of user interest (Fisher et al., 2005; Gao et al., 2021). This theory led scholars to believe that communities may influence one another and opened an area of research on cross-community influence (Belák et al., 2012). Besides, subreddit hyperlinks are an excellent fit for studying community interactions because they are commonly used on the platform and can be easily identified (Krohn & Weninger, 2022).

Belák et al. (2012) support the idea that communities' activity impacts other communities' activity. According to Krohn & Weninger (2022), subreddit hyperlinks induce the creation of new subreddits, drive activity in these subreddits, and emerge from a high activity in the referenced subreddit. In addition, the authors have distinguished between the links that cause an increase in user activity from the links that are the consequence of an increase in user activity and found that both allow users to create relationships between communities while also increasing participation in the referenced community.

However, inter-community interactions on Reddit can also generate conflicts. Kumar et al. (2018) studied intercommunity interactions and conflict on the web through subreddit hyperlinks and found that users mobilized by the negative sentiment of these posts had a long-term detrimental effect on the referenced subreddit. In fact, most of these conflicts (74%) are initiated by a minority of communities

(1%) that interact with subreddits similar to them (Kumar et al., 2018). Additionally, Datta & Adar (2019) demonstrated that most attacks (77.2%) are reciprocated and that subreddits engaging in conflict with multiple other subreddits tend to change their focus over time. That is, subreddits attacking other subreddits change their most targeted community over the months (Datta & Adar, 2019). Finally, Kumar et al. (2018) showed that attacks from users of the source subreddit were leading to a process of "colonization" in the referenced subreddit, where users of the source community became more active in the referenced community, forcing users of the referenced subreddit to leave the discussion.

To nuance these findings, the authors also found that neutral or positive mobilizations could lead to "immigration" processes, where the mobilized and more civilized users became more active in the referenced community without negatively impacting the incumbent users. In addition, Kumar et al. (2018) found that increased participation in discussions between members of different communities leads to improved outcomes. In any case, both types of successful mobilizations (negative and positive) are principally initiated by active users from the source community (Kumar et al., 2018).

2.4 Community cohesiveness

Festinger (1950) defines *group cohesiveness* as "the resultant forces which are acting on members to stay in a group" (Festinger, 1950, p85), such that community cohesiveness on Reddit is the capacity of subreddits to maintain their users in their community. According to Kim et al. (2022), visitation, a passive form of user participation, is influenced by community attachment, while active community members' involvement is influenced by community cohesiveness and community attachment. Accordingly, the authors argue that members who perceive their community as cohesive believe that their group is successful in attaining its objectives, motivating them to put work into it (a theory supported by Bishop et al. (2007)).

According to Dover et al. (2020), community cohesiveness is reflected in the overlap of interests among community members. From the authors, the degree of cohesiveness within a social group is crucial to its stability. In their research, Dover et al. (2020) explain that users who spend time with other members of their clique benefit from their group's resources and protection but expose themselves to the risk of seeing their group becoming fragmented from the rest of the community. Therefore, the authors argue that a subtle balance between cohesiveness (overlap of interests) and size (number of users) is primordial for communities to prevail in the long term.

Similarly, Hamilton et al. (2017) investigated the loyalty of users to communities and found that communities made of loyal users display denser user interaction networks that are more cohesive and less fragmented, where the average user is significantly more active in these communities than in their less loyal counterparts. In addition, the authors found that loyal users employ a language that signals

these communities' collective identity by engaging with less popular content that is more specific to them. Zhang et al. (2017) confirmed these findings by showing that the collective identities of communities strongly influence the participation of their users such that they are more inclined to stick to the communities if these show distinct and dynamic identities. Furthermore, the authors argue that users who join communities experience a cultural gap with incumbent users of these communities. Hsieh et al. (2013) nuanced these findings by demonstrating that incumbent users are more inclined to help newcomers if they feel a stronger sense of community and have socialized with other users.

Finally, Cauteruccio et al. (2020) investigated user assortativity (users who post on the same subreddit) and found that users sharing similar network characteristics, such as their centrality and eigenvector centrality within the community, tend to post on similar subreddits. While the research of Cauteruccio et al. (2020) does not address the topic of community cohesiveness, it brings interesting insight into the work of Hamilton et al. (2017) on community loyalty. In their study, the authors explain that assortativity exists in unloyal communities (i.e., communities that do not retain their users) but not in loyal communities according to the activity level of their users. This observation suggests that users tend to divide themselves into subgroups based on their level of participation when assortativity is present in unloyal communities (Cauteruccio et al., 2020), which indicates that unloyal communities are somewhat fragmented.

2.5 Activity diversity

The activity diversity of a community is the average activity diversity of its users (Waller & Anderson, 2019), such that activity diversity on Reddit is the tendency of users from a subreddit to spread their activity among other subreddits. According to Waller & Anderson (2019), the extent to which users are diversifying their activity reveals the degree of connectivity of an online platform at the global level. Concretely, if most users lean toward being generalists (being more diverse in their activity), the platform will be more cohesive and support greater engagement between members of various communities. In contrast, if most users lean toward being specialists (concentrating their attention on specific communities), the platform will tend to consist of isolated communities with little interaction between them (Waller & Anderson, 2019). An interesting insight from the authors is that both types of communities, generalists and specialists, tend to conserve their level of activity diversity over time, even when their user base changes significantly. While Waller & Anderson (2019) found that generalists' comments are receiving much more credit (higher scores), other researchers did not find that comment upvotes had any positive herding effect (i.e., users imitating group behaviors) on the engagement of users with these comments (Morrison & Hayes, 2013; Glenski & Weninger, 2017; Davis & Graham, 2021).

From Hessel et al. (2016), highly related communities coexist because users who explore newer communities tend to be more active in their original community than those who do not. Therefore, the likely explanation of this observation is that users who explore communities about a particular topic usually want to discover more about a subject related to the original community's topic, argue the authors. When Hessel et al. (2016) investigated the interactions between highly related communities, they found that about 75% of older communities are more active than newer ones. However, when the authors looked closer at the 25% newer communities that were more active, they concluded that they were either better named, more general, or facing less competition with other communities. Also, most of the newer communities did not share more than 10% of their early participants with communities highly related to them (Hessel et al., 2016).

Additionally, Tan (2018) demonstrated that new communities usually emerge from many existing communities from which early members originate. Accordingly, the authors found that a strong parent connection leads to community growth, while a diverse portfolio of users leads to community participation. Moreover, Tan (2018) mentioned that a structural requirement for emerging communities is that at least 10% of early members share experience in existing communities, which conflicts with the results of Hessel et al. (2016). Zhu et al. (2014) enlightened this contradiction by investigating how communities' survival is influenced by the membership overlap of their users with other communities and discovered that more significant degrees of membership overlap are associated with a higher level of activity in communities. More specifically, the authors found that the positive benefits of membership overlap are particularly potent when the community is young and its surrounding communities are established. Finally, a community is more likely to survive when its shared members are core members of intersecting communities and less likely to thrive when its shared members are core members of the community (Zhu et al., 2014).

2.6 Conceptual framework and hypotheses

Given the current state of literature, all three aspects, community interactions, community cohesiveness, and activity diversity, play a significant role in user participation among communities. However, investigating the nature of the relationships between these dimensions can nurture the current body of literature on the impact of community interactions on user participation. As a result, I want to examine the potential mediation effects of community cohesiveness and activity diversity on the influence of community interactions on user participation to understand this relationship better. Accordingly, I have developed three hypotheses to answer my research question. One investigates the relationship between community interactions and user participation, and two attempt to explain this relationship through community cohesiveness and activity diversity.

Since Reddit's initial purpose is to share webpage links, hyperlinks constitute a critical aspect of the social media platform. These hyperlinks initially directed users to other websites. However, with the sustained growth of the platform explained by the creation of many more subreddits, it became customary to redirect users to other Reddit communities. These redirections, induced via subreddit hyperlinks, nurtured the creation of new subreddits and increased user participation on both the source and referenced subreddit. Additionally, multiple studies investigated the impact of community interactions via subreddit hyperlinks on the platform and found that community interactions relate differently to user participation depending on the nature of these community interactions. While positive subreddit hyperlinks (e.g., users promoting a subreddit) had a positive impact on the activity of users of the referenced subreddit, negative subreddit hyperlinks (e.g., users criticizing a subreddit) had a negative impact on the activity of users of the referenced subreddit. Therefore, the first hypothesis investigates the relationship between the number of subreddit hyperlinks and user participation in subreddits while filtering for the type of hyperlink of this subreddit (positive or negative).

H1: *A higher number of positive (negative) community interactions is related to a higher (lower) user participation.*

Another significant aspect of online communities is their cohesiveness: their capacity to retain community members over time and stay united. Overall, a cohesive group gives a sense of accomplishment to its members, which motivates them to contribute to the community and ultimately prevents them from leaving prematurely. However, previous studies have shown that negative community interactions create conflicts among users, leading to the migration of users of the target community and the colonization of users of the source subreddit. Since community cohesiveness emanates from a distinct community identity and a feeling of belonging, it goes without saying that colonization processes negatively impact user activity. On the other hand, positive community interactions lead to improved outcomes, where more civilized users immigrate and become more active in the referenced community. Additionally, users who join a new subreddit are better integrated into the community by incumbent users when they feel a stronger sense of community. Accordingly, the second hypothesis suggests that positive (negative) subreddit hyperlinks are beneficial (detrimental) to the cohesiveness of the subreddit and, as a result, to the participation of its users.

H2: *A higher number of positive (negative) community interactions is related to a higher (lower) community cohesiveness, which is related to a higher (lower) user participation.*

The last characteristic of online communities investigated in this study is the activity diversity of their users, that is, how much subreddit users explore other subreddits and how concentrated or dispersed their activity is across the platform. The activity diversity of users is a defining aspect of how connected

or fragmented the platform is, and so are its community members. One of the structural requirements for subreddits to emerge and survive is that a certain proportion of their users were part of existing and more established communities. One of the reasons behind this is that community interactions allow users to explore newer communities and deepen their knowledge about a particular topic. Also, research showed that the tendency of users to spread their activity across multiple communities is positively related to the activity of users in these communities. On the other hand, while positive community interactions encourage users to explore new subreddits, negative community interactions discourage incumbent users from continuing to participate, ultimately forcing them to leave the community. As a result, the third and final hypothesis investigates if subreddit hyperlinks motivate users to explore and spread their activity across other subreddits and, consequently, drive or damage user participation within these subreddits.

