Volunteers' Engagement in Human Computation for Astronomy Projects

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The results of a volunteer engagement characterization study in two astronomy projects (Galaxy Zoo and the Milky Way Project) found a diversity of engagement patterns in terms of frequency, daily productivity, duration of typical contribution session, and the amount of time devoted to the project.

Over the past few decades, many studies have focused on increasing the performance of silicon-based computational systems. As a result, much progress has been made, allowing increasingly complex applications to be designed and executed. But despite these advances, there are still tasks that can't be accurately and efficiently performed even when the most sophisticated algorithms and computing infrastructures are used[1]—for example, those tasks related to natural language processing, image understanding, and creativity. A common factor in these kinds of tasks is their suitability to human abilities—humans can solve them with high efficiency and accuracy.

To take advantage of these human abilities, a new computing approach—called *human computation*—has emerged to let humans perform the tasks for which there's still no satisfactory solution via today's silicon-based computers.[1] Several human computation streams, such as games with a purpose,[2] marketplaces,[3] and volunteer thinking,[4] have arisen over the years. In this study, we focus on *volunteer thinking projects*, which gather volunteers willing to execute human computation tasks on citizen-science platforms.

Volunteer thinking projects are analogous to volunteer computing projects, such as SETI@home.[5] The main difference is that in volunteer computing projects, people volunteer the processing power of their silicon-based computers, whereas in volunteer thinking projects, people volunteer their cognitive skills to execute human computation tasks. The precursors of volunteer thinking projects include Stardust@Home[6] and Galaxy Zoo.[7]

Naturally, a volunteer thinking project's effectiveness relies on its ability to engage volunteers. However, volunteer engagement is still an emerging area of study. Some researchers have sought to determine *why* volunteers contribute,[8,9] but it's still unknown *how* volunteers make their contributions. A solid understanding of how volunteers typically behave in volunteer thinking projects can let us characterize their engagement and identify opportunities for designing new and more effective projects, as well as improve existing ones. As a first effort in this direction, we characterize and model engagement in two important volunteer thinking projects: Galaxy Zoo (galaxyzoo.org) and the Milky Way Project (milkywayproject.org).

Our characterization and model focus on four characteristics of volunteers' engagement: frequency, daily productivity, typical session duration, and devoted time. From this, we can then characterize and model inter-volunteers' variability and project

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dynamics. Inter-volunteers' variability expresses the similarities and differences among volunteers, while project dynamics expresses behaviors that arise in volunteer thinking projects when several volunteers act similarly.

Our results suggest that we can broadly divide participants into *transient volunteers* (those who execute tasks only one day and don't return) and *regular volunteers* (those who return at least one more day to execute more tasks after executing the first task in the project). Most volunteers on such projects (67 percent) are transients, but even though regular volunteers are the minority, they contribute the larger proportion of tasks executed (78 percent). Volunteers show similar session duration, regardless of task complexity. Consequently, they usually execute fewer tasks per day in projects with more complex tasks. Volunteer thinking projects also experience busy days, when a burst in the number of active volunteers occurs. Most active volunteers on these days are newcomers, indicating that such days might be suitable for recruiting new regular volunteers.

Materials and Methods

Now, let's take a closer look at what goes into this process.

Volunteer Thinking Projects

Galaxy Zoo and the Milky Way Project are hosted on the Zooniverse (www.zooniverse.org), a citizen-science platform. The Zooniverse has successfully built a large community of volunteers—more than 890,000 registered at the time of writing—eager to participate in scientific activities online. The original Galaxy Zoo[7] was launched in July 2007 but has since been redesigned and relaunched three times, building each time on the success of its predecessor. In 2010, the Zooniverse launched the third iteration of Galaxy Zoo, called Galaxy Zoo: Hubble, but for simplicity, we use the term Galaxy Zoo throughout this article to refer to this project.

Figure 1 shows the Galaxy Zoo interface. Each volunteer classifying on Galaxy Zoo is presented with a galaxy from the Sloan Digital Sky Survey (SDSS) or the Hubble Space Telescope as well as a decision tree of questions with answers represented by a fairly simple icon. The task is straightforward, and no specialist knowledge is required to execute it; a working version is online at http://zoo3.galaxyzoo.org.

