Crowd-Sourced Science

Societal Engagement, Scientific Authority and Ethical Practice

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Abstract

This paper discusses the implications for public participation in science opened by the sharing of information via electronic media. The ethical dimensions of information flow and control are linked to questions of autonomy, authority, and appropriate exploitation of knowledge. It argues that, by lowering the boundaries that limit access and participation by wider active audiences, both scientific identity and practice are challenged in favor of extra-disciplinary and avocational communities such as scientific enthusiasts and lay experts. Reconfigurations of hierarchy, mediated by new channels of information flow, are increasingly visible at the interface between professional and non-professional practice. Setting the scene by surveying the role of the media in defining twentieth-century contexts of lay science, the paper illustrates the appropriation and recuperation of scientific authority being played out in two contemporary models of active public engagement: so-called "citizen science" and varieties of "crowd-sourced science." Both participatory models are increasingly reliant on information exchange via social media, but may be implemented to support distinctly different societal goals and beneficiaries.

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Introduction

Active public participation in science changed markedly during the twentieth century and has evolved rapidly since the beginning of the present century. The flow of information has been an important factor in these developments: styles of non-professional activity have been influenced significantly by new channels of communication.

The terms "citizen science" and "crowd-sourced science" highlight the newly recognized societal dimensions of such activities. While used imprecisely, both labels hint at technology-mediated possibilities opened to professionals and non-professionals alike, and to the unprecedented scale of involvement by lay participants. Both "citizen" and "crowd" are loaded terms, however, that beg for careful analysis. The way in which information is channeled and controlled is a distinguishing feature having ethical implications. These new variants of established practices offer novel configurations of power relations between professional and amateur communities of science practice. Facilitating distinct societal interests, organizers and participants in such initiatives may identify benefits and beneficiaries in distinct ways.

Scientific practice, long understood as a hierarchical activity in which professional authority is hard-won and appropriately protected, is challenged by the increasing access to information and redistribution of expertise. For an early recognition of the theme of power relations between professional and amateur communities of science practice, see Morris Berman (1975). The role of non-professional scientific expertise has been highlighted more recently in fields as diverse as environmental planning (Heiman 1997), medical sociology (Prior 2003), and science and technology studies (e.g., Collins & Evans 2002), and the notion of lay experts as a professional or societal threat has been raised (e.g., Bennett *et al.* 2009; Welsh & Wynne 2013). With knowledge production itself a product of particular types of labor (known as immaterial labor), ethical issues concern access to the process of production and fairness in access to, and appropriate exploitation of, knowledge (e.g., Fuchs 2009).

Beginning from a baseline of twentieth-century models, the present paper traces social interests and information channels that became associated with lay science. Print media identified amateur scientists alternately as a societal resource, as proto-professionals, or as volunteer labor for professional scientists. Examples of electronically-mediated information flow illustrate the appropriation and recuperation of scientific authority being played out in contemporary models of active public engagement. In this dynamic process, the role of traditional publishing media as intermediaries in the flow of information has been significantly eroded.

This paper argues that information-sharing via electronic media can reshape scientific identity and practice for the better. By lowering the boundaries limiting access and participation by wider active audiences, it can enable more egalitarian expressions of "oppositional science" by extra-disciplinary communities (Longino 1990). By contrast, the channels of communication can alternatively be constituted to reproduce or reinforce conventional professional-amateur relationships. Thus redistribution of power is not an intrinsic property of the communication channels, but can instead be engineered by those designing and having access to particular implementations.

Historical Context: Twentieth-Century Media Portrayals of Lay Science

Scientific amateurism became increasingly visible through the twentieth century as a personal enthusiasm and leisure pursuit (e.g., Stebbins 1980). Print media were important vectors for this, actively championing scientific pastimes through a variety of publishing initiatives. From the first decade of the century, books and magazines increasingly promoted personal engagement with science and technology to broad audiences. Over subsequent decades, they shaped the aspirations and activities of scientific enthusiasts.

