Computer-Supported Collaborative Learning Series

Ulrike Cress
Johannes Moskaliuk
Heisawn Jeong *Editors*

Mass Collaboration and Education

Springer

Computer-Supported Collaborative Learning Series

More information about this series at http://www.springer.com/series/5814

Ulrike Cress • Johannes Moskaliuk
Heisawn Jeong
Editors

Mass Collaboration and Education

Springer

Editors
Ulrike Cress
Knowledge Media Research Center
Tuebingen, Germany

Johannes Moskaliuk
University of Tuebingen
Tuebingen, Germany

Heisawn Jeong
Hallym University
Chuncheon, Kangwon-do
Korea (Republic of)

Computer-Supported Collaborative Learning Series
ISBN 978-3-319-13535-9 ISBN 978-3-319-13536-6 (eBook)
DOI 10.1007/978-3-319-13536-6

Library of Congress Control Number: 2016931285

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Contents

Part I Introduction

Mass Collaboration as an Emerging Paradigm for Education? Theories, Cases, and Research Methods 3
Ulrike Cress, Heisawn Jeong, and Johannes Moskaliuk

Part II Theoretical Approaches to Mass collaboration

A Brief History of Mass Collaboration: How Innovations Over Time Have Enabled People to Work Together More Effectively 31
Allan Collins

Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration 43
Gerhard Fischer

Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration 65
Mark Elliott

Mass Collaboration as Coevolution of Cognitive and Social Systems 85
Ulrike Cress, Insa Feinkohl, Jens Jirschitzka, and Joachim Kimmerle

What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions 105
Aileen Oeberst, Joachim Kimmerle, and Ulrike Cress

From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration 125
Wai-Tat Fu

Part III Cases of Mass Collaboration

Patterns of Meaning in a Cognitive Ecosystem: Modeling Stabilization and Enculturation in Social Tagging Systems 143
Tobias Ley, Paul Seitlinger, and Kai Pata

Individual Versus Collaborative Information Processing: The Case of Biases in Wikipedia 165
Aileen Oeberst, Ulrike Cress, Mitja Back, and Steffen Nestler

Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future 187
R. Benjamin Shapiro

Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community 209
Deborah A. Fields, Yasmin B. Kafai, and Michael T. Giang

Supporting Diverse and Creative Collaboration in the Scratch Online Community 241
Ricarose Roque, Natalie Rusk, and Mitchel Resnick

Citizen Science: Connecting to Nature Through Networks 257
Brigid Barron, Caitlin K. Martin, Véronique Mertl, and Mohamed Yassine

Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study 285
Sabrina C. Eimler, German Neubaum, Marc Mannsfeld, and Nicole C. Krämer

Socio-Technical Procedures of Facilitated Mass Collaboration for Creative E-Participation 305
Thomas Herrmann

Part IV Methods to Empirically Analyze Processes of Mass Collaboration

Theoretical and Empirical Analysis of Networked Knowledge 331
Iassen Halatchliyski

Applying Network Models and Network Analysis Techniques to the Study of Online Communities 347
H. Ulrich Hoppe, Andreas Harrer, Tilman Göhnert, and Tobias Hecking

Mass Collaboration on the Web: Textual Content Analysis by Means of Natural Language Processing 367
Ivan Habernal, Johannes Daxenberger, and Iryna Gurevych

Identification of Causal Effects in the Context of Mass Collaboration 391
Olga Slivko, Michael Kummer, and Marianne Saam

Part I
Introduction

Mass Collaboration as an Emerging Paradigm for Education? Theories, Cases, and Research Methods

Ulrike Cress, Heisawn Jeong, and Johannes Moskaliuk

Mass Collaboration as Topic of Computer-Supported Collaborative Learning

The Internet has tremendously advanced the opportunities for collaboration and education; particularly the number of people that can be involved in learning and knowledge building processes has increased to unprecedented levels. Web 2.0 developments during the last 10 years have enabled mass collaboration in a literal sense. Thousands of users make contributions to Wikipedia. There is a growing number of massive open online courses (MOOCs) being created and offered. They make it possible to offer online courses that exceed traditional classroom sizes many times over. Hundreds of thousands of people from around the world can participate in online courses offered by well-known universities. Moreover, contributions of thousands of amateur scientists have been instrumental when it comes to collecting and/or analyzing large sets of data. As citizen scientists, they participate in scientific research—be it for counting birds or analyzing data from NASA Mars missions.

U. Cress (✉)
Leibniz-Institut für Wissensmedien Tuebingen, Knowledge Construction Lab,
Tuebingen, Germany
e-mail: u.cress@iwm-tuebingen.de

H. Jeong
Department of Psychology, Hallym University, Chuncheon, South Korea
e-mail: heis@hallym.ac.kr

J. Moskaliuk
Applied Cognitive Psychology and Media Psychology, University of Tuebingen,
Tuebingen, Germany
e-mail: johannes.moskaliuk@uni-tuebingen.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_1

Through their involvement, they not only contribute to novel scientific discoveries but also become more knowledgeable themselves and develop an identity as citizen scientists. Last but not least, educational platforms have been established that enable students to become members of a worldwide learning community, as they create and share digital products that can be reused and further refined by others. One of the most prominent platforms is Scratch, a platform that was established by MIT in 2007 and has now grown into a community with more than nine million projects and about three million user profiles.

In order to understand these fascinating phenomena of mass collaboration, we need new theoretical frameworks and methodological approaches that can deal with these mass phenomena and their specific dynamics. Existing findings and approaches from individual and small group research are a first basis to understand learning and collaborative processes in these new environments, but they are not adequate to deal with the unique processes occurring at the mass level. In recent years, numerous studies have been published on mass collaboration environments such as Wikipedia (cf. Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2014; Kimmerle, Moskaliuk, Harrer, & Cress, 2010), Scratch (cf. Kafai, Roque, Fields, & Monroy-Hernandez, 2011), and the blogosphere (cf. Cakir, 2013) or MOOCs (cf. Diver & Martinez, 2015; Muñoz-Merino, Ruipérez-Valiente, Alario-Hoyos, Pérez-Sanagustín, & Delgado Kloos, 2015). These studies focus mostly on specific environments. We need to understand how these individual environments develop and function, but we also need a more general understanding of the principles which drive masses of people to work together and achieve things that were previously unimaginable. When does mass collaboration nudge a learner to actively participate, and when does it lead to a feeling of being part of a community of learners? Where exactly in mass collaboration does learning happen? Is it the system that learns and influences its participants, or is it the other way around? What are the conditions that ensure that the involved individuals acquire knowledge and participate in knowledge production? What are the unique characteristics that set mass collaboration apart from other kinds of collaboration? What makes mass collaboration effective?

With their theoretical grounding in learning and in theories of social processes and enculturation, and with their specific consideration of the socio-technical design of learning environments, the learning sciences and explicitly CSCL (computer-supported collaborative learning) may be the right research community to deal with these questions adequately. This book (Cress et al., 2016) is part of a continuing effort to establish a research agenda on large-scale learning and knowledge construction within these communities. The effort began at the *Tenth International Conference on Computer-Supported Collaborative Learning (CSCL)* in Madison, Wisconsin (USA), where we organized a symposium about “Mass collaboration—an emerging field for CSCL” (Cress et al., 2013). The symposium brought together different topics like long-tail learning, Scratch, citizen science, cultures of participation, and theoretical models of mass collaboration. We continued and widened the discussion by seeking out contributions from further researchers who work on this topic worldwide. We held a workshop at the Leibniz-Institut für Wissensmedien (Knowledge Media Research Center) in Tuebingen, Germany, in May 2014.[1] Here researchers from different disciplines and research traditions presented their work and discussed a potential research agenda. During the workshop, the idea was born to edit a book that provides an overview of these approaches and points out the increasing relevance of mass collaboration for education and learning. We later issued an open call and asked for additional contributions from researchers who have done related work on the topic. In the end, we invited more than 30 authors to submit their work on mass collaboration and education.

The goal of this book[2] is to provide a broad overview of the research about mass collaboration and education that is currently being done in different disciplines, labs, and research groups. The book includes perspectives from psychology, pedagogy, computer science, computational linguistics, network science, and economics. Contributions are from around the world, mostly from Europe and the USA. The book introduces relevant theoretical approaches and methodological issues from different disciplines and research traditions, as well as various cutting-edge cases of mass collaboration. In doing so, the goal is to identify where the current research stands and what has been achieved so far.

In the 2014 workshop in Tuebingen, it was clear that participants had quite different conceptualizations of mass collaboration. Some use cognitive frameworks to understand the processes, while others rely on sociocultural or systemic frameworks. Some focus on how to stimulate masses of people in order to enable learning processes, while others state that masses of people are by definition self-regulated entities that cannot be guided externally. We also collected different definitions of mass collaboration in the process of soliciting and reviewing the chapters for the book. In an attempt to develop a shared understanding of mass collaboration, we documented and compared different conceptualizations of mass collaboration. In the following section, we first provide several definitions of mass collaboration that have emerged during our collaboration with the authors. In the main part of this introductory chapter, we summarize the contributions and provide a short overview of each chapter. In the last part, we discuss open questions and research challenges that need to be answered in future research.

---

[1] The workshop was financed by a grant provided by the Deutsche Forschungsgemeinschaft to Ulrike Cress (CR 110/10-1).

[2] We cordially thank Petra Hohls and Carolin Burmeister for their great help and their patience during the editing process. Without their great effort and passion, we would have not been able to align the chapters, proof the references, and do all the formatting that was needed.

What Is Mass Collaboration and How Does It Contribute to Education?: Definitions and Key Aspects of Mass Collaboration in Education

Mass collaboration is characterized by the large number of people being (mass) involved in it, the digital tools they use (Web 2.0), and the digital products they create. In the following, we summarize these aspects as **formal aspects** of mass collaboration. How users interact with digital tools and what kind of products they create are key parts of the interaction process going on in mass collaboration. As we will show, this process of **interaction** comprises elements that range from participation, coordination, and cooperation to collaboration. These elements describe an increasing amount of **interrelatedness** among the users involved. The more interrelated users become, the more mass collaboration unfolds its specific dynamics. Successful cases of mass collaboration in education show that masses of users can exhibit a special spirit that activates the users and leads to emergent processes. We describe this **spirit** as a defining feature of mass collaboration. Last, but not least, when it comes to education, we have to ask where the **learning** takes place. In mass collaboration settings, we can differentiate between learning that happens on the group level (knowledge creation) and learning that happens on the individual level, where an individual acquires knowledge. Of course both may happen and promote each other mutually.

Formal Aspects of Mass Collaboration: Number of People, Used Tools, and Creation of Artifacts

The most prominent feature of mass collaboration is possibly the **large number of people** involved. For example, Fischer (2016) describes mass collaboration with regard to education as follows: “Mass collaboration occurs when large numbers of people learn or work together.” The number of people involved in collaboration is indeed a prominent feature of mass collaboration. Wikipedia has more than 25 million registered editors,[3] who have collectively created more than four million articles, and Scratch has 6.8 million registered users,[4] to name perhaps the largest mass collaboration environments. Note, however, that even within a mass collaboration environment with a large number of users, the extent of participation can vary depending on the levels of the collaboration. Wikipedia itself is the result of mass collaboration by millions of users, but a specific article in Wikipedia may only have a handful of authors. In Scratch, a game programmed by users may be a remix of just two or three participants’ work. Not all activities happen on a large scale.

---

[3] http://en.wikipedia.org/wiki/Special:Statistics

[4] https://scratch.mit.edu/statistics/

Mass collaboration in the broad sense of Fischer's definition may have taken place before the digital age (Collins, 2016). But it is the Internet, especially the emergence of social software, that has made it much more commonplace and prominent. The Web provides numerous tools and communication channels that people can use with ease. They allow people to observe others, share their resources, coordinate their work, and/or even jointly create artifacts. Large numbers of people can easily collaborate with each other, because they can all access a shared product or workspace that each of them can change or modify. Joint writing of a text, for example, may have been possible before Web 2.0, but it was much harder. Nowadays, through wikis and other similar tools, people can do that much more easily. People have access to what was written by others without any time delay from their own device and can make modifications that are immediately visible to all other users. So a further critical feature of mass collaboration is the use of **digital tools**. They make possible communication and collaboration that are independent from time and geographic location. They also enable participants to collect and store large amounts of data and information, to interact with this data, and to coordinate their work around it. In this sense, Web 2.0 technology may even be a precondition for the development of large networks of people who collaborate to write, conduct research, and/or learn.

However, mass collaboration does not have to be necessarily or exclusively digital. An example for a mass movement that starts in the "real" world and provides "local" space is the makerspace movement. Makerspaces provide "real" rooms where people design and engineer tangible products. In chapter "Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future," Shapiro (2016) shows examples where people craft projects ranging from art installations to gigantic rideable robots. They share tools (real, non-digital) and make use of their neighbors' knowledge. Makerspaces start out as primarily local face-to-face collaboration projects, but are then later connected to broad networks of participants through crowd funding and resource sharing. According to Shapiro, the makerspace movement demonstrates a new model for how mass collaboration and mass learning can be distributed across online and in-person participation.

In mass collaboration, participants produce together both physical and virtual artifacts, supporting each other's learning by drawing upon the knowledge, tools, and monetary resources of physical and virtual communities. This feature is so central to mass collaboration that some authors make it the focus of mass collaboration: If a mass of users "explicitly collaborates to build a long-lasting artifact that is beneficial to the whole community" (Doan, Ramakrishnan, & Halevy, 2010, p. 1), this could be called mass collaboration. Elliott (2016) defines mass collaboration as digital stigmergic collaboration (collective creation of shared representations in digital media). By using Wikipedia, people can not only share links or other resources but also engage in joint writing of texts that, despite their many authors, are homogeneous and fluent. By using tagging systems such as delicious.com, people can share digital resources, tag them, and build a folksonomy that presents the conceptual knowledge of the community of taggers. Other forms of mass collaboration make use of platforms or portals, where learners have access to content, share information, and rely on the work of others. On the platform Scratch.org, for example, people can use a programming language and they can share self-made programs. In galaxyzoo.org, people classify galaxies by deciding if they are spiral shaped or not. On the platform Foldit, people manipulate representations of molecular biology in order to solve protein-folding puzzles that cannot be done by machines, but is easy for humans. MOOC platform like edx.org provides access to open courses and structure the learning process and possible collaboration. In sum, mass collaboration tools not only enable participants to use and share information and digital artifacts but also to engage in joint production of community resources and artifacts. Joint production of artifacts and resources is not restricted to tangible goods, however. In a project like *Project Hexapod*, people collaborate not only on the product of the project itself (in this case, a gigantic, rideable, six-legged machine named Stompy) but also on the establishment of norms, ideologies, tools, and communities for learning and production. In that sense, mass collaboration tools not only enable participants to use and share information and digital artifacts but also to engage in joint production of artifacts and tangible and intangible community resources.

Interactional Aspects of Mass Collaboration: Participation, Coordination, Cooperation, and Collaboration

The large number of people involved in mass collaboration is perhaps its most prominent defining aspect. The second defining aspect of mass collaboration is the process of interactive **collaboration** itself. There are different modes of collaborative actions in mass collaboration. On this point, many authors refer to the distinction between *collaboration* and *cooperation* in Dillenbourg (1999). Collaboration means that people have a common goal and engage in joint problem solving or learning. They have a shared understanding of the task and share the process of solving problems and/or learning. In contrast, *cooperation* refers to group work in which people divide the work into subtasks. Each person does one's own subtask, and individual contributions are later integrated into a whole. When cooperating, people do not necessarily share the processes of learning. They might not even have a shared understanding of the task. In a mass collaboration context, both collaboration and cooperation occur. Participants might divide the tasks and/or work on their own programs or articles, in some cases independently from other users. In other cases, they work on the same artifacts with a shared goal of improving the article or finding an answer to a puzzle.

In fact, there are a number of different ways to participate in mass collaboration. In addition to collaboration and cooperation, people may sometimes just *coordinate* their efforts and contributions. In the case of coordination, people might even have different goals. Coordination just means that people align their activities with those of others so that they could work together toward mutual benefit without disturbing each other. Coordination might happen through embedded roles or privileges, as those that administrators in Wikipedia have, for instance, rather than through explicit negotiation and discussion, as is often the case in cooperation. *Participation* can be considered to be a lower level of interaction than cooperation and even coordination. Participation just means that people get involved in some form of interpersonal process. They may simply read Wikipedia articles written by other users or submit a comment on another's contributions (e.g., press the "like" button in Facebook or Scratch) without having any intention of taking on some further task. So interrelatedness of people's activities might span a scale from pure participation, to coordination or cooperation, to collaboration.

Whatever the level of interrelatedness, the important thing is that all interrelated activities play a role in mass processes. People might not necessarily work on a shared artifact, but individuals' contributions might still advance individual and collective goals. In Scratch, for example, pupils work on individual programs, but once shared, other participants can use the provided code. They remix the codes from others and/or build on them, thereby making their code a "collective" artifact. Participants might not jointly work on the same program code. They might not collaborate (e.g., by working on a program for the same piece of software), or even cooperate (by distributing the programming task among the people), or coordinate (e.g., by deciding about rights and duties). However, their contributions are combined and transformed through participation so that the resulting products can reflect the emergent processes of knowledge development and creation.

Aspects regarding the Specific Spirit Exhibited in Mass Collaboration

The emergent process brings us to another aspect of mass collaboration: That of the **special spirit** that can be exhibited in mass collaboration. Many contributions in this book (the chapters of Cress, Feinkohl, Jirschitzka, & Kimmerle, 2016; Fischer, 2016; Roque, Rusk, & Resnick, 2016; Shapiro, 2016) describe participants' transition from a content-specific focus to a focus on the community itself. It is a shift from "participation for satisfaction of personal desires to participation for the benefit of a community" (Chapter "Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future" by Shapiro, 2016). In the collaboration process, an individual is transformed to have a new identity, such as a Wikipedian, a citizen scientist, or a Scratcher. The individual is not just an individual learner any more. He or she starts to feel like a member of the community and forms a social identity, acting as a member of the group (Tajfel, 2010; Turner, 1999). People do not just share and contribute information or revise or remix others' work and contributions. They also take on roles and act in the spirit of collective action (Olson, 2009). Users as individuals are no longer the main drivers of such a collective effort. Instead, the mass of people as an agent itself drives the effort.

To focus on this special spirit of mass collaboration is the key feature of the systemic or stigmergic perspective (see the chapters of Cress, Feinkohl et al., 2016; Elliott, 2016; Oeberst, Kimmerle, & Cress, 2016). These frameworks view mass collaboration not just as a process formed by activities of individual learners but more as an autopoietic process. They see "the mass" as the driving actor. The mass of course consists of individuals. But they may come and go over time. In contrast, the collective remains stable. For example, Wikipedia continues to exist even when all authors who are active at a certain time have changed as a new generation of authors continues their work in the spirit of Wikipedia. The artifacts that the community has created and the social norms that they have developed will ensure this process, and the community will continue to exist in more or less the same spirit established by the initial Wikipedia users. The community itself takes an active role determining what individual members do in the future. We may even state that when the mass itself exerts such a special dynamics and spirit, participation of different individuals is not a problem anymore. If people act too much like individuals, the mass environment may suffer from low participation and low identification with the group (see the low success rates and rates of active participation of learners in MOOCs presented in chapter "Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study" by Eimler, Neubaum, Mannsfeld, & Krämer, 2016). In such cases, mass collaboration may not be very likely.

Learning-Related Aspects Regarding Where Learning Happens

When we talk about mass collaboration in the area of education, we should consider *what* is learned and *who* learns. Shapiro (2016) raises the issue that effective knowledge creation may happen in mass collaboration environments, but not for the individuals who did the work but for a third party who set up the system (e.g., scientists). He describes, for example, that the crowdsourcing platform galaxyzoo.org enabled scientists to author many scientific papers, but the majority of the platform users who classified the galaxies unfortunately might not have learned anything. This might be due to the fact that this platform coordinates people's work, but it does not aim to promote learning or collaboration among participants.

If we examine mass collaboration in the context of learning, we need to consider different levels of learning (Kimmerle, Moskaliuk, Oeberst, & Cress, 2015)—the individual level and the collective level. Both processes are different and one does not necessarily lead to the other. Some forms of mass collaboration explicitly intend that individuals learn (e.g., see chapter "Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study" by Eimler et al., 2016 for MOOCs or chapter "Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community" by Fields, Kafai, & Giang, 2016 for Scratch). In other cases, learning may happen as a side effect of the collaboration (see chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" by Cress, Feinkohl et al., 2016). In still others, knowledge creation is explicitly intended on the collective level (see chapter "Socio-Technical Procedures of Facilitated Mass Collaboration for Creative E-Participation" by Herrmann (2016) for e-participation or chapter "Citizen Science: Connecting to Nature Through Networks" by Barron, Martin, Mertl, and Yassine (2016) for citizen science). Some mass collaboration settings explicitly aim learning at both levels. For example, chapter "From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration" by Fu (2016) and chapter "Patterns of Meaning in a Cognitive Ecosystem: Modeling Stabilization and Enculturation in Social Tagging Systems" by Ley, Seitlinger, and Pata (2016) show how social tagging creates knowledge on the community level (folksonomies) and how this in turn influences people's information search and induces learning processes.

Overview on the Chapters of This Book

Because mass collaboration is a new topic in educational research, there are many open questions and issues that must be examined. We see a need for research with regard to at least three topics: (1) theoretical considerations about mass collaboration in education, (2) description of individual cases of mass collaboration, and (3) identification and development of research methods that are suitable for this topic.

The phenomenon of mass collaboration calls for novel **theoretical conceptualizations** that can explain the workings of different mass collaboration scenarios. How do individuals behave in the mass of users? Is the mass more than the sum of individuals? How does the mass shape individual's behavior? What role do artifacts play in these mass collaboration processes? Do individuals in masses cooperate or collaborate? How do masses organize themselves? How can we shape and influence mass collaboration so as to foster intentional learning and education?

While these questions have been addressed in several disciplines in the past, the implication for learning and education has never been systematically considered. What we need are theoretical considerations of knowledge processes, such as knowledge acquisition, knowledge exchange, and knowledge creation, as they occur in masses.

In addition to developing theoretical framework for mass collaboration, we need empirical studies of **mass collaboration**. By observing education-relevant processes that take place in scenarios dealing with masses of users, we can understand how individual processes and mass processes are intertwined. To accomplish this, we can analyze processes in platforms such as Wikipedia, social tagging environments, MOOCs, e-participation, Scratch, or citizen science projects. We can also analyze whether there are any differences between mass collaboration that emerge in a self-organized way, like in Wikipedia, and settings like Scratch, which researchers and educators have intentionally developed for educational purposes.

The large-scale data that mass collaboration produces require **innovative methods** of analysis. How can we deal with both the individual and the group levels of analysis? How can we describe with individual data both individual behavior in masses and the mass behavior? Can we even study mass collaboration in the lab, where we fake the mass and just observe single and independent individuals? How can we identify causality in mass-related settings?

This book addressed these issues in three parts: The first part consists of six chapters that present theoretical approaches to mass collaboration. They include general views on the development of mass collaboration and how they have changed in the digital age, but also include more specific approaches based on cognitive psychology, biology (with the concept of stigmergy) or system theory. The first part also asks how our understanding of knowledge has changed through digital media. The second part presents empirical studies conducted in different scenarios of mass collaboration: They include Wikipedia, MOOCs, citizen sciences, social tagging, e-participation, and the platform Scratch. The third part deals with methods for analyzing processes of mass collaboration. Here social networks are considered, as well as computational semantics that are able to classify the semantics in large data automatically. With regard to research designs, it is examined how causality can be analyzed with the data collected from mass collaboration platforms like Wikipedia. A short overview of the chapters of the book follows, so that readers can see what research currently is being done with regard to mass collaboration and education.

Theoretical Approaches to Mass Collaboration

The first part of the book presents theoretical approaches to mass collaboration. In chapter "A Brief History of Mass Collaboration: How Innovations Over Time Have Enabled People to Work Together More Effectively" **Allan Collins** (2016) provides a **background history on mass collaboration**. It dates the beginning of mass collaboration back to the origin of our species, *Homo sapiens*, as it was the first species to trade goods. According to Collins, trading leads to specialization and division of labor. The chapter then describes major events and milestones in the history of mass collaboration, beginning from the development of cities, the invention of writing and printing, the development of the scientific community, to the invention of the Internet and Web. The development of cities was critical for human innovation, as it allowed people to come into contact with a greater variety of ideas. A burst of creativity occurred when people came to work together, as in the city of Cremona, Italy, for violin making, and Silicon Valley, USA, for the IT industry. Writing allowed people to share ideas with people who were geographically and/or temporally distanced. This also led to the development of world scientific communities, in which scientists collectively work toward the shared goal of advancing science. The chapter notes that scientific communities have a variety of norms and structures to support scientific practices, such as peer reviews and journal publications. More recently, the Internet and Web have made it even much easier to access and share information, thereby prompting the emergence of a host of examples of mass collaboration. The chapter discusses how mass collaboration can lead to a society in which adults and children can be in charge of their own learning as a community.

In chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" **Gerhard Fischer** (2016) provides an overview of theoretical frameworks developed in the last decade to describe knowledge creation and accumulation and sharing. The chapter asks what the **innovative socio-technical environments that foster and support mass collaboration** are. Users become part of a culture of participation that use media and technological tools to think, work, learn, and collaborate. They are meta-designers who create socio-technical collaborative environments that enable the burst of creativity described in the chapter by Collins. In his chapter, Fischer introduces models of knowledge creation, accumulation, and sharing. The *model-authoritative* depends on a large number of passive consumers (e.g., readers, learners) and a small number of experts (e.g., journalists, teachers) who act as strong input filters and reject unreliable and untrustworthy information. The *model-democratic*, in contrast, uses weak input filters, that is, the role of the experts is substantially diminished or nonexistent. It allows individuals not only to access but also to participate and to contribute to the process of knowledge creation. Fischer describes different roles that can be found in rich ecologies of participation and collaboration. He argues that for mass collaboration to work, there needs to be a critical number of active participants. Identifying different motivations of individuals helps to encourage and support the users to take on more demanding roles over time. The chapter concludes with an overview of research challenges and open questions such as how to ensure the quality of the artifacts generated via mass collaboration and how to explore the long-tail theory in the context of mass collaboration.

One puzzling aspect of mass collaboration is that teamwork is widely distributed and decentralized. In some cases, individual agents seem to be engaged in isolated activities. In spite of this, highly organized activities and outcomes emerge with seemingly little or no central control. How is this possible when so many people are involved? In chapter "Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration" **Mark Elliott** (2016) uses the concept of **stigmergy** to answer this question. This concept was originally developed to explain the behavior of social insects such as ants and termites. These insects behave in very organized fashion and in strong relation to each other. Such behavior is made possible by the use of physical signs in the environment (e.g., pheromones in ant colonies). These signs serve as messages to other agents. Individual agents communicate with other agents by changing the environment, that is, physical signs in the environment. The change in the environment in turn alters the behavior of other individuals. Applying this perspective to mass collaboration brings several surprising insights: Wikipedia, Scratch, MakerSpace, or communities of citizen scientists provide a kind of anthill that structures what people can do, where they work, how they interact, and what they contribute. It is a great notion that communities with their digital tools, their social norms, and ways of interacting and communicating leave their traces in artifacts, and these serve as external structures for further communication and activities. Like an anthill or mound, the artifacts provide a stable (with regard to time and space) structure for interaction, collaboration, and further creation of artifacts. So Elliott's chapter not only points to analogies between users in the social Web and social insects but also points to the relevance of the tools and artifacts created by the users in the mass collaboration environment. They not only result from cooperation but also determine future cooperation.

In chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems", **Ulrike Cress**, **Insa Feinkohl**, **Jens Jirschitzka, and Joachim Kimmerle** (2016) describe mass collaboration with the **paradigm of self-organization**. They state that masses of people are a self-organized autopoietic social system. Whereas Elliott (2016) in chapter "Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration" stresses the relevance of artifacts, the authors of chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" point to the relevance of communication and its closed character: Ongoing communication is closed, that is, it always bases on previous communication, and on the norms, this communication has established. Thus, like in the concept of stigmergy described in the preceding chapter, the systemic approach points to the fact that it is the mass that influences and determines how individuals act and contribute to the system. However, the coevolution model of Cress and her colleagues takes not only the social system but also individuals into consideration. Individuals are cognitive systems. They are also closed systems, because their thinking and understanding are based on their knowledge and previous thoughts. The coevolution model states that each system influences the other's development. Each system, the social system as well as the cognitive one, can irritate the other and provide an external stimulus for the other system. The irritation induces a cognitive conflict. On the side of the individual, this may lead to individual learning, and on the side of the social system, this may lead to knowledge construction. So, both systems coevolve and mutually stimulate each other. With concrete examples of knowledge processes in Wikipedia and in a nutrition forum (Urkostforum), the authors show how their research empirically builds on this model and which research methods fit their systemic approach.

The age of mass collaboration and information technology provides a new opportunity to reexamine an old philosophical issue about **what knowledge is** and **who creates and possesses** it. Chapter "What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions", written by **Aileen Oeberst**, **Joachim Kimmerle, and Ulrike Cress** (2016), provides an overview of different approaches to these questions. The authors first review the traditional perspectives in philosophy and psychology. Philosophy has conceptualized knowledge as justified true belief, whereas psychology tends to view it mainly in terms of semantic memory, but both traditions have regarded knowledge as being located within people's minds. This individual perspective reaches its limits when considering how knowledge advances collaboratively in science. In situations such as scientific collaboration, scientists are epistemically dependent on each other, as no one person possesses the full scope of knowledge or the competency to justify it. Knowledge claims become probabilistic rather than definitive. An alternative "social view" of knowledge emphasizes the collective nature of justifying knowledge claims. This is also the view put forth by the systemic perspectives of chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems".

These key considerations on the nature and relativity of knowledge from chapter "What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions" are especially relevant when it comes to education. If knowledge is socially constructed in a closed communication system, then we have to ask, what validity the knowledge has that users create in mass scenarios? If we use mass collaboration scenarios for education purposes, and if there not experts but novices provide content, how can we then prevent users and masses from constructing content without much validity? If it is not an expert or teacher who presents what has to be learned, how can we make sure that those pupils' collaborative process leads to valid knowledge? Chapters "Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration," "Mass Collaboration as Coevolution of Cognitive and Social Systems" and "What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions" may not provide final answers but make us alert to these questions.

Chapter "From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration," authored by **Wai-Tat Fu** (2016), deals with the very basic question as to what **collective intelligence** is. Coming from the cognitive tradition of describing humans as problem solvers (Newell & Simon, 1972), he considers humans to be cognitive computational systems which process symbols in order to achieve goals. He posits that humans not only process local information they have at hand but also retrieve distal symbol structures by making use of external resources, like the information in the Web. According to Fu, humans are intelligent if they achieve their goals by finding and processing relevant information without much effort. Their "search control knowledge" allows them to effectively process their internal symbol structures in order to infer where the distal knowledge is. Efficient representations of their environments furthermore make distal knowledge more accessible for individuals. Analogously to his description of individuals as cognitive computational systems, Fu describes the mass of users as a collective computational system. As a system, they collectively develop search control knowledge and efficient representations to make their search more efficient. Fu illustrates these processes with the example of social tagging systems. Social tagging systems provide distal knowledge structures that allow the users to extract knowledge. Tag reception and tag production shape the mental concepts of users and provide search control knowledge. Over time, the mass develops its own intelligence as it collectively develops and processes distal symbol structures such as tags. These tags are powerful representations of the information environment. They shape the user's internal knowledge and allow efficient search processes and efficient problem solving. Fu's chapter points us to the fact that collective activities are not a means to themselves. They should lead to collective intelligence, not just to collectively created artifacts. Fu proposes that collective intelligence can be measured through the efficacy of search processes and through people's ability to find and exploit relevant resources. So, different from the more systemic approaches clarified in chapter “Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration” by Elliott (2016), chapter “Mass Collaboration as Coevolution of Cognitive and Social Systems” by Cress et al. (2016), and chapter “What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions” by Oeberst, Kimmerle, and Cress (2016), Fu (2016) in chapter “From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration” sets up a normative approach and suggests efficacy as a relevant criterion for mass collaboration.

Cases of Mass Collaboration

The **second part of the book** contains chapters about concrete mass collaboration environments and shows processes of learning and knowledge construction in these environments.