Tasks in the Milky Way Project exhibit a larger cognitive load than those in Galaxy Zoo. Figure 2 shows the Milky Way Project's[10] user interface. Volunteers are asked to draw ellipses onto the image to mark the locations of bubbles. A short, online tutorial shows how to use the tool, along with examples of prominent bubbles. As a secondary task, users can also mark rectangular areas of interest, which can be labeled as small bubbles, green knots, dark nebulae, star clusters, galaxies, fuzzy red objects, or "other." Users can add as many annotations as they wish before submitting the image, at which point they're given another image for annotation.

Our volunteer engagement characterization study is based on analyzing task execution data collected from these astronomy projects, which differ in terms of task complexity. For Galaxy Zoo, we use data from 9,667,586 tasks executed by 86,413 volunteers over 840 days, starting on 17 April 2010; for the Milky Way Project, we use

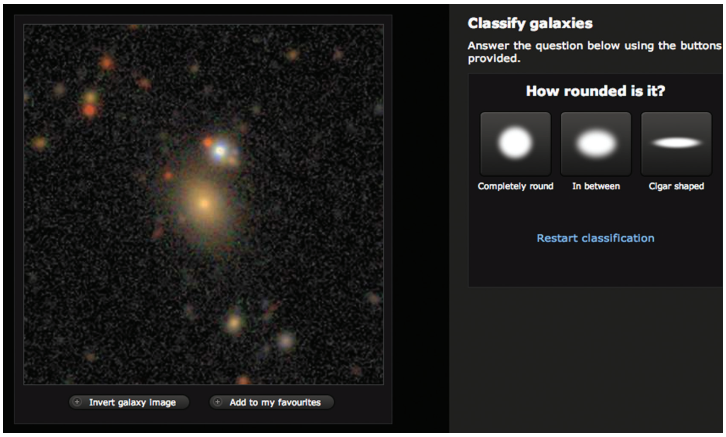

Figure 1. Screenshot of a task in the Galaxy Zoo project. The right side shows a sample question for a human volunteer to answer.

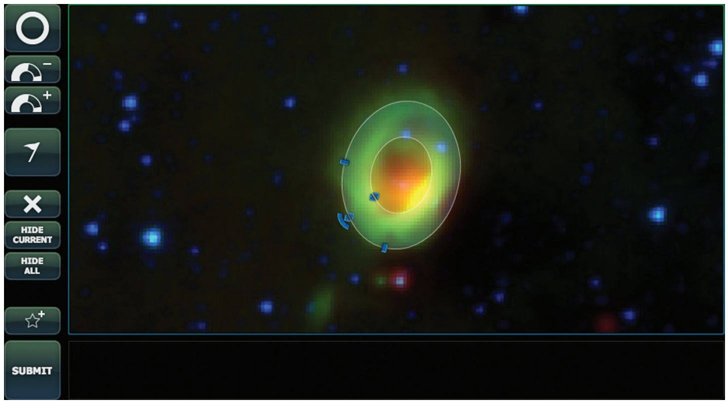

Figure 2. Screenshot of a task in the Milky Way Project. The options on the left side help users annotate the image.

data from 643,408 tasks executed by 23,889 volunteers over 670 days, starting on 3 December 2010. Naturally, as both projects were hosted on the Zooniverse platform, some volunteers executed tasks in both projects. In our data, this set consists of 10,290 volunteers, but only 12 percent of those volunteers were actively executing tasks in both projects for more than one day. In this study, we analyze the contribution of the volunteers in each project separately.