Popular writing, in fact, constructed a collective identity for lay scientists as active, innovative, and productive non-professionals. Boys' novels such as the *Tom Swift* series (1910–41) provided a heady new mixture of science, technology, and adventure (Dizer 1982; Molson 1994). Mirrored by other publishers, several thousand titles provided role models for three generations of American children and young adults. Practical engagement was inspired by magazines dedicated to hands-on experimentation and innovation. Publisher Hugo Gernsback (1884–1967) captured a growing public appetite for science after the First World War (Ashley 2004). His *Electrical Experimenter* (1913), for instance, segued into *Science and Invention* (1920), and *Everyday Mechanics* (1915–16) was reintroduced as *Everyday Science and Mechanics* (1931).

The rising societal role of science was sensed by an American journalist, Edward W. Scripps (1854–1926). His initial notions of science promotion sought to influence a receptive but largely passive readership. In 1919, he proposed an organization that would supply press stories to instruct the public "quickly and well" on the "painstaking research carried on by a few hundred, or at most a few thousand, well-trained men equipped with great mental capacity." Scripps' aim was to inspire an educated public to "think like a scientist" (Scripps 1919). Founded under the title "Science Service" in 1921, the organization provided news syndication and a periodical, *Science News Bulletin*, to communicate scientific culture to laypeople (Slosson 1921).

An important early initiative was articles supporting the growth of new scientific pastimes, with the expectation that such hobbyists would transmit their passions to friends and families. The first such campaign was Science Service's promotion of amateur radio experimentation. Radio amateurs had spunoff from professional activities during the First World War. With the availability of war-surplus components and the explosion of voice transmission experiments from the early 1920s, amateurs kept pace with commercial development and shaped government regulation. Their discoveries led to scientific and technological advances: experimental transmissions between radio amateurs, for example, revealed the utility of frequency bands that had not been considered by the nascent industry (Haring 2007).

Stronger support for such liberated scientific amateurism came from *Scientific American* magazine, founded in 1845 but reoriented in 1921 as a monthly magazine of popular science for a more discerning readership. Under one of its new editors, Albert G. Ingalls (1888–1958), it hosted a monthly column, "The Back Yard Astronomer," and successive editions of a book, *Amateur Telescope Making*, gained growing audiences of self-motivated "tinkerers" over the following three decades.

Ingalls credited his writings with fostering new cohorts of "scientifically minded persons," portrayed as "eager workers, young and old, skilled and less skilled, men and women" and characterized by intelligence, handiness and self-direction (Ingalls 1933 [3rd edition], viii). By uniting isolated individuals, Ingalls' columns picked out and knitted together a virtual community of science enthusiasts some seventy years before the arrival of Internet news groups.

Ingalls was succeeded after the Second World War by C. L. Stong (1902–1976), who transformed the *Scientific American* astronomy columns into a more generic "Amateur Scientist" department, bolstered by the availability of war surplus parts for tinkering projects. The magazine's depiction of lay scientists was consistent, however: Stong described his ideal reader as "the advanced amateur, the fellow whose interest in science keeps him on the job year after year," and who makes it "an avocation" (Stong 1951).

By contrast, the war transformed Science Service's vision of scientific amateurs, focusing the organization's attention on attracting younger enthusiasts. Through a radio series, *Adventures in Science* (1941–59), its director, Watson Davis (1896–1967), translated solitary scientific hobbyists into a collective force for national service: "telescope makers today are in great demand by optical firms around the country, since the experience gained in making a telescope is just the kind one needs to help make optical equipment for the army and navy" (Davis 1941). The organization championed an offshoot, Science Clubs of America, as a means of nurturing young scientists for the war effort and, with sponsorship by Westinghouse, founded Science Talent Search, a competition for university scholarships in science and engineering (Terzian 2013).

