Motivations for Sustained Participation in Crowdsourcing: Case Studies of Citizen Science on the Role of Talk

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Abstract

The paper explores the motivations of volunteers in a large crowdsourcing project and contributes to our understanding of the motivational factors that lead to deeper engagement beyond initial participation. Drawing on the theory of legitimate peripheral participation (LPP) and the literature on motivation in crowdsourcing, we analyze interview and trace data from a large citizen science project. The analyses identify ways in which the technical features of the projects may serve as motivational factors leading participants towards sustained participation. The results suggest volunteers first engage in activities to support knowledge acquisition and later share knowledge with other volunteers and finally increase participation in Talk through a punctuated process of role discovery.

1. Introduction

Crowdsourcing has received significant attention over the past decade, as promising organizations access to a potentially enormous pool of free or low cost labor with no formal connection to those organizations [1]. In many cases, individual crowdsourcing projects are open to all interested participants, leading to diverse online communities. For instance, crowdsourced projects like Wikipedia and Galaxy Zoo are defined by a primary objective that draws volunteers to participate, however such projects are multifaceted in the range of work that volunteers can contribute. Prior research demonstrates that the work of volunteers in crowdsourced settings evolves beyond the primary objectives of the project. For example, research on Wikipedia demonstrates how, after newcomers become sustained participants, their goals change as their relation to the project changes [2]. Similarly, Preece and Schneiderman [3] look at how users of social media sites change participation from passive consumers of media (e.g., reading content) to contributors (e.g., send messages, ask questions) and later collaborators with other participants (e.g., collaborative authoring of Wikipedia articles or producing YouTube videos) Also considering changing modes of participation, Antin [4] identify early diversification of activity, predetermined actions vs. learned through continued membership with and associations to identify correlations to participant involvement in administrative and organizational activity in Wikipedia.

Despite the evidence for evolving participation in crowdsourced settings, much of the research on motivation has focused only on factors that draw participants towards contributing to the primary goals of such projects. In this paper, we seek to advance this research on motivation by considering factors that motivate volunteers' contributions beyond the core task (i.e., other than writing articles in Wikipedia or classifying galaxies in Galaxy Zoo).

Understanding motivations for these additional kinds of contributions is important for two reasons. First, in most projects, a small handful of core users perform many important community functions (e.g., answering questions, moderating discussions, organizing site content, responding to newcomers). For example, core Wikipedia volunteers may combat vandalism or moderate disputes, in addition to or instead of writing articles. While such tasks go beyond the primary goal of editing articles, the work of vandal fighting and dispute resolution is necessary for the management and sustainability of Wikipedia [5]. Second, these additional kinds of participation may be helpful in developing participants' abilities to contribute. For example, work by Mugar et al. [6] and Østerlund et al. [7] describe how comments by experienced participants in the social spaces of Planet Hunters serve as resources to orient newcomers

towards normative participation. As such, understanding what motivates participants to engage in activities beyond the primary task of a project is important to support better design and management of crowdsourced projects. Specifically we ask: **What motivates sustained volunteers to contribute to areas of deeper engagement in online crowdsourced projects and how might a project's technical features support this movement?**

The paucity of research on motivation to participate beyond primary project objectives may be due to the difficulty of sampling from the full range of volunteers who contribute to projects or the uniqueness of motivations in different situational or contextual activities [8]. One exception is work by Rotman [9], who studied motivations of citizen and professional scientist that collaborate on projects and found volunteers are motivated by a multitude of factors (e.g., personal interest, attribution, acknowledgment, recognition) and over the course of membership in the project experience "motivational shift" where different motivations are amplified. Despite the attention to a range of motivations, our specific research question regarding how volunteers come to contribute beyond the primary task of the project and what shifts in motivations may be associated with different modes of participation in a crowdsourced project remains largely unanswered.

To pursue our question, we first conceptualize motivation for additional kinds of participation by drawing on the theory of legitimate peripheral participation (LPP) and the literature on motivation for crowdsourcing projects, specifically Crowston and Fagnot's motivational arc of contributions [10] to describe how activities and features of a project come to support motivations for sustained contributors, defined as contribution to activities beyond initial contribution. By joining LPP and the motivational arc we identify individual movements from initial to sustained contribution through constructs in the motivational arc and how volunteers come to develop identity around activities in the project. To explore this phenomenon of shifting participation, we study the crowdsourced citizen science project Planet Hunters. Our analyses of three cases show how the project's technical features support participants to move beyond contributing towards the primary goals of the project. Through the analysis of these three cases, we examine how the arrangement of systems features and activities possess motivational cues for participation beyond the initial goals of the project.