Volunteer Engagement Characteristics

To get a better handle on determining how volunteers make their contributions, we start by considering four engagement characteristics:

- *Frequency*, or the number of days in which the volunteer was actively executing tasks in the project. This metric considers that a volunteer is active on a particular day if he or she executed at least one task during that day. This lets us analyze how frequently volunteers return to the project to execute new tasks.
- *Daily productivity*, or the average number of tasks the volunteer executed per day in which he or she was active. This metric allows us to measure the total number of tasks executed by the volunteers weighted by their frequency in the project.
- *Typical session duration*, or the short, continuous period of time the volunteer devoted to execute tasks on the project. A session begins when a volunteer starts a task execution, but it may end for a variety of reasons, such as the volunteer achieving the time he or she wanted to devote to the project, or that person getting tired or bored because of something related to the task performed. The typical session duration is the median of the duration of all the volunteer's contribution sessions.
- *Devoted time*, or the total time the volunteer has spent executing tasks on the project. It's calculated as the sum of the duration of all the volunteer's contribution sessions.

We also analyze the variations of volunteer behavior in different days over the project's life cycle by taking into account the top 10 busiest days and the normal days. To choose the top 10 busiest days, we compute, for each day over the project duration, the number of executed tasks, the number of active volunteers, and the amount of traffic to the project website. The busiest days exhibit the largest values for these three characteristics. All the other days are normal, so our goal is to understand what generates the bursts of activities on busy days and whether volunteer behavior on busy days differs from behavior on normal days.

Extracting Sessions and Modeling Inter-Volunteer Variability

To analyze the duration of volunteer sessions, we extract data from the task execution logs. Using the tasks' execution time as stored in such logs, we can compute the intervals between two sequential tasks computed by each volunteer. Given these intervals, we use the threshold-based methodology[11] to determine the sessions.

The main idea behind the threshold-based methodology is to find a session threshold that distinguishes the short intervals between two sequential task executions in the same session and the long intervals between two sequential task executions in different sessions. In this work, a short interval represents the time over which the volunteer is solving a project's task, which indicates that the volunteer didn't end the session. A long interval, in turn, represents the time over which the volunteer isn't executing a project task, indicating that the volunteer ended the session. To find the suitable threshold for each volunteer, we use the method proposed by David Mehrzadi and Dror Feitelson,[12] which is based on their interactivity pattern.

We characterize and model the variability among volunteers by obtaining the probability distribution for each variability—specifically, frequency, daily productivity, typical session duration, and devoted time. For each of these characteristics, we conduct parameter fitting for various distributions, including log normal (LN), Zipf (Z), gamma (G), and Weibull (W). We analyze the goodness of fit of the resulting distribution using standard probability-probability plots as a visual method and the Kolmogorov-Smirnov (KS) test as a quantitative metric. All fitted distributions and parameters presented in this article have a KS test of $D < 1.36$ for a significance level of 0.05. We evaluate the correlation between engagement characteristics via the Spearman test. For all correlation coefficient values presented in this article, the p-value is less than 0.05.

Results

Before discussing the highlights of our results, we first describe how we analyze each engagement characteristic and the correlations among them.

Table 1. Summary of engagement characteristic models.*		
Engagement characteristics	**Galaxy Zoo**	**The Milky Way Project**
Frequency	Z (alpha = 2.30, N = 28, 690)	Z (alpha = 2.49, N = 6, 511)
Daily productivity	LN (mean = 2.69, sd = 1.30)	LN (mean = 1.55, sd = 1.16)
Typical session duration	LN (mean = 4.71, sd = 1.07)	LN (mean = 5.03, sd = 0.98)
Devoted time	LN (mean = 7.03, sd = 1.54)	LN (mean = 7.12, sd = 1.33)

* Kolmogorov-Smirnov goodness-of-fit test $D < 1.36$ for a significance level of 0.05. LN = log normal, Z = Zipf, sd = standard deviation.

We also analyze volunteers' behavior on normal versus busy days.

Engagement Characteristics

We characterize volunteers' engagement in terms of their frequency, daily productivity, typical contribution session, and devoted time. Table 1 summarizes the fitted distributions and parameters for each of these characteristics.