H3: *A higher number of positive (negative) community interactions is related to a higher (lower) activity diversity, which is related to a higher (lower) user participation.*

Accordingly, I propose the following conceptual framework:

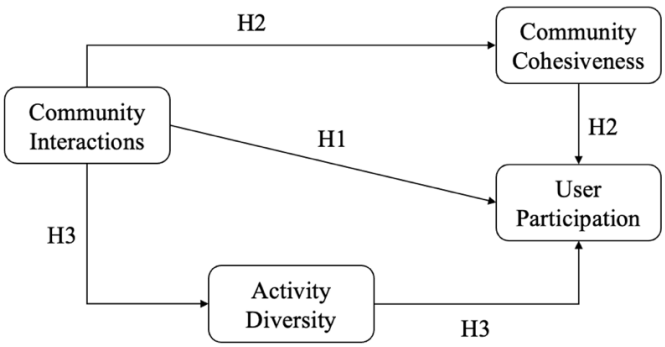

Figure 3: Conceptual Framework (Hypotheses)

3. Methodology

In this section, I introduce social network analysis as the cornerstone of my empirical setting and enumerate its practicalities for this research. Following this, I explain the data collection and processing methods and define each construct. Finally, I describe the statistical models and techniques used to test my hypotheses and answer the research question.

3.1 Research design

3.1.1 Social network analysis

According to Hanneman (2005), a *social network* is "a social structure between actors, where these actors can be individuals, organizations, computers, or any other interconnected information processing

entities" (Jamali & Abolhassani, 2006, p1). Given that online communities are a collective group of entities, individuals, or organizations (Plant, 2004), social network analysis is the optimal approach to study them.

The primary idea of social network analysis is to map and measure the relationships or flows between these entities, in which nodes represent actors and the link or flow between them by edges. Social network analysis can tell a lot about the behavior of the network (Jamali & Abolhassani, 2006), like how fast things are moving across actors, if and where conflicts can arise, and to what extent sub-structures overlap with each other (Hanneman, 2005). Moreover, these behaviors depend on various network properties, such as size, density, degree, or distance (Jamali & Abolhassani, 2006). Network properties can explain many phenomena among social networks, including the general influence of actors on their networks, by examining their Centrality and Power characteristics (Hanneman, 2005).

These characteristics are fundamental as they are properties of the network social structures and allow one to measure the number of opportunities, bargaining power, and brokering contacts of these actors. Most popular network statistics include the Degree of an actor (number of ties), its closeness centrality (the length of paths to other actors), betweenness centrality (where an actor is lying between each other pairs of actors), and eigenvector centrality, which like degree centrality, measures a nodes' influence but consider the number of ties of this node's connections (Jamali & Abolhassani, 2006).

Finally, another advantage of using social network analysis is that it provides a visual and mathematical analysis of entities' relationships and allows one to discover sub-structures, such as groups or cliques within the network. This is a critical aspect of a network social structure because the separation, size, and composition of sub-graphs allow to inspect overlaps between sub-groups and identify the number, size, and role some actors play among these sub-groups (Jamali & Abolhassani, 2006).

3.1.2 Graph theory

A social network is usually represented as a graph. A static, unweighted graph G is composed of a set of nodes V and a set of edges E: $G = (V, E)$, where the sizes of each component V and $\mathcal{E}$ are represented as N and E (Aggarwal, 2011). Alongside, a graph generally displays three significant characteristics. It can be directed or undirected, weighted or unweighted, and unipartite or multipartite.

When a graph has directed edges, a distinction is made between the actor who initiates the connection. For example, if user A sends a message to user B, the edge that connects A to B shows that A is the sender and B is the receiver. In the case of a weighted graph, edges are given a weight, such that an extra feature defines the connection between A and B; that is, their connection is assigned a specific strength or importance. For instance, if A sends a longer message to B than C, the edge between A and

B will have more weight than the edge between A and C. If a graph is unipartite, all its nodes belong to the same class, which means there is no difference between users A, B, and C in this case. If a graph is multipartite, its nodes belong to a specific class, such that A and B could pertain to category 1 and C to category 2. In this study, the graph is directed, unweighted, and unipartite. In addition to that, edges are signed, which means that edges do not only show the direction of the connection but also the type of connection. More about this later in the section.

When analyzing a graph (i.e., social network), the most popular approach is to rely on a snapshot of the network where all data is aggregated over a period of time, commonly named static graph (Tang et al., 2009). This analysis relies on this approach to investigate the data and test the relationships. However, dynamic graphs (i.e., multiple snapshots of the graph) are used to calculate the constructs over different time periods. As a result, the constructs contain dynamic information aggregated to analyze static networks.

3.1.3 Network properties

Several patterns can be identified depending on the nature of the network (static/dynamic, weighted/unweighted). Such patterns can be seen in the degree distribution, diameter, community structure, power laws, density, and variations of its components (Aggarwal, 2011). These patterns can be used to identify strange graphs and sub-graphs and provide answers to what-if scenarios and inquiries regarding the entities in a network. Moreover, analyzing network properties helps identify hubs and authorities and adequately design algorithms (Aggarwal, 2011). Finally, stressing out these properties helps my research discern the common from the unusual patterns usually found in social networks. It will be constructive when introducing the data and model used in this study, as these trends will be considered when testing the relationships between the different constructs.

Aggarwal (2011) states that one of the first properties of a static and unweighted network graph (graph used in this research) implies a power-law-like distribution of their nodes' degree, number of triangles (i.e., sub-graph consisting of three nodes), and eigenvalue where few nodes have high value and many nodes low value for these properties. As for the degree distribution, it is relatively common to see few nodes having many connections and many nodes having few connections in any given graph, explains the author. Following this, another famous pattern is the "small world phenomenon", where all nodes are separated by at most six degrees or less. This network characteristic describes how quickly one node can get to any other node of the graph and is a popular feature among social networks (Aggarwal, 2011). Finally, Aggarwal (2011) explains that any graph shows group and sub-group structures where the nodes from these groups are tightly connected.

In theory, this is how static and unweighted network graphs (social networks) are structured in most empirical settings. In my study, I explore the distribution of the data and the structure of the networks before running the models and answering each hypothesis. The data leading to the graphs used to conduct the research are described in the following section.

3.2 Empirical Setting

3.2.1 Data

To conduct my research, I combine datasets of Hamilton et al. (2017) and Kumar et al. (2018) publicly available in the Stanford Network Analysis Project library. While the dataset of Kumar et al. (2018), who studied Community Interaction and Conflict on the Web, provides the empirical setting for analyzing community interactions, the dataset of Hamilton et al. (2017), who studied Loyalty in Online Communities, provides the empirical setting for analyzing user participation within communities.

The first dataset, collected and processed by Kumar et al. (2018), is a subreddit-to-subreddit hyperlink network where the nodes are subreddits, and the edges are community posts hyperlinks connecting subreddits. The dataset includes the timestamp of the post (time at which the post was created) and sentiment (negative or neutral/positive) of the posts made on the source subreddit from January 2014 to April 2017. Since all Reddit posts contain a title and a body, this dataset has two versions—one for all titles and one for all bodies. In total, the authors collected 571,927 post titles and 286,561 post bodies across 36,000 subreddits, where the network is directed, signed, temporal, and attributed. For this research, both versions are combined.

The second dataset, collected and processed by Hamilton et al. (2017), is a list of 2046 subreddits containing the monthly user interaction network within the subreddit where nodes are users and edges the interactions between them. Each subreddit is a reply-based interaction network that connects users who directly reply to each other's comments. The authors selected subreddits that met a minimum activity requirement of at least 100 comments per week. In addition, the authors excluded two subreddits, /r/counting and /r/CatsStandingUp, whose commenting patterns are noticeably anomalous. Finally, these networks only contain users who posted at least 50 comments on Reddit in 2014 and represent the top 20% of users. The dataset contains data from January 2014 to November 2014.

Initially, all networks are dynamic, unweighted, directed, and unipartite. While the subreddit hyperlinks network contains information from January 2014 to April 2017, the subreddit monthly user comments network contains information from January 2014 to November 2014. After combining both datasets, the final dataset comprises one main hyperlink network of 1119 subreddits (representing community interactions), each made of a user reply-based network (representing user participation and used to calculate the two other constructs, community cohesiveness and activity diversity). All networks are

static, unweighted, directed, and unipartite, and contain data aggregated from January 2014 to November 2014. In addition, the subreddit hyperlink network is signed, such that its edges indicate if connections are positive or negative (i.e., if the source subreddit promotes or criticizes the referenced subreddit in its post). As a result, all variables are arranged in one subreddit node list, where each node represents one subreddit. Finally, each subreddit characteristics are attached, such all types of community interactions, community cohesiveness, activity diversity, and user participation, which ultimately represent the constructs investigated in this study. A sample of the data is presented in Table 1, and all constructs are described in the following section.

Table 1: Sample Data

subreddit	interactions_total	interactions_positive	interactions_negative	participation	cohesiveness	diversity
pics	3,340	2,966	374	5.4484	0.2071	0.0050
funny	2,997	2,616	381	6.6312	0.2195	0.0050
todayilearned	2,633	2,289	344	6.0638	0.2078	0.0046
videos	2,462	2,110	352	6.1356	0.2136	0.0048
worldnews	2,329	1,924	405	8.6779	0.2072	0.0044
news	1,603	1,260	343	6.8561	0.1927	0.0045

3.2.2 Variable definitions

The first construct, *community interactions*, is defined as the number of hyperlinks that are redirecting towards a subreddit and is measured by the in-degree centrality of the subreddit. For a given subreddit S (node) and all its incoming hyperlinks $\tilde{v}_{ij}$ (edges), the in-degree centrality of the subreddit is represented by the following equation:

$$Interactions(S) = \sum_{j} \tilde{v}_{ij}$$

This network statistic is inspired by Kumar et al. (2018) and Krohn & Weninger (2022) and makes a good proxy for community interactions because it counts the number of times a subreddit is shared via a hyperlink in a community post. Additionally, this measure is divided into three categories, the total in-degree centrality, the positive in-degree centrality, and the negative in-degree centrality. Accordingly, the type of interaction is distinguished, and the total number of interactions as well as the number of positive and negative interactions can be measured.