In chapter “Patterns of Meaning in a Cognitive Ecosystem: Modeling Stabilization and Enculturation in Social Tagging Systems,” **Tobias Ley**, **Paul Seitlinger, and Kai Pata** (2016) deal with **patterns of meaning in a cognitive ecosystem**. They show how users’ understanding and activities are shaped through their environment and under what conditions users internalize meaning provided by their environments. Social tagging systems link external resources to internal categories. By social tagging, users not only apply their own internal categories to describe resources but also get to know the categories used by other users. The authors present three studies. In the first, they observe the tagging behavior of learner groups over 10 weeks. Their results show how over time the groups develop a shared vocabulary and show a more specific level of categorization, which can be described as knowledge acquisition. In a second study, the authors present a system that observes a learner’s tagging and navigation behavior and identifies a user’s internal categories. This predicts the users’ tag choices very well. The third study is a simulation study. It provides evidence that the users’ tags converge over time. With the three studies taken together, the authors show how individuals form meaning patterns in interaction with their environment, how these patterns are amplified, and how interaction with other people enhances taking on a cultural pattern. The three studies not only provide interesting results, they also present a methodologically high-level description of the interrelation between individual and collective processes or between enculturation and development of cultural pattern in the language of the authors.

Chapter “Individual Versus Collaborative Information Processing: The Case of Biases in Wikipedia” deals with **biases in collaborative information processing. Aileen Oeberst**, **Ulrike Cress**, **Mitja Back, and Steffen Nestler** (2016) ask whether biases that are known from individual information processing are also relevant in the socially negotiated, collective representations of Wikipedia. Do individual biases translate into collective biases or do they level out in the process of collaboration? This chapter addresses two biases: hindsight bias and in-group bias. Hindsight bias refers to the tendency to overestimate one's previous opinion of the likelihood of an outcome after the outcome is known. It is a robust and widespread bias, difficult for individuals to avoid. In order to find out whether hindsight bias exists in Wikipedia articles, the authors selected Wikipedia articles about events (e.g., Fukushima Daiichi Nuclear Power Plant) and compared how the perception of the likelihood of the events changed before and after the event. The results indicated that hindsight bias in fact also exists in Wikipedia.

The other bias chapter "Individual Versus Collaborative Information Processing: The Case of Biases in Wikipedia" addresses is the in-group bias. It refers to systematic distortions that result from group membership: People perceive and represent the group they belong to more positively than other groups. In order to examine whether in-group bias also exists in Wikipedia, the authors compared different language versions of the same international conflicts. Using an automated tool to estimate similarity among article versions, they found that different language versions originating from two populations involved in the same event were less similar than two versions, written by one involved and one uninvolved nation, or the two versions written by two uninvolved nations. In sum, their findings indicate that Wikipedia is not free from biases. The many revisions that a Wikipedia article normally undergoes and the explicit rule that each article must provide a neutral point of view can obviously not protect an article to be biased. This is similar to individuals, who also cannot easily suppress their biases. They occur unintentionally and automatically—may it be individual thinking or in collective knowledge creation.

Over the past few years, participation in mass collaboration environments has grown dramatically. They support a diverse array of activities and practices such as scientific research, teaching and learning, or gaming, involving diverse participants including scientists, commercial enterprises, hobbyists, and students. Chapter "Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future" by R. Ben Shapiro (2016) examines the learning potentials of these emerging mass collaboration environments. In order to address this question, he lays out key pedagogical design principles from learning sciences research and uses them to analyze four mass collaboration environments: massive open online courses (MOOCs, also described in chapter "Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study" by Eimler et al., 2016), science crowdsourcing systems (e.g., citizen sciences as described in chapter "Citizen Science: Connecting to Nature Through Networks" by **Barron**, **Martin**, **Mertl, and Yassine**, 2016), massive multiplayer online (MMO) games, and maker communities. His analysis shows that these environments have different strengths and weaknesses. Crowdsourcing systems may sometimes illustrate how a mass public can participate in scientific discovery, and yet their roles are so marginal, they are not likely to learn anything deeply. In contrast, MMO games can support deep peer-supported apprenticeship for learning, though thus far this learning has been about the properties of imaginary digital worlds. MOOCs show that there is a huge public interest in learning about academic topics, but that the lack of social context or peer support for learning and knowledge production can severely hamper participation. MakerSpace, a rapidly emerging community that connects face-to-face collaboration around the design and creation of tangible products, encourages people to creatively express themselves through design, craft, and engineering. They demonstrate how primarily local collaboration projects are connected to broad networks of participants through crowd funding and resource sharing. In conclusion, Shapiro argues for recombining design principles from learning sciences with some of the design characteristics of these systems. He illustrates what might be possible when these environments are informed by solid research in how people learn with the participatory discovery network (PDNs).

Chapters “Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community” and “Supporting Diverse and Creative Collaboration in the Scratch Online Community” both deal with **Scratch**, an online community developed from the MIT, where users can use an easy-to-learn program language, program their own games, and make them accessible for others. Users can comment on other work, but also use it as a building block for their own work. Chapter “Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community” gives an overall impression of the participatory activities of users resulting from the observation of about 5000 users, whereas chapter “Supporting Diverse and Creative Collaboration in the Scratch Online Community” provides five use cases that show the emergent nature of this collaboration. What follows below are more details about each of these chapters.

Chapter “Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community” of **Deborah A. Fields**, **Yasmin B. Kafai, and Michael T. Giang** (2016) examines Scratch to understand its dynamics at a collective level. They observed a sample population of about 5000 Scratch users over 3 months. Their analysis first showed that only about half of these users created a project, while the rest did not engage in any online activities other than loggings. Latent class analyses additionally revealed that there are five classes of project creators on the Scratch site: Low Networkers, Downloaders, Commenters, Networkers, and High Networkers. All five classes of users were present in the first month of data collection, but gradually disappeared or were on the way to disappearance, except for a large group of Low Networkers and a small group of High Networkers. The increase in the Low Networker group was most noticeable among newcomers to the site. The duration of the membership in the Scratch site was related to user class type, so that the probability of being a High Networker increased with the length of membership, although the pattern of the relationships was not straightforward. Gender played a marginal role in terms of how users participated in the community, an uncommon finding in programming communities that are generally known to have a low representation of females. In many online communities, the activity is driven by only a small number of users. This evidently suggests that experience of the users is important in active participation, but more work is needed to be done to understand the kinds of experiences that are likely to prompt users to stay active and to assist users in developing participatory competencies in mass collaboration communities like Scratch.

Whereas chapter “Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community” provides an overall view on participation in Scratch, chapter “Supporting Diverse and Creative Collaboration in the Scratch Online Community” gives more fine-grained insights into the **synergic potential of mass collaboration. Ricarose Roque, Natalie Rusk, and Mitchel Resnick** (2016) present five cases of emergent collaborative activities that vividly demonstrate the creative potential of mass collaboration. They describe, for example, “MrBreakfast,” a middle school student, who creates a contest: He asked other Scratch members to design something using a simple line drawing which looked like a caterpillar. But the participants were not allowed to draw a caterpillar. His contest inspired more than 200 remixes where users found highly creative solutions, remixed projects, and built on each other’s work. Processes like this one show the dynamic and creative potential of mass collaboration. In the most positive cases, people develop shared interests and effectively use the community and crowdsource for ideas, projects, or elements of a new project. They receive support from the community of other creators, and they learn through peripheral as well as through proactive participation. This is exactly where mass collaboration becomes especially relevant for education.

Chapter “Citizen Science: Connecting to Nature Through Networks,” written by **Brigid Barron**, **Caitlin K. Martin, Véronique Mertl, and Mohamed Yassine** (2016), deals with an important application of mass collaboration: **citizen science**. It is an old idea from the early 1900s that citizens might be able to support science, for example, by identifying and documenting species they encounter in their environment. Digital technology has significantly enhanced the potential for citizen science and made the possibility of mass collaboration more widespread and interactive. Citizen science projects typically are interest based, and people participate in informal contexts. The chapter describes how citizen science can become part of learning and teaching in formal education in a small group of classroom learners. It provides an interesting and lively description of how citizen science is implemented in a school curriculum and what challenges it holds for teachers. The chapter is mainly focused on how teachers can implement citizen science, and how this improves pupils’ competences, such as those described in the Next Generation Science Standards in the USA (NGSS, 2013).

In chapter “Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study,” **Sabrina C. Eimler**, **German Neubaum**, **Marc Mannsfeld, and Nicole C. Krämer** (2016) deal with the problem that mass collaboration is not always as effective or attractive as is often expected. They consider the fact that many **massive open online courses** have a very high dropout rate and very low participation. To overcome this participation problem, they developed a course concept that combines small and large group interaction. Using a basis of social psychology theories, they compared individual learning with small and large group collaboration and identified barriers and motivators. In their chapter, the authors describe their experiences with an online course where they mixed collaboration of small groups in a forum with mass interactions in a wiki. Log file analysis, questionnaire data, and in-depth interviews were used to evaluate the course. They conclude that this mixture of small group and large group interaction led to promising results in terms of satisfaction, learning outcomes, and course completion rates. In the small group collaboration, participants were intensively engaged in the group activities, felt responsible for the results, and wanted to avoid negative evaluations by the other learners. In the large group interaction, they profited from the diversity of the group and the opportunity to broadly discuss the course topics. The authors conclude that the different interaction formats have specific strengths that should be combined and that they are applicable to other contexts and platforms.

Chapter "Socio-Technical Procedures of Facilitated Mass Collaboration for Creative E-Participation"—the last chapter of this second part—deals with another case of mass collaboration in the context of **e-participation**, where communication tools are used to run a democratic dialog among citizens. **Herrmann** (2016) describes a citizen dialog where more than 400 citizens took part in a round of meetings to collect ideas on how to deal with societal problems. The mass of participants was divided into groups of about ten members each, sitting around a table. The chapter describes the processes of participation and sharing of ideas among and across these groups. The results of each group table discussion were collected and made manifest in notes that were then shared among all the groups. These notes were the basis for the final report. Thomas Herrmann nicely shows that this process was not at all smooth: Stimulating creativity, participation, transparency, and the use of expert knowledge were all found to be lacking. For example, at each meeting, there were one or two opportunities to present the highlights of the discussion from a certain table to the other tables. This task was mostly taken over by the opinion leaders, and the continuously growing body of notes that evolved at each table was never made available to other tables. The citizens were not included in a real group decision process that determined the final result. The result was represented by the report, which was compiled by a separate editorial board, and again, the participating citizens had no influence. We may hope that the special case that is described here is just a very negative example of how e-participation processes might take place in our society. However, we may fear that this describes a rather prototypical case. Thomas Herrmann's contribution reveals where the idea of e-participation failed in a concrete scenario, and he makes concrete suggestions how technology could support and improve this kind of mass collaboration.

Methods to Analyze Processes of Mass Collaboration Empirically

In the **third part of the book**, some contributions are collected that deal with the need for **new and innovative methodological approaches** to handle data resulting from mass collaboration.

Chapter "Theoretical and Empirical Analysis of Networked Knowledge" by **Iassen Halatchliyski** (2016) provides a theoretical and analytical approach **to study networked knowledge** being constructed in online mass collaboration communities. It describes a theoretical framework for analyzing the co-creation of interlinked artifacts. It views online communities as complex systems in which networked knowledge emerges from the specific interconnections among knowledge artifacts. He proposes network analysis as a means of examining the development of knowledge, and he shows how this can be done concretely in Wikipedia and Wikiversity communities. He presents three empirical studies that demonstrate different approaches. With measures of centrality, he first identified pivotal articles within the text corpora of these communities. A cross-sectional analysis revealed the relation between these pivotal artifacts and the experience and centrality of their authors. A further longitudinal analysis showed the role of pivotal artifacts in the subsequent development of networked knowledge. His results show that pivotal articles attracted new knowledge, a mechanism he discusses as "preferential attachment." Finally, he applies another network method: the main-path analysis. This more fine-grained analysis observes the influence of pivotal contributions over time. Altogether his contribution nicely shows the potentials of network analysis for analyzing mass collaboration. He shows how the structure of artifacts shapes its development, providing an example of the stigmergy approach theoretically presented in the contribution of Marc Elliott in chapter "Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration" (Elliott, 2016). In the figurative language of stigmergy, the anthill shapes the ants' activities. In Halatchliyski's words, it is the structure that shapes the dynamics.

Chapter "Applying Network Models and Network Analysis Techniques to the Study of Online Communities" by **H. Ulrich Hoppe**, **Andreas Harrer**, **Tilman Göhnert, and Tobias Hecking** (2016) elaborates on three different methods of **social networking analysis** (SNA) that could be used to research mass collaboration. The authors provide an overview of network science to suggest a more general paradigm for studying the structure and development of networks. They differentiate among three relevant methods and provide examples from network collaboration in learning contexts that are (or could be) analyzed using these methods. In the first example, SNA could be used to identify central actors and roles within a network. This allowed for analyzing the structure of a network (e.g., the network of learners within a classroom wiki) and its development over time. In addition, these results could be used to provide feedback to the actors and support them in their reflections upon their collaboration, for example, with the goal of enabling the equal participation of different members. In the second example, SNA was used to identify and track subcommunities within a network and capture their overlaps. In future work such analyses could be used to detect brokers of information that mediate among subgroups. In the third example, SNA provided techniques to characterize the evolution of ideas in actor-artifact networks. This is relevant to identify knowledge building within a community. This again allows for describing and analyzing mass collaboration on the one hand and supporting the collaboration by providing feedback about the ongoing process on the other hand.

Chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" by **Ivan Habernal**, **Johannes Daxenberger, and Iryna Gurevych** (2016) provides an overview of **natural language processing** as a method for analyzing mass collaboration in educational settings. Natural language processing allows extracting and analyzing information from collaborative artifacts and other textual data. This method is suitable to handle the unstructured or semi-structured content that typically results from online mass collaboration. Given the large amount of data produced by the users in wikis, Web forums, or blogs, it is not possible to analyze the process and results of mass collaboration manually. So natural language processing is a highly useful tool for discovering knowledge construction and argumentative structures in natural language texts. In their chapter, the authors present a study where so-called edit-turn-pairs were analyzed. An edit is any modification of a Wikipedia article, e.g., a correction of spelling errors or an addition to content, while a turn is the corresponding edit on the discussion page of the same article. Based on a model that includes identifiers such as the similarity between edits and turns, the user name, or the time difference between the two edits, the authors developed a machine learning classifier which can automatically recognize corresponding edit-turn-pairs in Wikipedia articles. In another study, they analyzed the persuasiveness and argumentativeness of online documents. Their supervised machine learning system can be used for automatic argument analysis, classification, and summarization. Their results highlight the relevance of NLP for the analysis of mass collaboration in the educational domain, that is, for the detailed analysis of collaborative writing or computer-supported argumentation.

In chapter "Identification of Causal Effects in the Context of Mass Collaboration," **Olga Slivko**, **Michael Kummer, and Marianne Saam** (2016) review econometric approaches that deal with the problems of **identifying causal relation** within observational data. How can our research designs allow interpreting that some factors causally affect others? The authors discuss the use of quasi-experimental methods as a solution for these problems. These "natural experiments" follow an experimental design by comparing data with a base line, but have a high external validity. In their chapter they give an overview of how quasi-experimental methods can be used to analyze mass collaboration. They introduce econometric methods and present examples focusing on the production of knowledge in the Wikipedia. A natural experiment is possible if an environment (e.g., Wikipedia) experiences a large and unpredictable shock (e.g., the blocked access to Chinese Wikipedia from mainland China; cf. Zhang and Zhu, 2011). Such a situation allows clear differentiation between an exogenous variable (e.g., a natural disaster with sudden onset) and the resulting dependent variable (the number of readers and updates; cf. Kummer, 2013). Because natural experiments occur naturally within a specific time frame, the resulting observational data can be analyzed after the occurrence to identify causal relation. This allows in turn for combining the benefits of real-world observational data and experimental variation as preconditions for the interpretation of causality. If such shocks are unpredictable and random, they are not influenced by the existing environment (e.g., Wikipedia) or the measured dependent variables (e.g., the link structure of the Wikipedia). In this way, such occurrences can be used to analyze causality (e.g., how attention spills across links).

Research Challenges and Future Directions

What have we learned about mass collaboration after having considered this variety of theoretical approaches, case studies, and statistical analyses? What have we already achieved, what is still open, and what are the challenges for future research? We cannot provide an extensive review here, but we see four particularly relevant open questions and associated challenges.

Integrating Multifaceted Concepts and Theories

We are still far from having a unified theory of mass collaboration. Different authors have different understandings and provide different definitions of mass collaboration. Some highlight the development of artifacts as a main aspect, while others emphasize the interactive processes that range from participation, coordination, cooperation, to collaboration. Some authors describe the special spirit of mass collaboration can engender or focus on the negative results when this spirit does not unfold and people do not develop a shared identity. When reading through the different chapters, it becomes clear that perhaps there never can be *one* view on mass collaboration. On the contrary, we may seek to profit from the manifold approaches as they all shed light on different aspects of mass collaboration. We need to understand how different perspectives can complement each other and form an integrative view on mass collaboration. The cognitive view can show how knowledge is represented in individuals, how it is represented and structured in the digital environment, and how both kinds of knowledge interact. It can help us further to predict what knowledge an individual is likely to acquire. Complementing this perspective, the systemic view can be used to show the special dynamics of processes going on in masses of people. It may help us to see the dynamic process of knowledge creation happening in the group. It might, for example, remind us, that masses of minds—like individuals—develop systematic biases. The systemic view emphasizes the autopoietic character of mass collaboration and shows the relevance of norms for its dynamic development. The stigmergic view can further help us to understand the affordances of the environment. It shows how artifacts shape individuals' behavior and implicitly coordinate the behaviors of masses of users.

All these examples show that the learning sciences can benefit a lot from considering concepts and theories that have been developed in other disciplines to describe relevant aspects of mass collaboration. Mass collaboration is a complex phenomenon. It may be applied to learning and education, but it is much more than that. This is why research in the learning sciences and in CSCL needs to take into account concepts that come from biology, psychology, economics, sociology, philosophy, and other disciplines. Mass collaboration just started to become a relevant research topic for CSCL and the learning sciences, but we need not to start from the scratch. We can and should take into account and refer to the research about mass behavior that has been already done in other disciplines.

Elaborating the Notion of the Special Spirit of Mass Collaboration and Its Relation to Learning

What makes mass collaboration so dynamic and special is the spirit that mass processes can exhibit. The feeling of being part of a large mass of learners and the identification with a highly active and lively community can serve as strong motivators for the participation of individuals. But how does the experience of belonging to a mass of learners engender such a spirit? Is the main motivator for an individual to be part of the mass of learners? Does a learner in fact need to collaborate, in order to have a special benefit? For example, would a higher amount of collaboration with others and a stronger feeling of being part of the community reduce the high dropout rate that we often find in MOOCs? Or would e-participation work better, if there was more collaboration among the participants and they exhibit this special spirit? Is it possible by any chance that this special spirit leads to more biased and polarized discussions? Furthermore, are platforms like Scratch so successful because the users can present their work to such a large audience, or is it because the community develops a special sense of spirit in the process of remixing and referring to each other's work? In answering these questions, we can benefit from the research on group identity (Tajfel, 2010; Turner & Reynolds, 2010). Groups and social identities can exhibit a very strong effect on motivation. If we want to promote learning, however, we have to take into account the fact that such group-related processes can induce biases in information processing. We should aim for creating situations and environments where the group can make use of the heterogeneity of users and their different expertise, but not situations where the group exhibits a biased information processing.

Exploring Mass Collaboration as a Means to Overcome the Digital Divide

The book we introduced here considers mass collaboration in the context of education. Education is one of society's central responsibilities. It is not enough to merely describe processes of mass collaboration. We also have to ensure that the processes we propose lead to high-level learning outcomes for as many people as possible. Mass collaboration allows individuals to participate in the construction of knowledge, in the sharing of ideas, in the development of products and services, and in the processes of decision-making. It can lead to more equality and democratization of the society. But it is well known that the growth of the Internet simultaneously also strengthened the so-called digital divide, that is, the inequalities between people in different socioeconomic or other demographic categories (Norris, 2001). Not having access to information technology in general (e.g., a Web-enabled computer), language barriers, or deficient media literacy can all prohibit participation. How can we make sure that underprivileged people be supported in becoming active and autonomous members of a community or society in mass collaboration? The main concern may be that mass collaboration may not provide enough structure and incentives for people with low motivation and fewer abilities. It may be the case that the highly self-organized form of mass collaboration overburdens them even more than standard learning settings. This may be a risk, and we have to be aware that the success of mass collaboration for education strongly depends upon whether the key process of learning and collaboration is implemented in all groups of learners. We may need additional structure or script processes of mass collaboration in order to ensure that no learner is left behind. However, it is not clear how such an externally given structure interacts with the dynamics that result from the self-organization of the group. Self-organized bottom-up processes might compete with the instructions that are provided top down. Answering these questions and developing mass collaboration environments that can ensure wide participation of learners may be perhaps the most significant challenge for the future.

Developing and Applying Adequate Research Methods to Deal with the Vast Amount of Data

With regard to methodology, it is evident that there is a big gap between the analytic tools available to us and the kinds of questions we want to address with the data generated in various mass collaboration environments. Analyzing mass collaboration requires new research methods that can deal with big data that stem from highly dynamic and circular and self-referential processes, where the community influences individuals and vice versa. This book described a few tools that are already in use such as social network analysis and natural language processing. We also note that relevant methodological discussions are being carried out in areas of learning analytics, big data analysis, and visual computing. It is hoped that these methods will allow us to analyze more efficiently how learning takes places in mass collaboration settings. Additional methods need to be developed to complement qualitative analyses of single users and traditional experimental studies so as to deal with the highly dynamic processes going on in mass collaboration.

Conclusion

The goal of our book is to encourage scientific discussion about the fascinating phenomena of mass collaboration. Existing theoretical frameworks and research approaches have helped us to describe, understand, and design mass collaboration and education. But current theories and methods are still insufficient and sometimes even inadequate to deal with the unique processes occurring at the mass level. We hope that this book bring us one step closer to a more elaborated understanding of how masses of people can come and work together to develop new knowledge and achieve things that were previously unimaginable.

References

Barron, B., Martin, C. K., Mertl, V., & Yassine, M. (2016). Citizen science: Connecting to nature through networks. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cakir, H. (2013). Use of blogs in pre-service teacher education to improve student engagement. *Computers & Education, 68*, 244–252.

Collins, A. (2016). A brief history of mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cress, U., Barron, B., Halatchliyski, I., Oeberst, A., Forte, A., Resnick, M., & Collins, A. (2013). Mass collaboration—an emerging field for CSCL research. *To see the world and a grain of sand: Learning across levels of space, time and scale: CSCL 2013 Proceedings*, *1*, 557–563.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cress, U., Moskaliuk, J., & Jeong, H. (Eds.). (2016). *Mass collaboration and education*. Cham, Switzerland: Springer.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford, England: Elsevier.

Diver, P., & Martinez, I. (2015). MOOCs as a massive research laboratory: Opportunities and challenges. *Distance Education, 36*, 5–25.

Doan, A., Ramakrishnan, R., & Halevy, A. Y. (2010). Mass collaboration systems on the World-Wide Web. *Communications of the ACM, 54*, 86–96.

Eimler, S. C., Neubaum, G., Mannsfeld, M., & Krämer, N. C. (2016). Altogether now! Mass and small group collaboration in (open) online courses—A case study. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Elliott, M. (2016). Stigmergic collaboration: A framework for understanding and designing mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fields, D. A., Kafai, Y. B., & Giang, M. T. (2016). Coding by choice: A transitional analysis of social participation patterns and programming contributions in the online Scratch community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fischer, G. (2016). Exploring, understanding, and designing innovative socio-technical environments for fostering and supporting mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fu, W.-T. (2016). From distributed cognition to collective intelligence: Supporting cognitive search to facilitate massive collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Habernal, I., Daxenberger, J., & and Gurevych, I. (2016). Mass collaboration on the Web: Textual content analysis by means of natural language processing. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Halatchliyski, I. (2016). Theoretical and empirical analysis of networked knowledge. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Halatchliyski, I., Moskaliuk, J., Kimmerle, J., & Cress, U. (2014). Explaining authors' contribution to pivotal artifacts during mass collaboration in the Wikipedia's knowledge base. *International Journal of Computer-Supported Collaborative Learning, 9*, 97–115.

Herrmann, T. (2016). Socio-technical procedures of facilitated mass collaboration for creative e-participation. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Hoppe, H. U., Harrer, A., Göhnert, T., & Hecking, T. (2016). Applying network models and network analysis techniques to the study of online communities. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Kafai, Y., Roque, R., Fields, D., & Monroy-Hernandez, A. (2011). Collaboration by choice: Youth online creative collabs in Scratch. In *Proceedings of the 19th International Conference on Computers in Education* (pp. 189–193). Chiang Mai, Thailand: Asia-Pacific Society for Computers in Education.

Kimmerle, J., Moskaliuk, J., Harrer, A., & Cress, U. (2010). Visualizing co-evolution of individual and collective knowledge. *Information, Communication & Society, 13*, 1099–1121.

Kimmerle, J., Moskaliuk, J., Oeberst, A., & Cress, U. (2015). Learning and collective knowledge construction with social media: A process-oriented perspective. *Educational Psychologist, 50*, 120–137.

Kummer, M. (2013). *Spillovers in networks of user generated content—Evidence from 23 Natural Experiments on Wikipedia*. ZEW Discussion Paper No. 13-098, Mannheim, Germany.

Lead States, N. G. S. S. (2013). *Nest generation science standards: For states, by states*. Washington, DC: National Academic Press.

Ley, T., Seitlinger, P., & and Pata, K. (2016). Patterns of meaning in a cognitive ecosystem: Modeling stabilization and enculturation in social tagging systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Muñoz-Merino, P. J., Ruipérez-Valiente, J. A., Alario-Hoyos, C., Pérez-Sanagustín, M., & Delgado Kloos, C. (2015). Precise effectiveness strategy for analyzing the effectiveness of students with educational resources and activities in MOOCs. *Computers in Human Behavior, 47*, 108–118.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Norris, P. (2001). *Digital divide: Civic engagement, information poverty, and the Internet worldwide*. Cambridge, England: Cambridge University Press.

Oeberst, A., Cress, U., Back, M., & Nestler, S. (2016). Individual versus collaborative information processing: The case of biases in Wikipedia. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Oeberst, A., Kimmerle, J., & Cress, U. (in press). What is knowledge? Who creates it? Who possesses it? The need for novel answers to old questions. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Olson, M. (2009). *The logic of collective action*. Harvard, MA: Harvard University Press.

Roque, R., Rusk, N., & Resnick, M. (2016). Supporting diverse and creative collaboration in the Scratch online community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Shapiro, R. B. (2016). Toward participatory discovery networks: A critique of current mass collaboration environments and a possible learning-rich future. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Slivko, O., Kummer, M., & Saam, M. (2016). Identification of causal effects in the context of mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Tajfel, H. (2010). *Social identity and intergroup relations*. Cambridge, England: Cambridge University Press.

Turner, J. C. (1999). Some current issues in research on social identity and self-categorization theories. In N. Ellemers, R. Spears, & B. Doojse (Eds.), *Social identity: Context, commitment, content* (pp. 6–34). Oxford, England: Blackwell.

Turner, J. C., & Reynolds, K. J. (2010). The story of social identity. In T. Postmes & N. R. Branscombe (Eds.), *Rediscovering social identity: Core sources* (pp. 13–32). New York: Psychology Press.

Zhang, X. M., & Zhu, F. (2011). Group size and incentives to contribute: A natural experiment at Chinese Wikipedia. *The American Economic Review, 101*, 1601–1615.

Part II
Theoretical Approaches to Mass collaboration

A Brief History of Mass Collaboration: How Innovations Over Time Have Enabled People to Work Together More Effectively

Allan Collins

Origins of Mass Collaboration

Mass collaboration involves people working either together or separately and sharing ideas to advance society. Sometimes they are pursuing common goals and sometimes they are pursuing individual goals, but even in the latter case, their individual efforts may lead to benefits for the whole society. For example, a few people working on Wikipedia are clearly focused on making it the most accurate and informative resource possible. But most others are pursuing their individual goals of providing information about some topic they care about or making sure what is written is grammatically correct. Wikipedia provides a platform where people with different goals and interests can work separately, while contributing to the greater good. In this way it enables mass collaboration to take place. But for mass collaboration to occur, most participants must actively work to improve the information in Wikipedia. Our goal in the paper is to show how different innovations over history have provided new ways for societies to engage in mass collaboration. For a media-centric view of this history, see Fig. 1 in chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" by Fischer (2016).

I date the beginning of mass collaboration to the evolution of our species, but some might date it back even further to the development of *cultural evolution.* Cultural evolution got started when sentient animals started passing on their ways of knowing and doing to succeeding generations. Many writers have noted how

A. Collins (✉)
Northwestern University, Evanston, IL, USA
e-mail: a-collins@northwestern.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_2

cultural evolution goes much faster than genetic evolution. But our species has figured out how to speed up cultural evolution. As Matt Ridley (2010) points out, early humans (such as Neanderthals) were content to make the same stone tools to hunt and cut their meat for over a million years. What he finds incredible is that the stasis that characterized mankind and other species came to an end with *Homo sapiens*. We are a species of mass collaborators.

The reason why I start with the evolution of our species is the surprising fact that among the remains of our ancient ancestors you find goods, such as seashells, that traveled hundreds of miles, whereas no such signs of barter are found among Neanderthals. As Ridley argues, barter was the first great invention of mankind that made innovation possible. The more people exchange goods, the more they specialize. And the more they specialize, the better they get at producing things. Other species trade favors (you scratch my back and I'll scratch yours), but Ridley argues that we are the only species on Earth that actually trades goods.

The division of labor made possible by exchange led to a quiet revolution in learning—a speed up in cultural evolution. As people get better at producing particular goods, trading becomes more profitable and so more and more people begin to specialize in what they can best produce. It creates a virtuous cycle of ever-increasing trade, specialization, and learning.

The Development of Cities

The next invention of mankind leading to greater mass collaboration was the birth of cities, where people aggregated to specialize in particular trades and professions. As Steven Johnson (2010) points out, when you measure creativity in terms of patents, research and development budgets, inventors, and creative professions, a city that is 10 times larger than another is 17 times as creative. The reason cities are so creative is that people in cities come in contact with a greater variety of ideas. By putting together old ideas, we create new ideas. So cities provide the basic fodder for innovation and invention. Most people in cities outside of government are pursuing their own goals, but they are sharing ideas that provide the impetus for advances in society.

It has long been noted that some communities become centers of creative energy and innovation in particular specializations. For example, in the small city of Cremona, Italy, during the sixteenth to eighteenth centuries, there developed a tradition of violin making that has never been equaled anywhere in the world. Andrea Amati in 1564 is credited with developing the modern shape of the violin and the characteristic amber-colored varnish of the Amati instruments. His two sons followed him as string makers and his grandson Niccolo trained the founders of the other great violin-making families of Cremona, Andrea Guarnieri and Antonio Stradivari. The two sons of Andrea Guarnieri developed their own refinements on the Amati design, and one is credited with moving the F-holes further apart to improve the resonance. Antonio Stradivari, who is the most famous of the violin makers of Cremona, devoted his life to perfecting the design of the violin.

His improvements consist chiefly in lowering the height of the arch of the belly, making the four corner blocks more massive, giving greater curvature to the middle ribs, altering the setting of the sound holes, and making the scroll more prominent. The flowering of creativity in Cremona is a story that has many parallels in history.

The most famous recent story of such a concentration of industry and creativity took place in Silicon Valley, California. This story began when the vice president of Stanford University decided to help William Hewlett and David Packard start their own electronics firm, Hewlett-Packard, by providing capital and setting up a research park on Stanford land. Other occupants soon followed. The Research Park became the nucleus for the growth of Silicon Valley. It created a synergistic relationship, where Stanford benefited from the proximity of the new high-technology firms that were started by its staff and students, and the firms benefited from the rich source of knowledge and personnel that Stanford drew to the area. Many of the new startups in Silicon Valley were spun off from the early firms, so that it is possible to construct a kind of genealogical chart of the growth of firms in the Valley. Clearly ideas and techniques have spread easily from firm to firm, as, for example, the user-interface approach developed at Xerox spread to Apple and then to Windows. The strategies for supporting creativity in Silicon Valley are being widely copied in many other places with greater or lesser success.