Frequency. In both projects, volunteers show a very diverse pattern among themselves in terms of their frequency. In Galaxy Zoo, 57,723 volunteers (67 percent of the total) exhibit frequency of only one day, behavior that's also observed in the Milky Way Project, where 17,378 volunteers (73 percent of the total) exhibit frequency of only one day. We can classify this majority as transient volunteers, given that they execute tasks only one day and don't return to execute more tasks; as we mentioned earlier, the participants who exhibit frequency of more than one day we classify as regular volunteers.

These regular volunteers show a large variation among themselves in terms of frequency as well. Figure 3 illustrates the frequency distribution of these volunteers. The axes are in log-log scale: the vertical axis shows the frequency in number of days, and the horizontal axis shows volunteer ranks from the highest to the lowest level of frequency. Each point in the image corresponds to one volunteer in the observed data, and the lines are the fitted distributions of the observed data. This figure indicates that only a small group of regular volunteers shows a high frequency—that is, they return several times to execute other tasks. In contrast, a large number of regular volunteers shows a low frequency, indicating that, after the first task execution, they return few times to execute other tasks.

Looking at the number of tasks performed by transient and regular volunteers, we observed that, although transient volunteers are the majority, they show a low level of contribution to the projects. In Galaxy Zoo, they executed 1,635,166 tasks (17 percent of all project's tasks), and in the Milky Way Project, they executed 143,693 tasks (22 percent of all project's tasks). This result puts into perspective the importance of regular volunteers for project effectiveness. Identifying and properly keeping such volunteers motivated is a way to retain them and improve their participation.

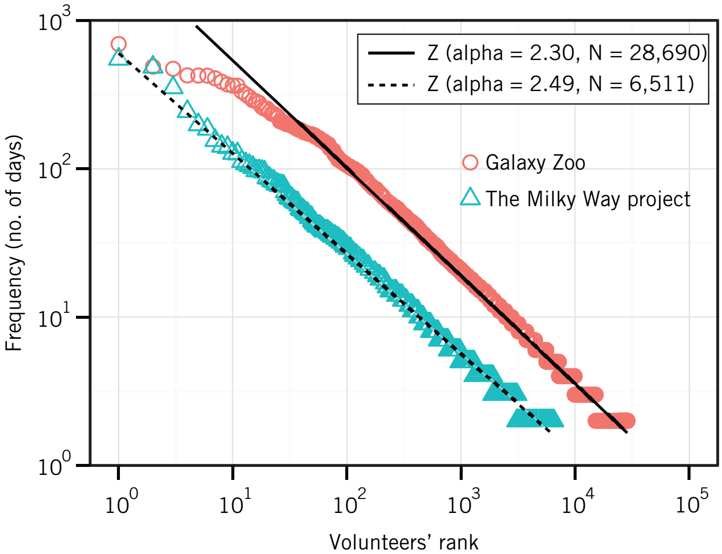

Figure 3. Volunteer frequency in the projects. The axes are in log-log scale: the vertical axis shows the frequency in number of days, and the horizontal axis shows volunteer ranks from the highest to the lowest level of frequency. Each point in the image corresponds to one volunteer in the observed data, and the lines are the fitted distributions of the observed data.

Daily productivity. We analyze volunteers' daily productivity as the number of tasks they usually execute per day (see Figure 4 for the distribution). Again, both horizontal and vertical axes are in