During the early Cold War, the Science Service vision of scientific amateurs was increasingly linked with government objectives to increase cadres of professional scientists and engineers. Enthusiasms were extended by the new medium of television (Lafollette 2013). *Watch Mr. Wizard* (1951–65) was telecast across North America, supported by a network of "Mr. Wizard Science Clubs" for primary school pupils (Herbert 1952). For teens, after-school science clubs were also organized as team-oriented activities mentored by professionals. As sketched by the Army Amateur Rocket Liaison Program, a typical group consisted "of seven bright young men between the ages of 13 and 17, one sympathetic and understanding parent or high-school teacher who acts as the adult adviser of the group, and one engineer or chemist who acts as a technical adviser … whose general interest in the advancement of scientific knowledge about the universe is mutually shared by all other members of the group" (Brinley 1960, 16).

But complementing both these distinct notions of self-motivated adults and mentored youthful aspirants to scientific careers, some scientists identified a fixed and subordinate role for amateur participants in science. A prominent advocate of this view was Vannevar Bush (1890–1974)—wartime overseer of the Manhattan Project and author of the postwar Presidential policy report, *Science: The Endless Frontier*—who characterized amateurs as a national resource, while subtly assigning them an inferior rank in scientific practice:

> Amateurs, generally, are content to be modest…. There are lots of amateur scientists, probably a million of them in this country. The Weather Bureau depends on some 3,000 well-organized amateur meteorologists. Other groups observe bird and insect migrations and populations, the behavior of variable stars, the onset of solar flares, the fiery end of satellites, earth tremors, soil erosion, meteor counts, and so on.... Many of them require no more than careful, patient observation [Bush 1960, xviii, xx].

Templates of Engagement

Thus, twentieth-century media portrayals encouraged active scientific amateurism, but evolved to promote distinct models of lay participation. A key distinction between these templates concerns information flow and power relations between professional and non-professional practitioners. The *Scientific American* model valorized autonomous adults engaged in non-professional scientific activities. At the most extreme, the lone amateur was depicted as a self-sufficient practitioner independent of advice, direction and external validation. By employing contributors' own texts and illustrations, the magazine sought to celebrate, communicate, and inspire such enthusiasms in a non-hierarchical fashion (Figure 1[a]).

By contrast, the Science Service and Bush portrayals both identified hierarchy of expertise and often age as common factors, linking the activities of professional mentors with younger and less capable amateur enthusiasts. Both templates also identified information exchange as a key attribute of amateur science, but conceived the flow of information in complementary ways. The Science Service notion imagined a transfer of expertise from professionals to