Paul Krugman (1991) describes how the early twentieth century economist Alfred Marshall explained the concentration of industries, in such places as Cremona and Silicon Valley. Marshall cited three basic reasons. First, Marshall cited the pooled market: "Employers are apt to resort to any place where they are likely to find a good choice of workers with the special skill which they require; while men seeking employment naturally go to places where there are many employers who need such skill as theirs and where therefore it is likely to find a good market" (p. 37). Second, such a center provides specialized products and services, such as hairdressers and film editors in Hollywood: "Subsidiary trades grow up in the neighborhood, supplying it with implements and materials, organizing its traffic, and in many ways conducive to the economy of the material" (p. 37). Third, information flows more easily: "The mysteries of the trade become no mystery; but are as it were in the air…Good work is rightly appreciated; invention and improvements in machinery, in processes and the general organization of the business have their merits promptly discussed: if one man starts a new idea, it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas" (pp. 37–38).

Marshall argues that specialized communities develop many varieties of expertise and that this knowledge flows through the community leading to new inventions and innovations. A close-knit community fosters expertise and refinements of products and processes, whereas outside influences and demands foster creativity. In a close-knit community, there are multiple exemplars of expert practice to learn from. Hearing the latest developments and watching them unfold provides a powerful learning environment. At the same time, it is necessary to understand what the outside world is thinking and to develop new ways to meet the demands and opportunities that the outside world offers.

John Seely Brown and Paul Duguid (2000) in their book *The Social Life of Information* elaborate on Marshall's third point, by developing an ecological metaphor to explain the success of Silicon Valley. They describe the Valley as made up of a set of firms and a crosscutting set of "networks of practice," which link the different communities of practice (Wenger, 1998) within each firm to the wider community within the Valley. For example, there are separate networks of computer engineers and graphic designers. These networks of practice form the connections through which ideas and techniques move through the Valley, since the members of each network have many informal ties to each other. "Knowledge that sticks within firms quickly finds ways to flow between them, as if seeking out the firm with the most suitable complementarity. In such circumstances, as firms keep a constant benchmarking eye on each other, the ecology develops as a whole. Both invention and innovation develop rapidly and together…" (p. 165). Further, they argue that failure of some firms may benefit the ecology as a whole. They cite the failure of the firm Zilog as seeding the Valley with local-area-network entrepreneurs. Finally, they argue that living in close proximity is essential to the success of the Valley. "In the Valley, people live in and out of each other's pockets, and this helps them see what's doing, what's doable, and what's not being done. This close proximity not only shows how to attack a particular niche, it provides the ability to see a niche before it is visible to most eyes" (p. 168).

The Invention of Writing and Printing

The next great invention of mankind to foster mass collaboration was writing. Writing first developed in the Near East 5000 years ago. The first uses of writing as far as we know were commercial, to keep records of trades that were made. The records were carved into stone tablets. Early writing was in hieroglyphs or picture writing, where the symbols used often resembled the objects depicted. As writing evolved, the symbols became more abstract in an attempt to express a wider variety of ideas.

Writing had two kinds of effects on the exchange of ideas. It allowed people to share ideas at great distances and to hand down ideas to later generations. So Copernicus in Poland could write a book about his idea of a sun-centered solar system, which Galileo in Italy some 50 years later read and promulgated widely with his discovery of the moons rotating around Jupiter, like the planets rotate around the sun.

Walter Ong (1982) has argued that "study" became possible only when there were written records. Writing down ideas makes them easier to evaluate and challenge and thus to be modified and refined over time. This was critical to the development of history, mathematics, and science. By writing things down, people found they could work through ideas much more thoroughly and could go over them later to reflect on and improve. Darwin's journals clearly illustrate the power of writing for thinking more deeply.

It is inconceivable to envision sophisticated mathematics without the invention of writing. Mathematics was transformed by the development in ancient India of what we call Arabic numerals. The critical number zero was first recorded in India in the ninth century BCE. It is very difficult to make computations such as multiplication with the Roman numerals used in the Roman Empire. Nor did the Romans have a way to represent zero. Hence, the introduction of Arabic numerals was critical to the evolution of mathematics and science.

The next great advance in the history of communication was the invention of the printing press. Printing was first developed in China, first with woodblocks in 220 CE and later with moveable type in the ninth century. They produced printed works on cloth and later on paper. Printing and paper came to Europe in the Middle Ages and a revolution in book making came with Gutenberg's printing press around 1450. His Gutenberg Bible in 1455 proved the value of printing, and the invention spread across Europe. Printing in turn led to widespread demand for literacy and a proliferation of books. Elizabeth Eisenstein (1979) argues that the invention of the Gutenberg printing press was the precipitating cause of the Protestant Reformation and the rise of universal schooling.

Bruno Latour (1986) argues that it was the invention of "immutable mobiles," such as books and maps, that was critical to the development of science. His term, immutable mobiles, emphasizes the permanence of the records and their widespread distribution. Universal schooling was ultimately a product of printing, and hence schooling is centered on the major products of literate thought, namely, reading, writing, history, mathematics, and science.

The Development of the World Scientific Community

The printing press gave rise to a new phenomenon, the worldwide scientific community, which constitutes one of the major steps forward in mass collaboration. The scientific community evolved a variety of norms and structures to support the development of new ideas and new methods for making sense of the world. One major structure was the formation of scientific journals in different fields, with control exercised by peer review to ensure that published works demonstrated sound reasoning, methodology, knowledge of prior literature, and presentation and analysis of data. The other major structure that the scientific community created included regular meetings where scientists present their findings to their peers and face questions about their work and their methodology. This feedback helps them to interpret their findings and provide better evidence and arguments to support their conclusions.

In conjunction with these institutional structures, the scientific community also developed a set of norms to ensure that steady progress in science would be made. Perhaps the most important norm is *objectivity*, which is aimed at insuring that scientists minimize their inherent biases, which can distort the data collected and the conclusions drawn from the data. Another established norm is *replication*, which requires specification of all critical aspects of the methodology so that other researchers can repeat the study to determine if they will find the same results. A norm often ignored by senior researchers is *equal standing*, which requires that all scientists are treated equally, and their arguments are judged not on their personal authority but on the logic and evidence presented. Another norm is *sharing of raw data*, so that other researchers can analyze the data in other ways to assess the validity of the conclusions drawn from the data. This norm prohibits withholding of data and has led further to sharing of materials used in experiments to support replication.

The success of the scientific community in spawning valuable ideas and products has led governments and corporations to fund ever more extensive research and development. This funding has led to a proliferation of scientific laboratories and ever-increasing numbers of practicing scientists. There has been a parallel explosion of tools and methods for conducting experiments and analyzing data. Science is a growth industry devoted to exchanging ideas and refining our understanding of the world.

The Invention of the Internet and Web

The last great invention for spreading mass collaboration is the Internet and its digital offshoots, such as smart phones and the web. These act in many new ways to foster collaboration among people around the world. New forms of collaboration such as flash mobs, Wikis, massive open online courses (MOOCs), collaboratories, crowdfunding sites, and web communities reflect the different ways that people are organizing themselves using the Internet to communicate and impact the world. As Clay Shirky (2008) argues, the Internet makes collaboration much easier, and so new forms of collaboration are evolving to do things that were never possible before.

Web communities were perhaps the first new way that collaboration developed on the Internet. Most specialized fields have formed web communities where they share their latest insights and work. Web communities are also a powerful new way for learners to develop expertise. Barron (2006) describes how a high school girl found a website called xanga.com where digital artists talk about and share their work. She learned much by studying the source code that the artists used to produce the works she found most appealing. Web communities provide a new way to learn and share work.

Black (2009) has been studying English language learners who participate in a fan fiction site (*fanfiction.net*) where they write their own stories, taking off from books they love, such as Harry Potter. To help learn English the girls she studied wrote stories on the site, with help from readers on the site who would correct their spelling and grammar. Black argues that participation fostered their literacy development in three ways: (1) It provided a sense of belonging to a community, (2) it provided confidence for attempting more complex endeavors, and (3) it enabled them to develop identities as accomplished creators and users of English.

As another example, Resnick et al. (2009) have developed a web community around Scratch, a sophisticated computer-programming environment for children. On the Scratch bulletin board, users can show off their work and receive feedback and questions from other users. One young girl developed a tutorial for other kids describing strategies for creating animé characters in Scratch. She received many comments applauding her for providing such a useful guide, as well as suggestions for additions to her tutorial.

Collaboratories have sprung up across the scientific world in recent years (Finholt & Olson, 1997). They make it possible for the greatest scientists in a field to work together on projects in a way that was never possible before the Internet. Scientists in collaboratories share experimental designs, data, specialized tools, preliminary results, and interpretations and publish their findings in a way that only colocated researchers did in the past. Many of the collaboratories focus their work around the use of expensive tools such as electron microscopes, telescopes, super computers, and modeling tools used to study complex systems like the economy and climate. Fields like biology, physics, and climatology have developed a pattern where large teams of researchers at different locations work together to make advances in the field. Collaboratories have become the norm in these fields.

Digital libraries have grown up in recent years to support the collaboratories developing in the sciences. Digital libraries have capabilities beyond traditional libraries. They can provide tools and data files of videos, animations, satellite data, and model runs under different input conditions. The storage capacity of digital libraries is many times greater than traditional libraries, and access to their resources is available in researchers' labs, offices, and homes. They multiply our access to resources that support collaborative innovations.

The web's support of many new forms of publication has been critical to the growth of mass collaboration. Publication is critical to spreading ideas widely through society. The web is the first medium that allows everyone including children to get their message out. Through outlets like electronic journals, blogs, bulletin boards, YouTube, Flickr, Facebook, Twitter, Wikipedia, and Epinions, masses of people are sharing their thoughts and ideas with the world.

Clay Shirky (2008, pp. 31–39) points out how Flickr has become a clearinghouse for photographs showing events that media organizations cannot cover. For example, when terrorists attacked the London transit system, the first photos went up on Flickr documenting the destruction in the sites that were attacked. Similarly when an earthquake in the Indian Ocean triggered a tsunami, photos of damage in different places and some of the missing people appeared with the "Tsunami" tag on Flickr. Shirky (2008, p. 36) tells the story of how one missing child's body was tracked down from a photo on Flickr. Similarly in Thailand, when the army prevented the media from reporting on a coup, people started using Flickr and Wikipedia to report on events that were happening in response to the coup. The web is becoming the source for instant reporting and analysis of what is happening in the world.

There are now many stories about how Twitter, Facebook, and other new media have been used to organize collective actions such as flash mobs and public protests. In Egypt, the Tahrir Square protests that brought down President Mubarak were largely organized through using these new media outlets. Shirky (2008, pp. 144–148) argues that the new media were critical to organizing the Catholic group Voice of the Faithful to protest the Church's unwillingness to deal openly with the clergy sex scandal that rocked the Church during the 2000s in America. The new media are increasing the power of non-elites to organize and press for reforms in institutions throughout society. This may well hasten the spread of democracy to the rest of the world.

The power of the people is also showing up in crowdfunding to collect money for new projects. Crowdfunding has been used to collect funds for disaster relief, political campaigns, making movies and records, and funding startup companies. A large number of websites have sprung up, such as ArtistShare and Kickstarter, to support crowdfunding. Even scientists have started to go to crowdfunding to get money to fund their research projects, often in the health sciences where there are constituencies interested in finding cures for different diseases. More and more people with a new idea are going to follow the model of public television and radio to collect money from everyday people who have an interest in seeing innovative projects happen.

Massive open online courses (MOOCs) may or may not have a large effect on education broadly speaking, but they are clearly bringing the best teachers in the world to people in far-flung parts of the world. As one example, Harvard and MIT's edX offered a circuit course as a MOOC, which a class of high school students in Mongolia took. One 15-year-old Mongolian student had a perfect score on the final exam, and a few years later, he enrolled as a scholarship student at MIT. In the first MOOC offered by Stanford computer science professor Sebastian Thrun on artificial intelligence, taken by thousands of students, the highest scores on the final exam were racked up by people outside of Stanford. MOOCs appeal to the best professors as a way to reach a large audience, and they appeal to poor people around the world as a way to get ahead. They are adding to the world community of people working in the mathematical and engineering sciences.

Even games may come to foster a new kind of mass collaboration to support innovation. The story of Foldit (see http://en.wikipedia.org/wiki/Foldit), a protein folding game developed at the University of Washington, holds promise as a way to design games to expand our understanding in different fields. In the game problems are presented for a given time, and individuals or teams try to find the best fold and receive a score computed automatically. In 2011 players deciphered the crystal structure of an AIDS-causing monkey virus that had eluded scientists for 15 years. More recently gamers redesigned a protein that catalyzes reactions widely used in synthetic chemistry, increasing the activity of the enzyme by 18 times. The game shows the power of crowdsourcing for solving difficult problems.

Linux and Wikipedia are prototypes of how people can create enterprises to accomplish large projects without the heavy managerial overhead of a corporation. Linux got started with a modest note to a discussion group from a Finn, Linus Torvalds, in 1993 about his plan to develop a free, open-source, operating system and asking for suggestions about what features would be useful. He received several responses from around the world offering to help him build the system.

Others joined as the movement grew. According to Wikipedia (see http://en.wikipedia.org/wiki/Linux), Linux runs 95% of the world's supercomputers and is embedded in many systems and devices, including the widespread Android-based systems. Linux shows how the open-source movement can work together with minimal management to produce a complex product that only a corporation could have produced prior to 1990.

As Shirky (2008, pp. 237–246) argues, the open-source movement mostly produces products that nobody ever uses. The few successes, like Linux, are the rare exceptions. In his view, the strength of the movement is that failure is not very costly, unlike for corporations. Innovative corporations spend a lot of money and time trying to avoid failure, carefully weighing the likelihood of success of different projects they might pursue. This leads them to weed out risky ideas, pursuing what seems safe. But since failure is cheap for the open-source movement, people can pursue whatever wacky ideas they come up with. And some of them pay off, like Linux. This makes it possible to pursue unlikely ideas that may have huge payoffs.

Wikipedia, which several papers in this volume describe in detail, illustrates another kind of large, complex product that only a corporation might have produced prior to 1990. But no corporation could produce an encyclopedia that changes daily as the world unfolds and that covers a wide variety of topics that few people would be interested in reading about. As an added feature, the articles appear in multiple languages. Wikipedia includes what Chris Anderson (2004) might call the long tail of knowledge and makes it easy to find. Wikipedia represents collaboration on a scale undreamed of in past centuries.

Implications

With the coming of the Internet, we see an explosion of collaboration that is worldwide in scope. Never before have people been able to collaborate effectively with people outside their local community. But we see with Linux, Wikipedia, MOOCs, Foldit, and web communities that people all over the world are working together to learn and solve problems. This is a radical change in the way the world works.

The proliferation of new forms of collaboration means that weird and risky ideas have a better chance to take hold and spread. The way society was organized in the past, organizations only wanted to pursue ideas that were likely to succeed. Since the Industrial Revolution, lone inventors often pursued their crazy ideas to produce great new inventions. Some like Edison even gathered the resources to create laboratories of people to work on their ideas. But in an age where new inventions are becoming more and more complex, it will take collaborative geniuses, like Linus Torvalds and Jimmy Wales (the progenitor of Wikipedia), to organize people around the world to work together to pursue their crazy ideas.

To be good collaborators, people need to develop adaptive expertise (Hatano & Inagaki, 1986). Adaptability depends on situation awareness and the strategies you develop for exploiting opportunities and coping with challenges. To be effective at situation awareness, you need to recognize what people around you are thinking and the goals they are pursuing, as well as any obstacles or opportunities that have arisen. This involves continually monitoring the situation for any changes or new insights you may have into what is happening around you. Because the world is changing faster these days, it is more important than ever to be adaptive enough to cope with new challenges and opportunities.

This rampant collaboration is slowly undermining the hierarchy of the elite. When mass communication was in the hands of the few, the elites could corner the market on what gets said and what gets done. Now many different kinds of people are spewing out their ideas and joining in collaborative activities that have wide impact. As Shirky (2008) makes clear, hierarchy was the way corporations organized work in order for managers to control what gets done. Now people are finding a variety of ways to organize themselves to accomplish both small and large endeavors. Society is becoming flatter, as Tom Friedman (2004) has noted, and power is being distributed around the world to those whose crazy ideas pay off. We need to understand better how all these new forms of collaboration are affecting society.

In his classic book *Mindstorms*, Seymour Papert (1980) describes the Samba schools that come together in preparation for Mardi Gras in Rio de Janeiro as a metaphor for what education should become. Whole communities, including adults and children, work together for months to build floats and prepare elaborate entertainments. The children help the adults in whatever tasks need doing. There is much learning going on, both among children and adults, where the more expert teach the less expert how to do various tasks. It is apprenticeship in its most benign form, since they all have a common goal to please the viewers of their floats and to win in the competitions. It is this vision of learning, but in a technology-rich environment, that Papert would like to see realized in schools.

Similarly Ivan Illich (1970) in his book *Deschooling Society* envisioned a world where adults and children were more in charge of their own learning. In a world before the Internet, he suggested four kinds of resources that could help youths define and achieve their own goals:

1. Reference services to educational objects—which facilitate access to things or processes used for formal learning. Some of these things can be reserved for this purpose, stored in libraries, rental agencies, laboratories, and showrooms like museums and theaters; others can be in daily use in factories, airports, or on farms, but made available to students as apprentices or on off-hours.
2. Skill exchanges—which permit persons to list their skills, the conditions under which they are willing to serve as models for others who want to learn these skills, and the addresses at which they can be reached.
3. Peer matching—a communications network which permits persons to describe the learning activity in which they wish to engage, in the hope of finding a partner for the inquiry.
4. Reference services to educators at large—who can be listed in a directory giving the addresses and self-descriptions of professionals, paraprofessionals, and freelancers, along with conditions of access to their services (pp. 112–113).

These are much more possible in to implement now that we have the web. Researchers and innovators would be wise to explore how the visions of Papert and Illich can be further developed and tested in the context of the web.

Education may be moving in the direction Papert and Illich envisioned, in that children are pursuing activities that interest them and that can lead to future careers. They are participating in web communities and online games. They are seeking knowledge that they care about in the huge web of knowledge and activities that has opened before them. Instead of schools that insist they learn a lot of stuff they don't care about, they are pursuing things they do care about (Collins & Halverson, 2009). As the Mongolian 15-year-old illustrates, the Internet allows children to participate as if they were adults. We need to study what kids are learning in the many different web environments that they are participating in today.

Currently whenever people think about how to improve education, they ask how to reform the schools. But as education moves out of the schools into other venues, it behooves us as a society to ask questions such as: How can we give children the tools to learn to communicate effectively using the new media? How can we create exciting games that require increasingly sophisticated problem-solving and collaboration skills? How can we support children to find web communities that reflect their deep interests? How can we help children create a web identity that will appeal to other children around their town or the world? These are all questions that could profoundly affect learning, but they are questions very few people are asking now. We need to radically rethink the ways we foster children's development in a world where collaboration is becoming pervasive.

Perhaps the most profound effect of all this collaboration will be the speedup of innovation and invention. As ideas come more readily into contact, and more people participate in this thinking community, knowledge creation is bound to take off. As we see with all the new forms of collaboration that are occurring, this innovation process may be an order of magnitude greater than any of the prior developments recounted in this brief history of mass collaboration. If the world was changing too fast for you before this, it will only get worse.

References

Anderson, C. (2004, October). The long tail. *Wired, 12*(10). Retrieved from http://archive.wired.com/wired/archive/12.10/tail.html

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecologies perspective. *Human Development, 49*, 193–224.

Black, R. W. (2009). English-language learners, fan communities, and 21st century skills. *Journal of Adolescent and Adult Literacy, 52*, 688–697.

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Cambridge, MA: Harvard Business School Press.

Collins, A., & Halverson, R. (2009). *Rethinking education in the age of technology: The digital revolution and schooling in America*. New York, NY: Teachers College Press.

Eisenstein, E. L. (1979). *The printing press as an agent of change*. Cambridge, England: Cambridge University Press.

Finholt, T. A., & Olson, G. M. (1997). From laboratories to collaboratories: A new organizational form for scientific collaboratories. *Psychological Science, 8*, 28–36.

Fischer, G. (2016). Exploring, understanding, and designing innovative socio-technical environments for fostering and supporting mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Friedman, T. L. (2004). *The world is flat: A brief history of the twenty-first century*. New York, NY: Farrar, Straus, and Giroux.

Hatano, G., & Inagaki, K. (1986). Two courses of expertise. In H. W. Stevenson, H. Azuma, & K. Hakuta (Eds.), *Child development and education in Japan* (pp. 262–272). New York, NY: W. H. Freeman.

Illich, I. (1970). *Deschooling society*. New York, NY: Harper & Row.

Johnson, S. (2010). *Where good ideas come from: The natural history of innovation*. New York, NY: Penguin.

Krugman, P. (1991). *Geography and trade*. Cambridge, MA: MIT Press.

Latour, B. (1986). Visualization and cognition: Thinking with eyes and hands. In H. Kuklick (Ed.), *Knowledge and society: Studies in the sociology of culture past and present* (Vol. 6, pp. 1–40). New York, NY: JAI Press.

Ong, W. J. (1982). *Orality and literacy: The technologizing of the word*. London, England: Routledge.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., … Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM, 52*, 60–67.

Ridley, M. (2010). *The rational optimist: How prosperity evolves*. New York, NY: HarperCollins.

Shirky, C. (2008). *Here comes everybody: The power of organizing without organizations*. New York, NY: Penguin.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, England: Cambridge University Press.

Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration

Gerhard Fischer

Mass Collaboration

Mass collaboration occurs when large numbers of people work and learn together. Specific components of mass collaboration (participation, coordination, cooperation, collaboration, and social production) depend on the nature of the problems being tackled. In general, it is better suited to problems with a nearly decomposable structure (Simon, 1996) in which the modularity allows that participants (or group of participants) can work on specific modules independently facilitating decentralized innovation. Mass collaboration has social and technical components and is best fostered and supported by *socio-technical environments* (Fischer & Herrmann, 2011). The focus of our research is on mass collaborations in which people voluntary participate and contribute because they want to and because they can. On the *social* side, an interesting *uniqueness* of mass collaboration is that the collaborative social practices and social production occurs not in tightly knit communities with many social relations to reinforce the sense of common purpose and community but in large groups of participants who are geographically, temporally, and conceptually dispersed (see examples in Table 2). On the *technical* side, mass collaboration is facilitated by new digitally networked environments (Tapscott & Williams, 2006). Projects exploit the technological infrastructure provided by the Internet and employ different social software and computer-supported collaboration tools.

Mass collaboration offers important and interesting possibilities to cope with *major problems* our societies are facing today including (1) problems of a *magnitude* which individuals and even large teams cannot solve and (2) problems of a *systemic nature* requiring the collaboration of many different minds from a variety of backgrounds. For these kinds of problems, mass collaboration is a necessity

---

G. Fischer (✉)
Center for LifeLong Learning and Design (L3D), University of Colorado, Boulder, CO, USA
e-mail: gerhard@colorado.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_3

rather than an optional approach. It represents not only a more democratic mode of production (von Hippel, 2005), and it is not only important for new approaches in learning and education (Fischer, 2009), but it represents an innovative approach in a broad spectrum of human activities (see Table 1 for specific examples). Mass collaboration works best when at least the following conditions are present (Tapscott & Williams, 2006): (1) the *objects of production* are digital facilitating sharing and remixing; (2) the *tasks* can be modeled as nearly decomposable systems (Simon, 1996) and can therefore be chunked into "pieces" that individuals can contribute; (3) the *costs of integration and aggregation* in an global, shared repository is reasonable.

Table 1 Environments of mass collaborations with unique features

Site	Objectives and unique aspects
Wikipedia	Web-based collaborative multilingual encyclopedia with a single, collaborative, and verifiable article; authority is distributed (http://www.wikipedia.org/)
iTunes U	Courses by faculty members from "certified institutions"; control via input filters; material cannot be remixed and altered by consumers (http://www.apple.com/education/itunes-u/)
YouTube	Video sharing website with weak input filters and extensive support for rating (http://www.youtube.com/)
Encyclopedia of life (EoL)	Documentation of the 1.8 million known living species; development of an extensive curator network; partnership between the scientific community and the general public (http://www.eol.org/)
PatientsLikeMe	Collection of real-world experiences enabling patients who suffer from life-changing diseases to connect and converse (http://www.patientslikeme.com/)
Instructables	Socio-technical environment focused on user-created and shared do-it-yourself projects involving others users as raters and critics (http://www.instructables.com/)
Scratch	Learning environment for creating, remixing, and sharing programs to build creative communities in education (http://scratch.mit.edu)
Stepgreen	Library of energy-saving actions, tips, and recommendations by citizen contributors for saving money and being environmentally responsible (http://www.stepgreen.org/)
SketchUp and 3D Warehouse	Repository of 3D models created by volunteers organized in collections by curators and used in Google Earth (http://sketchup.google.com/3dwarehouse/)
InnoCentive	Unleashing human creativity, passion, and diversity (http://www.innocentive.com/)
Open-source software	Software developed in a public, collaborative manner with its source code made available and licensed (Raymond & Young, 2001)
CreativeIT	Wiki to foster collaboration between all researchers interested in "Creativity and IT" (http://l3dswiki.cs.colorado.edu:3232/creativit)
SAP Community Network	Used by software users, developers, consultants, mentors, and students to get help, share ideas, learn, innovate, and collaborate (http://scn.sap.com/)
MOOCs	Courses offered for free for everyone (http://www.mooc-list.com/)

Transcending the Unaided, Individual Human Mind

Figure 1 provides a qualitative overview of the *historical developments* of new media that had a major impact on mass collaboration (discussed in detail in chapter "A Brief History of Mass Collaboration: How Innovations Over Time Have Enabled People to Work Together More Effectively" by Collins, 2016).

There is no media-independent communication, interaction, and collaboration: tools, materials, and social arrangements always mediate activity. The possibilities and the practice of mass collaboration are functions of the media with which we collaborate. Cognition is shared not only among minds but also among minds and the structured media and artifacts within which minds interact (Bruner, 1996; Resnick, Levine, & Teasley, 1991; Salomon, 1993). Chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" by Cress, Feinkohl, Jirschitzka, and Kimmerle (2016) explores related ideas.

The networked information society (Benkler, 2006) provides foundations and supports new possibilities for individual action and decentralized shared creation of artifacts (these items are discussed in more detail in the section "Examples" below):

- *Citizens* (not only professional film makers in Hollywood) can reach millions of people with YouTube movies.
- *Faculty members* can teach ten thousands of students (and not only students in their classrooms) with massive open online courses (MOOCs).
- *Developers* and users of complex software systems can help each other.
- *Niche communities* (e.g., researchers being interested in creativity and IT) can share information and artifacts.

In order to explain these developments, we have developed some theoretical frameworks that are discussed below.

Differentiating Different Modes and Models of Collaborative Actions

The concept of "mass collaboration" is interpreted and used in different ways, and the boundaries to the following related concepts are often not precisely defined (Kvan, 2000)—and to do so maybe an important research challenge for the future (Chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" by Elliott, 2016, also discusses these differentiations):

- *Participation* overlaps with many aspects of mass collaboration (how it is used in our framework for cultures of participation) (see section below and Fischer, 2011).

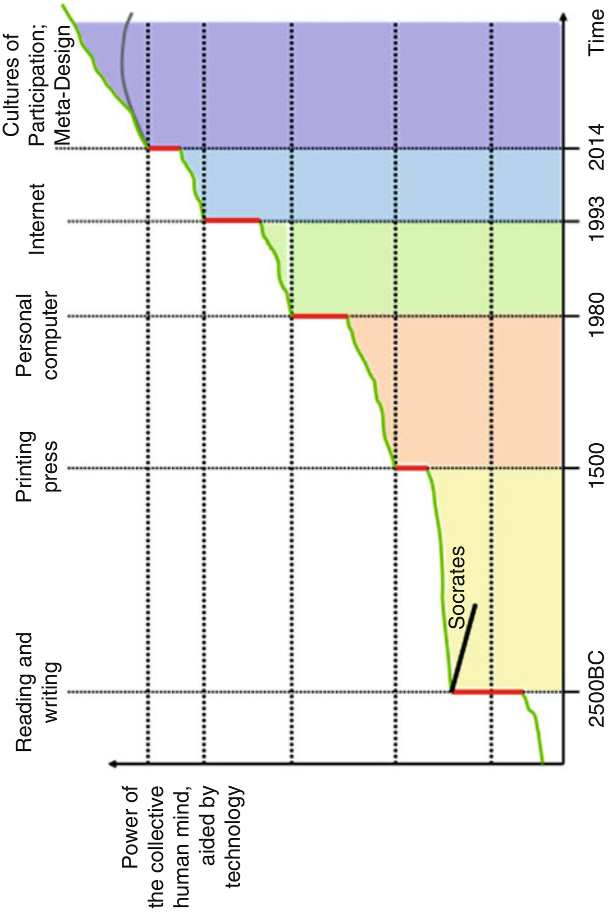


Fig. 1 Qualitative overview of major developments transcending the limitations of the unaided, individual human mind

- *Coordination* is characterized by establishing structures, processes, context, and relationships; for example, meta-designers (such as the designers of Wikipedia) create contexts to which everyone can contribute content, and curators organize individual contributions in collections (in the 3D Warehouse) and increase the overall quality and quantity of content in the Encyclopedia of Life (see Table 1).
- *Cooperation* is characterized by relationships in which subtasks are divided up, done separately by different people, and then the results are brought together; information is shared as needed and authority is retained by each contributor.
- *Collaboration* connotes more durable and pervasive relationships, everyone works together on a shared task, and shared problem spaces are jointly created (Stahl, 2006). Collaborations require a commitment to a common mission and authority is determined by the collaborative structure. The distribution of the individual contributions can be differentiated along the following dimensions: (1) *social distribution*, making activities more fun and more motivating, by sharing the burden of coping with large problems ("getting the job done effectively and more quickly") and (2) *epistemological distribution* by providing richer learning opportunities and suggesting new ways of thinking about problems.

Mass Collaboration and Education

An interesting *early vision of mass collaboration and education* was provided by Illich's concept of "Learning Webs" (Illich, 1971, chapter "What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions") in which he outlines educational systems (25 years before the Internet was developed) that "provide all who want to learn with access to available resources at any time in their lives; empower all who want to share what they know to find those who want to learn it from them; and, finally furnish all who want to present an issue to the public with the opportunity to make their challenge known."

Instead of funneling all educational programs through teachers, Illich envisioned educational environments focused on self-motivated learning supported by (1) links to open educational resources, (2) skill exchange between learners being knowledgeable in different domains, (3) peer-matching, and (4) reference services to educators at large as illustrated in Fig. 2.

Theoretical Frameworks

The four dimensions described in this section contributing to a theoretical framework are based on our research activities over the last decade to understand, explore, and support mass collaboration.

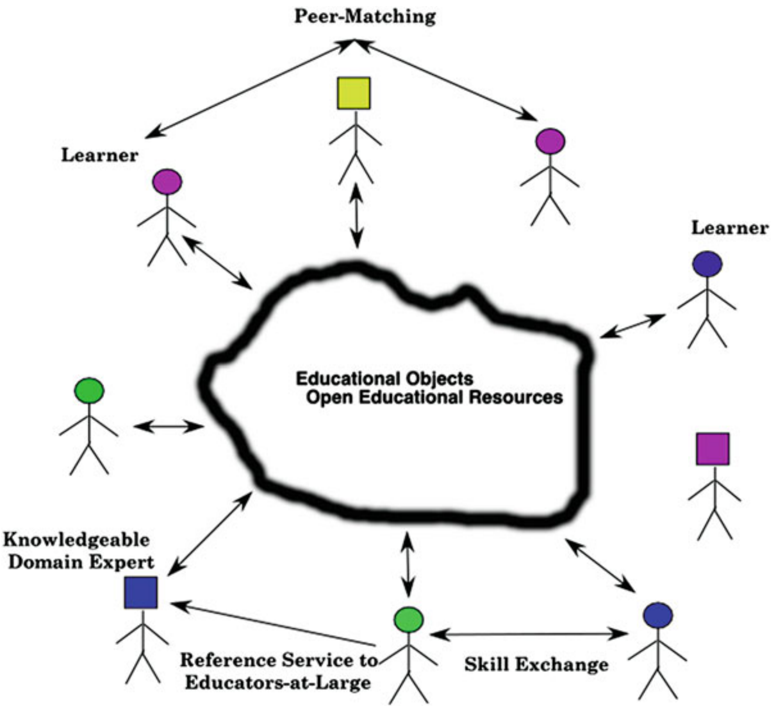


Fig. 2 An illustration of Illich's learning webs

Cultures of Participation

Mass collaboration represents a fundamental shift from *consumer cultures* (focused on passive consumption of finished goods produced by others) to *cultures of participation* (in which all people are provided with the means to participate actively in personally meaningful activities) (Fischer, 2011; Gee, 2004; Jenkins, 2009; von Hippel, 2005).