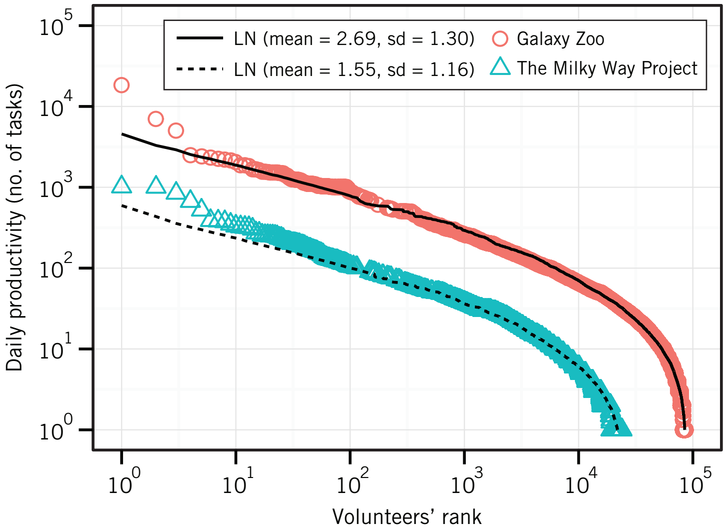

Figure 4. Volunteers' daily productivity. As in Figure 3, both horizontal and vertical axes are in log-log scale: the vertical axis shows daily productivity values, and the horizontal axis shows volunteer ranks from the highest to the lowest value of daily productivity. Each point in the image corresponds to one volunteer in the observed data, and the lines are the fitted distributions.

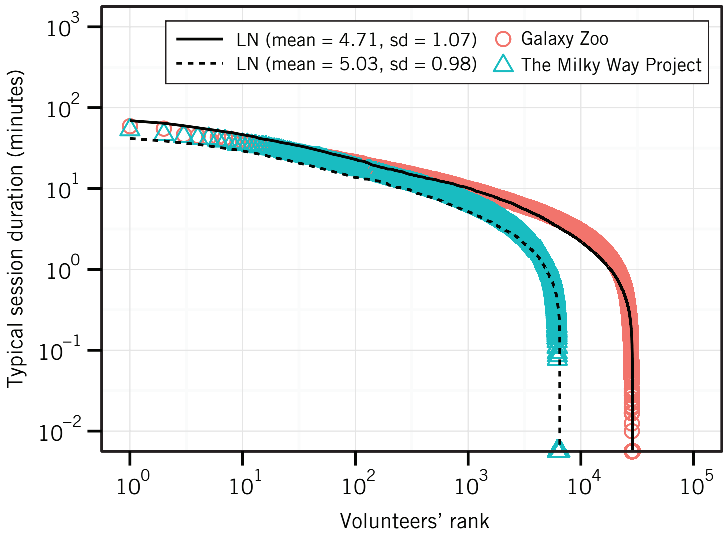

Figure 5. Volunteers' contribution session duration. Participants exhibit similar session duration patterns in both projects.

log-log scale: the vertical axis shows daily productivity values, and the horizontal axis shows volunteer ranks from the highest to the lowest value of daily productivity. Each point in the image corresponds to one volunteer in the observed data, and the lines are the fitted distributions. In both projects, the variation in volunteers' daily productivity is well modeled by a log normal distribution. This model indicates that, in terms of daily productivity, there's a moderate variation between volunteers who are at the beginning of the rank and those who are at the end of the rank. The distribution's tail isn't so long, indicating that the number of volunteers with low daily productivity isn't very large.

We note that daily productivity is a suitable measure to compare volunteers who are contributing in the same project, given that they're performing tasks with the same complexity. However, to compare volunteers in different projects such as Galaxy Zoo versus the Milky Way Project, other measures are needed that take into account the total time devoted to perform tasks.

Typical session duration. We analyze the typical duration of each volunteer's contribution session—typically, they're the typical continuous times that volunteers devote to run tasks on the projects. As Figure 5 shows, volunteers exhibit similar session duration patterns in both projects, although the Milky Way Project volunteers perform fewer tasks per day (as we discussed earlier). In each project, session duration variability among volunteers is well-modeled by a log normal distribution, indicating that a small group of volunteers has a contribution session that's longer than the others.

The relation between volunteers' typical session duration and their productivity is also useful to identify unusual behavior. For example, in Galaxy Zoo, we found a volunteer who executed 1,398 tasks in a single contribution session with duration of only 3 hours and 20 minutes. The interexecutions times were very low (average of 3.17 seconds) and presented low variation (standard deviation of 1.1 seconds). A deeper analysis into the Galaxy Zoo volunteers' community revealed that this person is an astrophysics researcher. He only cares for a specific and rare type of galaxy, so he browses as many galaxies as possible in a given time period and doesn't accurately classify the galaxies that he receives.