2. Theoretical framing: identity formation and motivational arc

To understand the move from initial to sustained participation we seek a theoretical framework that takes into account the unique features of crowdsourced environments. First, one finds a skewed pattern of participation that spans from large numbers of marginally involved people to a core group of highly committed participants. Second, a person's mode of participation is not necessarily static; rather some members move from initial participation to more sustained engagement such as increased use of Talk and possible project governance roles. Third, crowdsourced environments involve not only individual-level concerns but encompass socio-technical organizational processes that weave together the social, technical, and task structures. Two approaches allow us to address these unique features. One takes its point of departure in identity formation and the other in motivational factors. We will address these in turn and in the process build an integrated perspective on the move from initial to deeper participation in crowdsourced environments.

The literature on legitimate peripheral participation ([11]; [12]) seeks to explain the move from initial to sustained participation as driven by newcomers' identity formation, defined as not only how the person sees the world but also how the world sees the person. Originally coined in the analysis of apprenticeship, Lave and Wenger [11] describe how newcomers start out participating in the practices that make them legitimate but peripheral members of the community. Socially, as they become sustained participants they move towards the center of the community, that is, active participants increasingly fluent in the tasks, vocabulary and organizational principles of the community. This move goes beyond the person's relation to specific activities. It involves the whole person becoming a member of a socio-material community, a specific kind of person. The activities, tasks and functions people engage in a crowdsourced environment do not exist in isolation. The drive for sustained participation comes from having legitimate access to experienced participants and their mature practices. The newcomer can see what sustained participation will be like, the end result, their continuity-based "futures."

Many studies have highlighted the importance of identity formation and legitimate peripheral participation in crowdsourced environments. In a study of Wikipedia, for instance, Bryant et al. [2] describe how contributors develop an identity in the project by having a Wikipedia home page and engaging with more experienced participants through the Wiki talk pages. Likewise, Ke and Zhang [13] found that social identification with open source

projects had the greatest effect on participants' effort and goal commitment. Gaining access to areas of participation based on relationships with established members helped engage newcomers [14], as do being identified as a legitimate and valuable contributor in the eyes of established members [15]. Over time people's mode of participation evolve [3] by for instance, narrowing the type of work they do [4]. Sometimes this narrowing of focus depends on participants' perceived ability to master particular activities [7].

The literature on legitimate peripheral participation (LPP) highlights a number of task-related factors that contribute to newcomers' identity formation and thus motivation to move from initial to sustained participation. Many of these task-oriented factors overlap with the literature on motivation in crowdsourced environments and in particular motivating task design. Notably, Crowston and Fagnot provides a framework identifying motives for volunteer movement beyond initial contribution to sustained participation in crowdsourced environments [10]. Grounded in psychology and organizational science and specifically the literatures on helping behaviors [16], work motivation [17], and social movement [18] Crowston and Fagnot describe a motivational arc including three modes of involvement: initial, sustained, and meta-contribution. Within this larger motivational arc the movement from initial to sustained contributor becomes particularly important. Here participants shift their attention to the visibility of project needs, perceived benefits of contribution, being part of a group, identifying with project ideology, altruism/volunteerism, and intrinsically motivating task design.

Several of these elements articulated by the motivational arc relate to identity formation in crowdsourced environments as derived from LPP. While Crowston and Fagnot's motivational arc provide detailed suggestions for what motivates participation at different stages of participation, it does not describe how people move from stage to stage driven by changing modes of legitimate peripheral participation and identity formation. In other words, the two theories nicely complement one another. In an effort to build a comprehensive perspective on the move from initial to sustained participation we compare and contrast the two perspectives (see Table 1). The dotted line indicates areas with overlapping concepts and the solid line points to complementing categories, which have no corresponding term in the other.

First, as newcomers move towards full participation in, for instance, a citizen science project and develop a sense of identity as a participant, they gradually start to identify with the underlying project ideology exhibited by more experienced users (e.g., altruism and volunteerism) and in the process begin to feel part of the community. Second, both bodies of literature emphasize the importance of access to and visibility of the work. As newcomers gaining access to broader areas of mature practice so that project needs become visible, as do the benefits of contributing to the project. Their contribution gains value in the eyes of other participants, not least old-timers and the value of their contribution increases as the sustained participant become more adept to the needs of the community. For instance, [19] describe how newcomers learn by observing the work of others and [20] find that participation of newcomers grows if they have access to rich examples of other's peoples work.