Cultures are defined in part by their media and their tools for thinking, working, learning, and collaborating (McLuhan, 1964). In the past, the design of most media emphasized a clear distinction between producers and consumers (Tapscott & Williams, 2006). Television is the medium that most obviously exhibits this orientation (Postman, 1985) and in the worst case contributes to the degeneration of humans into "couch potatoes" (Fischer, 2002) for whom remote controls are the most important instruments of their cognitive activities. In a similar manner, our current educational institutions often treat learners as consumers, fostering a mindset in students of "consumerism" (Illich, 1971) rather than "ownership of problems" for the rest of their lives (Bruner, 1996). As a result, learners, workers, and citizens often feel left out of decisions by teachers, managers, and policymakers, denying them opportunities to take active roles in personally meaningful and important problems.

Meta-design

Meta-design (Fischer & Giaccardi, 2006) is a methodology that characterizes objectives, techniques, and processes for creating new media and environments that allow all participants to act as *designers* and contribute to and benefit from the creativity of the group. A fundamental objective of meta-design is to create socio-technical environments that will help all learners and workers to be creative by allowing them to go beyond the explicitly described functionality of any artifact, to use it in new ways, to evolve it by creating new content, and to explore its potential for new processes. Meta-design is instrumental for "the ability to reformulate knowledge, to express oneself creatively and appropriately, and to produce and generate information rather than simply to comprehend it" (National Research Council, 1999). It appeals to diverse audiences to be engaged as active contributors rather than just as passive consumers (1) by supporting them in designing and building their own socio-technical environments, (2) by situating computation in new contexts, and (3) by developing tools that democratize design, innovation, and knowledge creation.

The power and the coverage of systems supporting mass collaboration and of information environments created by mass collaboration are based on the fact that these systems can evolve not only by a small number of designers but by the contribution of all participants. In order for these processes to take place, the systems must be designed for evolution. In *conventional design approaches*, designers create complete systems and make decisions for users for situational contexts and for tasks that they can only anticipate. In meta-design approaches, meta-designers "underdesign" systems (Brand, 1995; Brown & Duguid, 2000): they create contexts in which participants can contribute content so that unexpected uses of the artifact or missing information can be accommodated by the participants. *Underdesign* is not less work and it is not less demanding, but it is different: it does create solutions, but it creates environments in which "owners of problems" in situated settings can create solutions themselves.

Meta-design is focused on the design of (1) the *technical infrastructure* providing mechanisms, such as end-user modifiability and end-user development, that allow stakeholders to evolve the system at use time; (2) *learning environments and work organizations* that allows stakeholders to migrate from passive consumers to end-users, users, and power users; and (3) *socio-technical environments* in which stakeholders are recognized and rewarded by their contribution and can accumulate social capital.

The goal of making systems extensible by users does not imply transferring the responsibility of good system design to the user. Normal users will in general not build tools of the quality a professional designer would. In fact, they are not concerned with the tool, per se, but in doing their work. However, if the tool does not satisfy the needs or the tastes of the users (which they know best), then users should be able to adapt the system without always requiring the assistance of developers.

Ecologies of Participation and Collaboration

Individuals (learners, workers, citizens) have different motivations for doing things, and those motivations create different levels of participation. To understand, foster, and support cultures of participation requires differentiating, analyzing, and supporting distinct roles that can be found in cultures of participation (Preece & Shneiderman, 2009).

For mass collaboration to become viable and be successful, it is critical that a sufficient number of participants take on the more active and more demanding roles. To encourage and support *migration paths toward more demanding roles* (giving people more responsibility, more authority, and more decision-making power), mechanisms are needed that lead to more involvement and motivation and that facilitate the acquisition of additional knowledge required by the more demanding and involved roles. Grounded in a "low-threshold and high-ceiling" architecture that allows new participants to contribute as early as possible and experienced participants to cope with complex tasks by offering broad functionality, mechanisms are needed to address the following requirements: (1) scaffolding to support migration paths, (2) special interaction features for different levels of participation, (3) supporting different levels of granularity of participation to account for different time and effort investments, and (4) rewards and incentives to reduce the funnel effect from one level to the next (Porter, 2008). Figure 3 illustrates these different roles and their relationships. In addition to migration toward more demanding roles, more research is also needed to identify and analyze factors that *cause people to move in the other direction* including not enough time, lack of challenges, and fading interests (Preece & Shneiderman, 2009).

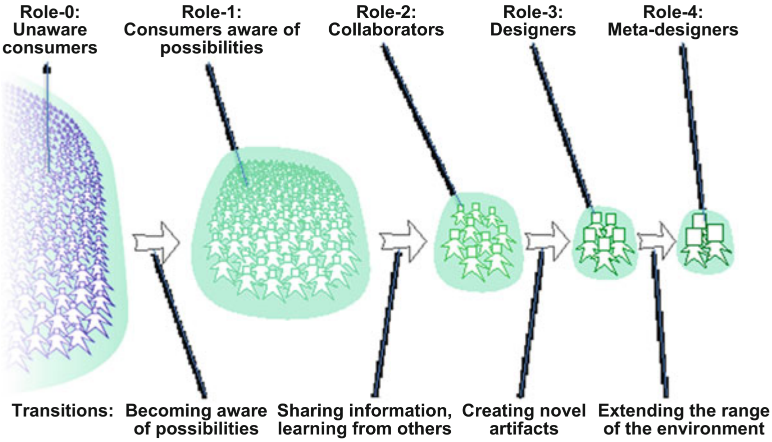


Fig. 3 Identification of different roles in rich ecologies of participation

Transcending the dichotomy between consumers and producers, new, middle-ground models for participation and collaboration have emerged such as:

- *Prosumers* (Tapscott & Williams, 2006), who are self-directed learners or techno-sophisticated and comfortable with the technologies with which they grew up. They do not wait for someone else to anticipate their needs, and they can decide what is important for them. They participate and collaborate in learning and discovery and engage in experimenting, exploring, building, tinkering, framing, solving, and reflecting.
- *Professional amateurs* (Brown, 2005; Leadbeater & Miller, 2008), who are innovative, committed, and networked amateurs working to professional standards. They are a new social hybrid, and their activities are not adequately captured by traditional frameworks that strictly separate work and leisure, professional and amateur, consumption and production, and formal and informal learning.

Different Models for Knowledge Creation, Accumulation, and Sharing

To exploit the full potential of mass collaboration (by promoting cultures of participation and being supported by meta-design) will require breaking down the barriers and distinctions between designers and users, teachers and learners (creating "communities of learners"; Rogoff, Matsuov, & White, 1998), consumers and producers (creating "prosumers"; Tapscott & Williams, 2006), and professionals and amateurs (creating "prom-ams"; Leadbeater & Miller, 2008).

Achieving these objectives will allow and support participants (not all of them, not at all times, and not in all contexts) to be and act as *active contributors in personally meaningful activities* (Fischer, 2002). This will lead to new processes of knowledge creation, accumulation, and sharing. For the information society of today, two basic models can be differentiated (Fischer, 2009):

Model-authoritative ("filter and publish") (Fig. 4) is characterized by a small number of experts (such as teachers) acting as contributors and a large number of passive consumers (such as learners). In such cultures, strong input filters exist based on:

- Substantial knowledge is necessary for contributions (e.g., the in-depth understanding of established fields of inquiry or the need to learn specialized high-functionality tools).
- Extensive quality control mechanisms exist (e.g., the certification of professionals or low acceptance rates for conference and journal articles).
- Large organizations and high investments for production are required (e.g., film studios such as Hollywood, newspaper production facilities).

The *advantage* of this model (this is at least the basic underlying assumption) is the likelihood that the quality and trustworthiness of the accumulated information is high because the strong input filters will reject unreliable and untrustworthy

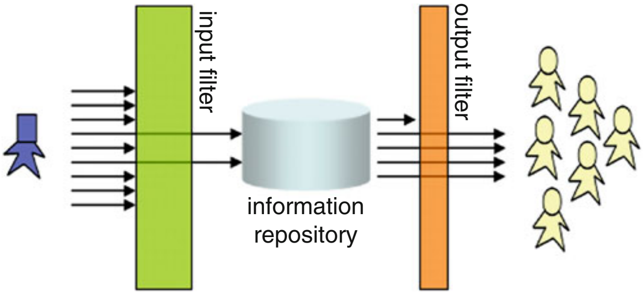


Fig. 4 Model-authoritative underlying professionally dominated cultures

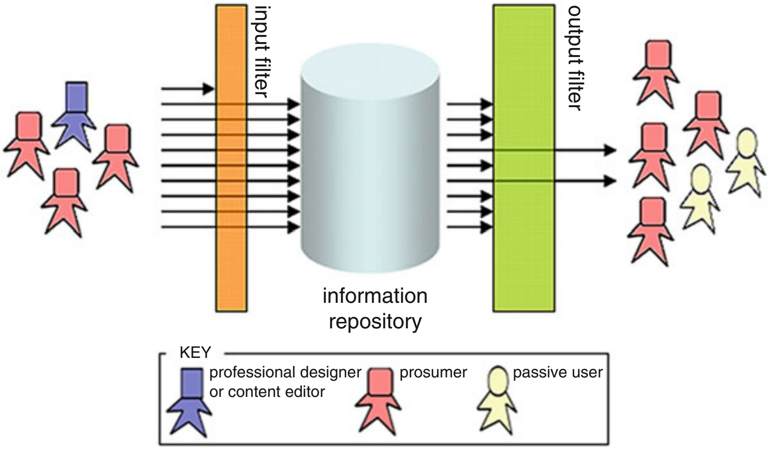


Fig. 5 Model-democratic underlying mass collaboration

information. Based on the smaller size of the resulting information repositories, relatively weak output filters are required. The *disadvantage* of this model is that it greatly limits that "all voices can be heard." Their intake is limited because with only a small number of contributors, too many views are unexplored and underrepresented because the controlling mechanisms behind the input filters suppress broad participation from different constituencies.

Model-democratic ("publish and filter") (Fig. 5) can be characterized by weak input filters allowing users not only to access information but to become active contributors by engaging in participation and collaboration. The weak input filters result in much larger information repositories (with information repositories such as the World Wide Web being the prime example).

Model-democratic on the technical side requires powerful support for creating content (such as meta-design environments), for organizing content (such as supporting collections by curators), and for distributing content (such as powerful search capabilities and recommender systems). On the social side, it requires active contributors (who master the design tools and who are motivated to contribute), curators (who organize the large information repositories), and coaches (who assist in helping learners to identify and locate relevant information).

Model-democratic provides the foundation for socio-technical environments in which information, knowledge, and artifacts can be produced not only by many more people but also by individuals and in subjects and styles that could not pass the filters of *model-authoritative.*

Artifacts created by *model-authoritative* and *model-democratic* can complement each other and they may fulfill different needs as articulated by Cory Doctorow (Lanier, 2006): “Wikipedia isn’t great because it’s like the Britannica. The Britannica is great at being authoritative, edited, expensive, and monolithic. Wikipedia is great at being free, brawling, universal, and instantaneous.”

Examples of Socio-Technical Environments Based on Mass Collaboration

The rise of large-scale collaborative efforts based on mass collaboration has created a number of success cases in a variety of different domains, and a brief overview will be provided in the first part of this section. The remaining parts will describe our own efforts anchored in the theoretical frameworks described in the previous section and illustrating it in specific domains: (1) the design of the CreativeIT Wiki, (2) an empirical study of the SAP Community Network (SCN), and (3) an analysis of massive open online courses (MOOCs).

A Spectrum of Interesting Examples

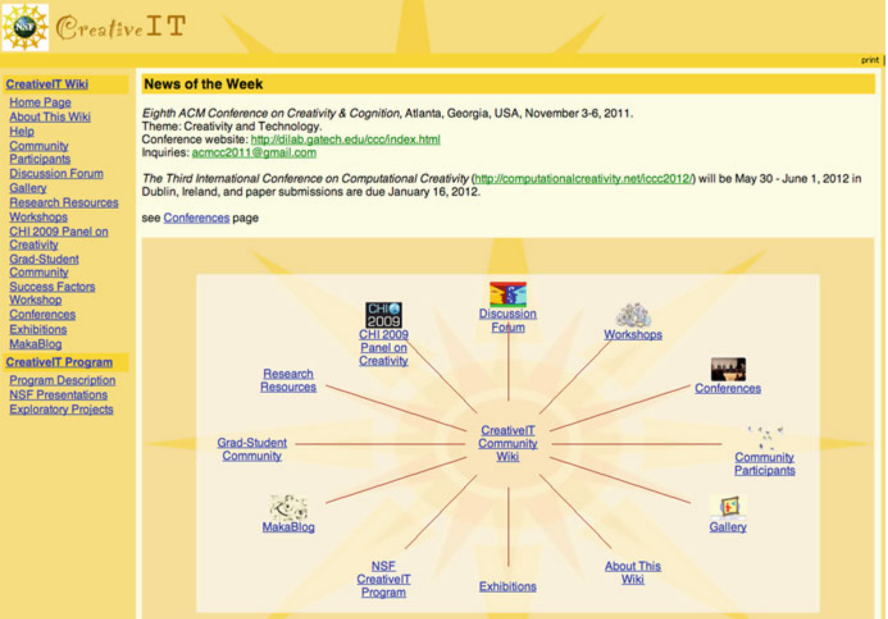
Table 1 provides an overview of a sample of environments created by mass collaboration with unique features. These systems (at least in principle) engage the talent pool of the whole world to make contributions and thereby have potentially millions of developers.

Our own research activities that have been focused on different aspects of the three environments mentioned at the bottom of this table will be briefly described in the following sections. Issues related to Wikipedia are discussed in chapter “Individual Versus Collaborative Information Processing: The Case of Biases in Wikipedia” by Oeberst, Cress, Back, and Nestler (2016).

The CreativeIT Wiki: Supporting Distributed Scientific Communities

We have designed and seeded a wiki-based socio-technical environment to support the (mass) collaboration between scientists, artists, and students in the application area of "Creativity and Information Technology," specifically in the context of the NSF research program "Creativity and Information Technologies."[1] The unique challenges of supporting this specific community are that people working in interdisciplinary projects or in niches of their disciplines are often isolated in their local environments unaware of relevant work in other disciplines.

The prototypes developed in this research project (Dick, Eden, & Fischer, 2009) (see Fig. 6 for an example screen image) had some success as a content management system (marked by the creation of 290 pages 80 literature references contributed by community members, workshop proceedings published as part of the wiki, a gallery of project exemplars, and hosting over 100 registrants). It fell short in creating and fostering an active community. Despite our best efforts to seed the wiki and to provide support mechanisms, we were unable to engage "masses of people" to participate and collaborate, and our prototype did not reach the "tipping point" (Gladwell, 2000).



News of the Week

Eighth ACM Conference on Creativity & Cognition, Atlanta, Georgia, USA, November 3-6, 2011.
Theme: Creativity and Technology.
Conference website: http://dilab.gatech.edu/ccc/index.html
Inquiries: acmcc2011@gmail.com

The Third International Conference on Computational Creativity (http://computationalcreativity.net/iccc2012/) will be May 30 - June 1, 2012 in Dublin, Ireland, and paper submissions are due January 16, 2012.

see Conferences page

Fig. 6 A screen image of the CreativeIT Wiki

---

[1] http://www.nsf.gov/pubs/2009/nsf09572/nsf09572.pdf

As a result of our research with the CreativeIT Wiki, we articulated a set of requirements (based on a deeper understanding of how technical and social environments can be changed through design interventions) that should be further explored as design foundations for social production and mass collaboration, including:

- Provide *awareness mechanisms* that will give participants better overviews over ongoing activities and changes taking place in the wiki
- Integrate *events (taking place insight the wiki or links to outside events) to provide specific objectives for participants to collaborate*
- Create *social support tools* that support participants to find and connect to other participants, represent themselves to other researchers, and create networks of interests can influence user activities
- Explore different design trade-offs for the *social environment* (e.g., making the environment more *permissive* and unstructured versus more *prescriptive* and structured) and their influence on participation and collaboration
- Assess whether *rating systems* will increase the trust and interest in existing content
- Support *paths* for contributors to migrate toward increased involvement (see Fig. 3)

SAP Community Network: Studying Mutual Learning in Communities of Practice

We have studied the *SAP Community Network (SCN)* (http://scn.sap.com/) (Gorman & Fischer, 2009) as an example of a successful socio-technical environment consisting of more than one million registered users forming a highly active online community of developers, consultants, integrators, and business analysts building and sharing knowledge about SAP technologies via wikis, expert blogs, discussion forums, code samples, training materials, and a technical library. We have collected a comprehensive data set that includes all of the posting activity of more than 120,000 users from June 2003 through May 2008.

To get a better understanding of processes and dynamics in a culture of participation such as SCN, we have developed an initial analytic framework to measure a number of factors, including attributes such as (1) *responsiveness* (how often and quickly members get responses to their requests), (2) *engagement intensity* (how many helpers and responses are required to answer questions), and (3) *role distribution* (the ratio of users who ask questions to those who answer questions). Our analysis allowed us to find patterns in the data that hint toward an environment that is supportive of mass collaboration. In addition to a *quantitative* analysis, we have engaged in a limited *qualitative* analysis to understand the impact of incentive systems on participation. SCN uses a point system to *reward users* for their participation, but these features can have negative effects. Points are highly valued, and some users resorted to “gaming the system” to earn points.

Our analysis allowed us to identify patterns in the data relevant for a deeper understanding of different aspects relevant for mass collaboration. SCN provides good support and motivation for users to contribute (which we measured by the time it took users to receive a response to their post which is significantly less than in other environments we analyzed for comparison). In addition to such *quantitative* analyses, we also did preliminary *qualitative* analysis to understand the impact of incentive systems on participation. SCN uses a point system to reward users for their participation, but these features can have negative effects. Points are highly valued, and some users did resort to “gaming the system” to earn points. Data sources like this will contribute to create better frameworks to understand and design effective means to support intrinsic motivation with appropriate incentives in mass collaboration.

Massive Open Online Courses: Enriching the Landscapes for Learning and Education

MOOCs are higher-ed courses with massive enrollments that promise “Education for Everyone and For All Interests.” They have generated enthusiasm, excitement, and *hype* worldwide and recently increasing *skepticism* (Fischer, 2014). They are being broadly discussed in the major news media. Rapidly increasing numbers of MOOC providers, MOOC courses, and articles, discussion groups, and blogs discussing MOOCs are indicators of the involvement of many stakeholders. Most of these analyses and developments are based on *economic perspectives* (such as scalability, productivity, being “free”) and *technology perspectives* (including platforms supporting large number of students in online environments and enrichment components such as forums, peer-to-peer learning support, and automatic grading). Few contributions analyze MOOCs from a *learning science perspective* and put them into a larger context with other approaches to learning and education. Our research has been focused on conceptualizing MOOCs as one component in a *rich landscape of learning*. We are particularly interested to explore MOOCs as a forcing function to identify to core competencies of residential, research-based universities (Eisenberg & Fischer, 2014).

While MOOCs attract masses of learners who sign up for them (see Fig. 7 for the geographical distribution of learners in a specific MOOC), the meaning of “participation” and “collaboration” needs to be better understood and analyzed in the years to come. The nature of MOOCs, being instructionist and supporting primarily a one-directional information flow from teacher to learners, enables the scaling-up of participants to very large numbers leading to an extremely low teacher/student ratio.

Fig. 7 A common image illustrating the worldwide participation in a MOOC

Signing-up for MOOCs is trivial (it requires often not more than providing a few information items) and it is free. Many people are signing up without any intentions to participate in the course as a whole (they may use MOOCs as the textbooks of the twenty-first century). This is a simple explanation why MOOCs have often extremely low completion rates. Educationally important objectives leading to collaboration including (1) feedback from instructors, tutors, and teaching assistants; (2) virtual forums; (3) local meet-up groups; (4) peer-to-peer collaboration (such as mutual criticism, feedback, and grading) are possible within the MOOC framework but up till now play a minor role in almost all MOOCs.

Research Challenges

Understanding and fostering mass collaboration requires paying attention to factors from political, economical, and social domains (Benkler & Nissenbaum, 2006). This section takes a brief look at a few of those factors.

Distances and Diversity in Mass Collaboration. By bringing together large numbers of participants, *distances* (spatial, temporal, and technological dimensions) and *diversities* (bringing stakeholders together from different cultures) are important factors influencing and determining mass collaboration. Table 2 provides an overview of the major distances and diversities.

These distances and diversities are double-edged swords for mass collaboration: if dealt with and exploited in the right way, they can provide interesting opportunities that participants can learn from each other and their collaborations result in more creative artifacts (Fischer, 2005).

Table 2 Differentiating distances and diversity

Distances and diversities	Rationale	Addressed by	Challenges
Spatial	Participants are unable to meet face to face; low local density of people sharing the same interests	Computer-mediated communication	Achieve common ground; involve large communities
Temporal	Support long-term, indirect communication and meta-design	Design rationale, building on previous work	Motivate efforts to document design decisions for others
Conceptual *within* domains	Shared understanding	Communities of practice (CoPs)	Avoid groupthink
Conceptual *between* domains	Make all voices heard	Communities of interest (CoIs); boundary objects	Establish common ground; integration of diversity

Motivation for Collaboration. Human beings are diversely motivated beings. We act not only for material gain but for psychological well-being, for learning personally meaningful information, for social integration and connectedness, for social capital, for recognition, and for improving our standing in a reputation economy. In most application areas, mass collaboration relies on intrinsic motivation for participation, and it has the potential to influence this by providing contributors with the sense and experience of joint creativity, by giving them a sense of common purpose and mutual support in achieving it, and in many situations by replacing common background or geographic proximity with a sense of well-defined purpose, shared concerns, and the successful common pursuit of these.

Control. Meta-design supports users as active contributors who can transcend the functionality and content of existing systems. By facilitating these possibilities, *control* is distributed among all stakeholders in the design process. The willingness to share control is a fundamental challenge in mass collaboration. The promise of sharing control is a gain in creativity and innovation: “Users that innovate can develop exactly what they want, rather than relying on manufacturers to act as their (often very imperfect) agents.” (von Hippel, 2005).

To increase social creativity requires (1) *diversity* (each participants should have some unique information or perspective), (2) *independence* (participants’ opinions are not determined by the opinions of those around them) (Surowiecki, 2005), (3) *decentralization* (participants are able to specialize and draw on local knowledge) (Anderson, 2006), and (4) *aggregation* (mechanisms exist for turning individual contributions into collections and private judgments into collective decisions). In addition, participants must be able to express themselves (requiring technical knowledge how to contribute), must be willing to contribute (motivation), and must be allowed to have their voices heard (control).

Quality of the Artifacts. Many teachers will tell their students that they will not accept research findings and argumentation based on articles from Wikipedia. This exclusion is usually based on considerations such as: “How are we to know that the content produced by widely dispersed and qualified individuals is not of substandard quality?”

The online journal *Nature* (http://www.nature.com/) has compared the quality of articles found in the *Encyclopedia Britannica* with Wikipedia and has come to the conclusion that "Wikipedia comes close to Britannica in terms of the accuracy of its science entries." This study and the interpretation of its findings have generated a controversy, and Tapscott and Williams (2006) have challenged the basic assumption that a direct comparison between the two encyclopedias is a relevant issue: "Wikipedia isn't great because it's like the Britannica. The Britannica is great at being authoritative, edited, expensive, and monolithic. Wikipedia is great at being free, brawling, universal, and instantaneous."

There are many more open issues to be investigated about quality and trust (Kittur, Suh, & Chi, 2008) in cultures of participation, including: (1) errors will always exist, resulting in learners acquiring the important skill of always being critical of information rather than blindly believing in what others (specifically experts or teachers) are saying; and (2) ownership as a critical dimension, the community at large has a greater sense of ownership and thereby is more willing to put an effort into fixing errors. This last issue has been explored in open-source communities and has led to the observation that "if there are enough eyeballs, all bugs are shallow" (Raymond & Young, 2001).

A Long-Tail Framework and Mass Collaboration. The *long tail theory* (Anderson, 2006) postulates that our culture and economy is increasingly shifting away from a focus on a relatively small number of "hits" (mainstream products and markets) at the head of the demand curve and toward a huge number of niches in the tail. Information technologies have greatly enhanced the ability to take advantage of the long tail by exploiting niche markets and connecting people with communities and products of interest. We have been exploring the implications of the long tail theory for *learning and education* (Collins, Fischer, Barron, Liu, & Spada, 2009) by focusing on two of its transformational aspects: (1) learning about exotic topics outside the mainstream education curriculum and (2) the opportunity to communicate with people who share similar interests somewhere in the world on a regular basis. The web (specifically the Web 2.0 supporting cultures of participation) gives children and adults the ability to pursue topics they are particularly interested and feel passionate about. These are topics learners never encounter in school unless they pursue them later in college.

Schools, however, have moved in the opposite direction. Even as computers become more ubiquitous in schools, curriculum standards and mandated assessments (based on frameworks such as cultural literacy (Hirsch, 1996)) have exercised a conservative force against the proliferation of idiosyncratic interests and passion by emphasizing that everyone should learn the same thing at the same time, as measured by the same standards. Similarly, the education establishment has tried to control what people learn by defining the curriculum in schools. The dramatically increasing amount of non-mainstream knowledge indicates a gap between the world we live in and the formal education, where the latter focuses mainly on limited amount of knowledge.

Measurements and Data. While some aspects determining cultures of participation can be easily measured, for example, (1) how many learners have signed up for a MOOC, (2) how many and how often people visited a particular site (see Table 1), and

(2) how well does a site live up to certain usability and sociability factors (Preece & Shneiderman, 2009), other aspects are much more difficult to assess and measure. Some researchers have great hopes that data gained from *learning analytics research* (http://www.solaresearch.org/events/lak/) will provide many new and interesting insights into learning processes. Mass collaboration (as it is conducted mostly inside computational environments in which activities can be tracked) provides rich data sets about interactions, collaborations, and engagement that computational processes can exploit.

The following issues related to learning analytics should be pursued and investigated:

- What are the fundamentally new aspects of learning analytics research in the context of mass collaboration? The idea of collecting data about student behavior and actions is not new: it has been pursued with dribble files in LOGO, user modeling in intelligent tutoring systems, and artifact analysis in designing activities.
- How valuable will the insights be that learning analytics environments are able to collect and analyze? How can we infer from low-level, quantifiable events (such as material looked at, how long and how often, errors made, help requested) the intentions, problems encountered, and objectives of the learner?
- While learning analytics may provide insights to understand the past and the present ("how things are"), how much will it help to envision and design alternatives to learning and education ("how things could/should be")?
- Are the potential misuses and privacy violations of the data gained with learning analytics? Some MOOC companies plan to sell data about their students to companies as part of their business model to make money.

Identifying Drawbacks of Mass Collaboration. Mass collaboration opens up unique new opportunities for education and learning in the twenty-first century, but as with all major innovations, some potential drawbacks should not be overlooked. One such drawback is that participants may be forced to cope with the burden of being active contributors in *personally irrelevant activities*. This shift provides power, freedom, and control to learners, but it also has forced them to act as contributors in contexts for which they lack the experience that teachers and professionals have acquired.

More experience and assessment is required to determine the design trade-offs for specific contexts and application domains in which the *advantages* of mass collaboration (such as extensive coverage of information, creation of large numbers of artifacts, creative chaos by making all voices heard, reduced authority of expert opinions, and shared experience of social creativity) will outweigh the *disadvantages* (accumulation of irrelevant information, wasting human resources in large information spaces, lack of coherent voices, and participation overload). The following research questions need to be explored:

- Under which conditions is a *fragmented culture* (with numerous idiosyncratic voices representing what some might characterize as a modern version of the "Tower of Babel" and others as refreshingly diverse insights) better or worse than a *uniform culture* (which is restricted in its coverage of the uniqueness of local identities and experience) (Lanier, 2006)?

- If all people can contribute, how do we assess the *quality and reliability* of the resulting artifacts (an interesting analysis comparing Wikipedia with Britannica is documented in Giles (2005); a summary of criticism by different authors is compiled at http://en.wikipedia.org/wiki/Wikipedia:Criticisms; and a specific critique by Nicholas Carr can be found at http://www.roughtype.com/?p=110)?
- How can curator networks effectively increase the quality and reliability? The mass collaboration taking place in the Encyclopedia of Life (see Table 1) has developed an interesting and extensive framework to engage and support curators to increase the overall quality and quantity of content on the EOL site (http://eol.org/info/255).
- What is the role of *trust*, *empathy*, *altruism*, *and reciprocity* between participants and how will these factors affect mass collaboration (Benkler & Nissenbaum, 2006)?

Conclusions

Mass collaboration in the networked information economy (Benkler, 2006) provides opportunities that masses of people can engage as active contributors and collaborate with each other in numerous human activities, including: (1) participation is invited, supported, encouraged, and valued rather than prohibited; (2) creative contributions and innovations are decentralized and extended and artifacts are developed as open, evolvable seeds rather than finished products (facilitated by meta-design and *model-democratic*); (3) new relationships between the individual and social and new control regimes between teachers and learners are established; and (4) the focus of education is shifted from teaching to learning.

The *theoretical frameworks* described in this article address some important aspects of mass collaboration and can be applied to *different domains*, *contexts*, and *tools* (as illustrated in the example section). The briefly described *research challenges* outline a research agenda to gain a deeper understanding of the opportunities and pitfalls associated with mass collaboration.

Mass collaboration in education (and beyond in numerous other human affairs) represents a new paradigm. While new technologies play an important facilitating role, the most important impact will be in fundamentally new opportunities for thinking, learning, working, and creating artifacts.

References

Anderson, C. (2006). *The long tail: Why the future of business is selling less of more*. New York, NY: Hyperion.

Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. New Haven, CT: Yale University Press.

Benkler, Y., & Nissenbaum, H. (2006). Commons-based peer production and virtue. *Journal of Political Philosophy, 14*, 394–419.

Brand, S. (1995). *How buildings learn: What happens after they're built*. New York, NY: Penguin.

Brown, J. S. (2005). *New learning environments for the 21st century.* Retrieved from http://www.johnseelybrown.com/newlearning.pdf

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston, MA: Harvard Business School Press.

Bruner, J. (1996). *The culture of education*. Cambridge, MA: Harvard University Press.

Collins, A. (2016). A brief history of mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Collins, A., Fischer, G., Barron, B., Liu, C., & Spada, H. (2009). Long-tail learning: A unique opportunity for CSCL? In A. Dimitracopoulou, C. O'Malley, D. Suthers, & P. Reimann (Eds.), *Proceedings of computer supported collaborative learning (CSCL) 2009* (Vol. 2, pp. 22–24). Rhodes, Greece: International Society of the Learning Sciences.

Council, N. R. (1999). *Being fluent with information technology*. Washington, DC: The National Academy Press.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Dick, H., Eden, H., & Fischer, G. (2009). Increasing and sustaining participation to support and foster social creativity. In N. Bryan-Kinns, M. D. Gross, H. Johnson, J. Ox, & R. Wakkary (Eds.), *Proceedings of the seventh ACM conference on creativity and cognition, Berkeley, CA* (pp. 363–364). New York, NY: ACM.

Eisenberg, M., & Fischer, G. (2014). MOOCs: A perspective from the learning sciences. In J. L. Polman, E. A. Kyza, D. K. O'Neill, I. Tabak, W. R. Penuel, A. S. Jurow, … L. D'Amico (Eds.), *Learning and becoming in practice: The 11th International Conference of the Learning Sciences (ICLS) 2014* (pp. 190–197). Boulder, CO: International Society of the Learning Sciences.

Elliott, M. (2016). Stigmergic collaboration: A framework for understanding and designing mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fischer, G. (2002, December). Beyond "couch potatoes": From consumers to designers and active contributors. *Firstmonday: Peer-reviewed journal on the Internet, 7*(12). Retrieved from http://firstmonday.org/issues/issue7_12/fischer/

Fischer, G. (2005). Distances and diversity: Sources for social creativity. In *Proceedings of the 5th conference on creativity & cognition* (pp. 128–136). New York, NY: ACM.

Fischer, G. (2009). Democratizing design: New challenges and opportunities for computer-supported collaborative learning. In C. O'Malley, D. Suthers, P. Reimann, & A. Dimitracopoulou (Eds.), *Proceedings of computer supported collaborative learning (CSCL) 2009* (Vol. 1, pp. 282–286). Rhodes, Greece: International Society of the Learning Sciences.

Fischer, G. (2011). Understanding, fostering, and supporting cultures of participation. *ACM Interactions, XVIII*, 42–53.