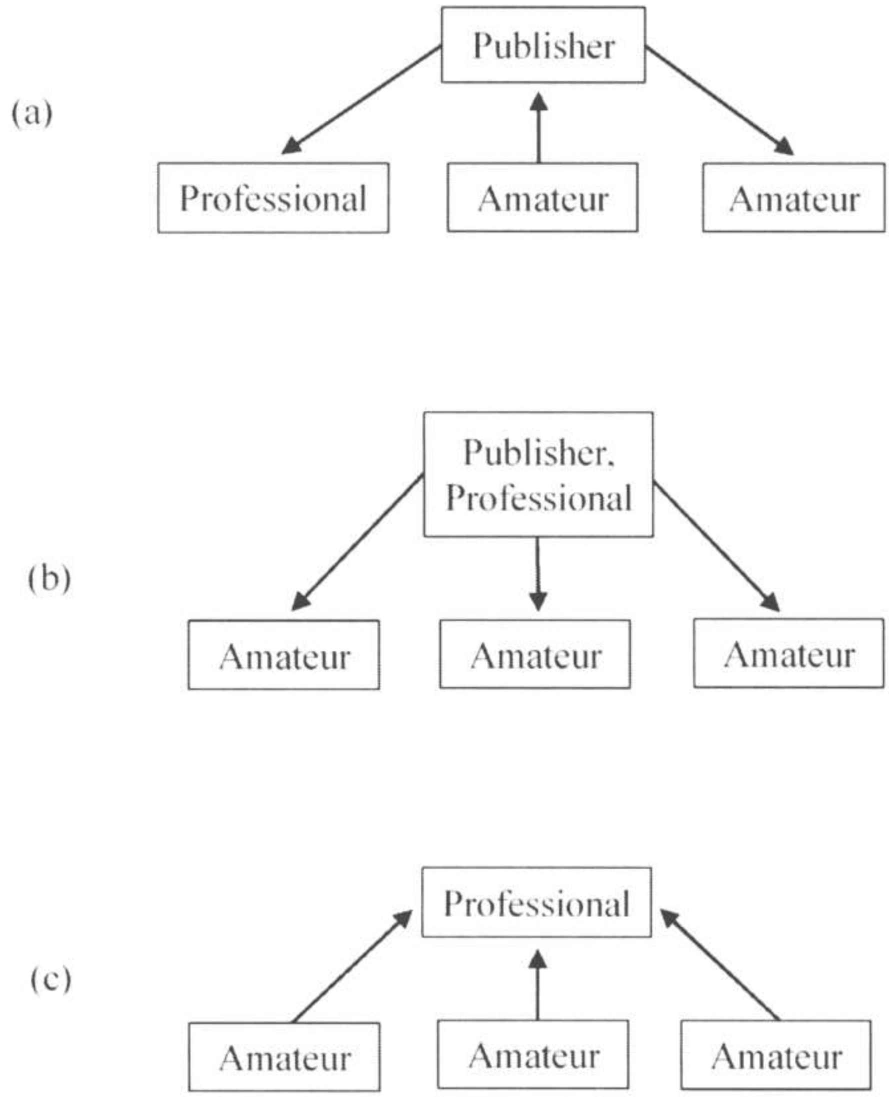

Figure 1: Three twentieth-century models of amateur and professional communications, indicating dominant information flows: (a) *Scientific American*; (b) Science Service/public understanding of science; (c) Vannevar Bush/citizen science.

aspiring adolescents or unskilled adults (Figure 1[b]). The Vannevar Bush portrayal revised the hierarchical model by foregrounding the value of amateur enthusiasts as data collectors for professional scientists. This valorized the opposite direction of information flow: from amateur observer to professional scientist and analyst (Figure 1[c]).

As important agents in organizing popular participation in lay science, media depictions thus offered models reliant on three distinct forms of information flow: (i) the publisher as intermediary and facilitator, channeling the voices of autonomous amateurs loosely linked to peers and, less commonly, to professionals (*Scientific American*); (ii) the mentored student receiving information from professionals relevant to personal interests, career aims, or wider societal benefit (Science Service); and, (iii) the data-collecting volunteer, supplying scientific information for the benefit of professionals (Bush). These characterizations provided prototypes that are recognizable in more recent instances of "crowd sourced science," "public understanding of science," and "citizen science" long before the terms were coined.

Contemporary Contexts: Socially-Networked Lay Science

Just as media initiatives shaped public understandings of, and participation in, lay science over the past century, contemporary media are enabling wide-reaching changes at the boundary between professional and non-professional science. The expression of amateur science has been revitalized by opportunities provided by electronic media and new participatory models (see, for example, Silvertown 2009).

The new communication channels becoming available from the end of the twentieth century included the Internet and its evolving facilities such as file transfer protocols, electronic bulletin boards, discussion groups, and user-created websites; digital telephony, and particularly Short Message Service (SMS, or texting); and social media via a variety of Internet-based platforms such as Facebook and Twitter. Importantly, each of these media was available to individual end-users rather than merely to intermediaries such as publishers and organizations. Public access flourished as hardware and network costs fell.

These media channels delivered additional advantages that differentiated them from twentieth-century alternatives. They provided immediacy, permitting near real-time (e.g., SMS, chat rooms, Twitter, Facebook) or relatively rapid (e.g., user webpages, discussion groups) communications. Equally significantly, they made possible two-way information flow between peers, and allowed for relatively unmediated communication. The new capabilities offered novel configurations and accelerated pace of engagement by lay scientists.