Devoted time. As a natural consequence of the presence of transient and regular volunteers, there's also a concentration of longer devoted time from regular volunteers. This pattern is similar in both projects, despite the difference in task complexity. The highest devoted time by a single volunteer is approximately 166 hours, while both the median and the average are approximately 1 hour. Given the total time devoted by each volunteer, we can

Table 2. Correlation among engagement characteristics.*				
Engagement characteristics	**Galaxy Zoo**	**Galaxy Zoo**	**The Milky Way Project**	**The Milky Way Project**
	All	**Regular**	**All**	**Regular**
Frequency—daily productivity	0.03	0.02	0.04	0.03
Frequency—typical session duration	−0.01	−0.01	−0.02	−0.02
Frequency—devoted time	**0.72**	**0.71**	**0.70**	**0.70**
Daily productivity—typical session duration	0.12	**0.31**	0.22	**0.38**
Daily productivity—devoted time	0.12	0.18	0.15	0.20
Typical session duration—devoted time	0.07	0.08	0.05	0.07

* Spearman correlation coefficient; in all cases p-value < 0.05.

calculate the total work time dedicated to perform all project tasks: approximately 31,646 hours in Galaxy Zoo and 6,384 hours in the Milky Way Project.

Correlation among Engagement Characteristics

We also identify the correlations among volunteer engagement characteristics. As Table 2 shows, the majority of characteristics exhibit low correlation. Our discussion focuses on the characteristics that have strong or moderate correlation among them, marked in boldface in the table.

There's a strong correlation between volunteers' frequency and their devoted time to the project—specifically, it's 0.72 in Galaxy Zoo and 0.70 in the Milky Way Project when we consider all volunteers, and 0.71 in Galaxy Zoo and 0.70 in the Milky Way Project when we consider just the regular volunteers. This strong correlation confirms the idea of a typical amount of hours that volunteers devote per day. Thus, the volunteers who devote more time to the project are those who contribute for more days.

There's also a moderate correlation between daily productivity and session duration for regular volunteers (0.31 in Galaxy Zoo and 0.38 in the Milky Way Project), indicating that regular volunteers, who usually have a contribution session per day, show a less variable speed than transient volunteers. Thus, the greater the number of tasks they perform, the longer their contribution sessions.

Project Activity Level

We also analyze the collective activity of volunteers over a project's life cycle. Both projects exhibit bursts in the amount of traffic to the project website and in the number of active volunteers per day. Bursts in the number of active volunteers occur together with bursts in the number of executed tasks—there's a strong correlation here (0.92 in the Milky Way Project and 0.81 in Galaxy Zoo). To better understand the reason for these bursts and how volunteers behave in such days, we analyze the 10 busiest days versus the normal days. The busiest days are the 10 days that exhibit the highest number of executed tasks, active volunteers, and amount of traffic to the project website; all other days are normal. We focus this analysis on the Milky Way Project because we have traffic data stored in Google Analytics for the entire project; this isn't the case for Galaxy Zoo.

The box-plots in Figure 6 show significantly more executed tasks in the 10 busiest days than in the normal days, indicating a clear separation between the two types of days. Given the set of volunteers who executed tasks in such days, we can classify them as *newcomer volunteers* (those executing tasks for the first time) and *returner volunteers* (those who executed tasks at least one other day previously). As the figure shows, on busy days, there are increases in the proportion of newcomer volunteers. Newcomers may become transient or regular volunteers. As we discussed earlier, the majority of volunteers in the projects are transient (67 percent in Galaxy Zoo and 73 percent in the Milky Way Project). Both in busy and in normal days, the majority of newcomers are transient volunteers.