The second construct, *community cohesiveness,* is defined as the average user retention of a subreddit. A similar measure used by Hamilton et al. (2017) intended to estimate the loyalty rate of a community. However, for this study, the number of months a user is active in the subreddit and the total number of users who participate in the subreddit are considered. For example, a subreddit that counts 25% of its users who stayed active in the community for a year is more cohesive than a subreddit that counts 50%

of its users who remained active in the community for a couple of months. As a result, for a given subreddit S, its community cohesiveness is measured by the following equation:

$$Cohesiveness(S) = \frac{1}{U}\sum_{i} u_i \frac{m_i}{M}$$

Where U is the total number of users who participated in the subreddit, u_i user i, m_i the number of months in which u_i was active, and M the total number of months. Two theoretical definitions are given in the literature, but this estimate stands on Festinger (1950)'s definition of community cohesiveness. This measure constitutes a good proxy because it captures the capacity of a subreddit to retain its users over time while penalizing the subreddit for users who participated casually. It also prevails other possible measures, such as the clustering coefficient of the network of users proposed by Dover et al. (2020), because, in the context of this study, users are connected through their replies to other user comments made on community posts. Hence, although the clustering coefficient of the network of users makes an interesting estimate to measure the global connectivity (vs. group fragmentations) of the community, it would not be apparent what types of social phenomenon this kind of network statistics would explain about the platform, mainly due the anonymity of users. Ultimately, the above definition of the variable is favored and attempts to explain users' potential attachment and identification with a particular community.

The third construct, the *activity diversity* of a community, is defined as the average activity diversity of its users and is measured by the average user exploration and dispersion of a given subreddit S among other subreddits. Considering the vector $\vec{w}_i$ which represents the number of replies w_j of user u_i made on each subreddit S_j, the activity diversity of a given subreddit S is defined by the following equation:

$$Diversity(S) = \frac{1}{U}\sum_{i} u_i\left(\frac{p_i}{P}\frac{1}{\sigma(\vec{w}_i)}\right)$$

Where U is the total number of users who participated in the subreddit, p_i the number of subreddits in which u_i participated, P the total number of subreddits, and $\sigma(\vec{w}_i)$ the standard deviation of the vector $\vec{w}_i$. In principle, this measure is inspired by Waller & Anderson (2019). Intuitively, this equation is the inverse of the standard deviation of the number of replies per community of a particular user, multiplied by the proportion of subreddits in which this user participated, averaged per user for a given subreddit. This estimate makes a good proxy for the construct because it measures the user activity diversity of the subreddit by considering the exploration and dispersion of its users among other subreddits. To better illustrate the exploration aspect, user u_1 who participated in a smaller proportion of subreddits

($\frac{20}{1000} = 2\%$) is less diverse than user u_2 who participated in a larger proportion of subreddits ($\frac{50}{1000} = 5\%$). To better explain the dispersion aspect, user u_1 who equally allocates his activity among two subreddits (50% in S_1 and 50% in S_2) is more diverse than user u_2 who unequally allocate his activity among two subreddits (75% in S_1 and 25% in S_2). Both aspects combined, the activity diversity of a subreddit made of users like u_1 is higher than that of a subreddit made of users like u_2 such that in this scenario, the dispersion of users prevails on their exploration.

The fourth and last construct, *user participation*, is defined as a subreddit's average user out-degree centrality. For a given user u_i and all its outgoing replies $\vec{x}_{ij}$ made within the subreddit S, the average out-degree centrality per user of a given subreddit S is represented by the following equation:

$$Participation(S) = \frac{1}{U}\sum_{ij} u_i \vec{x}_{ij}$$

Where U is the total number of users who participated in the subreddit. This network statistic constitutes a good proxy for user participation in a subreddit because it approximates the average number of replies a user makes in this subreddit.

The design of these constructs has two purposes; 1. To provide a reasonable estimate of the various definitions given by the different authors about the constructs, and 2. To control for factors that potentially play a role in the relationships between community interactions and user participation, that is, the type of subreddit hyperlinks and the size of the subreddit. For this, subreddit hyperlinks are divided into two categories (positive and negative) to differentiate the type of interactions, and all variables but community interactions incorporate a common element $\frac{1}{U}$, which averages the measure per user. With these definitions at hand, I estimate each construct of the conceptual framework while controlling for important factors. In the following section, I introduce the methods that test the relationships between these constructs.

3.2.3 Models

To test the relationships between the different constructs and provide an answer to the hypotheses, I employ a series of linear regression models and combine pairs of them to check for mediation effects.

Linear regression helps model the linear relationship between a dependent variable (i.e., user participation) and one or more independent variables (i.e., community interactions, community cohesiveness, and activity diversity). A linear regression aims to find the line of best fit that minimizes

the sum of the squared differences between the observed values and the predicted values, where the line of best fit is represented by an equation of the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon$$

In this equation, β_0 is the y-intercept and $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients that represent the magnitude of the relationships between the dependent variable Y and the independent variable(s) $X_1, X_2, \ldots X_n$, and ε the residuals (Chambers & Hastie, 1992). The coefficients can be estimated using various methods, but the one I use in this work is the ordinary least squares method.

Mediation analysis is used to evaluate the indirect effect of the independent variable (i.e., community interactions) on the dependent variable (i.e., user participation) through an intermediate variable (i.e., community cohesiveness or activity diversity), the mediator. Using this method, I can determine if community interactions are related to user participation through community cohesiveness and activity diversity, and measure how these factors explain the relationship between community interactions and user participation.

Specifically, a mediation analysis attempts to compute the average causal mediation effect (ACME), which measures the anticipated difference in potential outcomes when the mediator's value is determined by the treatment condition versus the control condition (Tingley et al., 2014). With the treatment status held constant, the ACME is estimated by the following function:

$$\delta(t) = E\{Y(t, M(t_1)) - Y(t, M(t_0))\}$$

Where t, t_1, t_0 are values of the treatment T such that $t_1 \neq t_0$, $M(t)$ is the potential mediator and $Y(t, m)$ is the potential outcome variable (Tingley et al., 2014). As a result, the average direct effect (ADE), which is the average effect of the independent variable (i.e., community interactions) on the dependent variable (i.e., user participation), is defined as:

$$\zeta(t) = E\{Y(t_1, M(t)) - Y(t_0, M(t))\}$$

This equation represents the expected difference in the potential outcome when the treatment is changed and the mediator kept constant at the value that would have been realized if the treatment was equal to t (Tingley et al., 2014).

Thanks to this approach, I can assess the causal relationships between the defined constructs and establish the mechanisms through which community interactions relate to user participation. First, I provide an exploration of the data via descriptive statistics, network visualization, scatter plots, and correlation plots. Then, I test all hypotheses in the following manner:

For the first hypothesis, I test the relationship between the two defined constructs $Interactions$ and $Participation$ while controlling for each type of community interactions by using the following models:

$$Participation = \beta_0 + \beta_1 Interactions\ (all) \quad (1a)$$
$$Participation = \beta_0 + \beta_1 Interactions\ (positive) \quad (1b)$$
$$Participation = \beta_0 + \beta_1 Interactions\ (negative) \quad (1c)$$
$$Participation = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) \quad (1d)$$

The results of the first model indicate to what extent community interactions relate to user participation. The results of the second and third models measure how each type of interaction, positive and negative, individually relate to user participation. Finally, the last model controls for the type of community interactions and indicates if their sign (positive or negative) plays a significant role in their relationship with user participation. It is also important to stress that the results of these models serve as a basis for answering the subsequent hypotheses.

For the second hypothesis, I start with testing the relationships between the defined constructs $Interactions$ and $Cohesiveness$, followed by $Interactions$, $Cohesiveness$, and $Participation$, using the following models:

$$Cohesiveness = \beta_0 + \beta_1 Interactions\ (all) \quad (2a)$$
$$Cohesiveness = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) \quad (2b)$$
$$Participation = \beta_0 + \beta_1 Interactions\ (all) + \beta_2 Cohesiveness \quad (2c)$$
$$Participation = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) + \beta_3 Cohesiveness \quad (2d)$$

In mediation analysis, an absolute pre-requisite is that the independent variable has a significant effect on the mediator. So, the results of models (2a) and (2b) determine how the independent variables community interactions relate to the mediator community cohesiveness, and the results of models (2c) and (2d) explain how the independent variables community interactions and the mediator community cohesiveness relate to the dependent variable user participation. Finally, mediation analyses are

performed by combining models (2a) and (2c), as well as (2b) and (2d) to test the potential mediation effect of $Cohesiveness$ on the relationships between $Interactions$ and $Participation$.

For the third and final hypothesis, I begin with testing the relationships between the defined constructs $Interactions$ and $Diversity$, and then test the relationships between $Interactions$, $Diversity$, and $Participation$, using the following models:

$Diversity = \beta_0 + \beta_1 Interactions\ (all)$ (3a)
$Diversity = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative)$ (3b)
$Participation = \beta_0 + \beta_1 Interactions\ (all) + \beta_2 Diversity$ (3c)
$Participation = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) + \beta_3 Diversity$ (3d)

Like community cohesiveness, the results of models (3a) and (3b) determine to what extent the independent variables, community interactions, relate to the mediator activity diversity, and the results of models (3c) and (3d) measure how the independent variables, community interactions, and the mediator activity diversity relate to the dependent variable user participation. Finally, mediation analysis is performed by coupling models (3a) with (3c), and models (3b) with (3d) to investigate the potential mediation effect of $Diversity$ on the relationships between $Interactions$ and $Participation$.

4. Results

In this section, I first explore the data before reporting the results of the linear regression models and mediation analyses. Following this, I summarize the central relationships between the constructs and complete the conceptual framework. Finally, I conduct additional analyses and extend the conceptual framework.

4.1 Data analysis

Summary statistics of each variable are pictured below:

Table 2: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
interactions_total	1,119	70.5273	230.3159	1	3,340
interactions_positive	1,119	62.7158	201.6063	0	2,966
interactions_negative	1,119	7.8114	30.6745	0	405
participation	1,119	6.1551	4.6061	1.3542	41.7695
cohesiveness	1,119	0.1755	0.0395	0.1023	0.3294
diversity	1,119	0.0048	0.0007	0.0013	0.0076

As represented in Table 2, all types of community interactions (total, positive, negative) and user participation are unequally distributed, while community cohesiveness and activity diversity are equally distributed across subreddits. Also, all variables are measured on different scales, with community interactions showing the most significant values and activity diversity containing the smallest values. Finally, while the Mean value of community interactions and user participation are closer to the smallest value than the largest value, the Mean value of community cohesiveness and activity diversity are more centered, providing a glimpse of the distribution of each variable. To support these assumptions, several histograms are provided in Figure 4:

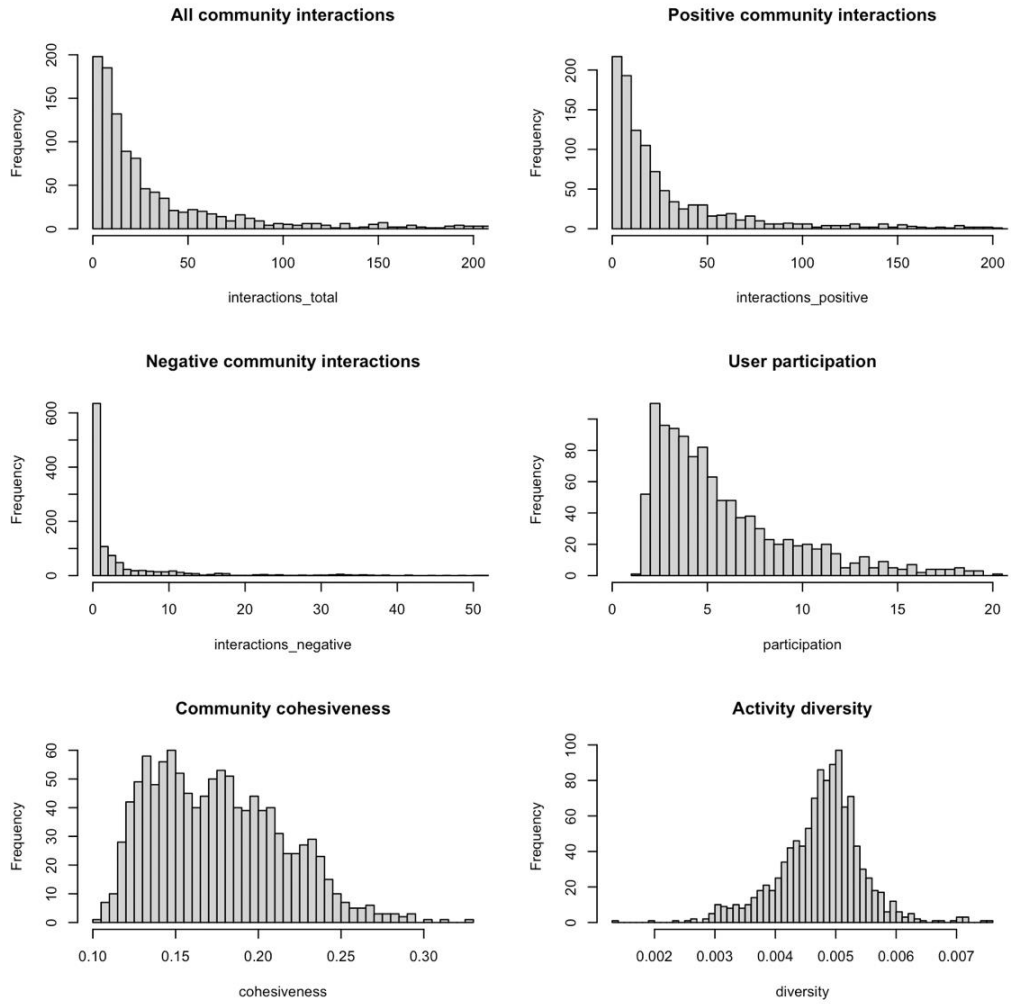

Figure 4: Histograms

Unsurprisingly, community interactions and user participation distributions follow a power law. As represented by the first four histograms, most communities have few interactions, and few communities have many interactions. On the other hand, the last two histograms show that community cohesiveness and activity diversity follow a relatively normal distribution, with fewer more-cohesive communities

than less-cohesive ones. An engaging way to visualize how community interactions and user participation are distributed among communities is to create networks of communities (Figure 5) and attach attributes to the size of their nodes.

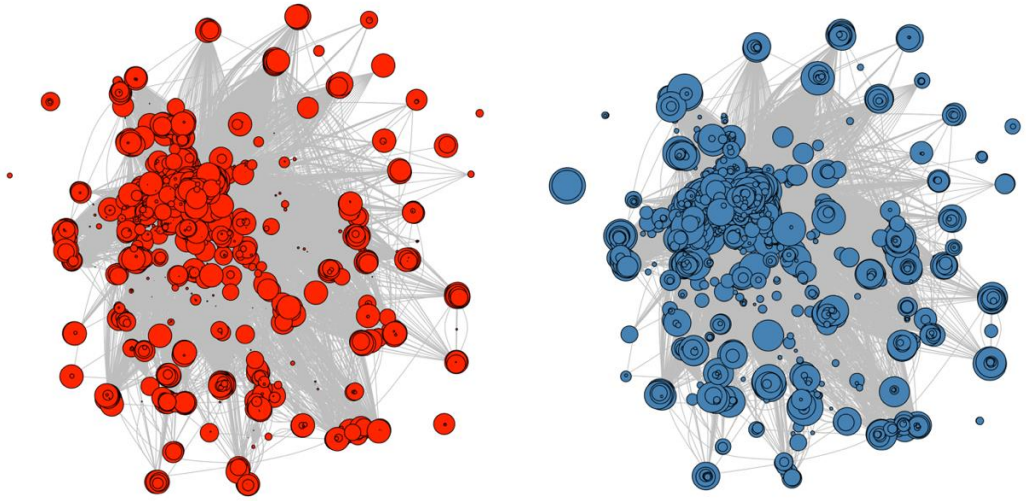

Figure 5: Networks of communities

While both graphs are networks of subreddits connected via hyperlinks, the nodes' size on the left graph (red nodes) represents community interactions, and the nodes' size on the right graph (blue nodes) represents user participation. According to these graphs, no obvious pattern can be discerned in the relationship between community interactions and user participation. However, more isolated communities, like those observed on the left and right ends of each graph (Figure 6), seem to have almost no interactions (i.e., small red nodes) but relatively high user participation on the right graph (i.e., big blue nodes).

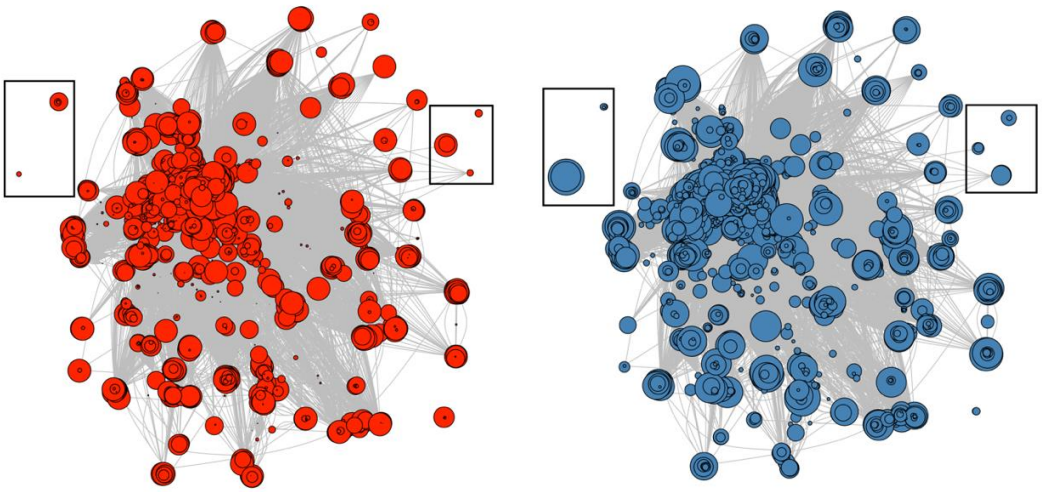

Figure 6: Networks of communities (isolated communities)

Additionally, communities sharing roughly the same number of interactions (i.e., red nodes sharing similar sizes and overlap), such as those at the top and bottom ends of each graph (Figure 7), seem to have varying quantities of user participation (i.e., blue nodes that differ in sizes and overlap) on the right graph.

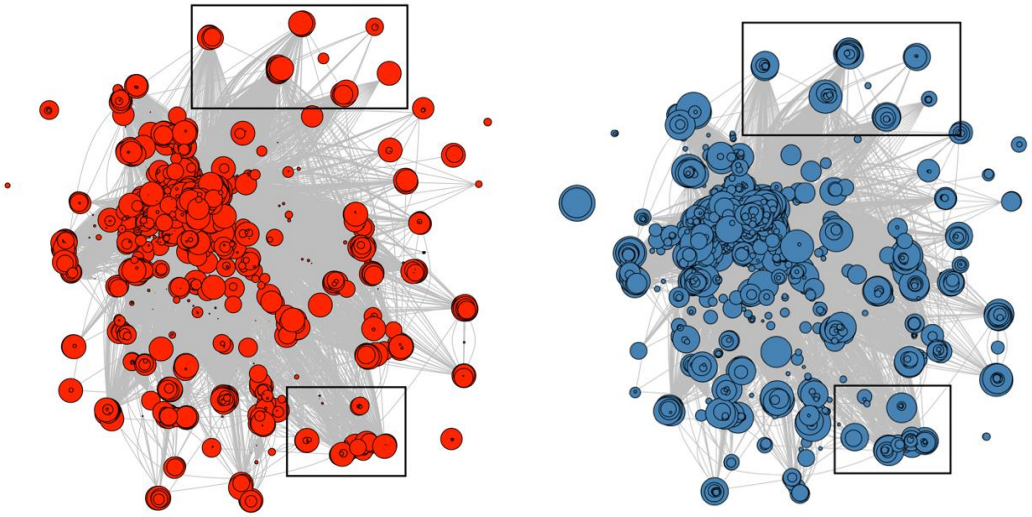

Figure 7: Networks of communities (overlapping communities)

These network graphs provide a first glance at the relationship between community interactions and user participation, which has yet to indicate any clear pattern. A more comprehensive way to investigate the relationships between the different constructs is to look at scatter plots (Figure 8) and correlation plots (Table 3).