Citizen Science: Scientists as Beneficiaries

Rising in usage since the early 1990s (Michel *et al.* 2011), the term "citizen science" captures a contemporary form of para-scientific avocational activity in which amateurs volunteer as data-contributors (Irwin 1995). Ecological surveys and meteorological reporting are long-standing examples of such activities cited by Vannevar Bush over half a century ago (Miller-Rushing *et al.* 2012; Morris & Endfield 2012). More recent implementations have no traditional counterparts, such as environmental monitoring (Roy *et al.* 2012).

Social media facilitate such grassroots provision of local data. Mobile devices can replace pencil, paper, film, and recording tape to send observer data to a central source. The density and timeliness of such data collection can significantly improve the potential for scientific insights. Yet field observations by a network of contributors, particularly when gathering time-dependent data, tend to be based on the hierarchical model of unidirectional information flow towards a central hub, where it is collated and interpreted. Depending on how projects are implemented, the local contributors may be connected only weakly with their peers or even organizers (a related ethical issue, in which social media are employed to gather information from participants as unconscious subjects rather than as voluntary lay science contributors, is beyond the scope of this paper; for an example, see Radzikowsky *et al.* [2016]).

Electronic media have enabled additional modes for distributing work and communicating data. An early Internet-based example was SETI@Home. Sponsored by the Space Sciences Laboratory of the University of California from 1999, the project searched for extra-terrestrial intelligence via the distributed analysis of radio telescope data. It relied on volunteers to make available the idle time of their internetworked home computers to run automated software for data analysis. In its original implementation, this required, and permitted, no volunteer participation beyond the provision of hardware time. Such examples represent one extreme of citizen science, requiring little, if any, volunteer input. While the participants may receive periodic or even real-time updates of the data analysis, there is little scope for selecting, collating, or interpreting — and, indeed, of acquiring — results.

Such instances of amateur participation represent current examples of Vannevar Bush's model (Figure 1[c]). By implication, the "citizen scientists" contribute to the collective good by communicating local or individualistic observations to benefit a wider community of professional science and, by presumption, society at large. Implementations of such networks are nevertheless typically hierarchical, involving a large number of geographically dispersed "grassroots" observers and a smaller elite of data analysts. Participants are often assumed to require relatively little, if any, specialist expertise; as Bush explained, such amateurs "plug away without acclaim, recognizing that they are a long way from the top in their subjects" but that "it is worthwhile to have a part, even a small part" in science (Bush 1960, xviii, xx). In this sense citizens provide voluntary, largely unrecognized labor for, initially, the benefit of the professional scientist. These lay practitioners gain intrinsic benefits from participation (developing skills, opportunities for socializing, minor prestige and increased self-worth) while the external benefits are accrued by the professionals who have discretion in how and with whom they are distributed.

Scientist-facing projects such as these distributed computing examples prioritize the acquisition of scientific data and insights, and favor scientists as beneficiaries of a new computing resource. This reallocates not only computing time but also the costs of professional science to unpaid and largely unacknowledged volunteers. For professional astronomers in particular, such a volunteer resource has been increasingly recognized and exploited, such as in the Internet-hosted Zooniverse platform (Lintott 2015). More recent online initiatives such as Socientize.eu and CitizenScienceAlliance.org seek to scale up such activities to link practicing scientists, scientific institutions, and companies with tens of thousands of citizen scientist volunteers.

The nature of the projects may limit participant access to data, biasing the information transfer towards the professional collators and analysts. The configuration of information transfer in such projects may further limit peer-to-peer communications between the dispersed contributors. A weak counterweight to this restriction is the open-access publishing movement, which aims to make available the eventual published findings of such collaborative projects at little or no cost to wider audiences, even if it does not favor the volunteer participants in particular. Amateur contributors in this model of citizen science are functionally subordinate to the professional participants, and the configuration of electronic information flow can consolidate this relationship.

