| | |
|---|---|
| Total number of active users | 3,831,147 |
| Total number of questions | 15,711,957 |
| Total number of answers | 24,492,236 |
| Mean reputation of active users | 111 |
| Mean number of badges earned by active users | 22 |
| Mean year when users joined the site | 2015 |

**Table 1: General statistics of users' activities in our dataset.**

also improve the functioning of the site itself [23]. The reputation points of users on Stack Overflow along with community activity dynamics are good predictors of the long-term value of questions and answers [2]. But, what attributes these virtual rewards can signal about users themselves is not yet well understood.

**Research Questions.** In this paper, we focus on finding important markers of user attributes since they are known to relate to dynamics of identity, crowdlearning, social benefits and societal acceptance [5, 36]. Specifically, we ask:

**RQ1:** According to Stack Overflow users, what social qualities (if any) do reputation scores and badges intend to signal?

**RQ2:** To what extent do these game elements actually signal or indicate the qualities that users expect them to?

The paper most closely related to ours is that of Trockman, et al [35]. They analyze various categories of badges such as Quality Assurance, Dependency Management, etc., in the `npm` ecosystem on Github as signals of *repository properties* such as dependency freshness, test suite quality and popularity. Some of these signals are subjective. Also, maintainers of the repositories can choose which badges they wish to display and which they do not. We consider Stack Overflow with a completely different and more complex system of reputation points and badges that it awards *to users* and is based on objective, pre-defined metrics [3].

We summarize our contributions below.

- We conduct a survey of Stack Overflow users and draw preliminary insights about how they view reputation points and badges as indicators of various social qualities.
- We perform empirical investigations on a large dataset of 3,831,147 users and the complete time-stamped history of their actions on Stack Overflow spanning a decade.
- Employing nonlinear regression models, we find that the presence of certain non-trivial badges correlates with higher popularity and impact. We also provide evidence that badges add more explanatory power compared to reputation scores.
- Statistical analyses of user activity show distinct differences in patterns of engagement between popular and impactful users.

Through these findings, we shed new light onto the role of virtual rewards in studying user qualities on crowdlearning platforms.

## 2 THEORETICAL FRAMEWORK

The widespread adoption of game elements on Stack Overflow invites a deeper examination of their effects on its users. Reputation scores are received for taking various positive actions whereas badges are awarded for "being especially helpful". We argue that given the variety of actions rewarded through reputation scores and badges, they are important signals of underlying qualities of users. We thus investigate their value from a signaling perspective.

**Adverse Selection.** Users on Stack Overflow possess different levels of information about various topics as well as other users on the platform. Users have a better understanding of their own expertise and limitations. They thus choose to participate selectively in order to maximize their benefits. Users however, tend to be uncertain about the preferences of heterogeneous audiences in terms of how they will respond to their actions. At the same time, the audience's qualitative assessment of users' abilities is based on limited information. Such a state where neither party has complete knowledge about the other is called information asymmetry [32]. This causes adverse selection, i.e. bias towards only particular kinds of actions [30]. For instance, most individuals prefer high returns and so they differentially choose low-hanging fruits, and broadly useful actions, while a few others may prefer more niche and challenging questions. As a result, participation is severely affected.

**Digital Signaling.** Signaling is a well-studied and popular solution to the problem of adverse selection [20, 32]. Signals are images, symbols and signs that allow users to communicate information and meaning with appropriate context. Signals that are costly to generate for the signaler and cognitively easy to process for the observer tend to be very reliable [11]. The design of sets of such assessment signals can specifically combat the inefficiencies arising due to information asymmetry [15]. The audience on Stack Overflow upvotes or downvotes posts to indicate that they approve or disapprove of them. This is a basic signal that is cheap to produce. Conversely, reputation scores and badges can help highlight deep technical qualities of a user since they require significant effort to achieve. This allows the user to potentially make better decisions in the future and the audience to gain more knowledge about him/her.

**Gamification.** Gamification is the use of game design elements in non-game contexts [14]. Badges on Stack Overflow are automatically earned by users based on their performance, unlike Github, where they are voluntarily displayed [7]. A single badge can holistically combine multiple qualitative actions whereas reputation points can be earned for every positive unit of action. This involves users in a social environment thereby motivating increased participation. In this paper, we consider game elements such as reputation scores and badges to be *digital signals* and investigate whether they are indicative of the performance and qualities of users.

## 3 DATA DESCRIPTION

Our experiments are conducted on a publicly available dataset containing all individual time-stamped actions of Stack Overflow users from the site's inception on July 31, 2008 to June 5, 2018 [33]. Table 1 describes a summary of the general statistics of our data.

**Reputation.** Reputation[1] scores are officially considered a "rough measurement of how much the community trusts you". Reputation is earned (or lost) when a user's question or answer is upvoted (or downvoted), when an answer is marked accepted by the user who originally asked the question, when bounties are received (or spent), or when suggested edits are accepted.

**Badges.** Badges are awarded in addition to reputation scores when the corresponding pre-defined set of actions and/or reactions are performed. They can be classified in two primary ways.

[1] https://stackoverflow.com/help/whats-reputation