Third, both bodies of literature emphasize task design as important in facilitating identity formation and thus motivating initial participants to become sustained contributors. Based on studies of apprenticeship, the literature on LPP highlights five types of task design characteristics that facilitate movement towards sustained participation in the

Table 1. LPP and motivational arc factors contributing to the movement from initial to sustained participation

	Legitimate Peripheral Participation (LPP)	**Motivational Arc**
Identity formation	Moving towards full participation in community and increased sense of identity	Identify with project ideology Altruism/voluntarism
Access & visibility	Broad access to areas of mature practice Contribution gains value with increased participation	Visibility of project needs Perceived benefits of contribution
Tasks design	Initial contributions are useful Tasks positioned at the end of work process branches Immediate opportunities for self-evaluation	Task significance Task identity Feedback
	Less demands on time and effort Little distinction between play and work	Autonomy Task variety

community. Initial contributions are useful tasks positioned at the end of work process branches with low risk of failure, (e.g., see [21]), little distinction between play and work, less demands on time and effort and immediate opportunities for self-evaluation. Comparably, the motivation arc includes five job design characteristics originally proposed by Hackman and Oldham [17] in their work on motivation task design: skill variety, task significance, autonomy of task, opportunities for feedback, and task identity, with the latter defined as the degree to which the jobholders can identify and complete a work piece with a visible outcome [17].

In summary, there is a significant overlap in motivational factors across LPP and the motivational arc theory when it comes to identity formation and access and visibility of work. As for task design some elements overlap as suggested in Table 1. LPP highlights the importance of designing the initial contribution as useful to the larger community. Likewise, the motivational arc theory emphasizes that the task should be seen as significant. There are also complementing constructs across the two theories as indicated in the last row of Table 1. LPP finds that less demands on task and effort facilitates newcomers' initial engagement and move towards sustained participation, as does a soft distinction between work and play. The motivational literature suggests that the work should be autonomous and offer skill variety. In our analysis we identify constructs in the motivational arc and how they are represented in the projects technical features. Also of interest is how LPP can, in come cases, explain how volunteers' relation to the features and their project identity shifts.

3. Methods

This study is situated in the Zooniverse Planet Hunters project, which asks volunteers to annotate light curves (graphs of measurements of the brightness of an observed star over time, as shown in Figure 1) from the Kepler space telescope by marking the possible transit events (brief dips in brightness that may indicate that a planet passed in front of the star). The goal of the project is to identify possible extra-solar planets, something it has done successfully, and which participants find motivating. The task requires volunteers to answer three core questions: (1) *Is this image a star?* (2) *What is the star's variability?* and (3) *Does the star have transit features*? At the time of writing, 168,997 volunteers contributed annotations, approximately 20 million in total.

While annotating light curves, volunteers have no control over the workflow. Only after completing an annotation are volunteers asked if they would like to discuss the image they annotated and are directed to Talk posts on the annotated light curve (Figure 2). Here, volunteers can post short comments (140 characters) about their work, point to interesting or related observations, or apply hashtags to facilitate future retrieval of the image, all of which may be beneficial to their own and others' learning, even though they do not directly contribute to the science goals of the project.

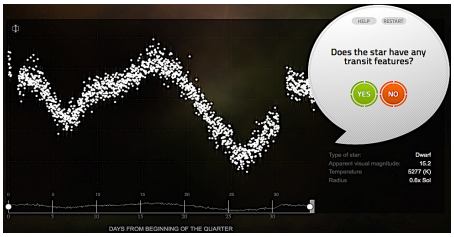

Figure 1. The Annotation interface

In addition to Talk, which is anchored to a specific light curve, [22] identified several project features (e.g., annotation, talk, discussion, and collections) and activities (e.g., user generated analysis, user moderation, user generated queries, and user generated annotation) in which volunteers can engage, which link them with other citizen scientist, moderators, and project scientist. Topics in the discussion forums, unlike Talk, foster in-depth conversations about specific scientific topics, e.g., "*NASA Animation of Two Neutron Stars Forming a Black Hole*" or "*Sonifications of pulsating stars*". In a study of 250,000 Zooniverse volunteers across multiple projects [23] found that 41% of the sample engaged in Talk in their respective projects. Talk and discussion support different activities such as user generated analysis (e.g. hashtags), user generated queries (e.g. asking questions), user generated analysis (e.g. independent data analysis) or user moderations (e.g. censoring users).