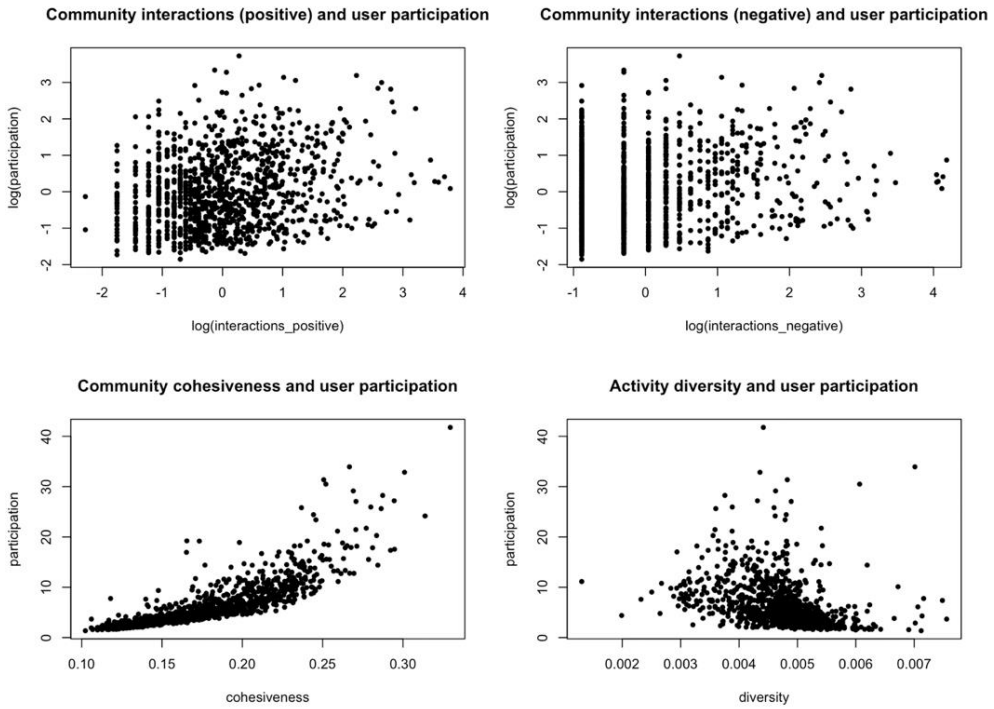

Figure 8: Scatter Plots (Note: plots 1 and 2 show standardized data)

By looking at scatter plots, it becomes clear that the relationship between community interactions and user participation is rather complex. While a slight positive relationship can be observed between positive community interactions and user participation, a relationship between negative community interactions and user participation is less apparent. On the other hand, the relationships between user participation and the two other constructs, community cohesiveness and activity diversity, are much more distinguishable. While user participation grows exponentially when community cohesiveness increases, it tends to decrease when activity diversity increases and shows more variations when activity diversity is lower. Overall, these plots indicate that community interactions and user participation have a relatively small relationship, while community cohesiveness and activity diversity are positively and negatively associated with the participation of users.

By looking at correlations (Table 3), a small positive relationship between all community interactions and user participation (0.12) appears to be very similar to that of community cohesiveness and user participation (0.12). However, the correlation between negative community interactions and user participation (0.08) is smaller than that of community cohesiveness (0.11) with user participation. Also, the correlation between all types of community interactions and activity diversity (Total: -04; Positive: -0.4; Negative: -0,3) suggests that the relationships between community interactions and activity diversity is minor or more complex. Finally, user participation is highly correlated with community cohesiveness (0.83) and negatively correlated with activity diversity (-0.37), as are community cohesiveness and activity diversity (-0.49). The negative relationship between community cohesiveness and activity diversity spurs interest because it indicates that they might mediate the effect of community interactions on user participation differently if they do so.

Table 3: Correlation Matrix

	interactions_total	interactions_positive	interactions_negative	participation	cohesiveness	diversity
interactions_total	1	1.00	0.94	0.12	0.12	-0.04
interactions_positive	1.00	1	0.93	0.13	0.13	-0.04
interactions_negative	0.94	0.93	1	0.08	0.11	-0.03
participation	0.12	0.13	0.08	1	0.83	-0.37
cohesiveness	0.12	0.13	0.11	0.83	1	-0.49
diversity	-0.04	-0.04	-0.03	-0.37	-0.49	1

Although preliminary, these simple statistics provide some interesting insights about the data and shed light on the directions of the hypotheses.

In terms of distribution, both types of community interactions and user participation are unequally distributed and follow a power law. While few communities have a lot of interactions, most of them have few interactions. Similarly, most communities are made of occasional users, and few of them are made of very active members. Finally, the two other constructs are relatively equally distributed. They

follow a relatively normal distribution, with most communities showing average cohesiveness/activity diversity and few being very or little cohesive/diverse.

Regarding relationships, positive community interactions are slightly correlated with user participation, and negative community interactions have an even smaller correlation. On the other hand, community cohesiveness and activity diversity significantly correlate with user participation, where user participation is strongly positively correlated with community cohesiveness and negatively correlated with activity diversity. Accordingly, community cohesiveness and activity diversity go in opposite directions.

So far, it is difficult to guess the magnitude and significance of the relationships between community interactions and user participation, leave alone the conditions under which these relationships hold (i.e., if community cohesiveness and activity diversity play a role in mediating this relationship). However, community cohesiveness and activity diversity are related in some way to user participation. The following section tests these relationships.

4.2 Linear regressions and mediation analyses

For this part, all variables are calculated on two different time periods, and all values are standardized. Regarding periodization, each variable is calculated over February – June 2014 and July – November 2014. Regarding standardization, the standardize function computes the root-mean-square of each variable using the following equation $\sqrt{\sum \frac{x^2}{(n-1)}}$, where x is a vector of the variable values and n is the number of variable values (Becker et al., 1988). The standardization results in a mean of 0 and a standard deviation of 1 for each variable. These manipulations increase robustness of causal effects between the different constructs and make the magnitude of all effects comparable. Finally, all mediation analyses are performed on 1000 bootstrap samples, and the 95% confidence interval is computed for each effect.

Importantly, when I write "all community interactions", I refer to the total number of community interactions represented by the variable $interactions\ (all)$ which is the sum of positive and negative community interactions such that $interactions\ (all) = interactions\ (positive) + interactions\ (negative)$. When I do not specify and write "community interactions", I refer to any of the three variable variables $interactions\ (all), interactions\ (positive), interactions\ (negative)$. Naturally, when I write "positive community interactions" and "negative community interactions", I refer to $interactions\ (positive)\ and\ interactions\ (negative)$ respectively.

4.2.1 Community interactions on user participation

To measure the impact of community interactions on user participation, I refer to models (1a-d) (Table 4). According to model (1a), all community interactions have a small positive effect on user participation (0.095; $p < 0.01$), which indicates that subreddits with a higher number of hyperlinks referencing them tend to be made of more participative users. To make the distinction between the type of interactions, models (1b) and (1c) show that positive and negative community interactions both have a positive individual effect on user participation, with only the effect of positive community interactions being significant (0.100; $p < 0.01$). According to these outputs, both types of community interactions share a similar relationship with user participation, but only positive community interactions can be established. As these regressions measure the effect of each type of interaction individually and do not control for the subreddit hyperlink sign, model (1d) demonstrates that positive community interactions have a positive effect on user participation (0.290; $p < 0.001$) while negative community interactions have a negative effect on user participation (-0.210; $p < 0.01$).

Table 4: Models 1a-d

	Dependent variable:			
	participation			
	(1a)	(1b)	(1c)	(1d)
interactions_total	0.095***			
	(0.031)			
interactions_positive		0.100***		0.290***
		(0.031)		(0.073)
interactions_negative			0.052	−0.210***
			(0.031)	(0.073)
Constant	−0.000	−0.000	−0.000	−0.000
	(0.031)	(0.031)	(0.031)	(0.031)
Observations	1,014	1,014	1,014	1,014
R^2	0.009	0.010	0.003	0.018
Adjusted R^2	0.008	0.009	0.002	0.016
Residual Std. Error	0.996	0.995	0.999	0.992
F Statistic	9.145***	10.256***	2.709	9.369***
Note:				*p<0.1; **p<0.05; ***p<0.01

According to these results, there is sufficient evidence to infer that more positive community interactions are associated with higher user participation. In comparison, a higher number of negative community interactions is associated with lower user participation, demonstrating that the type of interactions leads to a different impact of community interactions on user participation. As a result, the first hypothesis is fully supported.

Finding 1: *A higher number of positive (negative) community interactions is related to a higher (lower) user participation.*

The following paragraph analyses the role of community cohesiveness in this relationship and investigates its potential mediation effect.

4.2.2 The role of community cohesiveness

To measure the mediation effect of community cohesiveness, I first analyze the impact of community interactions on community cohesiveness and then the impact of community cohesiveness on user participation. To measure the effect of community interactions on community cohesiveness, I refer to models (2a-b) (Table 5). To measure the effects of community interactions and community cohesiveness on user participation, I refer to models (2c-d) (Table 5).

According to the results of model (2a), all community interactions are positively related to community cohesiveness (0.104; $p < 0.001$), but when I account for the type of interactions, model (2b) shows that only positive community interactions have a positive effect on community cohesiveness (0.163; $p < 0.05$) while negative community interactions have a negative but insignificant effect (-0.063; $p > 0.1$). These outcomes suggest that the type of community interactions influences their effect on community cohesiveness, with only positive community interactions having a positive relationship with user participation.

The results of model (2c) indicate that all community interactions and community cohesiveness positively affect user participation, but only community cohesiveness is statistically significant. Moreover, community cohesiveness (0.792; $p < 0.001$) has a much more substantial impact on user participation compared to all community interactions (0.013; $p > 0.1$). Accordingly, the cohesiveness of a subreddit is a more vital driver of user participation than the number of incoming hyperlinks redirecting users toward this subreddit. Also, due to the insignificant effect of all community interactions on user participation when accounting for community cohesiveness, community cohesiveness is likely embedded in the effect of all community interactions on user participation when the variable is not included in the model.

When controlling for the type of community interactions, the results of model (2d) demonstrate that positive community interactions are positively related to user participation (0.156; $p < 0.001$) and negative community interactions are negatively related to user participation (-0.153; $p < 0.001$). As in model (2c), community cohesiveness has a significant positive impact on user participation (0.790; $p < 0.001$) when controlling for the type of community interactions.

Table 5: Models 2a-d

	Dependent variable:			
	cohesiveness		participation	
	(2a)	(2b)	(2c)	(2d)
interactions_total	0.104***		0.013	
	(0.031)		(0.019)	
interactions_positive		0.163**		0.156***
		(0.073)		(0.044)
interactions_negative		−0.063		−0.153***
		(0.073)		(0.044)
cohesiveness			0.792***	0.790***
			(0.019)	(0.019)
Constant	−0.000	−0.000	0.000	0.000
	(0.031)	(0.031)	(0.019)	(0.019)
Observations	1,014	1,014	1,014	1,014
R^2	0.011	0.012	0.630	0.634
Adjusted R^2	0.010	0.010	0.629	0.633
Residual Std. Error	0.995	0.995	0.609	0.606
F Statistic	11.142***	6.136***	860.505***	584.117***
Note:				*p<0.1; **p<0.05; ***p<0.01

Thanks to these results, it is now possible to estimate the potential mediation effect of community cohesiveness on the relationship between all/positive community interactions and user participation (Table 6-7). According to the mediation analysis results (Table 6), about 86% (Prop. Mediated: 0.860; $p < 0.001$) of the relationship between all community interactions and user participation is explained by community cohesiveness, with a 95% confidence interval between 52% and 100%. This proportion is calculated by dividing the average causal mediation effect ACME (i.e., the effect of the mediator on the dependent variable) by the total effect (i.e., the sum of the average direct effect ADE of the independent variable and average indirect effect ACME of the mediator on the dependent variable). The average causal mediation effect of community cohesiveness (ACME: 0.083; $p < 0.001$) is positive and significant, and the average direct effect (ADE: 0.013; $p > 0.1$) is positive but trivial and insignificant. These results indicate that the effect of all community interactions on user participation is almost entirely mediated by community cohesiveness, leaving the effect of community interactions insignificant.