Fischer, G. (2014). Beyond hype and underestimation: Identifying research challenges for the future of MOOCs. *Distance Education, 35*, 149–158.

Fischer, G., & Giaccardi, E. (2006). Meta-design: A framework for the future of end user development. In H. Lieberman, F. Paternò, & V. Wulf (Eds.), *End user development* (pp. 427–457). Dordrecht, The Netherlands: Kluwer Academic.

Fischer, G., & Herrmann, T. (2011). Socio-technical systems: A meta-design perspective. *International Journal of Sociotechnology and Knowledge Development, 3*, 1–33.

Gee, J. P. (2004). *Situated language and learning: A critique of traditional schooling*. London, England: Routledge.

Giles, J. (2005). Internet encyclopedias go head to head. *Nature, 438*, 900–901.

Gladwell, M. (2000). *The tipping point: How little things can make a big difference*. New York, NY: Back Bay Books.

Gorman, A., & Fischer, G. (2009). Toward an analytic framework for understanding and fostering peer-support communities in using and evolving software products. In *Proceedings of the 4th International Conference Communities and Technologies (C&T'09) Penn State University, June (*pp. 1–9). New York, NY: ACM.

Hirsch, E. D. (1996). *The schools we need and why we don't have them*. New York, NY: Doubleday.

Illich, I. (1971). *Deschooling society*. New York, NY: Harper and Row.

Jenkins, H. (2009). *Confronting the challenges of participatory cultures: Media education for the 21st century*. Cambridge, MA: MIT Press.

Kittur, A., Suh, B., & Chi, E. H. (2008). Can you ever trust a wiki? Impacting perceived trustworthiness in Wikipedia. In *Proceedings of the 2008 ACM conference on Computer Supported Cooperative Work (CSCW'08)* (pp. 477–480). New York, NY: ACM.

Kvan, T. (2000). Collaborative design: What is it? *Automation in Construction, 9*, 409–415.

Lanier, J. (2006). *Digital Maoism: The hazards of the new online collectivism*. Retrieved from http://www.edge.org/3rd_culture/lanier06/lanier06_index.html

Leadbeater, C., & Miller, P. (2008). *The pro-am revolution: How enthusiasts are changing our economy and society.* Retrieved from http://www.demos.co.uk/files/proamrevolutionfinal.pdf

McLuhan, M. (1964). *Understanding media: The extensions of man*. Cambridge, MA: The MIT Press.

Oeberst, A., Cress, U., Back, M., & Nestler, S. (2016). Individual versus collaborative information processing: The case of biases in Wikipedia. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Porter, J. (2008). *Designing for the social web*. Berkeley, CA: New Riders.

Postman, N. (1985). *Amusing ourselves to death: Public discourse in the age of show business*. New York, NY: Penguin.

Preece, J., & Shneiderman, B. (2009). The reader-to-leader framework: Motivating technology-mediated social participation. *AIS Transactions on Human-Computer Interaction, 1*, 13–32.

Raymond, E. S., & Young, B. (2001). *The cathedral and the bazaar: Musings on Linux and open source by an accidental revolutionary*. Sebastopol, CA: O'Reilly & Associates.

Resnick, L. B., Levine, J. M., & Teasley, S. D. (Eds.). (1991). *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association.

Rogoff, B., Matsuov, E., & White, C. (1998). Models of teaching and learning: Participation in a community of learners. In D. R. Olsen & N. Torrance (Eds.), *The handbook of education and human development: New models of learning, teaching and schooling* (pp. 388–414). Oxford, England: Blackwell.

Salomon, G. (Ed.). (1993). *Distributed cognitions: Psychological and educational considerations*. Cambridge, England: Cambridge University Press.

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.). Cambridge, MA: The MIT Press.

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Surowiecki, J. (2005). *The wisdom of crowds*. New York, NY: Anchor Books.

Tapscott, D., & Williams, A. D. (2006). *Wikinomics: How mass collaboration changes everything*. New York, NY: Portofolio, Penguin Group.

von Hippel, E. (2005). *Democratizing innovation*. Cambridge, MA: MIT Press.

Stigmergic Collaboration: A Framework for Understanding and Designing Mass Collaboration

Mark Elliott

Mass Collaboration as Digital Stigmergic Collaboration

There are many opportunities for using mass collaboration in education (Cress et al., 2013). However, as an area that is still emerging, there are also many gaps in both understanding mass collaboration, as well as its effective design and delivery. This makes it challenging to conduct effective research, establish and manage mass collaboration in educational contexts or understand how they work in order to effectively engage pre-existing communities. This article aims to help address this challenge by outlining a framework for defining, understanding and, ultimately, designing mass collaboration.[1]

In the context of this paper and the framework presented here, mass collaboration is defined as digital stigmergic collaboration (collective creation of shared representations in digital media) where the membership is near or greater than 25 participants (Elliott, 2007). This definition is based upon an underlying understanding of collaboration as the process of a group collectively creating emergent, shared representations of a process and or outcome that reflects the input of the total body of contributors.

---

[1] The theory summarised here was developed and is described more fully in my doctoral thesis, Stigmergic Collaboration: A theoretical framework for mass collaboration (2007). This paper also draws on learning and insight gained from 7 years of industry experience following completion of my PhD. This has involved applying this framework to the design and delivery of mass collaborations focused on the creation of government policy, strategy and urban planning. While all these instances have required considerable strategic community building components, the core logic that stigmergic collaboration underpins scalable collaboration has held true and provided key design insights.

M. Elliott (✉)
Collabforge, Melbourne, VIC, Australia
e-mail: mark.elliott@collabforge.com

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_4

The framework presented here also draws upon a concept known as 'stigmergy'. Stigmergy is a form of mediated communication where signs placed in the environment by agents serve as stimuli to other agents to further transform the environment, for example, the use of pheromones in ant colonies. Stigmergy as a concept was developed in the context of the study of social insects and has recently been expanded through application in fields such as artificial intelligence (AI) and robotics. In the present context, stigmergy helps explain how collaboration scales from small group settings to large online communities, thereby shattering the 'glass ceiling' of face-to-face collaboration (Elliott, 2007). Stigmergy is also a behavioural mechanism that equates to the externalisation of collaborative interactions and creative contributions that take place in collaborative learning situations. Therefore, linking stigmergy to the role of media in collaboration provides a means for tracing an evolution from the manipulation of materials for the augmentation of face-to-face collaborative processes to the emergence of digital workspaces and mass collaboration.

In the context of education, through its inherently distributed process and mechanisms, stigmergy enables a radically more distributed and decentralised mode of interaction, production, teaching and learning. It puts participants more in control over their choice of roles, contribution, learning activities and experience. As a specific type of social system, stigmergy also shifts interactions from person to person to a site-of-work focus. This lowers the barriers to participation by reducing the need for social negotiation (Elliott, 2007) while allowing individuals to self-select topics and activities of interests.

The ideas presented in this chapter are organised with the aim of illustrating how collaboration is a specific type of collective activity that can only scale beyond small face-to-face groups through stigmergy. After a brief introduction to the ideas, the sections of this chapter are:

- *Frameworks for understanding and designing collaboration*—which provides the rationale and underlying assumptions made about collaboration in general
- *Stigmergy—scaling social interaction through indirect communication*—a brief introduction to the origins and key elements and aspects of stigmergy
- *Stigmergic collaboration—how collaboration scales membership and reach*—which applies stigmergy directly to collaboration and shows how it is extended as a result
- *Defining and designing mass collaboration*—reflects on several other design considerations and implications of stigmergic collaborative systems

The chapter ends with suggestions for future research and how the connections between the present work and CSCL might be further explored.

Frameworks for Understanding and Designing Collaboration

An Etymological and Action Research Approach to Defining Collaboration

Central to the approach for the framework for mass collaboration is a grounded understanding and position regarding collaboration in any context and at any scale. Therefore, the following section provides in brief the research rationale behind this particular understanding of collaboration.

From an etymological perspective, collaboration as a term is relatively new to the English language. First appearing in print in 1802, the term, *collaborator*, was used throughout the nineteenth century to refer to scientific (co-authorship) and artistic (playwright) co-creation. A key insight that etymological review reveals is that most early mentions were in relation to the collective creation of literary content (Elliott, 2007). This is a form of collective activity which not only incorporates the creative process but that of stigmergy. Expanded below, stigmergy is a mode of communication where agents make changes to their environment and interpret these changes as messages, which cue specific behaviours. In his *Expert Assessment of Human-Human Stigmergy*, developed for the Canadian Government, Parunak confirms, 'Joint authorship has always been a stigmergic activity, mediated by the emerging document itself. Each author is stimulated by what previous authors have written to add main-line content or marginal comments' (Parunak, 2005).

That stigmergy is integral to the etymological origins of collaboration provides a critical insight into its material nature and process. Further, the involvement of creative production represents a primary distinction between collaboration and cooperation, where cooperation involves more transactional interactions often characterised by maintained divisions of labour (Dillenbourg, Baker, Blaye, & O'Malley, 1996; Stahl, Koschmann, & Suthers, 2006). That this more specific usage of the term 'to collaborate'—the involvement of media in collective creative production, e.g. co-authoring—has been lost or subsumed within a larger, more generalised usage of the term (e.g. to work in conjunction with another[2]) is interesting in its own right.

This general, more commonplace definition, means that definitions of collaboration can and do occur in a wide range of research contexts. These include fine art criticism (Green, 2001), IT, organisational theory (Black et al., 2003), network theory (Newman, 2001), educational theory (Gifford & Enyedy, 1999) and artificial intelligence (Grosz & Sarit, 1999). When reviewing these definitions, a key reflection is that the definition of collaboration tends to vary depending upon the contexts, interests and applications of those who are defining it. While this is to be expected, a goal of the present research has been to develop a generalised understanding applicable across disciplinary contexts.

---

[2] *Oxford English Dictionary, Second Edition,* (1989). (Eds.) J. A. Simpson & E. S. C. Weiner. Oxford: Oxford University Press

Although some have expressed the need for a general theory or framework of collaboration (Wood & Gray, 1991), no specific field of research has attempted such a formulation that is designed for application in all contexts and at all scales. Any such framework would need to account for the collective generation of ideas where agents are in some way synchronised during the creative process. While the cognitive sciences provide a body of knowledge to draw upon, approaches in this area tend to view cognition as information processing within individual minds, often excluding wider social and contextual factors (Hollan, Hutchins, & Kirsh, 2000).

However, a number of disciplines acknowledge and even emphasise the role that the wider social, cultural and material context plays in the formation of cognition, meaning, relevance and intelligence. These include activity theory (Engeström, 1987; Gifford & Enyedy, 1999; Leont'ev, 1979, 1981; Vygotsky, 1978), situated action (Suchman, 1987), distributed cognition (Hutchins, 2000; Susi & Ziemke, 2001) and actor-network theory (Latour, 2005; Law, 1992) and CSCL (Stahl et al., 2006). This more holistic perspective provides a platform for understanding collaborative production as a process that is simultaneously social, cultural and material. It also provides a link to stigmergy and its role in coordinating the creative contributions through the material environment—whether physical or virtual. In fact, Susi and Ziemke concluded that stigmergy offers a minimal common ground between activity theory and situated and distributed cognition (Susi & Ziemke, 2001).

Aligned with this lineage of thought, I developed the following definition, specifically to inform the design of collaborative processes and technologies in any context, at any scale.

> *Collaboration is the process of two or more people collectively creating emergent, shared representations of a process and or outcome that reflects the input of the total body of contributors.*

Another version of this definition, one that preferences the process or mode of co-creation, is:

> *Two or more people adding, editing or deleting a shared pool of content.*

The shared representations or pool of content being created can comprise physical or virtual media and materials or simply the ideas within each another's minds. Therefore, this definition can account for situations where collaboration is driven primarily by language exchanges (i.e. a discussion where new ideas are formed). I call this *discursive collaboration*. This definition also covers scenarios where the goal is to externalise these shared representation or content into the environment (e.g. coding a new software application or creating a public artwork sculpture). This second form I call *stigmergic collaboration* (described in detail below). While discursive and stigmergic collaboration can occur in their pure form individually, it is more common to see them integrated with one another and taking place together.

While this definition also stipulates that the output of collaboration may be an ongoing process (such as in the case of business partners) and or a final outcome (such as a co-authored paper), it is also necessary to recognise that for all participants whose activity is deemed collaborative, their input must be supported by the process and represented in the outcome. Having said this, a collaborator's contribution may not be visible, having been incorporated at earlier stages and thus undetectable, but with its effects still affecting the overall process and outcome. Through the specification of unique, yet universally applicable processes and concepts, this definition aims to be applicable to collaboration in every field of human endeavour at any scale.

Collaboration, Cooperation and Coordination: So What's the Difference?

While the above definition provides a grounding to build upon for understanding *mass* collaboration, in order to develop a holistic and generalised understanding, it must be considered within and in relation to other collective activities where individuals come together to generate value together. Three broad collective processes are presented here, which are assigned to the commonplace terms, collaboration, cooperation and coordination.[3] This approach aims to bring higher resolution to these terms, while at the same time keeping their definitions simple enough to be used in a wide range of research and industry settings.

- Collaboration: two or more people collectively creating emergent, shared representations of a process and or outcome that reflects the input of the total body of contributors.
  - Examples: co-authorship of a single research article, jazz improvisation and wiki page collaboration (e.g. Wikipedia article)
- Cooperation: Separate and distinct, individualistic contributions are made, where the contributions are aggregated for overall gain, value or insight.
  - Examples: surveys; comments made on a research article or blog post, as opposed to editing it directly; and refuse recycling
- Coordination: Unrelated entities are drawn together or arranged within a space designed to align features and highlight patterns.
  - Examples: Web search returns, workplace environments and conferences and common protocols

While these definitions can be used individually in the analysis of existing situations, technologies and spaces, they can also be used to guide the design of new ones. Further, the distinctions drawn here between collaboration and cooperation are similar to those that have been made in other CSCL contexts (Dillenbourg et al., 1996; Roschelle & Teasley, 1995), where cooperation is related to apportioning

---

[3] Adapted from *Stigmergic Collaboration: A theoretical framework for mass collaboration* (Elliott, 2007)

discrete pieces of work to individuals and creating divisions of labour, while collaboration as linked to a coordinated effort of a group to problem solve together. The present framework extends this thinking, providing a basis for understanding how the two are supported by even deeper mechanisms and processes (e.g. coordination).

A Tool for Analysing and Designing Collaborative Process

While the above definition of collaboration and framework for collective activity provides insight regarding *what* collaboration can be considered to be, they are not focused directly on describing *how* collaboration gets done. And to reiterate, the goal of the present research is to develop approaches applicable at any scale, whether it is two people or two million. Therefore, the following statement is a theory of how collaboration gets done, in any context, at any scale, that is premised upon the above framework for collective activity:

> *Shared vision guides active contribution to a shared plan and outcome.*

This statement is comprised of three components, with each component generalising for specific approaches and techniques used in differing contexts. The following figure shows the relationships of these different components (Fig. 1):

1. Shared vision
    - Shared vision must be based upon a platform of shared understanding, also referred to as ‘grounding’ (Dillenbourg, 1999).
    - Many methods exist for supporting this part of the process, e.g. workshopping, the MG Taylor method.[4]
    - Shared vision also includes the need to cultivate shared purpose, inspiration, motivation and alignment of goals and interests.

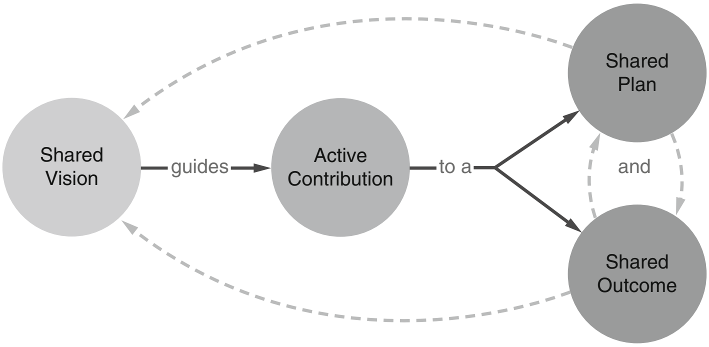


Fig. 1 Analysis and design tool for collaboration

---

[4] http://www.mgtaylor.com/public/2001/pat_pend.html

2. Active contribution
    - Contribution must be actively made by all participants.
    - For participants to make meaningful and substantial contributions, to 'add, edit or delete', they must be granted or enabled access to the shared content.
    - In order to cater to the interests, capabilities and capacities of participants, efforts should be made to support multiple modes and means of contribution.
3. Shared plan and outcome
    - Continued alignment of a group's shared vision is premised upon a collective understanding of what the group is doing now and in the future. Hence, a shared plan is often a key enabler.
    - A shared plan may exist as an explicit document or artefact or as an element of shared understanding.
    - If a collaborating group is to grow in membership, new participants must be onboarded. A shared plan is key to alleviating onboarding bottlenecks, with documentation of shared vision and journey to date often being included.
    - The ability to share in contributing to the outcome is imperative, which necessitates access to the outcome (whereas, in cooperative settings, outcomes may be the sole property of those responsible for the aggregation of individual contributions).
    - The necessity for continuous negotiation of the shared plan and outcome means that this overall process is cyclical, with active contribution to the plan and outcome leading to an ongoing redefinition of shared vision.

Like the framework for collective activity, this tool can be applied in an analytical capacity, as a health check, to determine if genuine collaboration (as defined above) is taking place. Or, it can be used as a design tool, to determine the requirements for a collaboration that is to take place.

Stigmergy: Scaling Social Interaction through Indirect Communication

The concept of stigmergy was originally developed in study of social insects such as ants and termites. While each individual agent in isolation appears to pursue their own agenda, somehow, the colony as a whole exhibits high levels of organisation (Theraulaz & Bonabeau, 1999). This became known at the time as the 'cooperation paradox', with early scientific concepts and technology being unable to identify how this organisation was coordinated. However, when pheromones were able to be detected and their role as a sign within the environment was understood, the theory of stigmergy could be substantively developed.

As a result, in 1959, Pierre-Paul Grassé coined the term stigmergy from the Greek words stigma 'sign' and ergon 'action' (1959) in order to capture the notion that signs left in the environment may produce action from agents. Not only do individuals provide stimuli for other individuals through cues such as pheromones trails, but they can also provide cues by reorganising the environment in such a way which produces structures that also serve as stimuli. This allows highly complex structures to self-organise due to the collective input of large numbers of individuals performing extraordinarily simple actions in response to configurations of and encodings within their local environment. This total stigmergic system comprises three key components: agents, environment and the interactions between the two. Further, these interactions give rise to emergent, system-level dynamics.

Agents in the Stigmergic System

In order to make changes to their environment, agents must have the capacity to sense and assess the environment's state, as well as make changes to it in conjunction with their assessment. The ability to sense, assess and change the environment evolves over time in response to a given environment, giving rise to a set of dynamics unique to each stigmergic system. For example, termites have evolved the ability to sense punctures in their mounds, along with corresponding ability to assess repair the damage (Grassé, 1984; Kennedy, Eberhart, & Shi, 2001). Ants create piles of dead ants (cemeteries), by sensing existing piles and moving ants from smaller into larger piles (Bonabeau, Theraulaz, Fourcassié, & Deneubourg, 1998).

The Role and Characteristics of a Stigmergic Environment

The environment in a stigmergic system can be broadly characterised by the three components of topology, variables and processing dynamics.

Stigmergic systems may employ any form of topology, including graphs (networks), indices (catalogues) and Cartesian coordinates (space) (Elliott, 2007). While the environment's structure may vary, it is important that the agent's activities are situated within some form of spatial domain that provides for the agent's experience of localisation. This experience restricts their engagement and senses and limits the demands placed upon their interactive capacities (Parunak, 2005). This enables the system to scale no matter how large the environment grows since there is no centralised organisation or regulatory network needed to span it. Instead, the coordinative and information processing rules and dynamics are distributed throughout the environment and individual agents, forming emergent patterns relevant to the interaction of the agents and environment.

An environment's structure also lends itself to a certain set of state variables that agents may change. For example, in ant systems, variables supporting pheromone deposit include permeability of soil and vegetation, while in animal trail systems, obstacles, ground cover and terrain mutability contribute to the possibility of encoding trails. In human contexts (expanded below), online media lends itself to variables related to document collaboration, where text and numerical variables are most broadly supported.

Finally, an environment's processing dynamics govern the evolution of variables through time, with the stigmergic system typically incorporating these dynamics to its advantage. This provides the function of additional information processing capacity to the agent-environment interactions. For example, the aggregation and evaporation of pheromones in insect systems have the effect of 'truth maintenance and discarding obsolete information' (Parunak, 2005). Similar effects can be observed in animal trail systems where trodden earth, erosion and dying vegetation produce the trails, while regrowth and continued erosion maximise fidelity through diminishing those which are unused. In human systems, such as textual wiki collaboration, the system's processing capabilities might include notifications of new contributions to other participants, alerts indicating number of +/- characters changed in an edited wiki page (e.g. Wikipedia's "Related changes" feature), or spelling correction suggestions.

Types of Stigmergic Interactions

Interactions in stigmergic systems can be classified into four primary categories:

1. Sematectonic stigmergy: Agents interpret certain configurations of their actual environmental or agent placements as signs.
2. Marker-based stigmergy: Agents interpret specialised markers deposited in the environment as signs (similar to the notion of 'metadata'; Parunak, 2005; Brueckner, 2000).
3. Quantitative signs: These are scalar and of a single type, representing varying intensities of cues.
4. Qualitative signs: These form a unique, discrete set of cues (Kramer, 2005; Parunak, 2005; Theraulaz & Bonabeau, 1999).

Both sematectonic and mark-based interpretations may be comprised of quantitative and or qualitative signs. These four types of interaction provide a means of discriminating and classifying stigmergic activity in a wide range of contexts. For instance, the stigmergic collaboration of co-authoring a Wikipedia article entails for the most part sematectonic/qualitative interpretation of the current state of the article's content (Parunak, 2005). However, common wiki tools such as 'recent changes' provide marker-based/quantitative feedback through positive and negative counts of characters added or deleted during past revisions.

System-Level Dynamics That Emerge as a Result of Stigmergy

The stigmergic system functioning as a whole (all agents plus the environment and its capabilities) produces emergent, system-level dynamics. These dynamics are a distinguishing factor of stigmergy and appear on a level above that of the local interactions of agent and environment. For instance, regarding the above example of Wikipedia article co-authoring, the emergent system-level behaviour is the expression of a jointly held consciousness that leads to a uniform and holistic conception of an encyclopaedia (Parunak, 2005). In termite mound building (the placement of single, pheromone-impregnated mud balls upon one another), the system-level behaviour is the construction of complex nests and architectures such as arches and ventilation systems (Grassé, 1984; Kennedy et al., 2001; Theraulaz & Bonabeau, 1999).

The emergent capacities of stigmergy also mean that such systems are evolvable, adaptable and able to develop new behaviours (Kelly, 1994; Parunak, 2005). This is an ideal feature for collaborative groups seeking multiple solutions in a continually changing environment. It is also in many ways an excellent fit for learning communities who must constantly adapt to the integration of new knowledge, perspectives and experiences. This ability to adapt and develop new behaviours as an overall system is also closely linked to the notion of intelligence. In stigmergic systems, intelligence is understood to reside 'in the interactions among the agents and the shared dynamical environment' (Parunak, 2005). This raises interesting questions in the context of education with regard to where to locate learning and the outcomes it generates (Cress, 2013).

Human Applications and Adoption of Stigmergy

There are many examples of human-human stigmergy. These include trail and track formation (Helbing, Keltsch, & Molnár, 1997; Helbing, Schweitzer, Keltsch, & Molnár, 1997), graffiti and illegal garbage dumping, where an initial refuse pile attracts more dumping at the same location.[5] On the larger scale, applications comparable to nest building in social insects include the constraints and impositions placed upon development in urban areas by previous building works. However, many smaller-scale instances easily blend into our day to day without our notice, such as how we might place our cutlery on our plate to signal to a waiter that we are finished with our meal. All of these examples are of the sematectonic variety (configurations of the environment) with trail formation, garbage dumping and cutlery placement being quantitative (of a single scalar quantity), while graffiti and building works being largely qualitative (unique, discrete cues).

However, types of stigmergic interaction in human activity tend to be nested, reflecting the complexity of human culture and engagement. For instance, while graffiti might on the outset appear qualitative to those who engage in the art (a good work's techniques and or subject matter inspiring a response in a common location) from outside the graffiti community, it would seem to be an activity governed more

---

[5] Garbage dumping as stigmergy is mentioned by Dylan Shell on comment to Joe Gregorio's (2002) Stigmergy and the World Wide Web. *Bitworking* (web log): http://bitworking.org/news/Stigmergy, retrieved 20 December 2005

by quantitative means (the more works existing on one particular wall, regardless of merit, the more likely it is that more will be attracted). Of course, both are correct. Additionally, many applications of stigmergy mixes marker based with sematectonic mechanisms. For instance, when a editing a Wikipedia article, it is a common practice to make a revision note, explaining an edit made. Such notes place a marker outside of the content of the focus activity (i.e. improving an article), the equivalent of making a note in a document's margins when co-authoring.

Whether sematectonic, marker based, physical or virtual, the large extent of human-human stigmergy represents a significant area of further research in a wide range of fields, not the least of which CSCL.

Stigmergic Collaboration: How Collaboration Scales in Membership and Reach

While the examples provided above are of human-human stigmergy, they are not necessarily stigmergic *collaboration*. Stigmergic collaboration arises when two or more people utilise some form of material media for the encoding of their collective creative endeavour. For example, and drawing upon the framework for collective activity, graffiti 'canyons' (laneways and walls that attract graffiti) might be best classed as stigmergic coordination, whereas signalling to waiters with your cutlery would be considered stigmergic cooperation. However, drafting Wikipedia articles with other Wikipedians is a classic example of stigmergic collaboration.

The theory of stigmergic collaboration helps understand the role that the externalisation of shared representations plays in scaling and extending collaborative activity. Specifically, it describes how and why this is important. It is important because it extends participants' collaborative capabilities across four primary lines, space, time, mind and the process of emergence.

More Space for Collaboration

Stigmergic collaboration extends the space for collaboration beyond our minds, into the physical and virtual world around us. As we encode aspects of our media environment (e.g. a whiteboard), more surface area (conceptual, physical or virtual) provides for increased access.

More Time for Collaboration

Similarly, material representations of the collaborative output provides an increased level of permanence to contributions through time. This can expand the influence and presence of contributions to those beyond the participants immediately present.

This can be as immediate as emailing a picture of a whiteboard to those not able to attend a meeting or as extended as spanning thousands of years as is the case with cave paintings.

Increased Cognitive Ability for Collaboration

Stigmergic collaboration also allows us to better ‘see what we think’, providing an enhanced capacity to remember, review, reflect upon and learn from contributions (Cress, 2013; Flower & Hayes, 2008; Webb, 1982). By externalising our otherwise internal representations, we enable the possibility for our consciousness to subject these representations to the workings of components of the brain which are otherwise less connected internally (Baars, 1997; Cress & Kimmerle, 2008). In collaborative contexts, not only does this augment our individual minds but also helps better distribute cognitive load across the group by optimising for working capacities spread throughout the group that would also be otherwise less connected. Externalising into our media environment also opens up the possibility of taking advantage of any transformational dynamics this environment may possess or make possible. For example, calculating, correcting, reformatting, connecting, synthesising, visualising and distributing content—these all extend the mind’s capacities and cognition into the wider environment.

Accelerating the Emergence of Collaborative Outcomes

The combination of extended space, time and cognition through stigmergy also extends one of the most important outcomes of collaboration, the process of emergence—larger patterns arising as a result of lower-level, individual contributions. The opportunity for more varied, detailed, persistent and meaningful contributions by more participants means more emergent outcomes are possible. The experience of witnessing this emergence can be both exciting and stimulating (as most with collaborative experience would likely attest). This can have the effect of contributing positive feedback back into the stigmergic system, catalysing even further emergent outcomes. Ultimately, the emergence of outcomes generated by the group above and beyond those generated by any one participating individual is the primary goal and value of collaboration.

Extending Stigmergic Collaboration Through Digital Networks

Extensions of collaborative capability through stigmergy enable numerous forms of collective creation which would otherwise be beyond the scope of our unassisted mental capacities, such as co-authoring books, research articles, plays and films or the collective creation of sculptures, murals, dramatic performances and research projects. However, even greater potential is unleashed when stigmergic collaboration is amplified with networked digital media. Tools such as Google Docs are providing synchronous collaborative editing opportunities that were previously unavailable even several years ago. These types of tools (to take a simple example) provide the opportunity to shift co-authoring from being reliant upon digital stigmergic *cooperation* procedures (emailing a word processing document around to collaborators, whose contributions must be carefully managed and integrated so as to avoid revision conflicts) to much more genuinely collaborative processes (participants seeing each others' contributions being made in real time and thus being able to manage the integration of their own input). In addition, as outlined in the following section, when digital stigmergic collaboration has the requisite features to support scalability, mass collaboration may also become possible.

Opportunities for Stigmergic Coordination and Cooperation

While this present work is focused on stigmergic collaboration, it is important to note that stigmergy is present in applications of both coordination and cooperation as defined above. Much like collaboration, the encoding of media and especially in digital contexts, stigmergy can act as a powerful extension of cooperation and coordination. Whether it is in cases such as Google's search engine (digital stigmergic coordination), or eBay's online marketplace (digital stigmergic cooperation), the combination of stigmergy, coordination and cooperation, along with networked digital technologies, is transforming our society in significant ways.

Defining and Designing Mass Collaboration

Mass collaboration is defined in the current context as digital stigmergic collaboration (collective creation of shared representations in digital media) where the membership is near or greater than 25 participants. Further, mass collaboration is typically characterised by a number of features described below:

1. Social workspaces: a digital environment or platform that helps attract, coordinate and govern participation
2. Content negotiation: where content creation is the primary mode of interaction, as opposed to social negotiation in the case of face-to-face or smaller-scale collaboration
3. Emergent teaming: where group formation is based more on interest and meritocratic capability than existing relationships or functional roles

The Social Workspace: Where Stigmergic Collaboration Gets Done

Through the process of stigmergic activity, digital artefacts and their corresponding annotations tend to build up, forming a field of work or a social 'workspace' (Ricci, Omicini, Viroli, Gardelli, & Oliva, 2006). These artefacts and their supporting workspaces mediate interaction, providing the coordinative and cooperative functions that support collaboration. Artefacts (e.g. a Wikipedia article) may be linked to one another and/or shared across different workspaces. Workspaces themselves may overlap, sharing both participants and artefacts, and can be nested recursively.

Mass collaborative workspaces also tend to reflect the attributes of a 'boundary object' as identified by sociologist of science Leigh Star (1989). Boundary objects serve the function of coordinating the perspectives of multiple constituencies for some purpose or activity and traditionally may be conceptual or tangible artefacts, simple or complex in their structure (Star, 1989; Star & Griesemer, 1989). Star identifies four main features of the boundary object:

1. Modularity: Each perspective can attend to one specific portion of the boundary object.
2. Accommodation: The boundary object lends itself to various activities.
3. Abstraction: All perspectives are served at once by deletion of features that are specific to each perspective.
4. Standardisation: The information contained in a boundary object is in a pre-specified form so that each constituency knows how to deal with it locally (Star, 1989 as summarised by Wenger, 1998).

The below table provides several examples of these characteristics as represented in mass collaborative social workspaces (Table 1).

The specific technologies that underpin mass collaborative workspaces can vary greatly (as is evident by the above examples). However, their core, high-level functionality is the provision of a site of work accessible to a number of participants that enables one to work as if alone via the ability to add, edit and delete a shared pool of content. Another way of saying this is that the technology must provide for individual contributions to a larger unified work consisting of dynamic content. It must be stressed that this entails not just adding content but also editing and deleting pre-existing material contributed by other participants. This is necessary in order to enable the emergence of *shared* representations held by the total collaborative group.