Finally, the collections feature allows volunteers to pin images as favorites, which can be retrieved later through their profile and are visible to other volunteers. One volunteer collection titled "Potential Transits" holds examples of light curves with transits, more relevant examples of users curating exemplary light curves images that might support future learning or analysis.

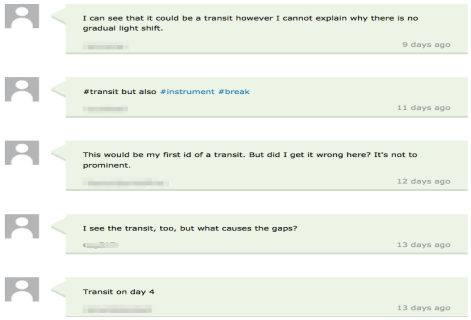

Figure 2. Talk Thread for object: APHE10007nf

3.1 Case selection

Our analysis is based on an in-depth analysis of three volunteers in the project. These three were chosen as follows. First, we sent survey requests 1000 randomly selected participants (500 newcomers and 500 sustained) and received 111 valid responses (these survey data are reported elsewhere). Of the survey respondents, 20 accepted an invitation to participate an interview where they were asked about their use of Planet Hunters social features and how their use changed over time. Three researchers, conducted interview sessions, transcribed content, and identified motivations, project perceptions, and engagement in project features and activities for the purpose of identifying participants who were active commenters and what prompted increased use of the feature. In the analysis of the interviewees, three volunteers (referred to pseudonymously as Patrick, Emily, and Roger) emerged as exemplary cases, as their experiences and motivations seemed to reflect the range seen across the active interviewees. Accordingly, we focus on these three in presenting the interview results.

3.2 Trace and virtual ethnography

To supplement the data from the interviews, we also used forms of ethnographic inquiry to gain a more accurate and complete account of how the volunteers work and interact in the project, specifically trace ethnography [24] and virtual ethnography [25]. Trace ethnography, which focuses on using data from server logs obtained from the project organizers, allowed the researchers to reconstruct the experience of participants as it appeared in the records of their classifications, talk comments, and number of sessions contributing to Planet Hunters. Virtual ethnography drew on more traditional ethnographic data collection techniques such as interviews with project participants as well as observation of activity as it appeared in publically accessible spaces of the online environment, for example, the Talk and Discussion pages. The traces of activity as they appear both publically on the Talk pages and within the server logs were used as evidence of the "lived experience" of projects participants as they interact with the project [25], [23]. By using these approaches, the researchers were able to build a more holistic account of the experiences of contributors in the research site. Table 2 summarizes the contributions of the three volunteers to Planter Hunters based on these data.

Table 2. Participant contributions

	Sessions	Classifications	Talk +Discussion Comments	Active Days
Emily	170	1245	121	51
Roger	35	2718	152	24
Patrick	107	4507	98	55

4. Results

4.1 Participant identity

Patrick, Emily, and Roger have collectively contributed more than 8,000 annotations in the project at the time of writing. Roger is semi-retired and has degrees in chemistry, physics, and biosciences. Patrick has a degree in Hungarian literature and Emily is currently seeking a degree at a university. While none of the interviewees have formal training or education in the science of astronomy, they all describe their interest in Planet Hunters as stemming from a life-long interest in astronomy. Interviewees describe their participation in Planet Hunters as primarily supporting project goals and ideology—discovering planets through annotation of data. Roger describes having been interested in astronomy for more than 20 years, and has read many books and written papers on astronomy. He describes his motivation for contributing to the project as helping find planets similar to earth and says "*that prompted me to join the group and why I continue looking for light curves*". Patrick's enthusiasm for joining Planet Hunters is a result of fascination with the existence of stars and planets that could be similar to Earth. Patrick manages a radio show and writes a blog addressing topics in astronomy and astrophotography and considers himself an amateur astronomer. Patrick notes that *"Even if we as a citizen science community discover nothing, it's still worth the effort because it*

draws our attention toward astronomy and real sciences" and spoke of the excitement of being able to touch the data before it was fully analyzed. Emily was drawn to the project because she has always been interested in the bigger questions of life, describing herself as having always been a "*philosopher*" in her free time. Emily says that she was "*really into stars and the galaxies in general*" that she really wanted something where she could just, "*get a sense of everything going on astronomically, or theoretically*".