However, the type of interactions changes the effect of community interactions on user participation. Since only positive community interactions significantly affect community cohesiveness, I can only infer the mediation effect of community cohesiveness for positive community interactions (Table 7). Consequently, by controlling for the type of community interactions, the outputs of the mediation analysis indicate that 45% (Prop. Mediated: 0.452; $p < 0.01$) of the relationship between positive community interactions and user participation is explained by community cohesiveness, with the 95% confidence interval ranging between 20% and 76%. Moreover, the average causal mediation effect

(ACME: 0.129; $p < 0.01$) and average direct effect (ADE: 0.156; $p < 0.05$) are both significant this time. Naturally, the effect of negative community interactions on user participation is not mediated by community cohesiveness (Table 8 in appendices). These results indicate that the relationship between positive community interactions on user participation is partially mediated by community cohesiveness.

Table 6: Mediation cohesiveness on all interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.083	0.054	0.136	0.000
ADE	0.013	-0.027	0.098	0.594
Total Effect	0.096	0.039	0.218	0.000
Prop. Mediated	0.860	0.516	1.697	0.000

Table 7: Mediation cohesiveness on positive interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.129	0.035	0.311	0.006
ADE	0.156	0.034	0.289	0.014
Total Effect	0.284	0.121	0.570	0.004
Prop. Mediated	0.452	0.203	0.762	0.006

Consequently, there is sufficient evidence to infer that most of the effect of all community interactions on user participation goes through community cohesiveness. There is also sufficient evidence to infer that the relationship between positive community interactions and user participation is partially explained by community cohesiveness. However, there is not enough evidence to show that the impact of negative community interactions on user participation is mediated by community cohesiveness. As a result, the second hypothesis is partially supported.

Finding 2: *A higher number of (positive) community interactions is related to a higher community cohesiveness, which is related to a higher user participation.*

The following paragraph dives into the potential mediation effect of activity diversity.

4.2.3 The role of activity diversity

Like with community cohesiveness, I measure the mediation effect of activity diversity by first analyzing the effect of community interactions on activity diversity and then the impact of diversity on user participation. To measure the impact of community interactions on activity diversity, I refer to models (3a-b) (Table 9). To measure the effects of community interactions and activity diversity on user participation, I refer to models (3c-d) (Table 9).

According to the output models (3a-b), community interactions do not impact activity diversity. While both all community interactions (-0.048; $p > 0.1$) and positive community interactions (-0.076; $p > 0.1$)

are negatively related to activity diversity, negative community interactions are positively related to activity diversity (0.030; $p > 0.1$). However, none of these relationships is statistically significant. These results indicate that activity diversity cannot be considered a mediator of the effect of community interactions on user participation since a significant effect of community interactions on activity diversity is an absolute requirement to assume a mediation of activity diversity. On the other hand, the signs of the coefficients indicate a negative relationship between positive community interactions and activity diversity.

According to model (3c), all community interactions are slightly positively related to user participation (0.076; $p < 0.05$), and activity diversity is negatively related to user participation (-0.302; $p < 0.001$). When controlling for the type of interactions, model (3d) shows that positive community interactions are positively related to user participation (0.260; $p < 0.001$), negative community interactions are negatively related to user participation (-0.198; $p < 0.01$), and activity diversity conserves its negative effect (-0.300; $p < 0.001$). However, these outputs suggest that the impact of positive community interactions is more substantial than negative community interactions on user participation compared when controlling for community cohesiveness.

Table 9: Models 3a-d

	Dependent variable:			
	diversity		participation	
	(3a)	(3b)	(3c)	(3d)
interactions_total	−0.048		0.076**	
	(0.031)		(0.030)	
interactions_positive		−0.076		0.260***
		(0.073)		(0.069)
interactions_negative		0.030		−0.198***
		(0.073)		(0.069)
diversity			−0.302***	−0.300***
			(0.030)	(0.030)
Constant	−0.000	−0.000	0.000	0.000
	(0.031)	(0.031)	(0.030)	(0.030)
Observations	1,014	1,014	1,014	1,014
R^2	0.002	0.003	0.100	0.108
Adjusted R^2	0.001	0.001	0.098	0.105
Residual Std. Error	0.999	1.000	0.950	0.946
F Statistic	2.334	1.295	55.922***	40.608***
Note:			*p<0.1; **p<0.05; ***p<0.01	

Accordingly, there is insufficient evidence to infer that activity diversity explains the relationships between community interactions and user participation (Tables 10-12 in appendices). Moreover, the

effect of community interactions on activity diversity, although not statistically significant, is contrary to the assumption made in the third hypothesis. As a result, the third and final hypothesis is rejected.

Finding 3a: *A higher (lower) number of community interactions is not related to a higher (lower) activity diversity.*
Finding 3b: *A higher (lower) activity diversity is related to a lower (higher) user participation.*

The following section summarizes this study's findings and completes the conceptual framework. In addition, further analyses are provided on activity diversity in the section afterward.

4.3 Summary results

As a result, the conceptual framework is completed as such:

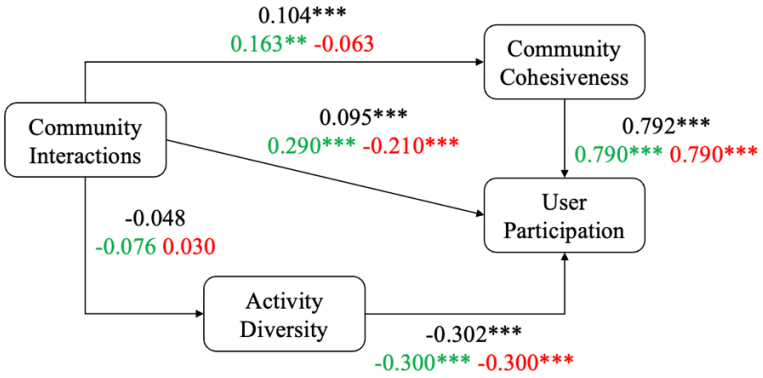

Figure 9: Conceptual Framework (Results)

The positive effect of all community interactions (black) on user participation is 0.095, the positive effect of positive community interactions (green) on user participation is 0.290, and the negative effect of negative community interactions (red) on user participation is -0.201. Also, the effect of all community interactions and positive community interactions on user participation is partially mediated by community cohesiveness, with the indirect effect of all community interactions being $0.104 \times 0.792 = 0.083$, and the indirect effect of positive community interactions on user participation being $0.163 \times 0.790 = 0.129$. Finally, the effect of community interactions on user participation is not mediated by activity diversity.

4.4 Additional analyses

Activity diversity, as defined in methodology, is a slightly more sophisticated construct than community cohesiveness. While community cohesiveness estimates the average user retention of a subreddit, activity diversity is composed of two dimensions; the average user exploration and the average user

dispersion of community members across the platform for a given subreddit. Although not defined separately in the conceptual framework, I find it interesting to dive deeper into this construct and examine how these two dimensions relate to community interactions and user participation.

4.4.1 The (complex) role of activity diversity

User exploration is defined as the proportion of subreddits in which the average user participated for a given subreddit S and is represented by the following equation[1]:

$$Exploration(S) = \frac{1}{U}\sum_{i} u_i(\frac{p_i}{P})$$

Where U is the total number of users who participated in the subreddit, p_i the number of subreddits in which u_i participated, and P the total number of subreddits.

User dispersion is defined as the activity allocation of the average user among all subreddits for a given subreddit S and is defined by the following equation[1]:

$$Dispersion(S) = \frac{1}{U}\sum_{i} u_i(\frac{1}{\sigma(\vec{w}_i)})$$

Where $\vec{w}_i$ is a vector representing the number of replies w_j of user u_i made on each subreddit S_j and $\sigma(\vec{w}_i)$ the standard deviation of the vector $\vec{w}_i$.

In this section, I investigate the roles of $Exploration$ and $Dispersion$ on the relationship between community interactions and user participation by testing the following additional models and performing mediation analyses according to the results of these models.

$Exploration = \beta_0 + \beta_1 Interactions\ (all)$ (4a)
$Exploration = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative)$ (4b)
$Participation = \beta_0 + \beta_1 Interactions\ (all) + \beta_2 Exploration$ (4c)
$Participation = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) + \beta_3 Exploration$ (4d)

$Dispersion = \beta_0 + \beta_1 Interactions\ (all)$ (5a)
$Dispersion = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative)$ (5b)

[1]For more details on the intuition behind this equation, please refer to the definition of activity diversity p20, 21.

$Participation = \beta_0 + \beta_1 Interactions\ (all) + \beta_2 Dispersion$ (5c)

$Participation = \beta_0 + \beta_1 Interactions\ (positive) + \beta_2 Interactions\ (negative) + \beta_3 Dispersion$ (5d)

The first thing I noticed about these sub-constructs is that, like community cohesiveness and activity diversity, user exploration and user dispersion are negatively related but in the form of a non-linear relationship (Figure 10). While subreddits made of users who stay among the same few subreddits (low exploration) tend to equally distribute their activity among these few subreddits (high dispersion), subreddits made of users who explore the platform (high exploration) tend to have users that unequally participate in these subreddits (low dispersion).

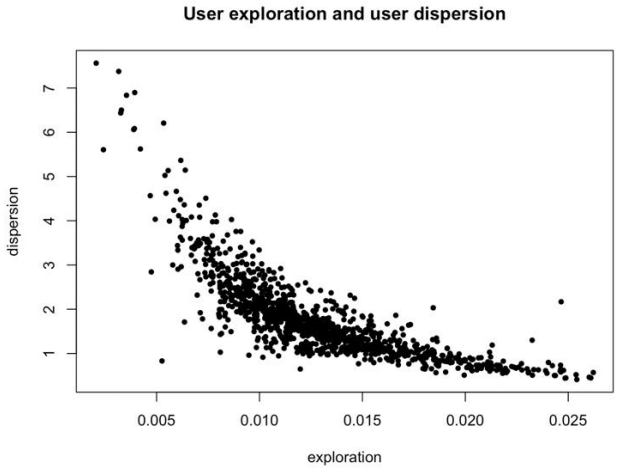

Figure 10: Scatter Plot (user exploration vs. user dispersion)

4.4.2 The role of user exploration

By looking at models (4a-b) (Table 13), controlling for the type of interactions is necessary to observe a relationship between community interactions and user exploration. While positive community interactions are negatively related to user exploration (-0.226; $p < 0.01$), negative community interactions are positively related to user exploration (0.264; $p < 0.001$), and like activity diversity, both types of community interactions together have an insignificant impact on user exploration. On the other hand, model (4c) (Table 13) shows that all community interactions have a positive statistically significant effect on user participation (0.097; $p < 0.01$), and user exploration has a negative impact on user participation (-0.326; $p < 0.001$). Finally, model (4d) (Table 13) indicates that positive community interactions are positively related to user participation (0.214; $p < 0.01$), while negative community interactions (-0.126; $p < 0.1$) and user exploration (-0.319; $p < 0.001$) are both negatively related to user participation. These insights reveal that each type of community interaction has an opposite effect on user exploration compared to its effect on user participation.