Citizen Science: Participants and Wider Society as Beneficiaries

While many so-called "citizen science" projects are configured to favor information flow towards scientists as beneficiaries, others explicitly define goals to favor participants and other beneficiaries. At least three motivations can be identified, although they are commonly conflated: (i) encouraging active public engagement in science; (ii) fostering scientific education; (iii) fostering scientific careers. Each can be related to the fulfillment of individual participants and to wider societal benefits. These themes can also be traced back to the model promoted by Science Service through the twentieth century.

The argument for citizen science as a means of promoting scientific education and literacy has motivated a growing number of initiatives. Some conceive participant education as a side-benefit of data acquisition for scientists or highlight the potential for educating wider publics and altering attitudes (e.g., Brossard *et al.* 2012). The societal dimension has been explicitly vaunted in projects that seek to promote "environmental citizenship" and to encourage wider publics to contribute to science policy (Ellis & Waterton 2004). The new communication channels of social media have increasingly been recognized and exploited (e.g., Foth *et al.* 2011). It is an education model based on encouraging citizen participants to endorse the focus, methods, and goals of scientific practice. Through involvement, the citizen will be endorsing and legitimizing the main social structures of knowledge production and exchange.

As with the mid-century template championed by Science Service, such examples prioritize information flow from professional scientists to amateur practitioners (Figure 1(b)). In each case, the schemes involve a configuration in which expertise flows towards recipients who are assumed to be relatively inexperienced, unskilled, and perhaps unmotivated. Education projects, particularly when aimed at young people, may align with the rubric of the "public understanding of science," in which wider audiences were understood as relatively passive, uninformed, or misinformed (Irwin 2001). To make parallels with postcolonial approaches to indigenous or folk knowledge, these generally become legitimized within policy making when they serve Western institutional practices (Coombes 2007); so, too, amateur knowledge production may be ignored or marginalized, except when it conforms to, or can be exploited by, professional bodies.

Citizen science initiatives nevertheless differ implicitly in how the amateur-professional interface is conceived. Thus, the "citizen as beneficiary" and "scientist as beneficiary" variants closely follow the distinct twentieth-century understandings described by Science Service and Vannevar Bush, respectively. Professional scientists either provide information to, or receive information from, subordinate non-professionals, but rank the lay contributors as junior participants. Both varieties consequently embody traditional understandings of scientific authority. These models define and constrain the recognized activities of amateur scientists and can be consolidated by configuring information networks appropriately.

Crowd-Sourced Science: Redefining Hierarchies

The term "crowd sourcing," scarcely a decade old, originated as a special case of "outsourcing" in the business world (Safire 2009). Applied to science, it has been narrowed to practices that rely on the connectedness of relatively large groups of contributors enabled by electronic and social media. Contributors can share data by computer, smartphone, or other internetworked device. Identifying "crowds" rather than "citizens" as key elements, the term vaunts social clusters more explicitly than do the examples of non-professional participation cited above.

Crowd-sourced science is a genuinely novel form of networking in which observations, actions, and analyses can be shared and disseminated with ease. In its most familiar and conventional guise, crowd-sourcing permits scientists to acquire data from dispersed observers, and can conform closely to the "citizen science" examples cited above. There are indications, however, of mixed outcomes for lay participants: this widespread form of crowd-sourced science, while potentially benefitting professional researchers and research budgets, may fail to retain volunteer participants for long, or to develop their scientific skills (Franzoni & Sauermann 2014).

The technology nevertheless can permit distinctly different attributes that can challenge traditional forms of science activity. Particular implementations of crowd-sourced science may enable more egalitarian networking to permit collective participation, less-mediated sharing of results and potential co-production of knowledge. This inbuilt versatility liberates amateur activities by allowing novel forms of interaction. Virtual communities can be enabled simply by defining a shared interest among peers, along with a virtual space, access privileges, and shared norms concerning how contributors interact. A crowd-sourcing initiative consequently may embody a communication protocol that provides significantly more autonomy for a virtual community or redefine the interactions between practicing amateurs and professionals.