To better understand the sources of newcomer volunteers on busy and normal days, we analyze traffic in the project website. This analysis takes

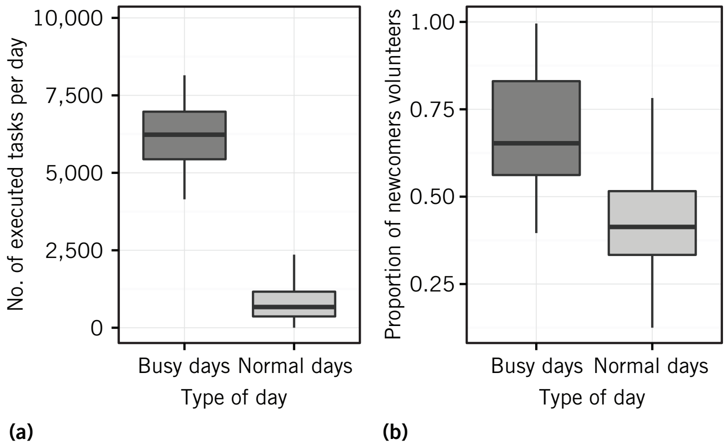

Figure 6. Busy days versus normal days. (a) Number of tasks executed per day and the (b) proportion of newcomer volunteers.

into account both traffic sources and users' geographical location, revealing that on busy days, volunteers come to the project primarily through media coverage. Geographical location and the channel via which the volunteer comes to the project differ with the day and the project.

In the Milky Way Project, the main change from normal days to busy days is that the proportion of traffic from the UK increases from 16 to 34 percent, and the proportion of users that came to the project through the BBC's website (bbc.co.uk) increases from 3 to 24 percent. Specifically, on 16 June 2011 (the day with one of the highest bursts), 77 percent of the traffic came from the BBC site, probably the result of a specific story, "Spitzer Snaps Stunning Image of Ring Nebula" (www.bbc.co.uk/news/science-environment-13779261) on the image of the RCW 120 nebula. This story contained a link to the Milky Way Project website.

Implications for System Design

So what are the implications of our results in the design and management of volunteer thinking projects?

Recruitment Strategies

Our results show that the minority of volunteers in these projects are regular but that such volunteers contribute the larger proportion of executed tasks. This result puts into perspective the importance of regular volunteers for project effectiveness. Identifying and properly keeping such volunteers motivated is a way to retain them and improve their participation, which calls for strategies that let you identify if a newcomer volunteer shows characteristics of regular volunteers and thus deal adequately with that volunteer to encourage a longer engagement.

The engagement characteristics we analyzed, such as the correlation between regular volunteers' session duration and their daily productivity, can be further explored via easy-to-access and real-time data (such as Google Analytics) to monitor how the volunteers are working and whether individuals seem to be transient or potential new regular volunteers.

Contribution Encouragement Strategies

Our results show that massive press coverage is effective in attracting new volunteers. However, the observation that most volunteers are transient puts into perspective a demand for contribution encouragement strategies. Such strategies can be effective in encouraging volunteers who are already registered with the project to actually contribute.

Galaxy Zoo and the Milky Way Project currently send periodic email newsletters to their respective volunteer communities. Further study could appropriately assess this mechanism's effectiveness as well as that of different email strategies such as asking specific volunteers to make more contributions by sending emails with different periodicity or by using a personalized contribution appeal (in contrast with broadcasting the same contribution requests to the whole volunteer community periodically).

Task Design Strategies

Galaxy Zoo and the Milky Way Project have tasks with different characteristics in terms of cognitive load and time required for execution. By comparing volunteer behavior in these projects, we show that they exhibit different numbers of tasks executed per day but similar session durations. These observations might indicate that session duration is affected primarily by the amount of continuous time that volunteers reserve to contribute to the project.

This result has several implications for task design strategies. For example, one challenge in volunteer thinking projects is to define the amount of time a task requires to be executed. If a task is too short, it may be boring to execute a large number of them in a single session, which may contribute to a reduced session size. On the other hand, long tasks may require more time than the volunteer is willing to devote. Our statistical models let you estimate the time each volunteer is willing to devote, which can be used to estimate the appropriate task duration time for volunteers and automatically package tasks in a way that motivates participation.

Volunteer engagement in a volunteer thinking system is an emerging area of study. Our work is only the first step toward a better understanding of volunteer behavior and the formulation of improved engagement strategies. Other studies may take advantage and build on the set of engagement characteristics that we analyzed—for example, one promising work is to build a framework that simulates volunteer thinking projects. Perhaps the next frontier will be to analyze volunteers' behavior in other projects as well. ■

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