Table 13: Models 4a-d

	Dependent variable:			
	exploration		participation	
	(4a)	(4b)	(4c)	(4d)
interactions_total	0.020		0.097***	
	(0.031)		(0.030)	
interactions_positive		−0.226***		0.214***
		(0.073)		(0.069)
interactions_negative		0.264***		−0.126*
		(0.073)		(0.069)
exploration			−0.326***	−0.319***
			(0.030)	(0.030)
Constant	−0.000	−0.000	−0.000	−0.000
	(0.031)	(0.031)	(0.030)	(0.030)
Observations	1,014	1,014	1,014	1,014
R^2	0.0004	0.013	0.115	0.119
Adjusted R^2	−0.001	0.011	0.113	0.116
Residual Std. Error	1.000	0.994	0.942	0.940
F Statistic	0.386	6.660***	65.811***	45.353***
Note:				*p<0.1; **p<0.05; ***p<0.01

According to the mediation analyses (Tables 15-16), 25% of the relationship between positive community interactions and user participation is mediated by user exploration (Prop. Mediated: 0.252; $p < 0.001$), with a 95% confidence interval between 10% and 70%. Additionally, 40% of the relationship between negative community interactions and user participation is mediated by user exploration (Prop. Mediated: 0.401; $p < 0.01$), with a 95% confidence interval between 17% and 100%. Hence, these results indicate that user exploration partially mediates the effect of positive and negative community interactions on user participation, with a higher effect on negative community interactions.

Table 15: Mediation exploration on positive interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.072	0.028	0.180	0.000
ADE	0.214	0.036	0.449	0.020
Total Effect	0.286	0.127	0.567	0.000
Prop. Mediated	0.252	0.098	0.701	0.000

Table 16: Mediation exploration on negative interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.084	-0.215	-0.037	0.000
ADE	-0.126	-0.304	0.019	0.084
Total Effect	-0.210	-0.455	-0.082	0.004
Prop. Mediated	0.401	0.170	1.137	0.004

4.4.3 The role of user dispersion

By looking at models (5a-b) (Table 17), all community interactions (-0.075; $p < 0.05$) and negative community (-0.212; $p < 0.01$) interactions are negatively related to user dispersion, and positive

community interactions are positively related to user dispersion (0.122; $p < 0.1$). Moreover, when accounting for the type of interactions, each impact of community interactions on user dispersion is more substantial. According to model (5c) (Table 17), both all community interactions (0.113; $p < 0.001$) and user dispersion (0.282; $p < 0.001$) are positively related to user participation, while for model (5d) (Table 17), negative community interactions are negatively related to user participation (-0.153; $p < 0.05$). Naturally, positive community interactions (0.256; $p < 0.001$) and user dispersion (0.276; $p < 0.001$) are positively related to user participation, according to this model. These results indicate that the relationship between community interactions and user dispersion is comparable to that between community interactions and user participation.

Table 17: Models 5a-d

	Dependent variable:			
	dispersion		participation	
	(5a)	(5b)	(5c)	(5d)
interactions_total	−0.075**		0.113***	
	(0.031)		(0.030)	
interactions_positive		0.121*		0.256***
		(0.073)		(0.070)
interactions_negative		−0.212***		−0.153**
		(0.073)		(0.070)
dispersion			0.282***	0.276***
			(0.030)	(0.030)
Constant	0.000	0.000	−0.000	−0.000
	(0.031)	(0.031)	(0.030)	(0.030)
Observations	1,014	1,014	1,014	1,014
R^2	0.006	0.013	0.088	0.093
Adjusted R^2	0.005	0.011	0.086	0.091
Residual Std. Error	0.998	0.994	0.956	0.954
F Statistic	5.732**	6.730***	48.882***	34.695***
Note:				*p<0.1; **p<0.05; ***p<0.01

According to the mediation analyses (Table 18-20), user dispersion mediates 23% (Prop. Mediated: -0.229; $p < 0.001$) of the effect of all community interactions on user participation, with a 95% confidence interval between 7% and 72%. This statistic holds on an average direct effect ADE of -0.021 ($p < 0.001$) and an average causal mediation ACME effect of 0.113 ($p < 0.01$). When controlling for the type of community interactions, user dispersion mediates 12% of the impact of positive community interactions (Prop. Mediated: 0.116; $p < 0.1$; 95% CI ranging between 0% and 30%) on user participation, and 28% (Prop. Mediated: 0.276; $p < 0.01$; 95% CI ranging between 10% and 78%) of the effect of negative community interactions on user participation. These outputs suggest that user dispersion partially mediates the relationships between community interactions and user participation, with a more substantial effect on the impact of negative community interactions.

Table 18: Mediation dispersion on all interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.021	-0.041	-0.009	0.000
ADE	0.113	0.054	0.235	0.000
Total Effect	0.092	0.034	0.207	0.000
Prop. Mediated	-0.229	-0.722	-0.069	0.000

Table 19: Mediation dispersion on positive interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.034	-0.001	0.082	0.056
ADE	0.256	0.107	0.533	0.002
Total Effect	0.289	0.132	0.568	0.000
Prop. Mediated	0.116	-0.004	0.303	0.056

Table 20: Mediation dispersion on negative interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.058	-0.115	-0.024	0.004
ADE	-0.153	-0.343	-0.021	0.032
Total Effect	-0.212	-0.419	-0.071	0.004
Prop. Mediated	0.276	0.098	0.781	0.008

After diving into the dynamics of the two sub-constructs of activity diversity, there is sufficient evidence to infer a partial mediation of user exploration and user dispersion on the impact of community interactions on user participation. More specifically, the mediation effect is more potent on negative community interactions for both dimensions, with user exploration and user dispersion negatively related. Finally, user exploration is negatively related to user participation, while user dispersion is positively related to user participation.

4.4.4 Summary additional results

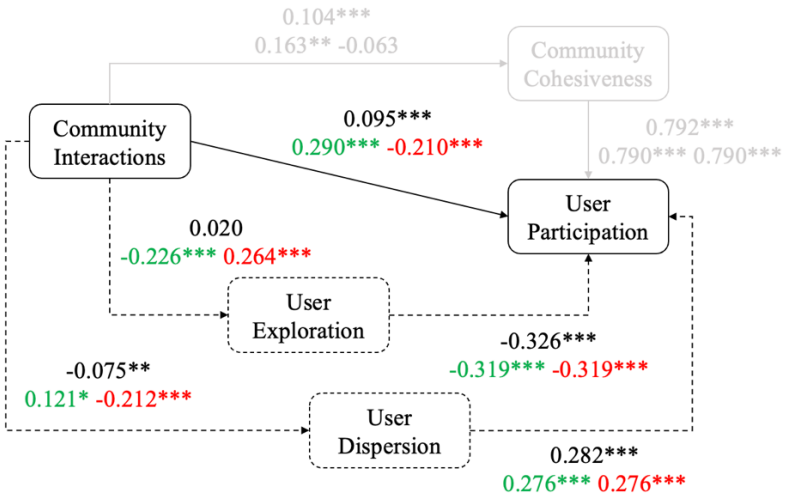

Figure 11: Conceptual Framework (Additional results)

The effect of positive (green) and negative (red) community interactions on user participation is partially mediated by user exploration, with the indirect effect of positive community interactions being $-0.226 \times -0.319 = 0.072$, and the indirect effect of negative community interactions on user participation being $0.262 \times -0.319 = -0.084$. The effect of all community interactions (black) and negative community interactions on user participation is partially mediated by user dispersion, with the indirect effect of all community interactions being $-0.075 \times 0.282 = -0.021$, and the indirect effect of negative community interactions on user participation being $-0.212 \times 0.276 = -0.058$.

5. Discussion

In this section, I discuss the results of this study and answer the research question. First, I discuss how findings relate to the hypotheses, share my thoughts on the potential reasons for these outcomes, and answer the research question. Following this, I explain the implications behind these results, how they can help different stakeholders achieve different outcomes, and how they contribute to the current body of literature. Finally, I describe the main limitations of this study, give potential areas of improvement, and suggest future research directions.

5.1 Findings and answer to the research question

This study analyzes the relationships between community interactions, community cohesiveness, activity diversity, and user participation. Each construct is operationalized as incoming subreddit hyperlinks, average subreddit user retention, average subreddit user activity diversity, and the average number of user comments per subreddit, respectively.

The first important insight about the data is the uneven distribution of community interactions and user participation. While most subreddits have few hyperlinks redirecting users to them, a small proportion of subreddits are mentioned many times on the platform. Also, the data shows that Reddit has few subreddits with engaged users (high user participation) and many subreddits whose users tend to participate occasionally (low user participation). These insights make sense in the context of this study because community interactions and user participation are represented by network statistics, which according to previous research (Tenorio-Fornés et al., 2022) and theory (Aggarwal, 2011), usually follow a power law distribution. On the other hand, community cohesiveness and activity diversity follow a normal distribution, which indicates that most subreddits retain about the same proportion of users, and few subreddits are made of loyal or casual users. Similarly, a large proportion of subreddits share a similar portfolio of diverse users, and a small proportion of subreddits are made of "homebodies" or "travelers".

Following this, visualizing the relationships between community interactions and user participation does not indicate any clear pattern. On the other hand, community cohesiveness and activity diversity are positively and negatively related to user participation. Moreover, the exponential relationship between community cohesiveness and user participation shows that the longer users stay in a subreddit, the more likely they are to be highly involved in this subreddit. Finally, subreddits with a low activity diversity share various levels of user participation, and subreddits with diverse users are associated with low levels of participation. These patterns suggest that subreddits whose users gravitate among a restricted number of subreddits do not necessarily show a higher or lower user engagement than subreddits whose users explore the platform. However, subreddits with an exceptionally high activity diversity inevitably tend to be limited in terms of participation at the user level, which supports Backstrom et al. (2018)'s findings. It also demonstrates that users exposed to numerous contents cannot focus their attention on some specific subreddits, as their time and effort on the platform are finite. A phenomenon called "diversity-bandwidth trade-off" by Aral & Van Alstyne (2011).