How a Focus on Content over Social Relationships Supports Scalable Collaboration

The coordination of individuals working as if alone, but in relation to one another, has the effect of providing a site of collaborative work where activities do not have to be mediated by turn-taking social negotiation. Instead, focus is shifted to the

Table 1 Boundary object features associated with mass collaborative projects

Project	Modularity	Abstraction	Accommodation	Standardization
Wikipedia	Any number of people can edit any number of articles at any given time	Contributors can attend separately to issues of content, layout, technical infrastructure, community discussion etc.	Encyclopaedias are abstractions by nature, attempting to represent a 'neutral point of view', the 'no original research' rule	Community-defined standards for content layout, drafting procedures (no copyright material), neutral point of view
Minecraft	Many people may inhabit and build objects in many places	Many activities are open to participants: building objects and the environment, organising events, exploring, socialising	The environment's underlying rules (its 'laws of physics') provide a uniform and common experience by restricting all other possibilities	There is a single set of procedures, software code and licensing rules regarding the modification and adaptation of existing work which is uniform for all residents
Open-source repositories (e.g. GitHub, SourceForge)	Modular by nature, sections of code may be developed by any number of different participants	Various activities are open to participants: writing original functionality, bug fixes, testing	The objectives of the project (i.e. to provide software with 'x' functionality) unify perspectives by restricting and focusing possibilities	Specific coding languages and programming methods are agreed upon or are present as existing code, thereby standardising ongoing contributions[a]

[a] For example, see Apache HTTP Server style guide (online resource) <http://httpd.apache.org/dev/styleguide.html> retrieved 11 December 2014

immediate engagement with a shared site of work through indirect communicative exchanges. This streamlines the creative process, freeing up time and energy that participants would otherwise use in negotiation, while not closing off the options for social negotiation typically supported by workspaces' wider features (e.g. Wikipedia's talk pages or a wiki's related discussion forum or email list serve).

Significantly, this also enables the number of collaborative participants to scale from several dozen (at best) in face-to-face contexts (Lipnack & Stamps, 2000) towards tens and even hundreds of thousands. This is because the capacities of the individual participants are not overwhelmed by the high demands of maintaining social relations with numerous others across an ever-expanding domain and having to negotiate their contributions with them. This lowers the 'costs' of contribution by reducing the need to become acquainted with other participants and to maintain relationships and negotiate contributions with them as they are made. This exploits the potential inherent in digital stigmergic systems for the global coordination of local input, while supporting potentially unlimited scaling.

However, from a design and education perspective, it is important to remember that while social negotiation may be reduced, cultural aspects such as working methods, styles, language and various technological literacy still must be negotiated. Similarly, it is also critical to understand that social negotiation still takes place in mass collaborative contexts and may even be essential to growing and supporting the collaborative community. Most, if not all, mass collaborations have discussions associated with content creation. The key dynamic is here is that negotiation takes a back seat in the creative process as compared to content creation—it is possible to contribute to Wikipedia or Minecraft, for instance, without discussing what you are creating. In the case of Wikipedia, this manifests as encyclopaedic articles; for Minecraft it is the evolving digital landscape and constructions within it; and for open-source software projects, it is the software application.

One key outcome of mass collaborative content creation is that the site of work amounts to a 'single source of truth'. A single source of truth provides coordination effects for participants because everyone has access to the same information about the state and focus of the collaboration (the shared plan) as well as its outcomes. A single source of truth also drives a sense of equity in the creation, or shared ownership, because it is the same object of creation that everyone is contributing to. Therefore, in design contexts, consideration of these dynamics can be important through ensuring that participants can maintain relevant ownership of their contributions through licensing schemes such as Creative Commons.

Management-Free Teaming and Co-production

While a shift from social to content negotiation largely characterises the individual experience of mass collaboration, the collective experience has a corresponding change from interactions driven by more explicit social coordination to one of distributed decision-making and action. Specifically, the formation of teams without explicit member coordination or hierarchical management, what I call *emergent teaming*, is a feature of stigmergic activity. For example, signs in the workspace environment such as prominently placed links to interesting sites of work can guide groups of contributors to converge on locations of mutual interest. Like pheromones in ant colonies guiding teams to a food source for collection, participants create stigmergic cues in their workspace that rally and coordinate the contributions of subgroups.

This same dynamic of emergent teaming can be understood from the alternate perspective of 'group-forming networks' (GFNs). These are networks that support the formation of communicating groups within a larger network. These subgroups create value that scales exponentially with network size. This scaling occurs at a rate of 2 to the power of N where N is the number of nodes in the network (Reed, 1999). Value in this context is defined as 'the value of potential connectivity for transactions. That is, for any particular access point (user), what is the number of different access points (users) that can be connected or reached for a transaction when the need arises'. GFNs have therefore been identified in research as being one of the more powerful drivers of network value which may have contributed significantly to the growth of giants such as eBay, the popularity of chat rooms and even the Internet itself (Reed, 1999). This effect is now generally referred to as 'Reed's law'. Therefore, mass collaboration can also be seen as a GFN, with emergent teaming as evidence of value being generated within a given network.

Conclusion

It is my belief that there is considerable scope for developing more nuanced and specific definitions for collaboration that improve our ability to analyse and design it. For example, collaboration is a form of collective production where a group has add, edit and delete rights to a shared pool of content and provides specific requirements for functionality that can be designed into software. The application of stigmergy further expands the understanding and definition of collaboration by showing how collective production can scale from small face-to-face teams to large, distributed groups who are not managed by any central function.

With regard to educational and learning contexts, further research should be undertaken to connect theories of stigmergy and collaboration presented in the CSCL literature to that presented here and in other contexts (such as AI, robotics, distributed cognition, etc.). There are likely many findings in CSCL that can be reinterpreted from the perspective of stigmergic systems and their dynamics. For example, stigmergic collaboration challenges notions of what synchronicity and its requirements for collaboration (Dillenbourg, 1999; Stahl et al., 2006).

Another area for further exploration in CSCL contexts is how stigmergy drives self-direction of engagement and interaction, requiring the participant to take more responsibility for their actions and activity than in more traditional working contexts. This creates an environment that the agent is able to independently traverse, exploring for own interests, while still enabling collective outputs and outcomes. This represents both opportunities and challenges in educational settings, enabling more 'self-directed' and 'student-owned learning outcomes', while at the same time requiring educators develop more nuanced understandings of how learning can and is already happening in mass collaboration contexts.

The effective application of mass collaboration to educational and learning situations also must address a key challenge: Collaboration is a capability that is shared between its participants and can only be cultivated through its application. Therefore, learning the skills of mass collaboration follows the same pattern as learning in CSCL contexts: The perspectives and practices are intersubjective and reside between the participants as much as within individuals (Stahl et al., 2006; Suthers, 2005). So in essence, to be able to build the skills needed to collaborate, as well as understand mass collaboration, one must do mass collaboration. In order to address this, I advocate an action research approach. This will allow researchers and educators alike to cultivate a more full and genuine understanding of mass collaboration, through engaging in the actual activity of mass collaboration.

This echoes Stahl's reflections on potential collaborative future for CSCL, 'CSCL may in its next phase collaboratively construct new theories, methodologies and technologies specific to the task of analyzing the social practices of intersubjective meaning making in order to support collaborative learning' (Stahl et al., 2006). In this context, the most logical and compelling idea may then be to establish a mass collaboration on mass collaboration in education.

References

Baars, B. (1997). *In the theater of consciousness: The workspace of the mind.* Oxford, England: Oxford University Press.

Black, L. J., Cresswell, A. M., Luna, L. F., Pardo, T. A., Martinez, I. J., Thompson, F., … Cook, M. (2003). A dynamic theory of collaboration: A structural approach to facilitating intergovernmental use of information technology. *Proceedings of the 36th Annual Hawaii International Conference on System Sciences, 36,* Maui, HI.

Bonabeau, E., Theraulaz, G., Fourcassié, V., & Deneubourg, J.-L. (1998). The phase-ordering kinetics of cemetery organization in ants. *Physical Review E, 4*, 4568–4571.

Brueckner, S. (2000). *Return from the ant: Synthetic ecosystems for manufacturing control.* (Doctoral dissertation). Retrieved from http://edoc.hu-berlin.de/dissertationen/brueckner-sven-2000-06-21/PDF/Brueckner.pdf

Cress, U. (2013). Mass collaboration and learning. In R. Luckin, P. Goodyear, B. Grabowski, S. Puntambekar, J. Underwood, & N. Winters (Eds.), *Handbook on design in educational technology* (pp. 416–425). London, England: Taylor & Francis.

Cress, U., Barron, B., Halatchliyski, I., Oeberst, A., Forte, A., Resnick, M., & Collins, A. (2013). Mass collaboration—An emerging field for CSCL research. In N. Rummel, M. Kapur, N. Nathan, & S. Puntambekar (Eds.), *To see the world and a grain of sand: Learning across levels of space, time and scale* (pp. 557–563). Madison, WI: International Society of the Learning Sciences.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with Wikis. *International Journal of Computer-Supported Collaborative Learning, 3*, 105–122.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford, England: Elsevier Science.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In P. Reimann & H. Spada (Eds.), *Learning in humans and machine: Towards an interdisciplinary learning science* (pp. 189–211). Oxford, England: Elsevier Science.

Elliott, M. A. (2007). *Stigmergic collaboration: A theoretical framework for mass collaboration* (Doctoral dissertation). Retrieved from http://hdl.handle.net/11343/39359

Elliott, M. (May 2006). Stigmergic Collaboration: The Evolution of Group Work. *M/C Journal*, 9(2). Retrieved 23 Nov. 2015 from http://journal.media-culture.org.au/0605/03-elliott.php.

Engeström, Y. (1987). *Learning by expanding: An activity—Theoretical approach to developmental research*. Helsinki, Finland: Orienta-Konsultit.

Flower, L., & Hayes, J. R. (2008). The cognition of discovery: Defining a rhetorical problem. *College Composition and Communication, 31*, 21–32.

Gifford, B. R., & Enyedy, N. D. (1999). Activity centered design: Towards a theoretical framework for CSCL. *Proceedings of the 1999 Conference on Computer Support for Collaborative Learning.* Retrieved from http://dl.acm.org/citation.cfm?id=1150262&dl=ACM&coll=DL&CFID=463054783&CFTOKEN=78842260

Grassé, P.-P. (1959). La reconstruction du nid et les coordinations inter-individuelles chez Bellicositermes Natalensis et Cubitermes sp. La théorie de la stigmergie: Essai d'interprétation du comportement des Termites Constructeurs. *Insectes Sociaux, 6*, 41–84.

Grassé, P.-P. (1984). *Termitologia*. Paris, France: Masson.

Green, C. (2001). *The third hand: Collaboration in art from conceptualism to postmodernism*. Minneapolis, MN: University of Minnesota Press.

Grosz, B. J., & Sarit, K. (1999). The evolution of SharedPlans. In M. Wooldridge & A. R. Dordrecht (Eds.), *Foundations of Rational Agency (Applied Logic Series)*. The Netherlands: Kluwer.

Helbing, D., Keltsch, J., & Molnár, P. (1997). Modeling the evolution of human and trail systems. *Nature, 388*, 47–50.

Helbing, D., Schweitzer, F., Keltsch, J., & Molnár, P. (1997). Active walker model for the formation of human and animal trail systems. *Physical Review E, 56*, 2527–2539.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction, 7*, 174–196.

Hutchins, E. (2000). Distributed cognition. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences*. Oxford, England: Elsevier Sciences.

Kelly, K. (1994). *Out of control: The new biology of machines*. London, England: Fourth Estate.

Kennedy, J., Eberhart, R. C., & Shi, Y. (2001). *Swarm intelligence*. San Francisco, CA: Morgan Kaufmann.

Kramer, R. S. S. (2005). *Stigmergic communication: Achieving so much without saying a word*. Sussex, England: Author.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford, England: Oxford University Press.

Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity. *Systemic Practice and Action Research, 5*, 379–393.

Leont'ev, A. (1979). The problem of activity in psychology. In J. Wertsch (Ed.), *The concept of activity in soviet psychology*. Armonk, NY: M. E. Sharpe.

Leont'ev, A. (1981). *Problems of the development of mind (English translation)*. Moscow, Russia: Progress Press.

Lipnack, J., & Stamps, J. (2000). *Virtual teams*. Toronto, Canada: Wiley.

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *Proceedings of the National Academy of Sciences of the United States of America, 16*, 404–409.

Parunak, H. V. D. (2005). *Expert assessment of human-human stigmergy*. AnnArbor, MI: Altarum Institute. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a440006.pdf

Reed, D. P. (1999). That sneaky exponential—Beyond Metcalfe's law to the power of community building. In *Context Magazine*, n.P. Retrieved from http://www.reed.com/dpr/,last:10.5.2012

Ricci, A., Omicini, A., Viroli, M., Gardelli, L., & Oliva, E. (2006). Cognitive stigmergy: A framework based on agents and artifacts. In *The Third International Workshop on Environments for Multiagent Systems.*

Roschelle, J., & Teasley, S. D. (1995). *The construction of shared knowledge in collaborative problem solving*. Heidelberg, Germany: Springer.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409–426). Cambridge, England: Cambridge University Press.

Star, L. (1989). The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving. *Distributed Artificial Intelligence, 2*, 37–54.

Star, L., & Griesemer, J. R. (1989). Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology. *Social Studies of Science, 19*, 387–420.

Suchman, L. (1987). *Plans and situated actions: The problem of higher psychological processes*. Cambridge, England: Cambridge University Press.

Susi, T., & Ziemke, T. (2001). Social cognition, artefacts, and stigmergy: A comparative analysis of theoretical frameworks for the understanding of artefact-mediated collaborative activity. *Cognitive Systems Research, 2*, 273–290.

Suthers, D. (2005). Technology affordances for intersubjective learning: A thematic agenda for CSCL. Paper presented at the *International Conference of Computer Support for Collaborative Learning (CSCL 2005)*, Taipei, Taiwan.

Theraulaz, G., & Bonabeau, E. (1999). A brief history of stigmergy. *Artificial Life, 5*, 97–116.

Vygotsky, L. (1978). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher order psychological processes*. Cambridge, MA: Harvard University Press.

Webb, N. M. (1982). Student interaction and learning in small groups. *Review of Educational Research, 5*, 421–445.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, England: Cambridge University Press.

Wood, D. J., & Gray, B. (1991). Toward a comprehensive theory of collaboration. *The Journal of Applied Behavioral Science, 27*, 139–162.

Mass Collaboration as Coevolution of Cognitive and Social Systems

Ulrike Cress, Insa Feinkohl, Jens Jirschitzka, and Joachim Kimmerle

Jointly Produced Artifacts as the Heart of Mass Collaboration

When people are in a small group and physically copresent in a given space, they can communicate directly with one another. Even if communication is transient and the content is bound to the communication partners, the group members are aware that something was communicated and may then ask other members for its content. This does not apply to masses of people. Here, the group is too large to be aware of all the actions and communications going on between any two people. Such a large group is not created by bonds or bidirectional contacts but by a shared goal or identity that is common to all group members. So, in the following, we define a *mass* of people as any large group of individual members who share commonalities, such as a goal, disposition, an activity, or interest. With regard to knowledge or interests, such masses are often called "communities" (Rheingold, 2002). Their members are more or less interchangeable and do not have to explicitly know each other in real life, be physically connected, or even be aware of the existence of one another. Communication among masses, as seen in the World Wide Web, for instance, takes on a very different shape compared with smaller and physically copresent groups. In masses, a *shared platform* is a prerequisite for reaching all members. Such a platform builds the basis for awareness of others and for all kinds of coordination. Group members can determine that an activity has taken place anywhere in the communication space only if the communication has left some kind of a manifest trace. Thus, mass collaboration requires *artifacts* that capture their members' activities. This is why we characterize *mass collaboration* as an activity where masses of individuals work collaboratively on common products that capture the current state

---

U. Cress (✉) • I. Feinkohl • J. Jirschitzka • J. Kimmerle
Leibniz-Institut für Wissensmedien (IWM), Knowledge Construction Lab,
Tuebingen, Germany
e-mail: u.cress@iwm-tuebingen.de; i.feinkohl@iwm-tuebingen.de;
j.jirschitzka@iwm-tuebingen.de; j.kimmerle@iwm-tuebingen.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_5

of the group. The emergence of Web 2.0 sites represents a major step in the development of mass collaboration. Technology no longer only provides people with access to artifacts but additionally enables large groups of users to interact with these artifacts and to actively manipulate them. These artifacts represent the centerpieces of the community. In a wiki, for instance, a mass of authors collaborates to edit a single text, and that text represents the activities of the group of authors as a whole.

A prime example of an artifact-centered community is the online encyclopedia *Wikipedia* (Wikipedia.org). It is the largest online wiki today and prides itself on being a provider of objective information and facts that are reported from a neutral point of view. Volunteer authors have created a vast number of different language editions of Wikipedia over the years, with the English-language version currently being the most dominant. Any person with Internet access is able to contribute to an article and may do so even without exposing their identity. The Wikipedia articles result from the collaboration of a multitude of individual contributions by numerous authors. During any given time of observation, some text passages of an article may remain unchanged, while others may be revised or deleted. Perhaps surprisingly, given the vast number of authors who may work on a single article, it represents a coherent and homogeneous text at almost any point in time. The fact that the articles are viewed as reliable and consistent products of a joint effort by a mass of people is reflected in Wikipedia's popularity as a one-stop source of information to people around the world.

History flow diagrams are useful tools to illustrate the number of individual edits as well as the evolution and dynamic changes that occur within a Wikipedia article over time (Viegas, Wattenberg, & Dave, 2004). The history flow diagram in Fig. 1 shows the first 100 versions of the German-language Wikipedia article on the

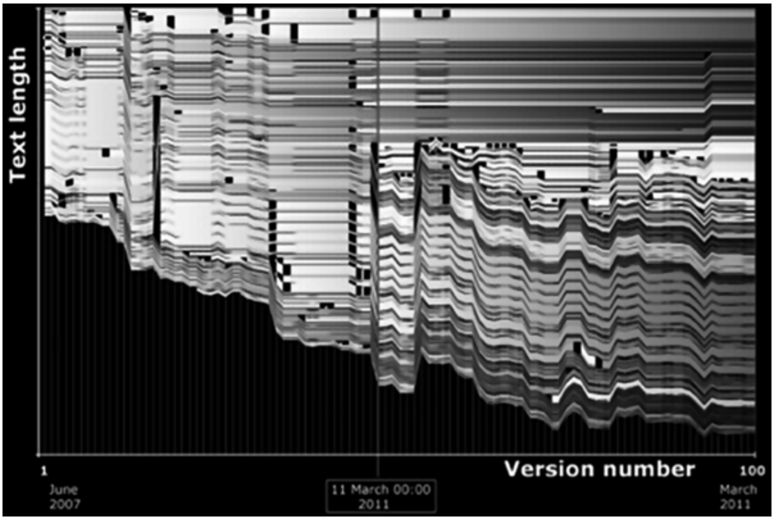


Fig. 1 History flow diagram of the German-language Wikipedia article on the Fukushima Daiichi Nuclear Power Plant spanning June 2007 to March 2011

Fukushima Daiichi Nuclear Power Plant, created between June 2007 and March 2011. The different contributing authors are represented with various shadings of gray; the *x*-axis of the diagram represents the chronology of the article's development. Each vertical line stands for a certain article version after an edit has been performed. The sum of the lengths of all the text passages illustrates the relative length of the entire text of a certain article version. On March 11, 2011, the Tōhoku earthquake and resulting tsunami damaged the power plant in Fukushima. The history flow in Fig. 1 shows that prior to this, there was relatively little activity in the article, but this changed rapidly that day. Suddenly, new facts were made public at a very fast rate and were selectively incorporated into the article. This is evidence showing that the mass of contributors was responsive to new facts as they occurred in the world. The German-language Fukushima article thereby became a prime example of online mass collaboration, as we expand upon in the sections to follow.

The Need for a Systemic Perspective

Every single sentence within a Wikipedia article may be the result of a multitude of authors who contributed new content, deleted words or parts of sentences, and performed revisions and modifications with regard to content, language, and style. The article thereby becomes more than a shared repository into which people upload individually produced content in order to make it accessible to the group (see Cress, Barquero, Schwan, & Hesse, 2007, for a summary of knowledge exchange with shared databases). When people work collaboratively on a shared artifact, such as a Wikipedia article, the individual contributions become an integrated part of that artifact, because the different text passages have to provide a coherent text. Different sections become interlinked and interwoven over time. Furthermore, some contributions may be picked up by others to become central and influence succeeding contributions over the long run, while others may remain distinct and ultimately disappear over time or may even be rejected outright. The community may revise or even remove content that is seen as disruptive, redundant, or in other ways non-fitting. These processes show that the creation of the shared artifact is not simply a one-way, *bottom-up process*, meaning that the behavior of individuals forms the basis of the community. Rather, it also has a *top-down mechanism* through which the community determines what individuals do. An individual cannot simply add text passages independently of what others wrote, what the current state of the group product looks like, or what the current shared opinion on the subject matter entails. Any text passage added by an individual author will only persist in the article over a longer period of time if the contribution fits the text as it stands. The edited passage must pursue thoughts and ideas that are central to the existing text and that are relevant to the community.

When adding content to the article, individual authors therefore have to take a range of aspects into consideration in order for their contribution to be successful. These include the topic's relevance, the expectations of others, and the writing style of the community. The contribution of an author who fails to consider these aspects is typically deleted soon after the contribution has been made, and the chance of that author's influencing the article in the future diminishes. In a mass context, earlier contributions by the mass of members thereby strongly determine the existing product and also inevitably shape future contributions. These top-down processes demonstrate complex self-cleaning, self-regulating, and self-developing dynamics of the mass of participants that are akin to a kind of evolution. The mass of contributors thereby inevitably exerts power over its members. This is not to say that online masses are always homogenous; the extent to which hierarchies among users apply varies between masses. On some online platforms, administrators or moderators give the impression of dominating the mass of users, while other platforms appear to be more egalitarian systems with equally distributed power.

From the description above, it becomes clear that when investigating the processes underlying mass collaboration, we must consider the complex interplay of individuals with a mass of people from a viewpoint that takes both bottom-up and top-down processes into account. A *systemic* approach is able to include individual processes and, at the same time, considers a mass of people as a single agent.

Applied to the context of knowledge-related processes, a systemic perspective can examine a range of aspects: How individuals process incoming information and build up knowledge in the form of *learning*, how a mass of people processes that type of information and engages in *knowledge construction* to establish a kind of "collective knowledge," and how these two processes are structurally coupled. By the term "learning," we mean changes within individuals' *cognitive systems*, whereas by the term "knowledge construction," we refer to changes within *social systems*. Both systems play a crucial role in our *coevolution model*, which we will describe in detail in the sections to follow.

Mass Collaboration and Learning: The Coevolution Model

With the proposal of the "*coevolution model* of individual learning and collaborative knowledge construction," we attempted to approach the highly convoluted processes of mass collaboration both from a cognitive and from a systemic perspective. We first presented the model in 2007, subsequently developed it further (Cress & Kimmerle, 2007, 2008; Kimmerle, Cress, & Held, 2010; Kimmerle, Moskaliuk, Cress, & Thiel, 2011; Kimmerle, Moskaliuk, Oeberst, & Cress, 2015), and used it as a theoretical basis for our empirical research in a range of online communities (e.g., Bokhorst, Moskaliuk, & Cress, 2014; Cress & Held, 2013; Kimmerle, Moskaliuk, Harrer, & Cress, 2010; Oeberst, Halatchliyski, Kimmerle, & Cress, 2014). The model borrows from Luhmann who was among the first to introduce systems theory to sociology (Luhmann, 1995), from Piaget (1977) who presented a cognitive-constructivist perspective of systems theory, and from Vygotsky (1978) to add a sociocultural perspective. The model considers individuals' cognitive systems and communication in masses as dynamic, self-organized entities that are created through their own operations. It describes the interaction of individuals with a given mass of people as an interplay between these entities that in themselves are distinct *autopoietic* systems (Maturana & Varela, 1987).

Assume that we have deconstructed the complex processes of individual-mass interactions and limited our view to a single individual who is a member of a single mass of people. Of course, such a deconstruction does not occur as such in real life; masses of people may overlap and each individual may interact with multiple facets of the mass manifestations concurrently. However, in this case deconstructed for the purpose of our analysis, the two systems involved would be (a) an individual's cognitive system and (b) the communication in a mass of people as a social system. The cognitive system can be investigated using traditional psychological techniques that try to look "inside" the head; the social system becomes apparent and analyzable through its shared artifacts.

The coevolution model (an advanced version that is based on the 2007/2008 model) that is depicted in Fig. 2 distinguishes among three dynamical processes: circular processes within the system, border-crossing processes between systems, and system drifts.

Circular Processes Within Each System

Systems are autopoietic entities that exist through their own operations (Luhmann, 1995; Maturana & Varela, 1987). A cognitive system (individual level) exists through the processes of cognition, and in this context, we consider acts of cognition to include a range of operations comprising thinking, problem-solving, learning, and evaluating information. Whenever a person thinks and tries to understand the world,

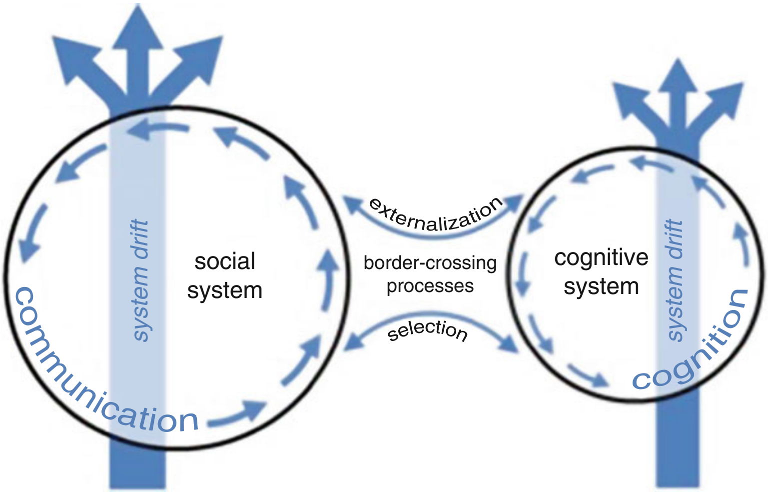


Fig. 2 The dynamic processes as described by the coevolution model

this is inevitably influenced by one's own expectations and prior understanding. As a consequence, the operations of a system are circular. Learning, however, takes place when a cognitive system encounters a situation that is new or contradicts its expectations, that is, when a system encounters something exceeding its boundaries. This irritates the system and induces a cognitive conflict that needs equilibration. The cognitive system reduces the conflict by assimilation (adapting the new information to its own cognitive schemas) or accommodation (changing cognitive schemas). However, the perception of irritations is a constructive act of the cognitive system itself. No cognitive system can process any information outside the boundaries of its own cognitive operations. Consequently, all information processing and opinion formation are based exclusively on the individual's understanding of the world.

Analogous circular dynamics take place in social systems (social level). They exist through communication. Communication requires common ground and mutual understanding among individuals. Messages have to be "connectible" in order to guarantee continuity. Thus, a social system, too, considers new information exclusively on the basis of existing group norms and information that has already been shared or exchanged. Like a cognitive system, a social system strives for meaning. It continuously decides whether information is meaningful or not. Irritations, here again, serve as triggers for the development of the system. They induce a conflict that can be solved by assimilation or accommodation. This describes the collaborative process of knowledge building.

Given that assimilation and accommodation occur in both types of systems, we refer to the processes as *internal* and *external* assimilation or accommodation, respectively. In terms of learning and knowledge construction, accommodative processes may be more important than assimilation, because they involve deeper processing and reveal an openness of the system toward allowing alterations to its own schemas.

Border-Crossing Processes

A cognitive and a social system coevolve through *structural coupling* of those systems: Through *externalization*, each system can irritate and stimulate the other continuously by providing novel content. This may induce a conflict which one or the other system can solve by assimilation or accommodation, making that system develop and mature over time. But, as systems are autopoietic entities, externalizations of one system do not directly and automatically influence the other system. It is the system itself that decides if it will react to any information or not. So, each system *self-selects* which information is relevant and which is not. This selection is determined by a community's expectation about whether certain input is of relevance to the community or not. Wikipedia, for example, is sensitive to facts. This means that a piece of information that provides a new fact is relevant for Wikipedia but not a piece of information which is speculative. For a person who wants to contribute, this means that if a social system rejects an individual's input at this stage, the person's options are to either give up and leave the community or to adjust further contributions to match the code. Once a contribution has successfully passed this stage, further information is processed by a system.

One system will irritate the other system by externalization only, if some incongruity exists between the externalized information and the current state of one of the other systems. Any information that is externalized by one system and that is equivalent to the information of another system is redundant and will therefore not contribute to the other system's development. Only if incongruity between the externalized product and the individual or social system in terms of content is sufficient, it can serve as a trigger by leading to a conflict and inducing equilibration processes. But incongruity is not always such a trigger of mutual stimulation and coevolution: If the incongruity between the externalized information and a system's processes is too large, a system will not see the novel information as relevant. It will not select it, and so the externalization will not serve as trigger.

System Drifts

Assimilation and accommodation lead—in the long run—to a *system's drift*. During system drifting, the knowledge content that is processed in their respective circular dynamics due to learning (cognitive system) and collaborative knowledge construction (social system) undergoes a development: Specifically, some content may be added and become relevant to the current knowledge base, while other content may be, either individually or collectively, "forgotten" over time. Such shifts not only imply knowledge processes but also attitude changes. For instance, consider a person who favors veganism. Such a person's cognitive system would be stimulated by external information about the influence of food on health. Mainly information about the negative effect of eating meat would be selected, and this could lead to assimilation processes that further confirm the existing attitudes about meat. Incongruent information, for example, about the risks of veganism, may be seen as irrelevant or may lead to accommodation processes only under specific conditions, for instance, if the person knows how to handle these risks. Consequently, the cognitive system would drift to an increasingly extreme position regarding veganism. Confronted with and being part of a social system that shares the same ideas about veganism, the person's view would become further polarized. Conversely, if the person were to be part of a social system that was more heterogeneous with regard to the polarity of its views, a coevolution might take place that would lead at least to slight changes of attitude in their cognitive system. Alternatively, the person might choose to leave the community.

Relative to border-crossing processes, which become apparent in immediate communication between systems and in short-term learning within a cognitive system, system drift occurs and develops over longer periods of time. It is therefore substantially more difficult to capture both in the laboratory and in the field than is the case for border crossing.

Coevolution: An Analogy

To summarize, the dynamic and systemic processes that are assumed to be at play in the coevolution of individuals and masses of people are circular dynamics, border-crossing processes, and system drifts. An analogy to the field of astronomy may be useful to help illustrate these complexities to the reader: Two astronomical objects or celestial bodies each spin along their respective axes (analogous to circular dynamics within the two systems in the coevolution model). At the same time, their respective gravity forces work on and influence each other (analogous to border crossing in the coevolution model). Their own trajectories then drift as a result of their own spinning and of the mutual impact of the gravity forces (analogous to drifting dynamics) over time.

Empirical Evidence for Coevolution in Mass Collaboration

Leaving behind a complex and relatively abstract description of the coevolution model, we will now describe findings from empirical studies from our own lab that have systematically investigated its applicability to the field, with specific application to online mass collaboration settings. We will first visit two online communities that each has its own complex circular dynamics with associated rules and norms, before providing empirical evidence of system drift in one of the communities. Finally, a set of laboratory studies will identify selected factors that appear to facilitate and thereby accelerate coevolution of individuals and masses of people.

Two Different Communities: Wikipedia and the Urkost Forum

Speaking in terms of the coevolution model, communication that occurs on any social media platform yields a social system. Wikipedia, for instance, is self-regulated and deals with input through external assimilation (integration of input without changes of the basic meaning of a wiki article) or through external accommodation (integration of the input into the article through a more or less intensive rearrangement of its original passages). For the purpose of regulation, Wikipedia applies two core content policies: (a) *neutral point of view* and (b) *verifiability*. The policy of neutrality states that "all Wikipedia articles and other encyclopedic content must be written from a neutral point of view, representing significant views fairly, proportionately and without bias." The policy of verifiability implies that "material challenged or likely to be challenged, and all quotations, must be attributed to a reliable, published source" and "that people reading and editing the encyclopedia can check that information comes from a reliable source" (retrieved on November 20, 2014, from http://en.wikipedia.org/wiki/Wikipedia: Core_content_policies).

These core content policies may be seen as rules of the system that ensure the application of the system's norms. With the overall goal of producing artifacts that are based on the "truth" according to Wikipedia's own definition, the norms determine whether the social system of Wikipedia accepts incoming information through assimilation and accommodation or simply rejects it by means of deletion. Specifically, Wikipedia's rules imply that there is no room for individual opinion within an article. Any input that is introduced into the article and that does not fulfill the criteria that Wikipedia has set itself is deemed incorrect and rejected outright. Wikipedia is also characterized by a relatively lively discussion of its rules within the community. Discussions among users are also possible on the respective talk pages of the articles, which further highlight the collaborative and egalitarian nature of knowledge construction in Wikipedia. Altercations between opposing camps on Wikipedia talk pages are not a rare observation and illustrate the difficulties associated with the collaborative writing of an article (Morgan, Mason, & Nahon, 2012).