As the volunteers begin to make decisions to become engaged beyond just contributing to annotation, we see volunteers engaging in more mature practices and increased sense of identity within the project. As an initial contributor, Emily showed a seriousness about her participation and described how she worked hard to make sure she got work done and used resources internal and external to the project website to learn how to "*find something*". Patrick and Roger's sizable and steady contributions to the project show a sort of identity developing around regularities in contributing. Roger identified himself as a helper who we see supporting the larger goals and needs of the project stating:

"I'm a helper…to try to sift through data that Kepler has produced, and to try to whittle it down to those light curves that might have a possibility of transits, let the scientists take it from there"

Roger spoke of his increased proficiency in annotating images. In the trace data, we can see that the speed at which he annotates increases, annotating a single image taking on average 1 minute 13 seconds in his first quarter of annotations but only 41 seconds during last quarter of annotations. This speed up could be in part due to what Roger describes as an improved understanding of what to look for in light curves, allowing him to make better and faster decisions as to whether or not a transit exists in the data. Patrick's contribution in annotating light curves spanned 108 sessions over the course of one year, averaging approximately 82 annotations per session with more than 4,500 annotations in total. Patrick attributed his ability to transition into the project and complete many annotations in a short time period to having witnessed a transit of a planet past the sun in person and as a result had an increased understanding of light curves and how transiting planets may appear in the data objects.

4.2 Initial activities beyond annotation

While volunteers may experience project ideology, identity formation and project needs around annotating light curves, activities in developing, viewing, or engaging in other project features and activities can serve to support mature practice and increased relation with the project ideology, visibility of needs, and benefits. It is also where we see volunteers become full participants in the projects. When Roger first came to Planet Hunters, he often referred to the tutorial page when he had questions about how to participate or when he had specific questions about classifying data objects. For referential knowledge in annotating, he referred to blog posts written by members of the science team where examples of specific phenomenon in light curves were found. Roger also was a passive user of Talk, as he would view comments left by other participants to learn to identify transiting planets.

Although not as central to his participation, Patrick used other resources when he started contribution stating *"...when I was just starting, I was looking at the tutorial more"*. As a beginner Patrick showed a hesitation to engage other members stating, *"how should I know that another user is to be trusted or not*". When asked of his interaction with the collections feature Patrick described its use as a reference to know what stars to look for saying he focused on looking at collections with binary stars or transits. He mentioned that if he found an interesting star, he clicked similar images that were part of a collection, suggesting that he would spend a significant amount of time observing the collections that other volunteers have created to help him identify exemplary stars and improve his ability to annotate. Referencing one collection in particular he stated,

"I find binary stars and their light curves rather beautiful, because one particular light curve made me realize how they orbit, and its orbital plane is oriented in space in three dimensions."

Emily talked of reading books on astronomy and astrophysics to help her become more comfortable annotating light curve images in the project and refers to her initial contribution as a focused period of time where she was in "learning mode". She attributes the time spent poring over talk comments and textbooks with her efficacy in contributing. Emily also made note of her use of collections in the projects. Emily made two collections, but stated after some time she stopped using them. However, she said that she would look at the collections of other volunteers who were in the project for a longer period of time, stating she performed "background checks"

to verify their qualifications. As an observer of discussion posts, Emily mentioned how she came across links to external websites, which provided exemplary stars.

We see interviewees moving beyond initial contribution by engaging in activities like viewing/building collections, viewing posts in Talk, reading science team blogs, and accessing external resources. These resources support the practice of annotating and increased recognition of project needs, ideology, reinforce project ideology, and as mature practice is representative of a movement towards full participation in the range of project features and activities. They are also exemplary of a desire to become contributors fluent in the task and to increase the value of their contributions to the community.