After running the linear models, the relationship between community interactions and user participation becomes more apparent, and the type of interactions proves to be an essential factor to consider. Positive subreddit hyperlinks are positively related to the participation of users (0.290; $p < 0.001$), while negative subreddit hyperlinks are negatively related to user participation (-0.210; $p < 0.01$). Also, not accounting for the type of interactions (positive vs. negative subreddit hyperlink) results in a trivial relationship between all community interactions and user participation (0.095; $p < 0.01$), which supports the idea that the actual effect of each type of interaction is averaged out when not considered. These effects also align with previous research (Kumar et al., 2018; Krohn & Weninger, 2022) and lay the foundation to study the drivers of these relationships.

Accordingly, community cohesiveness is crucial in the relationship between community interactions and user participation. Specifically, the construct explains almost entirely (86%; $p < 0.001$) the effect of all subreddit hyperlinks on user participation and partially (45%; $p < 0.01$) the effect of positive community interactions on user participation. A reasonable explanation for this finding is that increased participation in the referenced subreddit originates from new users who feel integrated into the subreddit when this one displays a stronger sense of community (Hsieh et al., 2013). Another potential reason is that positive subreddit hyperlinks often serve as community recommendations for users who post on the wrong subreddit. Hence, recommending a more relevant, or even more niche, subreddit to inexperienced users could explain the role of community cohesiveness in increasing participation when a subreddit is referenced (i.e., positive subreddit hyperlink). Nevertheless, community cohesiveness does not mediate the impact of negative subreddit hyperlinks on user participation. This last finding is surprising given the results of previous research (Kumar et al., 2018), where negative subreddit hyperlinks result in long-term adverse effects for the attacked community.

Finally, activity diversity does not mediate the relationship between community interactions and user participation, but its two sub-constructs, user exploration and user dispersion, do. While positive subreddit hyperlinks are associated with a lower user exploration and a higher user dispersion, negative subreddit hyperlinks are associated with a higher user exploration and a lower user dispersion. On top of that, user exploration is negatively related to user participation, and user dispersion is positively related to user participation. For this reason, the adverse effect of negative subreddit hyperlinks on user participation is neither explained by a lower community cohesiveness nor a higher activity diversity but by a higher exploration of users, where users potentially leave the subreddit, and a lower user dispersion, where users likely try new subreddits after leaving their home subreddit. Respectively, user exploration and user dispersion mediate 40% ($p < 0.01$) and 28% ($p < 0.01$) of the relationship between negative community interactions and user participation.

To answer the research question "*How community interactions relate to user participation on Reddit*", all community interactions and positive community interactions relate to user participation through community cohesiveness, and negative community interactions relate to user participation through user exploration and user dispersion. More specifically, 86% ($p < 0.001$) of the effect of all community interactions on user participation (0.095; $p < 0.01$) goes through community cohesiveness, 45% ($p < 0.01$) of the effect of positive community interactions on user participation (0.290; $p < 0.001$) goes through community cohesiveness, and 40% ($p < 0.01$) and 28% ($p < 0.01$) of the effect of negative community interactions on user participation (-0.210; $p < 0.01$) goes through user exploration and user dispersion respectively.

5.2 Managerial implications and research contribution

The result of this research has implications for platform developers, policymakers, and moderators of online communities. As for platform developers, I recommend designing algorithms that promote (positive) community hyperlinks if the goal is to stimulate user participation. Moreover, given the possible uneven activity levels on community platforms (i.e., power law distribution of user participation among communities), engineers could tune these algorithms to emphasize posts whose hyperlinks promote low-activity communities. It would simultaneously reward users who create new communities, promote new communities, and contribute to the overall platform growth, a tripartite benefit. Similarly, other algorithms could play down negative community hyperlinks that target communities with a low user dispersion (i.e., subreddits whose users unevenly distribute their activity on the platform), as user dispersion tends to explain the negative impact of negative community interactions on user participation.

Furthermore, policymakers could implement strict guidelines on community hyperlinks to protect communities from a potential decline in user participation. For instance, community hyperlinks

intended to criticize or leave negative comments on the reference subreddits could be banned or severely limited on the platform. On the other hand, it implies solid moderation from users and poses an ethical challenge. Such regulations would protect target communities against a drop in user engagement; however, they could go against some fundamental principles like free speech.

Finally, moderators in charge of communities lacking identity (i.e., communities usually displaying low cohesiveness) should not encourage their users to promote the community across the platform because it would encourage them to explore other communities (i.e., participating in other subreddits) at the expense of contributing to their home community. On the contrary, these users should focus on building the community identity and let other users recommend their community across the platform.

This work contributes to theories about online communities and user activity. More specifically, this research attempts to provide an empirical explanation of the effect of community interactions on user participation, where this effect is explained by different community-level constructs such as community cohesiveness and activity diversity. While online communities are an established topic, community interactions constitute a more niche and explorative area of research at the time of this study, for which the body of literature is limited to a few studies (Belak et al., 2012; Kumar et al., 2018; Datta & Adar, 2019; Krohn & Weninger, 2022). As a result, this study strives to relate community interactions to a broader corpus of research and connect the dots between several meaningful aspects of online communities, such as user participation, community cohesiveness, and activity diversity.

Correspondingly, I propose new measures of community cohesiveness and activity diversity and demonstrate the dynamics of the latter. For community cohesiveness, I developed a measure that reflects the capacity of a community to retain its users over time. For activity diversity, I elaborated a dynamic measure that captures the exploration and dispersion of its community members across the platform. On top of that, each construct is operationalized at the user level to make its values comparable across communities. Finally, this research is one of few that combines network data at two levels (i.e., networks of networks).

5.3 Limitations and future directions

The first limitation of this study is the sample data. While my research connects to a recent body of literature, it relies on less recent sample data dating from 2014. Also, my sample contains over one thousand communities, while Reddit was made of over 340,000 subreddits as of January 2014, according to u/Aschebescher's post on r/dataisbeautiful. As a result, my sample combines two pre-processed sample data from Hamilton et al. (2017) and Kumar et al. (2018), where the sample of communities is limited to the common timespan of the two datasets (i.e., 1119 usable subreddits against 36,000 provided) and the sample of users limited to the pre-selection made by the authors (i.e., users

who participated at least 50 times to the website in 2014, representing the top 20% of users). Another limitation of this research is the data aggregation and choice of methods. While my data contains rich information measured over several months, I aggregate the effects over two time periods, leaving out potential dynamic effects. Mediation analysis relies on linear regression models, so I did not account for potential user participation, community cohesiveness, or activity diversity variations over time. Finally, this study is limited by the variable definitions attributed to each construct which are based on my understanding of the literature and generalized over a combination of different authors' definitions. While some researchers provide different definitions (e.g., Dover et al., 2020), and others rely on different measurements (e.g., Waller & Anderson, 2019), I strived to provide the most accurate approximation of the constructs given the literature and empirical setting. Nevertheless, the variables defined in this study cannot perfectly reflect the factors measured in previous research.

That being said, the present work opens the door to further research. While my study relies entirely on Reddit, other popular community websites such as Stack Exchange, Stack Overflow, or Baidu could constitute optimal empirical settings to generalize my findings and investigate user participation from another angle (e.g., other centrality measures and network density) or context. Additionally, exploring the potential variation of effects by community topic could help understand under which circumstances and possibly "why" some external factors play a role in the impact of community interactions on the engagement of users. Another exciting avenue could incorporate content-related factors such as the popularity of posts and type of content (e.g., text, images, videos) or system-related factors such as strictness of community policies and the number of upvotes. Also, investigating the moderation effects of the presented constructs or additional factors could constitute a perfect second chapter to my approach. Going further, incorporating dynamic effects may provide more details about the results of this analysis while potentially demystifying the influence of time-related factors or events. Appropriate methods to enrich my analysis include Granger Causality (Zhao & Luo, 2019) and Transfer Entropy (Korbel et al., 2019). Finally, the lack of mediation of community cohesiveness on negative community interactions and the absence of relationships between activity diversity and community interactions calls for considering different measurements of these constructs, preferably in different contexts.

6. Conclusion

This study aims to explain the relationship between community interactions as subreddit hyperlinks and user participation as user comment replies on Reddit. For this, I theorized that community interactions impact user participation through two primary constructs; community cohesiveness and activity diversity, where the former operationalizes the average user retention of a community, and the latter captures the average exploration and dispersion of users across the platform for a given community. Also, I controlled for the type of community interaction (positive or negative) and the size of communities by defining all constructs at the user level. Accordingly, I developed three hypotheses; one assumes a relationship between community interactions and user participation depending on the sign of community interactions, and two suggest a mediation effect of community cohesiveness and activity diversity on this relationship. To measure these effects, I combined a couple of network data and performed a series of linear regressions and mediation analyses. Results show that 1. Positive community interactions are related to higher user participation, while negative community interactions are related to lower user participation, 2. Community cohesiveness mediates the relationships between (positive) community interactions and user participation, and 3. Activity diversity has no mediation effects and is negatively related to user participation. Besides, I decomposed activity diversity into two sub-constructs; user exploration and user dispersion, and demonstrated that each dimension has an opposite (mediation) effect on user participation, which illustrates the complexity of activity diversity. Following this, I discussed the potential reasons behind the main findings of this research and answered the research question. Finally, I provided actionable recommendations to different stakeholders, enumerated the limitations of this study, and suggested potential avenues for further research.

7. References

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8. Appendices

Table 8: Mediation cohesiveness on negative interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.050	-0.209	0.029	0.250
ADE	-0.153	-0.286	-0.050	0.010
Total Effect	-0.203	-0.452	-0.060	0.004
Prop. Mediated	0.245	-0.269	0.601	0.246

Table 10: Mediation diversity on all interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.014	0.003	0.039	0.006
ADE	0.076	0.024	0.177	0.002
Total Effect	0.090	0.033	0.203	0.000
Prop. Mediated	0.161	0.032	0.383	0.006

Note: Prop. Mediated 0.161 ($p < 0.01$) cannot be considered (see 4.2.3, p34).

Table 11: Mediation diversity on positive interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.023	-0.005	0.090	0.102
ADE	0.260	0.101	0.481	0.004
Total Effect	0.283	0.127	0.561	0.000
Prop. Mediated	0.081	-0.018	0.302	0.102

Table 12: Mediation diversity on negative interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.009	-0.066	0.016	0.432
ADE	-0.198	-0.387	-0.069	0.004
Total Effect	-0.207	-0.439	-0.072	0.004
Prop. Mediated	0.044	-0.136	0.248	0.436

Table 14: Mediation exploration on all interactions

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	-0.006	-0.026	0.005	0.264
ADE	0.097	0.040	0.220	0.000
Total Effect	0.091	0.035	0.205	0.000
Prop. Mediated	-0.070	-0.329	0.057	0.264