Other online platforms have developed very different norms. One example, which appears to lie at the opposite end of the spectrum to Wikipedia in terms of self-reflection and neutrality, is the German-language Web forum "Urkost forum" (Kimmerle et al., 2013). Here, the subject of discussion is the *Urkost* approach to a healthy way of living.[1] The Urkost approach was first suggested by Konz (1999) and is an extreme form of a raw diet. According to the Urkost ideology, the human diet should be similar to that allegedly consumed in prehistoric times. Only uncooked raw food is to be eaten, along with items such as grass and, occasionally, soil. Animal products are to be rejected. Besides nutrition, the forum addresses a range of other topics that are discussed within the framework of a "right" way of living (e.g., animal rights, vaccination, and other health-related issues). Like Wikipedia, the Urkost forum as a social system also applies a code to determine whether input fits into that system's specific framework. Additionally, both platforms apply norms that represent manifestations of each respective ideology. In this way, Wikipedia and the Urkost forum both determine whether input that introduces irritation into the system is allowed to be integrated into the community or whether it is rejected outright. Crucially, however, the Urkost forum directly contrasts with Wikipedia in that its norms are not based on scientific evidence and objectivity but mostly on the views of a single administrator managing the forum. This administrator routinely refers back to the original proposer of the Urkost diet and allows no critique of the diet or of the proposer himself.

In the following, we present findings from analyses of circular dynamics and system drift in Wikipedia and in the Urkost forum, before describing border-crossing processes from laboratory studies. Studies from the well-controlled environment of the laboratory supplement the analyses of Wikipedia and the Urkost forum. They are aimed at identifying *causal* factors that trigger coevolution.

---

[1] "Urkost" is a made-up German word and to be translated as "primordial food."

Circular Dynamics in These Communities

Wikipedia Article on Fukushima Daiichi Nuclear Power Plant

Let us return to the German-language Wikipedia article on the Japanese Fukushima Daiichi Nuclear Power Plant and its development shortly after the Tōhoku earthquake, which was mentioned at the beginning of this chapter and is illustrated in Fig. 1. We used the article to study the circular dynamics of a social system as it responds to irritations due to an unforeseen event. For that purpose, we selected the period from March 11, 2011 to March 19, 2011 to observe the article (Oeberst et al., 2014).[2] To summarize briefly, the article that had previously been very limited in size saw a substantial increase in activity when the tsunami damaged the nuclear power plant. Many volunteer authors, who apparently had no specific background in the domain of nuclear power, integrated new information into the existing knowledge artifact as the event unfolded. The question that follows is: Was Wikipedia indeed successful in applying its norms while dealing with this "wave" of information that was to hit Wikipedia?

During the 9-day observation period and particularly during the days shortly after the catastrophe, we found that the pieces of information that were introduced into the article in fact stemmed from a range of sources and were characterized by substantial degrees of inconsistency, ambiguity, and ephemerality. Yet, by the end of our observation period (March 19, 2011), ratings of the article by independent experts, who could be seen as "leading scientists in the domain of nuclear power from various independent research institutions" (Oeberst et al., 2014, p. 167), revealed a change in article quality over time: Eventually, the article was of a high level of quality and factual correctness. How was this possible given that the article was so obviously flawed, at least according to the norms of Wikipedia, during the first few days?

To answer this question, let us apply the coevolution model in light of the Wikipedia-specific rules of (a) neutral point of view and (b) verifiability. As would be expected on the basis of the model, we found that any biased edit and any deviation from a neutral point of view were deleted from the article within only a few minutes. Thus, only externalizations by users which conformed to the rule of neutrality had a chance of survival within the circular system dynamics and of becoming a part of the evolving artifact. For example, on March 12, 10:57 AM, the statement "a nuclear catastrophe becomes apparent" was deleted by another user within only two minutes (see Oeberst et al., 2014, p. 166). Regarding the Wikipedia principle of verifiability, we found that most of the edits performed during the observation period (168 of 213) referenced a source. For the remaining edits, the following observations were made: (a) a reference already existed or was added subsequently (26 edits), (b) an unreferenced edit remained without any reference (13 edits), or (c) an unreferenced edit was deleted (six edits). As an example, we

---

[2] http://de.wikipedia.org/wiki/Kernkraftwerk_Fukushima-Daiichi

looked at the development of the article's content relating to the possibility of a nuclear meltdown in Reactor 1 of the nuclear plant. On March 12, 2:00 PM, the article contained the following statements: "According to the press release from 12:19 PM (CET) Japanese authorities assume that a nuclear meltdown occurred. [Reference to press release] It has been confirmed that a nuclear meltdown occurred" (see Oeberst et al., 2014, p. 159). In accordance with the rules of the system, the quasi-factual statement "it has been confirmed that a nuclear meltdown occurred" was deleted within only a few minutes. Yet, it was also the case that information which was initially deleted due to missing references was later reintroduced, this time with accompanying references, by another author, and therefore remained a part of the article. These observations demonstrate that through the involvement of its different authors, the article appeared to "clean itself" of contributions that failed to adhere to the system-specific norms.

Overall, the development of the Wikipedia article about the Fukushima Daiichi Nuclear Power Plant is a fine example of how a system's norms guide both the individual externalizations and the knowledge construction processes in order to produce an artifact of high quality, which satisfies and adheres to requirements inherent to the system. Importantly, it was not the case that the resulting artifact was attributable to a high level of domain-specific expertise or to the merit of only a few highly active authors: A multitude of authors interacted to collaboratively create an artifact that mirrored the events as they unfolded. Most of them had no formal education in the respective domains, and the few who had were not very active. So it was not the expertise or knowledge of some domain experts that made such a high-level article possible. Instead, the social system with its norms led "normal" laypeople to write an article of such extraordinary quality in a collaborative effort.

Urkost Forum

Knowledge development and "social constructions of reality" (Berger & Luckmann, 1966) can be guided by norms which come into operation through rules which are very different from those we see in Wikipedia. These norms may reflect more extreme ideologies and world views. For illustration purposes, we will present some results obtained in our study of the Urkost forum as one example of a platform with such norms and rules (Kimmerle et al., 2013). Although the forum's main focus was on the Urkost approach to nutrition, the forum's content also extended to other topics related to lifestyle and health (e.g., speculations about HIV/AIDS). In our analysis of the forum, we included all posts that had been written by users from July 2008 to March 2011.

We found that active participation within the forum was only allowed for registered users, and crucially, registration was performed not automatically but through personal introduction to the administrator via email. In this way, the administrator already had the means to sift out any potential dissidents who might not be followers of the Urkost diet. Within the forum, active members typically answered questions and pointed out what was correct and incorrect in the Urkost sense. The underlying premise was the unquestionable acceptance of the Urkost principles as the one and only “correct” approach to nutrition and health. The distinctions between “correct” and “incorrect” and between Urkost consistency and inconsistency seemed to be essential for the communication dynamics within this Web forum. However, in contrast to Wikipedia, it was not a large mass of users but only a few active contributors that were involved in a majority of the circular dynamics within the forum. This was especially true for the administrator of the Web forum. She had taken on the role of a guru within the community, made decisions about the admission of new forum members, rebuked deviant users for their “incorrect” views, and often had the last word in cases of doubt about consistency with Urkost principles. For example, one user wrote to this moderator: “You were right, once again … so far you have been right in the end in all discussions” (March 26, 2010, 01:41 PM; see Kimmerle et al., 2013, p. 1085).

A balanced debate about the Urkost principles was not the aim of the forum. Rather, the goals seemed to be to differentiate between information that was consistent or inconsistent with the Urkost principles. The purpose was to devalue inconsistent information and bolster consistent views, to defend the Urkost lifestyle, to support one another, and to attract and persuade new members. The Urkost forum thus appeared also to be very important to the social identity of the Urkost followers. Specifically, users differentiated between their positively valued ingroup and the negatively valued outgroup of “Schlechtkost eaters,” which included any person who did not follow Urkost.[3] Moreover, conventional medicine was only accepted with a kind of “fundamentalist eclecticism” (anecdotal knowledge was indiscriminately mixed with scientific findings; see Kimmerle et al., 2013, p. 1086). Information consistent with Urkost was accepted (e.g., particular medical diagnoses), but medical information in contradiction with Urkost principles (e.g., medical treatment recommendations) was ignored or marginalized. For example, one user wrote about conventional medicine: “Whoever cures is right! And somebody has to prove to me that physicians have ever cured anything with their conventional medicine!” (June 10, 2010, 05:11 PM; see Kimmerle et al., 2013, p. 1085). Another one wrote: “The majority still believes in the lies of science and does not make any effort to question them” (June 13, 2010, 08:13 AM; see Kimmerle et al., 2013, p. 1086).

At the same time, critical questions and skepticism were not accepted in the forum. For example, one user wrote about a deviant member who had had a dispute with the moderator: “She really hasn’t understood anything. Moreover, she lets herself be influenced by propaganda against the Urkost forum and against you [the moderator], instead of thinking for herself” (June 16, 2010, 10:54 AM; see Kimmerle et al., 2013, p. 1084). This pressure for conformity, the overarching aim of defending the Urkost principles, the refusal of critical discussions, the high value of personal experiences, and the social construction of perceived reality seemed to prevent knowledge construction processes akin to those that we had observed in Wikipedia. During our period of observation, the Urkost forum cleaned itself of any information inconsistent with Urkost, devalued such information, and simultaneously

---

[3] “Schlechtkost” is also a made-up German word and can be translated as “bad food.”

allowed border crossing only of information that was in line with the Urkost principles through selection. The social system protected itself from irritations and incongruities by rejecting and depreciating such input or by reinterpreting such information. From a scientific point of view, the results of such processes can be seen as extremely problematic, as is shown in a post in the forum that was in accordance with some views of Konz (1999): "[…] AIDS is not a disease caused by a 'virus', and it is curable at any time" (July 17, 2010, 12:31 PM; see Kimmerle et al., 2013, p. 1086).

Both social systems, the Wikipedia community and the Urkost forum, are therefore fundamentally different with regard to their norms and the way in which they operate. But both represent systems of self-organization that perform circular processes: They both select which information is relevant and which is irrelevant, they both have their own ways to deal with incoming information, and they both develop new knowledge through accommodation and assimilation. The fact that we, as scientists, value the one community more highly than the other is merely due to our external views causing us to set our own individual standards. But from a systemic view, both are social systems that process information according to rules they set themselves.

Both examples illustrate that the circular dynamics determine how information is processed within a social system. In the long run, these circular processes will affect system-specific developments, which we call system drifts. It may be plausible to assume that in the long term, artifacts in Wikipedia become more and more objective and scientific, whereas the direction of developments of social systems like that of the Urkost forum will become increasingly one sided and ideological. Future longitudinal investigations are needed to determine whether there is any truth in these assumptions.

Identifying Coevolution and System Drifts in Wikipedia

In an attempt to identify system drifting processes in the field, we once again chose Wikipedia as the key source of a real-life wiki. Specifically, we identified the German-language article on schizophrenia and its "neighboring" articles (articles that are linked to the article on schizophrenia) as an example in which knowledge construction and system drifts could potentially be demonstrated. Schizophrenia is a complex mental disorder, and there has been an ongoing scientific debate about its causes. Three originally distinct positions have been identified, which state that disease genesis is due to (a) genetic or biological factors, (b) a person's social environment and associated psychosocial factors, or (c) an expression of interplay between an inherent vulnerability to the condition and environmental stress. The third integrates the first two and is called the diathesis-stress model. Finally, there is also a (d) psychoanalytical approach to the cause of schizophrenia, which, however, is not strongly linked to the other three positions.

In contrast to the content analyses described for the Fukushima article and the Urkost forum, in this case, we took advantage of cluster analysis in order to investigate retrospectively any changes in the link structure of the Wikipedia articles relating to schizophrenia over time. In this way, we were able to treat drifting processes as a quantitative measure to provide empirical support for the model. Six different versions of the cluster structure of articles were extracted over the period between 2003 and 2008 (Kimmerle, Moskaliuk et al., 2010). Specifically, one cluster analysis was performed for each year of analysis. Our analyses focused both on the content of the articles and on the contributing authors. On the basis of the coevolution model, we expected to make the following observations: (a) Over time, the articles would become more complex and would also arrange in clusters according to viewpoints as to the causes of schizophrenia (biological/psychosocial/diathesis-stress/psychoanalytic), and (b) author participation would undergo a change that would parallel the change in the article content. Using social network analysis (SNA), we initially identified three distinct clusters representing the biological, psychosocial, and psychoanalytic approaches. These three points of view were indeed relatively distinct at the outset: Only a few connections existed among articles corresponding to the respective camps, meaning that the respective articles were linked by very few cross-references. Over time, this picture underwent a change: The articles corresponding to biological and psychosocial approaches appeared to converge and finally merged into a single common cluster, providing an integrated approach as posited by the diathesis-stress model. Contextual connections among previously distinct articles, many of which had often been empty pages (so called red links) at the start of our observation, appeared to develop concurrently even within the relatively brief follow-up period of 5 years. The psychoanalytical cluster was the only one to remain separate throughout the entire observation period.

We additionally tracked the authors' activities in other Wikipedia articles during our period of observation and categorized their articles according to whether they were concerned with topics purely of biology, psychology, or psychoanalysis or whether they were concerned with the integration of biology and psychology (like the diatheses stress model). We observed that contributors who were initially active in the biologically or psychologically "pure" camps tended to shift toward activity in articles which integrated both topics, whereas those who were active in psychoanalytic articles continued to focus their activity on that sole subject even 5 years later. Importantly, author shifting appeared to be largely unidirectional: Once authors had shifted toward the integrative view, they tended not to contribute any longer to any of the more polarized articles. Thus, people's work in the articles linked to schizophrenia shaped their further activities and led them either to a perspective integrating biology and psychology or reinforced them in their psychoanalytical beliefs. Assuming that an integrative view represents an example of a "more successful" knowledge construction than polarized views, our analysis therefore offered a demonstration of successful coevolution of users and artifacts as it occurs through mutual stimulation and structural coupling in the real world.

Incongruity as Trigger of Border Crossing: Evidence from Laboratory Studies in a Simulated Mass Collaboration Scenario

The aforementioned analyses of Wikipedia and the Urkost forum provided useful insights into the processes involved in knowledge construction on the basis of the resulting artifacts alone. However, with their focus on the artifacts, they did not allow systematic investigation of circular dynamics, border crossing, and system drifting particularly of the cognitive systems of users. For this reason, we supplemented our research with experimental investigations of coevolution in the laboratory to study these processes and cognitive changes within individuals.

In two complementary studies, we used bogus wiki texts designed to mirror the real platform of Wikipedia as artifacts with which to study coevolution processes in the laboratory. These wikis once again dealt with the topic of schizophrenia. The topic is generally perceived by student participants to be interesting, while at the same time, prior knowledge tends to be relatively low in this sample group. We used the debate on the causes of schizophrenia to systematically create situations in which cognitive systems, that is, the individual participants, had knowledge that was incongruent to the social system, that is, the content of the wiki. In Study 1, we manipulated the content included in a wiki with prior knowledge of participants held constant; in Study 2, we manipulated their prior knowledge with the wiki held constant.

In the first study (Moskaliuk, Kimmerle, & Cress, 2009), participants were invited to the laboratory and exposed to bogus wikis of varying quality in a between-subjects experimental design: The wiki either (a) included information on all three positions on the causes of schizophrenia, (b) contained only "biological" or only "psychosocial" arguments, or (c) was free of any concepts related to the causes of schizophrenia. Prior knowledge was held constant by providing the same information to the participants in all three conditions: All participants received a total of ten newsletters that were introduced to them as "info alerts" during the experiment and that contained one item of information on the causes of schizophrenia each. In combination with the newsletters, the three conditions therefore reflected "low incongruity" (identical information in the existing wiki text and in the newsletters), "medium incongruity" (information in the wiki restricted to either all biological or all psychosocial arguments in the newsletters), and "high incongruity" (no overlap in information between the existing wiki and arguments in newsletters). Task instructions specified that participants should proceed with writing the wiki. Outcome measures that were used to quantify external assimilation or accommodation were the number of words that were added to the wiki (assimilative knowledge construction) or the extent to which information stemming from the two camps (biological vs. psychosocial causes) was integrated into the wiki by participants (accommodative knowledge construction). Post-experimental factual and conceptual knowledge were measured to tap the cognitive systems of the users and to identify any border crossing that had resulted in learning. In this study, we were able to demonstrate correlations between learning of factual and of conceptual knowledge by participants and both assimilative and accommodative knowledge construction in the wiki. We found that medium incongruity facilitated external accommodative (though not assimilative) knowledge construction as well as individual learning.

The second study had an analogous but mirrored design: This time we held the information provided by the wiki constant and manipulated participants' level of knowledge of schizophrenia (Kimmerle, Moskaliuk, & Cress, 2011). Student participants without detailed prior knowledge of the topic were again assigned to low incongruity, medium incongruity, or high incongruity conditions. In this case, incongruity was defined by the disparity between their individual level of knowledge (which was manipulated) and the information that was presented in the wiki (which was held constant). Outcome measures were identical to Study 1. Again, external accommodative knowledge construction was most apparent in the group of participants who had been exposed to medium levels of incongruity, with evidence of accommodation equally low in the low and in the high incongruity condition. Conceptual learning tended to also be highest for participants in the medium incongruity condition.

Taken together, these studies represent fine examples of coevolution in the controlled environment of a laboratory and thereby provide empirical support for the coevolution model. The level of (in)congruity was identified to be an influential factor for both individual learning and collaborative knowledge construction. We assume that medium level of incongruity initiates higher levels of cognitive conflict in the user, which in turn facilitates the integration of the new information into existing cognitive structures, while allowing active resolution of any controversies that arise. In contrast, such integrative processes may be cognitively too demanding in conditions of high incongruity, and they may be irrelevant in cases where there is no incongruity at all. As we will revisit below, this portion of our findings may be of particular relevance to the future design of artifacts in formal educational settings.

The Educational Perspective: How Education Could Make Use of Social Systems

From the case studies described above, it becomes clear that the products of mass collaboration align on a spectrum. They may be present in relatively maladaptive border-crossing processes and system drifts toward biased views and highly selected knowledge (e.g., the Urkost forum), or they may result in processes that lead to a fast and efficient construction of shared and scientifically valuable knowledge that is built up even with a lack of specialization in the contributors (e.g., the Fukushima article in Wikipedia). How, then, can we use the example of successful mass collaboration to help guide knowledge construction in the formal educational settings of the future (Casey 2013)? How can we foster fruitful collaboration both in terms of productive knowledge advancement and balanced opinion formation in the classroom?

We believe that our studies have offered preliminary answers to these pressing questions. Although they have so far been limited to informal learning contexts involving (presumably) mainly adult users of online knowledge platforms, the systemic approach may be relevant for formal education of school students as well. First of all, this approach states that a school class shows defining features of a social system, as it is autopoietic and self-organizing. It then stresses that the circular processes which occur in a social system, including a school class, determine the activities of the individuals. In a social system, people's behavior is shaped by the rules and norms of that system. This guides our attention primarily not to processes of teaching and instruction but to social processes that occur in a community or class. Strictly speaking, any forms of instruction including learning targets, grades, and curricula that are communicated by the teacher are no more than irritants to the social system and its individuals according to our approach. The influence of instruction on individual learning may perhaps be smaller than the effects of classmates and social rules or procedures, that is, the circular dynamics of the social system.

Instead of considering teaching and instruction as the main stimulus for learning, the systemic approach would stress the relevance of an "ecosystem of learning." This term aims to reflect that a learner is embedded in an entire ecosystem that consists of classmates, teachers, instruction, tools, content, rules, and so on. Such an ecosystem of learning may provide more or less appropriate conditions and stimulation for knowledge construction and learning, depending on the circular processes within this environment. Which rules determine students' interactions? What shapes their communication? Are processes occurring in the classroom more similar to the examples that we have seen in Wikipedia or to those that we have identified in the Urkost forum? In school classes, a teacher may attempt to induce circular dynamics that are similar to those of Wikipedia (with regard to the evaluation of neutrality and objectivity of information), but outside the school, the students may have their own rules and norms among their peers. They may have other ways of evaluating information that are quite different from and may even interfere with those being taught in school.

As a social system is autopoietic and self-organized, its processes cannot just be *induced* by anybody, including a teacher. A system simply operates and continuously actualizes itself. The fact that students are embedded into a social system that influences their development in the way that we have shown in our coevolution model could provide a teacher with a good opportunity to make use of an already existing social system with already developed circular processes that support and enhance learning. In that scenario, it would not be "instruction" that attempts to influence students. Instead, pupils would become part of a social system that naturally influences their activities and way of thinking. In the Web, some of such ecosystems of learning already exist. They allow the combination of formal and informal learning and, crucially, focus on learning as a social process. Examples of ecosystems of learning include collaborative platforms such as *Scratch*, online makerspaces, and citizen science projects. They are each described in other chapters of the book at hand, so we will present them only briefly here.

The online platform Scratch (http://scratch.mit.edu; chapter "Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community" by Fields, Kafai, & Giang, 2016; and chapter "Supporting Diverse and Creative Collaboration in the Scratch Online Community" by Roque, Rusk, & Resnick, 2016) supports a community of children and teens in programming their own games and multimedia applications. It allows publishing these online, taking advantage of other users' games and applications, and communicating with others about their work. It is made in a way that lets users build on each other's work, using and remixing parts of others' codes and playing other users' games. So very naturally, it provides an ecosystem where students work on each other's products and optimize them. Makerspaces, described in detail in chapter "Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future" in this book (Shapiro, 2016; see also Meehan, Gravel, & Shapiro, 2014), are real-life or online platforms that aim to facilitate multidisciplinary, collaborative, and creative exploration of ideas or products (Sheridan et al., 2014). In the informal learning environments of libraries and museums, for instance, makerspaces have long been appreciated as tools to facilitate the understanding of complex information (Sheridan et al., 2014). Makerspaces do not only provide spaces for activities and learning, but they also provide social environments where people share, use, and optimize products collaboratively. Finally, in citizen science programs, laypeople participate in science projects where they collect data, for example, or observe their environment during their everyday activities. The Birdwatch program based in the UK is a prime example of citizen science: As many as 500,000 people from the general population respond annually to an animal charity's call to monitor birdlife in their gardens (https://www.rspb.org.uk/birdwatch/). In this case, a collaborative and mutually beneficial relationship may develop between volunteers and researchers: Researchers receive data and the volunteers may become scientifically empowered along with increasing their level of scientific literacy (Price & Lee, 2013).

Online platforms such as Scratch and makerspaces, as well as citizen science programs, may be very useful in formal educational settings. To apply our coevolution model, each of these platforms represents a social system with unique rules and norms. When students participate, their intrinsic interest would motivate them to engage actively with one another and externalize knowledge while adhering to the common set of rules and norms that have been established in these systems. The respective social system would exert forces and implicitly shape the activities of its users. Thereby, the platforms provide an ideal basis for teaching professionals to work with, and some platforms have already been successfully applied to the classroom. For instance, the GLOBE program provides training to teaching professionals who wish to introduce a citizen science project into their classroom (Penuel & Means, 2004). Makerspaces, too, are increasingly used for formal educational purposes (Sheridan et al., 2014).

In all of these platforms, learning as the educational goal does not necessarily have to be confirmed by a teacher. Students' motivation may be self-directed and inherently intrinsic. Ultimately, interactive tasks on such platforms promote learning by focusing on the process rather than on the final, measurable result of acquired knowledge. The findings described in the respective chapters of this book have provided evidence that this type of active, participatory, and playful engagement is indeed successful in fostering learning. In the future, we hope to see students learn in interactive ecosystems of learning that take advantage of a range of educational tools and where they are appreciated both as individuals and as parts of a greater social system.

References

Berger, P. L., & Luckmann, T. (1966). *The social construction of reality: A treatise in the sociology of knowledge*. Garden City, NY: Anchor Books.

Bokhorst, F., Moskaliuk, J., & Cress, U. (2014). How patterns support computer-mediated exchange of knowledge-in-use. *Computers & Education, 71*, 153–164.

Casey, G. (2013). Social media in the classroom. *Journal of Educational Multimedia and Hypermedia, 22*, 5–24.

Cress, U., Barquero, B., Schwan, S., & Hesse, F. W. (2007). Improving quality and quantity of contributions: Two models for promoting knowledge exchange with shared databases. *Computers & Education, 49*, 423–440.

Cress, U., & Held, C. (2013). Harnessing collective knowledge inherent in tag clouds. *Journal of Computer-Assisted Learning, 29*, 235–247.

Cress, U., & Kimmerle, J. (2007). Guidelines and feedback in information-exchange: The impact of behavioral anchors and descriptive norms in a social dilemma. *Group Dynamics: Theory, Research, and Practice, 11*, 42–53.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer-Supported Collaborative Learning, 3*, 105–122.

Fields, D. A., Kafai, Y. B., & Giang, M. T. (2016). Coding by choice: A transitional analysis of social participation patterns and programming contributions in the online Scratch community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Kimmerle, J., Cress, U., & Held, C. (2010). The interplay between individual and collective knowledge: Technologies for organisational learning and knowledge building. *Knowledge Management in Research & Practice, 8*, 33–44.

Kimmerle, J., Moskaliuk, J., Cress, U., & Thiel, A. (2011a). A systems theoretical approach to online knowledge building. *AI & Society: Journal of Knowledge, Culture and Communication, 26*, 49–60.

Kimmerle, J., Moskaliuk, J., Harrer, A., & Cress, U. (2010). Visualizing co-evolution of individual and collective knowledge. *Information, Communication and Society, 13*, 1099–1121.

Kimmerle, J., Moskaliuk, J., Oeberst, A., & Cress, U. (2015). Learning and collective knowledge construction with social media: A process-oriented perspective. *Educational Psychologist, 50*, 120–137.

Kimmerle, J., Moskaliuk, J., & Cress, U. (2011). Using wikis for learning and knowledge building: Results of an experimental study. *Educational Technology & Society, 14*, 138–148.

Kimmerle, J., Thiel, A., Gerbing, K.-K., Bientzle, M., Halatchliyski, I., & Cress, U. (2013). Knowledge construction in an outsider community: Extending the communities of practice concept. *Computers in Human Behavior, 29*, 1078–1090.

Konz, F. (1999). *Der große Gesundheitskonz*. Berlin, Germany: Universitas.

Luhmann, N. (1995). *Social systems*. Stanford, CA: Stanford University Press.

Maturana, H. R., & Varela, F. J. (1987). *The tree of knowledge: The biological roots of human understanding*. Boston, MA: New Science Library/Shambhala.

Meehan, R.J., Gravel, B.E., & Shapiro, B. A. (2014). Card-sorting task to establish community values in designing makerspaces. Retrieved from http://fablearn.stanford.edu/2014/wp-content/uploads/fl2014_submission_55.pdf

Morgan, J. T., Mason, R. M., & Nahon, K. (2012). *Negotiating cultural values in social media: A case study from Wikipedia*. Maui, HI: 45th Hawaii International Conference on System Science (HICSS*)*

Moscovici, S., & Zavalloni, M. (1969). The group as a polarizer of attitudes. *Journal of Personality and Social Psychology, 12*, 125–135.

Moskaliuk, J., Kimmerle, J., & Cress, U. (2009). Wiki-supported learning and knowledge building: Effects of incongruity between knowledge and information. *Journal of Computer Assisted Learning, 25*, 549–561.

Oeberst, A., Halatchliyski, I., Kimmerle, J., & Cress, U. (2014). Knowledge construction in Wikipedia: A systemic-constructivist analysis. *Journal of the Learning Sciences, 23*, 149–176.

Penuel, W. R., & Means, B. (2004). Implementation variation and fidelity in an inquiry science program: Analysis of GLOBE data reporting patterns. *Journal of Research in Science Teaching, 41*, 294–315.

Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures*. New York, NY: Viking.

Price, C. A., & Lee, H.-S. (2013). Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. *Journal of Research in Science Teaching, 50*, 773–801.

Rheingold, H. (2002). *Smart mobs: The next social revolution*. Cambridge, MA: Basic Books.

Roque, R., Rusk, N., & Resnick, M. (2016). Supporting diverse and creative collaboration in the Scratch online community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Shapiro, R. B. (2016). Toward participatory discovery networks: A critique of current mass collaboration environments and a possible learning-rich future. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Sheridan, K. M., Rosenfeld Halverson, E., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*, 505–531.

Viegas, F. B.,Wattenberg, M., & Dave, K. (2004). Studying cooperation and conflict between authors with history flow visualizations. In *Proceedings of SIGCHI'04* (pp. 575–582). Vienna, Austria: ACM.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions

Aileen Oeberst, Joachim Kimmerle, and Ulrike Cress

Conceptualization of Knowledge in Psychology and Philosophy

Communication and coordination among large groups of people have become omnipresent and pervasive with the emergence of Web 2.0 environments. Such platforms are able to support collaboration in large networks of participants. This kind of *mass collaboration* allows for an enhanced connectivity among the people involved and provides them with the opportunity to come together as communities. Usually, mass collaboration comes along with the potential to establish digital knowledge bases and, accordingly, may result in openly accessible knowledge that can be shared by masses of people. In mass collaboration situations on such shared platforms, large groups of participants may interact from different places and at different points in time. But this type of knowledge exchange, knowledge acquisition, and knowledge construction clearly has a collective quality and can hardly be adequately addressed with a traditional view of knowledge as an individual phenomenon (Kimmerle, Moskaliuk, Oeberst, & Cress, 2015). Hence, mass collaboration and education challenge some old insights and concepts.

One direct challenge is to that very old question of fundamental theoretical value, namely, the question of what knowledge is in fact. A review of the literature of philosophy and psychology clearly shows that knowledge is predominantly conceptualized as individual property, that is, as information (of a special quality) that

A. Oeberst (✉) • J. Kimmerle • U. Cress
Leibniz-Institut für Wissensmedien, Knowledge Construction Lab, Tuebingen, Germany
e-mail: a.oeberst@iwm-tuebingen.de; j.kimmerle@iwm-tuebingen.de;
u.cress@iwm-tuebingen.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_6

is located in a person's mind or memory (see below). Such conceptualizations, however, reach their limit when it comes to processes on the collective level, such as in situations of collaboration or even mass collaboration. This dilemma has received little attention in recent scientific discourse. Novel forms of knowledge construction (e.g., in Wikipedia or on other online platforms that aim at developing knowledge) thus require novel conceptualizations of knowledge itself. The goal of the present chapter is therefore to provide insight into traditional and more recently proposed social conceptualizations of knowledge. To this end, we will first outline traditional (individual-focused) accounts of knowledge in philosophy and psychology and point out their limitations. Second, we will refer to more recent approaches that go beyond individual conceptualizations and deal with interindividual exchange and knowledge (social views of knowledge). Finally, we will shift from small-scale social interaction to the system level in order to address the phenomenon of mass collaboration. We will present various approaches of system-oriented epistemology and outline how knowledge is embedded in social systems and in effect shaped by them.

An Individualistic View of Knowledge

Individualistic View of Knowledge in Philosophy

Looking back on a long and prolific tradition, philosophy offers a considerable variety of approaches to defining knowledge. One of the most prominent and widespread definitions is the tripartite conception of knowledge as "justified true belief." That is, for a person to *know* a proposition (p), p must be true, the person must believe that p is the case, and his/her belief that p is the case must be justified. Consider, for instance, the proposition that the earth is a sphere. For a person to *know* this proposition, the proposition must be *true* (let's assume that), and he/she must believe that it is true. Moreover, he/she must have a good reason to believe that it is true. This is to ensure that he/she is not only accidentally convinced of a true proposition—which would not qualify as knowledge. Take an astronaut, for instance, who has actually seen the spherical earth rotate from outer space. One might argue that she or he is *justified* in believing that the earth is a sphere (we will return to this example and issues of truth and justification throughout this chapter).