4.3 Talking in Planet Hunters

As volunteers engage with they project, we see many viewing Talk posts, but remaining on the periphery of contribution. When volunteers begin frequently contributing to talk, discussion, and private messaging, we see them experiencing many other motivations as they begin to exhibit more sustained contribution. Trace data reveal interviewees experiencing an initial period of silence in the project before contributing to Talk. Patrick's first post was after 279 annotations and during his 19th session. Patrick tells of how he began making contributions to Talk by providing feedback on light curves when volunteers suggested they found planets. His comments reflected those of a moderator, what we see as mature practice, in commenting on the hypothesis of other volunteers, stating: "*agree, there are dips Q1: d30, Q3.2 d177 ... something"* or *"Appears to have a dimming each 0.6-0.7 days in Q1. Some other features like d559.6 also present. Although, very noisy signal"*. This fluency with the project terminology allowed him to contribute where he was qualified, what we see as skill variety. Patrick could choose which comments he wanted to leave, who to communicate with, and frequency of contact, all of which required no instruction from science team members indicating some autonomy in contributing to the project.

Like Patrick, Roger's participation allowed him to experience skill variety and autonomy in the project. Roger contributed his first comment in Talk after his first annotation; he waited until after his 95th classification before making his next comment. The first comment attempted to describe the presence of a transit based on a single point in the light curve and the comment content reflected a novice understanding of the project and incorrect use of data to describe the presence of a transiting planet. While it took some time for Roger to become familiar with project terminology, he eventually began to engaging in Talk by supporting other volunteers' observations leaving comments like, "*Possible transits at days 91, 132, 277.5?, 326?, 545, 578.*" or "*5-8 "transits" per cycle--only first cycle marked. But more likely an #eclipsing_binary?*". From trace data we see Roger developing regularities around his contributions where they had the same semantic structure.

Like Roger, Emily left one comment in the beginning of her participation and returned after 200 additional annotations, 7 sessions later. Unlike Patrick and Roger, Emily participated broadly to talk, discussion, and direct messaging with most posts being in the discussion forums. Emily describes her reluctance to Talk saying she *"wasn't qualified"* to make a contribution. To Emily, having something valuable to talk about was important. When Emily did contribute to talking, her initial contribution provided feedback to another volunteer about the annotation interface where she stated, "*The y axis is the luminosity of the star, the x axis is time. Each dot represents a measure of the brightness of the star that's been captured very precisely by the Kepler telescope.*" Another post she provided in the beginning gave feedback about another volunteer's observation, stating, "*Actually this is most likely (contamination due to) a background galaxy!".* As Emily's participation in talk increased most of her contributions were concerned with understanding the project or focused on interesting observations she came across. In one message, Emily attempts to understand some project jargon:

"*... If you don't mind my asking though, I'm not really sure I'm fully grasping the last part.. HZ as in.. habitable zone..?! (and I'm almost ashamed to ask, but what does RE and Teq stand for? I'm guessing 5.1x the radius of earth, and teq to refer to something like the approx. surface temperature?... This is all beyond my level of astrophysics jargon knowledge.)*"

This attempt to engage more deeply with the project by becoming more fluent in the projects jargon represents maturation in her commitment to the project. Wanting to understand/use accurate terminology in the project shows her commitment. Emily also had specific reasons for contributing more frequently to discussion forums versus talk stating "*I like the forums better to keep up to date with not only the targets and the images but more just all the action that is going on - all the side quests and all the questions that are being asked by new people that is*

really fascinating to me." In her interview Emily mentioned an additional mode of talking in the project, which increases autonomy in communication- direct messaging. Emily revealed having sent a substantial number of direct messages to other volunteers.

Roger and Patrick's use of Talk attends primarily to providing feedback to the community, we suggested that as their knowledge about the project increased, the necessity of sharing that knowledge with others lead to their initial Talk contribution. Their identity with Talk changed from being peripheral members in the beginning observing and information gathering, to involvement in tasks reserved for moderators or core contributors. Only through their movement to Talk did they come to experience many motivations that shift their participation to sustained contribution. We attribute Emily's shift towards sustained contribution to her dedication to personal learning. Gaining feedback about a potential transit and having exchanging direct messages with more experienced members seemed to satisfy her motivation for increased contribution.

4.4 Discovery

While we see the motivational factors apparent in annotation and Talk and how volunteers may experience shifts in motivations to contribute, we still face the question of how volunteers become sustained contributors in Talk. In Planet Hunters, we identified an emergent motivational factor that combines project needs and identity to motivate movement towards sustained participation in Talk- discovery.