A relatively conventional implementation is the re-creation of peer-to-peer communications in the virtual domain. This can be akin to a mid-century science club, in which participants meet, share and collectively produce; or, it may be configured much like the *Scientific American* model (Figure 1[a]), in which a website or central information hub brings together and mediates the activities of a group of enthusiasts, who may contribute to the co-production of scientific knowledge alongside professional scientists (along these lines, see Mims III 1999).

Crowd Sourced Science as Oppositional Science

In its most radical form, however, such socially-mediated activities may decouple amateur scientific practices from professional scrutiny or validation. The rise of perspectives independent of professional science became more evident from the 1970s, when popular critiques of environmental, medical, and military sciences increasingly were voiced. Examples include confrontations of interpretation between patients and researchers (Kielmann & Cataldo 2010), and between citizens and government scientists concerning the implications of chemical accidents (Allen 2003). Such examples of "citizen scientists" represented an unfamiliar and disputed role for wider publics. Instead of amateur scientists motivated by personal enthusiasms and overseen by either publishers or professionals, the new portrayal was of individuals and groups motivated by their concerns about official communications from professional scientists. Indeed, the low status of expertise implicit in common usage of the term "amateur scientist" has declined as a descriptor of such activities, being superseded by the more egalitarian term "lay expert" (Vetter 2011).

Such challenges to authority and expertise were enabled initially by the (limited) flow of scientific information from organizations, and by the (limited) dissemination of activists' views by the conventional media. The Internet significantly augmented this information exchange by enabling dissemination of relatively unmediated information and by directly representing views of activists communicating counter-narratives via discussion groups, self-produced webpages, and, within a decade, via proliferating social media platforms.

These autonomous scientific activities have been recognized as challenging scientific authority and practice, on the one hand, and empowering previously scattered individuals, on the other (Wilson *et al.* 2007). So-called "hacker" and "maker" communities, whose devotees innovate by re-purposing existing science and technology, have flourished via the sharing of information by electronic media (Thomas 2003). Public participation in biology, for example, has both traditional "citizen science" dimensions, and also "bio-hacker" potential, in which individuals may appropriate skills in contemporary biology for personal or peer-defined goals (Curry 2014). The activity may seek not to co-produce knowledge with professionals, but instead to bypass them (Figure 2).