First, Patrick's involvement in the project changed character after a discovery moved him beyond just annotation. He discovered a glitch in the data collection that other volunteers were identifying as a transit. This discovery led to a new identity as a curator of a glitch. After the discovery, Patrick's use of Talk became amplified and subsequent posts were related to confirmation of the glitch and later warning others. He spoke of this in his interview stating,

"… there was a glitch, I don't know which quarter was it, it was day 4.5 there was a glitch which was hardware glitch or something because a bunch of stars had that dip, and for example, for that dip I frequently clicked discuss because I wanted to see where it is the formation quarter and whether other people missed it; other people think it is a planet...and then I was consciously looking for this particular glitch"

Regularities in posts warning others emerged, as Patrick participated in Talk leaving the comment "*?error? "q14.1 d4.5"*" on multiple threads. He later created a hashtag (*#Q141glitch*), which made it easier to find posts discussing the glitch.

Second, as Roger's comments reflected an increased understanding of the project's practice, he began contributing descriptions of the annotation decisions he made where short analyses of the presence of particular characteristics were contributed. Some posts are highly specific, "Two LARGE transits at days 8 & 24, possibly two large planets or one big planet with a very short 16-day period" showing fluency in project jargon which relates to full participation and identifying with project ideology. Roger also used Talk to systematically identify a feature in which science team members were interested, namely overcontact binaries. Roger would search through Talk pages and regularly post "*#Over-contact_binary? See end of "Eclipsing Binaries" discussion at [link]*" to fulfill a need presented by the science team. Roger states,

"...the science team said they are interested in type of stars and want to go back and study them and I thought, okay, I will mark them in a way that they will all be put into one class".

Such comments reflect what Roger describes as his role in helping scientists sort through vast amounts of information and was the catalyst for his increased contribution to Talk.

Lastly, Emily describes excitement in being able to communicate with people actually working on identifying planets, and it is this interaction that has kept her with the project. She said that after a couple of hundred stars she was able to find something and it was at this point that she really started to become active in the community. In the process of annotating, Emily identified what she believed to be a transit, i.e., a sign of a planet. Emily's discovery also motivated her to continue digging deeper into the science behind the Planet Hunters project, a practice that contributed to her transition from conducting primary annotation to interacting primarily with sustained participants conducting additional analysis on project data.

Emily began socializing regularly in the project only after 500 classifications, but in the interviews states that her conversations are what contribute to drive her participation. After her discovery, she sought an authoritative source to provide advice about next steps. She began using direct messaging to frequently contact a member of the "*core group*" whom she identified in a manuscript she read. Her contact with him drove her participation in talk (i.e. direct messaging) where she stated they exchanged videos and other information about exo-planets. From

the comment below and many other posts left by Emily, we see her excitement to dig deeper in to the science of astronomy and planet hunting specifically.

"*Can't wait to find out the density of this candidate…and for good measure, can't wait to someday be able to calculate this kind of stuff myself. I'll be hunting down some books for sure, this (not so) little candidate planet and my subsequent quest to know more about it just confirmed how much I want to learn more about astrophysics and planet hunting.*"

Emily's discovery has prompted her to continue returning to the project. From trace data, 45% of Emily's session on in the project composed of only contribution to Talk, with no annotations contributed.

Discovery—of Patrick's glitch, Roger's helper role, and Emily's potential transit—we see as motivating increased contribution to Talk. Many volunteers dabble in Talk as the project prompts volunteers to engage in the interface, but we see less sustained contribution to the interface. We see Talk supporting additional motivations and discovery driving volunteer movement to Talk as full participation in the community and thus sustained contribution.

Table 3. Motivational Factors in Planet Hunters

Construct from Motivational Arc and LPP		Planet Hunters Annotation Interface	Planet Hunters Talk Interface	Other Activities
Visibility of project needs		X	X	Tutorials, FAQ pages, Science Team Blogs
Project Ideology		X	X	FAQ pages, Science Team Blogs
Altruism/Volunteerism Benefits		X	X	Collections, HashTags, External Resources
Work Design	**Skill Variety**		X	Collections, HashTags
	Task Significance	X	X	
	Feedback		X	
	Autonomy		X	
	Task Identity	X		HashTags

5. Discussion

Table 3 summarizes the motivational factors identified in the theories and where we see them being expressed in the Planet Hunters project, in annotation and in the talk features. The analysis suggests that the annotation task alone lacks some motivational cues. We argue that only through contribution to both annotation and talk do volunteers experience the full range of motivations in Planet Hunters and as a result leading them to become sustained contributors. As volunteers in Planet Hunters move beyond only annotation work to gradually engaging in mature practices like knowledge seeking (e.g., viewing collections of others to identify transits) or information organizing (e.g., developing hashtags to curate images) motivational factors like experiencing project ideology or project needs are amplified or emerge where they were previously non-existent. Overall, we see a trajectory in volunteer's movement towards sustained contribution where motivational factors become apparent as supported by the projects technical arrangements.

Volunteers experience the annotation interface as a solitary task, designed to reduce volunteer bias in the process of annotating. The order of the work, questions, tools, and lack of interaction with other volunteers during annotation lead to anonymity and little feedback and skill variety, which may cause volunteers to experience a void in motivation. As volunteers seek to contribute more efficaciously in the annotation interface, they begin to engage in other activities supporting increased knowledge and decreased efforts required to make an annotation. It is here where we find an evolution of volunteers' identity in the project. Once self-efficacy is attained, volunteers make contributions to the Talk features. This initial engagement in Talk can support autonomy, skill variety, and feedback for volunteers and we see a movement to full participation in activities. The initial contributions to Talk tend to become sustained, however, only after volunteers make a discovery in the project.

Task significance of annotation work offers a conundrum. While we see volunteers experiencing task significance through statements about scientific contribution, the nature of the project supports little verification of the significance of annotating. Volunteers may not experience scientific findings until after publication and analysis of data, which may take many months. The conundrum of task significance suggests, in cases where the significance of the task may not be experienced for some extended period of time, efforts should be made to address how volunteers' contributions directly relate to project goals or ideology.

Overall, our finding suggests projects should provide authoritative resources as volunteers seek more

knowledge, access to sustained members, and highlight how volunteers may take on additional roles once discovery is made. We see these additional resources supporting knowledge seeking about the primary goal of the project and addressing volunteers' general curiosity about astronomy. These features and activities come together to support a motivational trajectory towards full membership, in the LPP sense. This mature practice of knowledge seeking help volunteers become fluent in the task and provide them with requisite knowledge to become efficacious in performing annotations and familiar with the project jargon, which seemed to motivate contribution to Talk.

As volunteers gain the requisite knowledge to perform annotations accurately, they can experience immediate impactful contributions in Talk, as in the case of Emily where she sought knowledge from other members about project terminology. The Talk interface can serve many functions in the project from providing responses to newcomers to supporting the feeling of community. Volunteers have control over many aspects of their engagement with the project. In Talk, some popular activities of volunteers, which support their autonomy and skill variety, are asking questions about their observations, describing work they completed, use hashtags to curate helpful content, and starting discussion boards. More experienced volunteers act as moderators providing feedback and posting links for other volunteers explore which might support their learning or curiosity. This engagement exemplify movement towards full participation enacting a range of project features and activities; participants can feel they make an impact [26].

While Talk is important to the interviewees, many initial contributors engaged only by viewing the comments of others [7]. Providing more motivational cues for volunteers to contribute to Talk when they are unsure of a potential discovery may increase the rate at which volunteers contribute to Talk. For example, we witness Patrick attempting to determine if he had indeed made a discovery. The role of discovery is further exemplified by Patrick's case where more than 60 percent of his Talk comments were concerned with the glitch he identified. This is the type of contribution that led to the discovery of *Hanny's Voorwerp* in Galaxy Zoo where citizen scientist created collections of images with green globs leading to the detection by a non-scientist of the first quasar light echo [27]. Making a discovery is not a linear process. Volunteers' trajectories to discoveries are sure to be influenced by their diverse educational backgrounds and time commitments. This observation suggests that moderators and developers consider the diversity of the community as they set out to design new system features and tasks. While discovery was an important factor for sustained contribution to Talk, the temporality of discovery motivating contribution could affect the longevity of contributions.

6. Conclusion

As organizations continue to embrace crowdsourcing managers and designers need to develop a nuanced understanding of what motivate the diverse volunteer communities forming around a particular project. A number of studies have addressed participants' initial motivation to contribute [8], but few have examined the motives of sustained participants. While the present study might be directly relevant to other citizen science projects (e.g., discovery as a motivational factor), our findings suggest that a broader range of crowdsourced projects could benefit from considering how the project's technical features posses motivational factors that help move volunteers to become sustained participants engaging in diverse tasks.

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