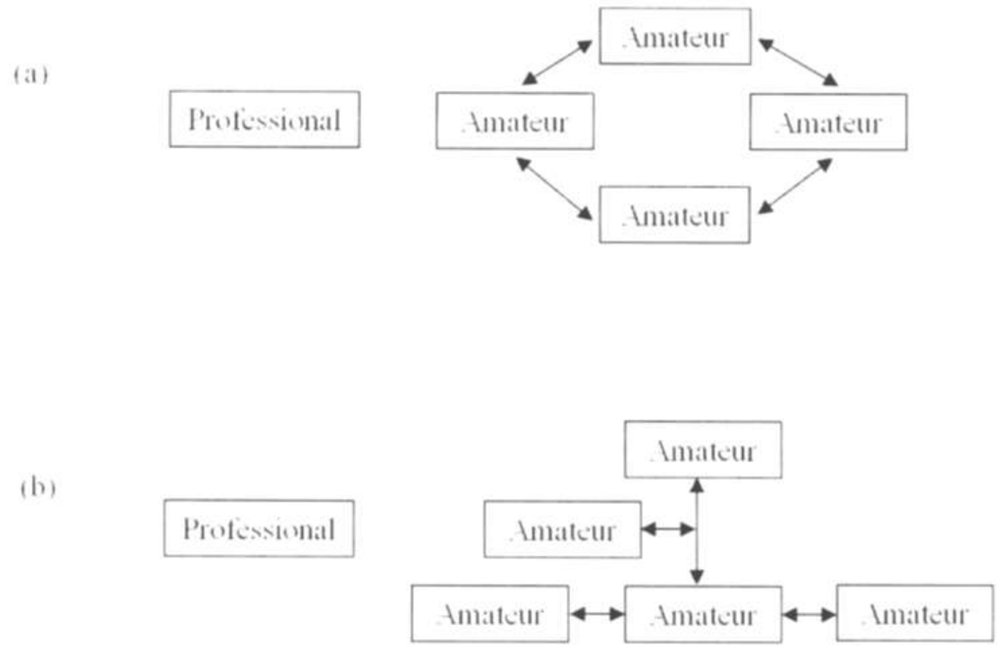

Figure 2: Two variants of peer-to-peer crowd-sourced knowledge, the second illustrating a more hierarchical configuration than the first.

The threat to professional autonomy and to power relations more generally has led to a variety of responses, with some professionals seeking actively to recuperate oppositional and independent scientific activities. One approach is to welcome hackers and lay experts into the fold as co-producers of knowledge (Williams & Calnan 1996). Another is to extend public outreach to encourage educational and career-fostering activities in science, thus converting lay practitioners into professionals. Thus far, however, the most effective form of recuperation has been via professional science initiatives that implement crowd-sourcing models to reposition professional scientists at the center of information flow (e.g., Fox *et al.* 2005). This reconfiguration of "crowd-sourced science" into conventional "citizen science" currently represents the majority of public science and lay expert initiatives.

However as the examples of hacking and open source movements demonstrate, they are not always anti-hierarchical and may mirror professional models of knowledge production (Figure 2[b]). Like the amateur science promoted by Science Service, where participants were encouraged to view their scientific endeavors as a stepping stone into professional practice, demonstration of skill in Linux coding may, for example, be used as a calling card for career entry. Positions in amateur hierarchies can be gained via demonstrable skills within the particular knowledge community, by time served, or by other social factors. Such hierarchies might be more significant where amateur groups are attempting to contest professional science and thus require a spokesperson of apparently similar authority. By interacting with other established institutions which seek representatives, horizontal egalitarian groupings start to generate hierarchies of delegates and spokespeople for those they represent.

Conclusion

The practice of science by non-professionals has been liberated by electronic media, which provide unprecedented access and immediacy coupled with novel options for relatively unmediated communication. These new channels of communication initially mapped twentieth-century templates of practice, but have been adapted by their users to host new participatory modes of lay science. These distinct protocols play with information flow and, in the process, alter power relations between professional and non-professional participants. This paper has argued that peer-to-peer communications, enabled by discussion groups and social media, encourage information flow unrestricted by the conventional barriers of recognized expertise and refereed publication — effectively an appropriation of authority by disparate interests. In its most cooperative implementation, this can foster co-production of scientific knowledge by heterogeneous communities of professionals and non-professionals.

By contrast, the most common form of lay-professional interaction at present is the "citizen science" model, in which professionals either provide educational information to less-skilled recipients, or gather information from distributed observers, again assumed to be of inferior rank or competence. While the beneficiaries are different in each case, the conventional hierarchy of professional science is maintained. This amounts to a recuperation of power via the control of information flow.

More novel forms of lay scientific practice are able to re-appropriate information and power by tailoring information flow within a peer community while excluding other audiences such as professionals. Thus the activities of "hackers" and "makers" may seek to re-purpose scientific knowledge and activities by suitably configuring their use of electronic media. Labeled détournement (hijacking or redirecting a practice for new purposes as a tool of radical movements), this form of crowd sourced science destabilizes conventional hierarchies between professionals and non-professionals (Downing 2001).

Thus, social media provide means to explore alternative relationships between lay and professional scientists, and means of both obtaining and recovering control. Whether the non-professional contributors are understood as science enthusiasts, would-be professionals, avocational volunteers, or critical and independent activists, their disparate motivations can be satisfied by particular configurations of information flow. The ways in which such innovations can encourage similar changes in practice within professional communities is the subject of the authors' ongoing research.

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