The idea of this tripartite theory of knowledge dates back to Plato (see Gettier, 1963), and since then, all of its three conditions have been repeatedly challenged and are still the targets of ongoing debate (for a recent review, see Ichikawa & Steup, 2014). Nevertheless, the overwhelming majority of proposed conceptualizations of knowledge have two main points in common: First, they are concerned with the pursuit of *truth*, which may be understood as the correspondence to facts (David, 2013; please note, however, that there are numerous concepts of truth in philosophy). Second, they are *individualistic* in nature (Goldman & Blanchard, 2010; Kusch, 2002b). This becomes immediately evident from the very definition: To be able to speak of knowledge, it is one specific person for whom it is to be determined whether they believe that p is the case and are justified in doing so (see also Ayer, 1956 and Chisholm, 1957 as cited by Gettier, 1963). With regard to our example of the earth, this person was the astronaut. But of course, one could think of other individuals with or without justified true beliefs (see below). But it is precisely the fact that knowledge can only be a property of individuals that characterizes classical epistemological approaches. Knowledge in this context is by definition grounded in individuals (Goldman, 1987, 2010).[1]

With this as a starting point, most analyses of knowledge focus on the specific standards that must be met in order to be able to speak of knowledge. Particularly, there has been a lively discussion about the issue of justification. Given that justification distinguishes knowledge from mere belief, its conceptualization is crucial. To date, a number of different theories have been put forward (Matthiessen & Willaschek, 2009). Their focus is on the mental processes that may or may not be able to ensure knowledge. In this regard, some of the questions dealt with are whether sensory input (Russell, 1910) or intuition (Kant, 1778, quoted by Popper, 1968) may be a source of knowledge, whether the quality of the believer's evidence determines epistemic justification (*evidentialism*, Feldman & Conee, 1985), whether the justifying conditions need to be accessible by reflection (*internalism*, e.g., Pappas, 2009), whether a reliable mental process is needed in order to speak of knowledge (*reliabilism*, e.g., Goldman, 1979), or whether standards of justification are context dependent (e.g., Schiffer, 1996).

Consider again the spherical earth example. By suggesting that an astronaut who observed the rotating earth *knows* that the earth is a sphere, we have implicitly granted justification to this kind of sensory input. But one might ask, of course, whether visual perception indeed qualifies as justification, given that it is fallible (e.g., illusions) and constructed (e.g., guided by expectations; Bartlett, 1932), which does not apply, for instance, to mathematical proofs. Such are some of the questions dealt with in classic epistemology. Beyond this, some normative aspects are debated, such as whether the epistemic subjects themselves should be taken into account, for instance, in terms of whether they are fulfilling a duty in order to arrive at knowledge (*deontic/deontological concepts of epistemic justification*, Alston, 1988; Vahid, 1998) or in terms of which virtues guided their belief formation (such as elaborateness and objectivity, *virtue epistemology*, Greco & Turri, 2011).

This—only very broad and incomplete—list of some of the accounts of epistemic justification clearly illustrates focus on the individual they all share. It is about what a person can or must do in order to be able to *know*. What differs is only the specific mental process an individual engages in that is drawn upon or emphasized in each account. Hence, classic epistemology focuses on the question of how an *individual* arrives at justified true belief. This focus holds even if individual boundaries are exceeded, as in the case of knowledge transmission. Dealing with the

---

[1] It must be acknowledged, however, that the branch of mathematics has been granted a special role even in traditional epistemology. This is due to the fact that mathematical knowledge is generated by stringent and complete proof. Such knowledge has therefore been proposed to be "a priori" (e.g., Peressini, 2008; Womack, 1993). As such, it may be regarded to be independent of any individuals recognizing it. This particular concept is closely linked to Popper's third world (see below).

question of how knowledge is transferred from one person to another, again the discussion centers around which epistemic standards need to be met in order to speak of knowledge in the receiver. Hence, in addition to the fact that a speaker must be justified in believing a true proposition, a hearer needs to be justified in believing that the speaker is justified in believing that proposition (for an overview, see Adler, 2010). In the context of our example, we could imagine that the astronaut tells others about his/her observation. A hearer—in this regard—would only be granted *knowledge* of the earth being a sphere if he/she had good reason to believe that the astronaut is justified in his/her belief that the earth is a sphere. One might further think that such a good reason was provided if the hearer knew that the speaker was indeed an astronaut and had actually been in space and thus was able to make this observation. But the fact that, again, the same requirements must be met for the question of whether the hearer *knows* the speaker to be an astronaut makes it obvious that knowledge—in the classic epistemological sense—is not easily gained. Nonetheless, although other people may enter the stage as potential sources of knowledge, the essence of the discussion is still whether some specific *individual* can acquire knowledge (see Kusch, 2002a for an exception).

Some difficulties that arise from these conceptualizations with focus on the individual are of crucial importance when considering mass collaboration and education. First, advancement in knowledge is difficult to explain in terms of a conception that localizes knowledge solely within individuals (see Popper, 1968). Second, knowledge that results from collaborative work distributed among several people would be difficult to understand, as the requirement for individual justification might not be met for each person involved. This becomes most evident in the realm of science, where collaboration is widespread. When a research project is based on the expertise of very different contributors, the knowledge resulting from the project can hardly be attributed to only one person (Hardwig, 1985). We will return to this issue below.

Individualistic View of Knowledge in Psychology

The search for a psychological definition of knowledge is a remarkably difficult task. Despite the fact that the very core of educational psychology is the *acquisition* of knowledge (i.e., learning), and despite the fact that one of the main research areas of cognitive psychology is how knowledge is represented, both educational and cognitive psychology (and the other areas in psychology alike) mostly remain silent about a definition of knowledge itself. Encyclopedias of the cognitive sciences (e.g., Wilson & Keil, 1999) as well as of research in education (e.g., Alkin, 1992) lack entries on knowledge itself, but they do offer elaborate remarks on knowledge acquisition, comprehension, and representation. These, however, do not start from a definition, either. In the same vein, Mandl and Spada (1988)—who argue for a "psychology of knowledge"—only rather casually comment on their concept of knowledge by mentioning that they not only include "static factual knowledge" but also "algorithmic capabilities, heuristic knowledge etc." (p. 2, translated by the authors). Despite the fact that a precise definition is missing, their statement makes clear that their understanding differs remarkably from the view most philosophers advance, because neither truth nor justification seem to play a role. This also applies to those cases where explicit concepts of knowledge are put forward. Bar-Tal and Kruglanski (1988), for instance, define knowledge as "the totality of a person's *beliefs* on various topics" (p. 6, italics added by the authors). This definition represents an explicit deviation from the philosophical stance: Knowledge is defined as belief. Sperling and Schmidt (2009), on the other hand, denote knowledge as "organized *information* that is saved (represented) in memory" (p. 74, translated and italics added by the authors). This definition explains the close association to learning and memory and the partly interchangeable use of the respective concepts (e.g., Gruber, 2011).

Interestingly, however, vaguely the concept of knowledge itself is treated in psychology; one can easily find several distinctions regarding what kind of knowledge is stored and how accessible it is (e.g., Tulving, 1985a, 1987). Psychologists differentiate, for instance, between the representation of factual world knowledge (*semantic memory*), knowledge about experienced events (*episodic memory*), and knowledge about how something has to be done (*procedural memory*). Hence, knowledge about the earth being a sphere, about one's own graduation, or about how to ride a bike would fall into different categories. Likewise, psychologists often differentiate between knowledge that is consciously accessible (*explicit memory*) and knowledge that is not consciously retrievable (*implicit memory*, Dienes & Perner, 1999). Particularly, this distinction makes the differences between psychology and philosophy obvious. From a philosophical perspective as described above, something like implicit knowledge would be a contradiction in itself. Psychology, on the other hand, rarely explicitly elaborates on what qualifies knowledge. This is not to say, however, that psychology completely ignores the concepts of truth or justification.

Take truth, for instance. Hardly any researcher would credit someone who states that the earth is flat with knowledge. Likewise, in many areas of psychological research, the distinction between correct and incorrect representations is certainly made. In the overwhelming majority of learning and memory research, it is of central concern whether a person has learned and represented something correctly (e.g., from predetermined materials, Ballard, 1913; Bartlett, 1932; Ebbinghaus, 1885/1964; Erdelyi, 2010). Also, a substantial number of studies explicitly address *deviations from truth*. Much research on *biases* in information processing (e.g., Gilovich, Griffin, & Kahnemann, 2002; Pohl, 2004), *misconceptions* (e.g., Caramazza, McCloskey, & Green, 1981; Griffith & Preston, 1992; Oeberst, 2012), *heuristics* (e.g., Gigerenzer, 2004), or *false memories* (e.g., Steffens & Mecklenbräuker, 2007) falls into this category. Common for all this research is that what is considered truth is determined by the experimenter, by the to-be-remembered material, or by logical standards (e.g., for heuristics). Specifically, researchers compare participants' responses either to what is regarded as unquestionable knowledge (e.g., the earth being a sphere) or compare it to the information that was presented to the participant within the study (e.g., learning material or whatever has been witnessed). Hence, truth is predetermined in such settings. The goal of this research, however, is often to identify certain determinants and indicators of truth (e.g., memory accuracy) which might provide guidance for assessing the validity of recollections where no objective comparison can be made (e.g., in forensic settings; Steck et al., 2010). This is particularly important, since numerous studies show that subjectively perceived truth (e.g., the conviction an individual has that something remembered was indeed presented) is highly malleable and fallible (e.g., Higgins & Rholes, 1978; Lindner, Echterhoff, Davidson, & Brand, 2010; Reber & Unckelbach, 2010; Shaw & Porter, 2015; Sporer, Penrod, Read, & Cutler, 1995).

Much less research in the realm of psychology is found for conceptualizations corresponding to justification. This is not surprising given that justification does not constitute a necessary precondition of knowledge. There are, however, studies that investigated the basis of participants' claims. Various measures have been taken, for instance, to identify the extent to which guessing contributes to correct answers (e.g., Fiedler, Russer, & Gramm, 1993; Oeberst & Blank, 2012; Schroeder, Richter, & Hoever, 2008). Taking it one step further, some researchers distinguish whether a person can explicitly remember having had some experience or merely knows by "feel" that this experience has taken place (Dunn, 2004; Gardiner, 1988; Tulving, 1985b, 1989). Relatedly, research in the formation of opinions investigates whether people base their belief in a proposition on thorough elaboration (e.g., Petty & Cacioppo, 1986) and "epistemic validation" through other sources (e.g., Maier & Richter, 2014; Richter, 2003) or whether they are instead persuaded by superficial aspects such as attractiveness of the communicator. Hence, issues that implicitly relate to the philosophical concept of justification are sporadically found in psychology as well. But again, these side issues dealing with the basis for an individual's claims remain unrelated to a more encompassing elaboration regarding what knowledge is.

Taken together, one might summarize that reference to philosophical epistemological considerations about truth and justification is rare in psychology (see Dienes & Perner, 1999, for an exception). It seems that researchers in psychology prefer to circumvent any debate about knowledge and its possibly qualifying status and use concepts such as *information* and *cognition*, instead. And what is counted as knowledge in psychology might be termed *information* or *belief accumulation* from a philosophical stance. Whatever we may name it, however, it must be stressed again that it was traditionally viewed and investigated as a feature of individuals.

A Social View of Knowledge

A Social View of Knowledge in Psychology

In the 1990s, some approaches were put forward in social and organizational psychology that explicitly challenged the individual perspective and extended it to social processes. This includes research about socially shared cognition (Resnick, Levine, & Teasley, 1991; Thompson & Fine, 1999), groups as information processors (Hinsz, Tindale, & Vollrath, 1997), groups as problem-solving units (Kerr, MacCoun, & Kramer, 1996; Larson & Christensen, 1993), distributed cognition (Giere & Moffatt, 2003; Salomon, 1993), shared mental representations and schemata (Hinsz et al., 1997; Moussavi & Evans, 1993), team mental models (Klimoski & Mohammed, 1994), joint complementary memory systems (e.g., transactive memory; Wegner, Erber, & Raymond, 1991), and collective memory (Hirst & Manier, 2008). These approaches apply relevant cognitive concepts to groups as a whole and their information processing. Similar to the more individual approaches, all these social psychological approaches consider neither truth nor any kind of justification. In sum, they aim to overcome the exclusively individual perspective that is typical for a traditional psychological approach, but they likewise refrain from any elaboration on a precise definition of knowledge.

A Social View of Knowledge in Philosophy

One of the first attempts to overcome the individualistic view on knowledge in epistemology was made by Popper (1968). He criticized that classic epistemology can hardly contribute to understanding scientific knowledge (see also Popper, 1978) and argued that the traditional focus on knowledge in the subjective sense needs to be extended by the notion of knowledge in the objective sense. He distinguished between thought *processes*, which are bound to specific individuals, and thought *contents*, which are independent of individuals (as the same thought may come to various people's minds). Although thought contents certainly result from thought processes (also Scardamalia & Bereiter, 2010; but see Klemke, 1979 for a more radical conceptualization), Popper broke with the idea that knowledge is dependent on someone's claim to know (see also Footnote 1). Rather, once a thought is verbalized, it is the potential of being understood that matters more in Popper's proposal. Moreover, he stressed that only by making thought contents explicit can they be criticized intersubjectively and thereby lead to growth in (objective) knowledge. Since traditional approaches are restricted to individual knowledge, they cannot contribute to this line of thought. Popper (1968), instead, proposed that growth of knowledge is the very core concept in an epistemology that takes an objectivist view. Therefore, he introduced a general schema of growth of knowledge.

This process starts from a first problem, which leads to a tentative solution or tentative theory, which is then subject to error elimination, through theoretical discussions or empirical investigations. In the course of this error-elimination process, new problems arise. Thus, knowledge growth basically results from the elimination of errors. Hence, it is not undefeatable truth that is to be expected from this process. Popper questioned the existence of such truth and thus challenged one of the core aspects of the philosophical definition of knowledge. He expected instead an increasing approximation of what corresponds best to the facts, as a result of the process of error elimination (see also Wood & Nezworski, 2005 for the notion of science as a history of corrected mistakes). Thus, within this process, some ideas may fail to withstand critical discussion, and some theories may be empirically proven to be false. At the same time, however, other solutions and new ideas will emerge. What is expected to survive then are—in analogy to Darwinian selection—the best (tentative) theories.

Although this conceptualization does not exclude the possibility of single subject inquiries, Popper (1970) argued that progress and growth of knowledge requires exchange among researchers. For the vast majority of problems in science, indeed, more than one person is usually involved. This becomes immediately evident if one considers that involvement starts with the reference to others' opinions and the reliance on others' justified beliefs. Contrary to the traditional view that promotes the idea of arriving at direct knowledge by thinking for oneself, Hardwig (1985) argued that it may be much more rational to accept such *epistemic dependence*. Hence, not only individual mental processes such as perception, reasoning, and introspection but also other people may be seen as a source of knowledge or justification. This notion introduces a social aspect, which has long been neglected in traditional epistemology (Goldman, 2010). Accordingly, the question arises as to how knowledge is transmitted (which also refers again to the astronaut example). One possibility is through the statements from other people one hears or reads (i.e., testimony, Adler, 2010). The main challenge in terms of philosophical considerations that emerges in this case lies with the issue of justification, because the hearer's justification for the belief that *p* is true (i.e., the content of the testimony) is dependent upon the speaker's justification for believing that *p* is true (Lehrer, 1987). Moreover, the hearer must be justified in believing the person who testifies. This may be least questionable in the case of experts. If the speaker is an intellectual authority, it follows that the hearer will believe that the speaker has good reasons to believe some proposition (Hardwig, 1985). Experts' knowledge, however, relies on others' findings and thoughts as well, as concisely pointed out by Hardwig (1985). Hence, even those people we expect to be the most knowledgeable are actually epistemically highly dependent, thereby revealing that justification is frequently linked in chainlike fashion to other people and their findings, rather than being independently and individually derived.

But again, Hardwig (1985) argues that accepting such epistemic dependence may be more rational than trying to replicate all results for oneself in order to arrive at direct and independent knowledge. If such epistemic dependence is accepted, the field becomes open for other sources as well, thereby providing the opportunity to expand beyond the individual focus. In line with this reasoning, Lehrer (1987) argued for taking groups as a source of knowledge into account as well, given that groups "contain more information" (p. 93). In the same vein, Kitcher (1990) stated that cognitive diversity is beneficial for progress. Thus, for growth of knowledge, it is optimal that more than one person is involved and, at best, that these people differ substantially from one another in terms of background, skills, and ideas.

As mentioned before, classic standards of justification are inapplicable for cases like these. This does not mean, however, that the idea of justification must be abandoned completely. Instead, two implicit premises should be questioned: First, there may not be only one correct answer to the question of what justifies a belief (Boghossian, 2006). Critics contend that there is no objectively correct set of norms that is universally valid. Rather, they suggest the existence of "local" norms that vary across cultures or communities (Goldman & Blanchard, 2010). Second, the premise of a dichotomy in epistemic valuation (justified vs. not justified) may not hold. It could be beneficial not only to consider whether certain standards of knowledge are met or not but also to distinguish among a variety of different states that are considered valuable from an epistemic standpoint (e.g., having true beliefs, having justified beliefs, having rational beliefs, having knowledge, Goldman, 2010). This becomes obvious if one considers in how many instances science gathers *support* for one or the other hypothesis, yet lacks *unquestionable evidence* for its truth (Greenwald, 1975; Lakatos, 1970; Vicente & Brewer, 1993). Hence, even in the most professional enterprise of knowledge construction, researchers deal much more with justified beliefs than with knowledge. Nevertheless, by *aiming* to determine how knowledge is constructed, we might be likely to come closer to knowledge, even if our best tentative theory is only an approximation and probably not the final answer.

The social aspect of knowledge is stressed particularly in *social epistemology* (Goldman & Blanchard, 2010), which not only takes social exchange into account but also acknowledges that individuals receive the overwhelming majority of their information from other people. But how can a belief be justified under such complex circumstances? We will outline briefly two accounts that deal with this question: Lehrer (1987), on the one hand, proposed a coherence-based theory of knowledge. The basic idea is that incoming information is evaluated in terms of background information. This may be applied to personal knowledge (of individuals) as well as to social knowledge (of groups), which is more relevant for the present purpose. Lehrer (1987) introduces the idea of *consensual justification*. According to this, “a group is consensually justified in accepting that *p* is true if and only if *p* coheres with what is consensually accepted” (p. 90). Truth, in this respect, is not simply abandoned, but the notion of dichotomy is replaced by the concept of probability—a sufficiently high probability of the truth of a proposition must be assigned. Thus, according to this view, the evaluation of new information is determined by its relationship to previously existing information. Nevertheless, the idea of some kind of social consensus is already implied here.

Faulkner (2006) took a similar line and developed the notion of *social warrant*. Consider the case that a belief has been previously justified in science but then is discovered to be false in the progress of research. If not made public, such revision may go unnoticed. But Faulkner referred to the case that even though the novel findings are published widely, a subject *S* fails to take notice of this recent development. Although *S*’s knowledge then may be objectively and subjectively warranted, as the previous belief had been justified and *S* does not hold any contradicting justified beliefs, *S should* not continue believing, since it has been *socially recognized* that contradictory evidence is available. The crucial point is that no individual is capable of establishing whether a belief is socially warranted. Rather, it requires a community to determine the absence of such *normative defeaters*. In another line of reasoning, Faulkner (2006) made justification *essentially social*. In proposing this, he referred to Hardwig (1985), who analyzed collaboration and who based his argument on a scientific publication with 99 authors. Hardwig wondered in this extraordinary case to whom we would attribute knowledge. Given that different authors probably contributed their domain-specific knowledge, none of them would be individually justified in claiming to have knowledge according to classic epistemological standards, because each person's knowledge would in some way depend on their collaborators' knowledge. Following from this, Hardwig (1985) proposed the notion that not individuals but groups may actually be the bearers of knowledge. Faulkner (2006) added that it might be the very premise that knowledge is in the mind of individuals which is problematic.

Taken together, the arguments outlined above clearly demonstrate the limits of the definition of knowledge proposed by classic (individualistic) epistemology. As precise and straightforward as the traditional accounts may be, they cover only a very small subset of instances (propositions and persons). Also, they fall short of taking into account the epistemic dependency and social construction of expert knowledge, not to mention their inapplicability for collaborative creation of knowledge or growth in of knowledge in general. Thus, precision comes at a price. But so does the extension of the individual perspective. All of the accounts outlined have weakened either the truth claim or the standards for accepting justification. Note, however, that the notions of truth and justifications have rarely been rejected entirely. By allowing more latitude for truth and justification, however, it has been possible to cover a much broader range of phenomena.

At this point, another branch of philosophy needs to be recognized, one that emerged from traditional epistemology but soon acknowledged the social nature of human knowledge—the philosophy of science. Here, scientists such as Thomas Kuhn (1962) and Hilary Putnam (1975, just to mention two) stressed the importance and influence of social aspects on knowledge (construction). In his famous book about scientific revolutions, for instance, Kuhn (1962) emphasized that scientific knowledge always results from a research *community*. Moreover, he stated that every research community is characterized by a similar education and a shared scientific practice (e.g., theories referred to, methods used), which, in turn, affects what this scientific community can find out. Hence, scientific knowledge construction depends fundamentally on social practice.

In a similar vein, Fleck (1935) had pointed out that researchers are always embedded in a "thought collective," which is characterized by a particular "thought style." In Fleck's view, it is this shared thought style that determines what is accepted as a scientific problem, an appropriate method, and a conclusive judgment and—ultimately—as truth. Consequently, scientists as well as their research and their findings are fundamentally affected by a scientific community. In other words, they are essentially socially constructed. In the following, we will pursue this line of thought and present system-oriented approaches to knowledge.

A Systemic View of Knowledge

Beyond his social epistemology (Goldman & Blanchard, 2010) that was described above, Goldman (2010) proposed a system-oriented epistemology. There, he considered groups as epistemic agents and elaborated on *collective agents* (group of individuals, whose individual judgments are aggregated) and *social systems*. For the present purpose, we will focus on epistemic systems. According to Goldman (2010), an epistemic system is "a social[2] system that houses a variety of procedures, institutions, and patterns of interpersonal influence that affect the epistemic outcomes of its members" (p. 2). And it is precisely the impact these have on epistemic outcomes which Goldman views as the subject of investigation in system-oriented epistemology. Epistemic outcomes in his view can be (1) having true beliefs, (2) avoiding errors, (3) having justified beliefs, (4) having rational beliefs, and (5) having knowledge. Hence, he avoids a knowledge-no knowledge dichotomy and considers different epistemic states to be valuable. Nonetheless, it becomes clear that he takes a normative stance, as epistemic outcomes are valued differently. Moreover, he stresses that epistemic systems can thus be evaluated by the set of epistemic outcomes they foster or generate: Better outcomes merit higher epistemic evaluation of the system.

Goldman (2010) suggests that it is the central task of system epistemology to analyze and compare different systems with regard to their epistemic outcomes. For instance, he points to different legal systems (which also have the task to seek the truth in a trial), such as the common law system where judgment is passed by juries of laypersons and civil law systems that limit judgment to professionals. From the epistemic systems perspective, it would be of interest which of the two systems provides better epistemic outcomes that would be in this case fewer false verdicts. Likewise, one may take features of the science system (e.g., reward structure) and ask how these features affect the epistemic outcomes.

In a similar vein, Goldman (2010) emphasizes that harvesting "dispersed knowledge" can lead to better epistemic consequences than reliance on a small group of experts. With reference to the Internet, he acknowledges that mass collaboration may enable "democratic epistemic systems to reap significant epistemic bounty" (p. 13). Despite these considerations, he mainly focuses on the epistemic states of *individuals*. That is, he mainly pursues the epistemic outcomes of epistemic systems on individuals. Although he does acknowledge that epistemic systems may sometimes also affect collective agents, he does not further elaborate on this aspect. With regard to justification, however, he suggests that not only objective justification but also "local" justification according to the epistemic system should be taken into account. In other words, he suggests that a person is justified in believing that a certain proposition is true if it conforms to the "governing set of epistemic norms, norms that permit belief in light of the agent's evidential situation" (p.18). However, he would suggest labeling it "local justification," in contrast to "objective justification," if there is universally valid reason for believing that the proposition is true. As an illustrative example, Goldman (2010) refers to Galilei, who may have been objectively justified in stating that heavenly bodies move. Yet, within the context of the predominant epistemic system at that time, which was based on Scripture, he was locally unjustified, whereas the reversed pattern of justification was applied to his opponents. Hence, Goldman brings together two perspectives that have been

---

[2] An epistemic system is thus by definition a social system, not an individual system.

usually presented as irreconcilable views—an objectivist approach as well as a relativistic point of view. Moreover, his viewpoint enables a discussion of truth and justification (a) that takes epistemic systems into account, (b) that is partly independent of the individual in question, and (c) that provides a solution for the difficulties that arise with an objectivist conceptualization of truth and justification. What is still missing, however, is an elaborated account of knowledge *construction* in the context of mass collaboration within an epistemic system. After all, the focus of Goldman's system epistemology is by definition a focus on the effects that epistemic systems have on their members. It does not, however, address the very construction of the epistemic basis itself that might influence the members.

In the following, we will propose another systemic approach that focuses on that specific context. This systemic-constructivist approach is the basis for our coevolution model of individual learning and collaborative knowledge construction as it takes place in masses of people (Cress & Kimmerle, 2008; Kimmerle et al., 2015; Kimmerle, Gerbing, Cress, & Thiel, 2012; Oeberst, Halatchliyski, Kimmerle, & Cress, 2014). We present our coevolution model as applied to collective knowledge construction in more detail in chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" of this book (Cress, Feinkohl, Jirschitzka, & Kimmerle, 2016).

The systemic perspective, we propose in our work, fits within the tradition of constructivist theory. It radically breaks not only with the individual focus on knowledge but also with the concept of knowledge as *true* belief. It proposes that no system in general can ever truly capture reality. Even though systems process input from the outside, that is, from their environment, all processes in a system are self-referential and are therefore always strongly defined by the system itself (Maturana & Varela, 1987; von Foerster, 2003). Hence, in the case of knowledge, acceptance of the truth of a belief and its justification always count only within the context of the knowledge-related system from which it originates. Applying Goldman's (2010) distinction between local and objective justification, this means that from a constructivist point of view, we always and exclusively deal with local justifications of knowledge. The sociologist Niklas Luhmann adopted this constructivist perspective for his influential "social systems theory" (1984). This theory states that all systems are autopoietic: they permanently create and recreate themselves through their own operations. The mode of operation for social systems is communication: through communication, a social system constructs meaning about (i.e., makes sense of) its environment. It observes the environment, selects relevant information, and applies a so-called binary code to it, which makes an either-or decision. In the "science system," which is concerned with the creation of knowledge (Luhmann, 1990), this binary code regards truth, and thus it distinguishes itself from its environment by deciding whether or not a finding or a statement is true. But truth in Luhmann's terms is not meant in an objective sense. Luhmann (1990) abandons the existence of objective truth. Rather, truth is referred to in a systemic sense: The system is self-referential and thus defines what is accepted and what is rejected as being true within its boundaries (see Knorr-Cetina, 1981, for the notion of relative truth in science). Hence, again, truth judgments are based on "local" (i.e., system-bound) norms. The scientific system has developed quite elaborate methods for testing truth. These methods make sure that the system deals with all information in an adequate and reproducible manner and "objectively" decides what it accepts and what it rejects. But the system can only operate upon (i.e., apply its code to) what it perceives from the environment, and these perceptions are also selections made by the system itself. So a system can never sense the environment or reality directly. From a system's perspective, the environment is always contingent, chaotic, and infinitely complex (Luhmann, 1984). A system cannot entirely capture and deal with this complexity. Therefore, its perception of the environment is always selective. It can only observe that part of the environment which is already meaningful for the system. Hence, a knowledge-related system that processes input from its environment can only respond to that information in the environment which it considers potentially relevant. This means that a system is open to information from the environment but "operationally closed." It self-selects its own operations and thus behaves circularly (for a recent summary, see Kimmerle, Moskaliuk, Cress, & Thiel, 2011).

As a sociologist, Luhmann was mainly interested in social systems. But in his general systems theory (Luhmann, 1984), he also regards individuals as cognitive (or as he calls it, "psychic") systems. Such a cognitive system also strives for meaning. It operates by cognitive processes such as thinking, reasoning, and problem solving. As systems in general, a cognitive system is self-referential and operationally closed as well. It cannot experience the environment directly but is bound to its perception (which represents, again, an active process of selection). From the perspective of the individual, a social system belongs to the environment and vice versa. That is, for one system, another system is always contingent, chaotic, and infinitely complex. Moreover, due to its operational closeness, a system can never directly interact with another system. Two systems, however, can irritate each other and thus stimulate each other's development. Luhmann assumes that systems mainly develop when confronted with new and unexpected observations (i.e., irritations) from the environment. A system then has to deal with this irritation, and it does this in its typical manner: it applies its specific code to the unexpected event and tries to make meaning of it. Hence, a knowledge-related system that is confronted with a novel and unexpected observation has to decide whether or not the new observation or its explanation can be considered to be true. If so, this new knowledge modifies the system's expectations for future events. The integration of new knowledge then enhances the complexity of the system, but reduces the (perceived) complexity of the environment. This means that the system now has more concrete expectations about the environment, which—from the system's perspective—makes the environment less unpredictable. Cognitive systems can be irritated by their environment and deal with a novel and unexpected stimulus by thinking about it and making sense of it. Likewise, a social system can be irritated by another system that stimulates its development and leads to higher complexity. Thus, cognitive and social systems may never directly interact. But they can build expectations about each other, and if they do so—over some time—they can mutually irritate each other in some way. As a consequence, both systems coevolve and develop higher complexity. This kind of mutual irritation of two systems is called *structural coupling* (Luhmann, 1984).

Combining Luhmann's theory with concepts of Vygotsky (1978) and Piaget (1977), Cress and colleagues presented the coevolution model of learning and collective knowledge construction (Cress & Kimmerle, 2008; Kimmerle, Cress, & Held, 2010; Kimmerle et al., 2011; Kimmerle, Moskaliuk, Harrer, & Cress, 2010; Moskaliuk, Kimmerle, & Cress, 2009). The model describes individual learning and collaborative knowledge creation as structural coupling between the cognitive systems of human beings and the community as a knowledge system. In order to interact with the social system, an individual has to externalize his/her own knowledge and subjective beliefs. This has to be done in such a way that the social system can apply its binary code and decide whether or not it will be accepted as knowledge. So it is the individual who externalizes his/her own individual knowledge (e.g., into a written text), but it is the knowledge-related social system that shapes how this is done. The social system determines if the individual's knowledge is incorporated. A scientist, for example, can publish a new theory, but it is the scientific community that decides whether it accepts this theory, refers to it, and develops it further. In this process, the individual scientist (with his/her own individual expertise) always remains a particular environment for the knowledge-related social system. His/her individual beliefs and expertise build the basis for her operations (publishing an article), but it is the scientific system that decides if this externalized individual knowledge is received and how it is processed. Hence, an individual could have his/her own specific opinions and beliefs, which he/she then expresses, but it depends upon the social system as to how these beliefs are understood, integrated, or rejected. The externalized knowledge of an individual is only a stimulation for the social system. Both the individual scientist and the scientific community are operationally closed systems that cannot simply merge, but can stimulate each other and lead to development processes in the individual as well as in the community.

Taken together, the systemic perspective emphasizes the relative nature of all kinds of standards and norms, as these are always defined by and only valid within a given system. Hence, systems define what is considered to be true, as well as how the truth of a given proposition shall be evaluated—thereby ultimately defining knowledge itself. *Growth* of knowledge, in this perspective, results from interacting systems that may coevolve through mutual stimulation.

Discussion

Our starting point was the question as to what knowledge is, and we considered a variety of accounts originating from different disciplines. Within this process, three fundamental themes emerged that are closely related to the question of when a proposition is *known*: the requirement of truth of the proposition, the justification for believing in the proposition, and the question of who bears the knowledge. Our elaborations have shown that these three aspects are given consideration to differing degrees in the various disciplines and are to some extent conflicting issues.

If one's analysis is restricted to individuals, one can draw upon a prolific philosophical tradition that may not provide an ultimately valid answer but that provides a fairly consensual concept of knowledge (*justified true belief*). The philosophical tradition also delivers extensive detail regarding specific standards for ensuring knowledge. As precise as such an understanding may be, its applicability to real life is highly limited. This philosophical tradition does not explain fundamental phenomena such as mediated information (i.e., beyond the direct transmission from one person to another), collaboration, or growth of knowledge.

It may be questionable to use as a starting point for any analysis the implicit premise that knowledge exists only in individuals' minds. Philosophical accounts that transcend the single person perspective provide broader coverage of real-world issues at the expense of only a small degree of precision. Here, truth has been conceptualized in weaker terms (e.g., probability), and justification has been given more latitude by introducing mediated forms and by embedding justification into social context (e.g., social consensus, social warrant). In this broader analysis, justification, and thus knowledge itself, is made essentially social. Last but not least, the systemic-constructivist perspective radically breaks with the idea that any definitions or standards can be generalized. It denies that any proposition can be universally considered as true. It proposes instead that only the social or cognitive system itself defines truth and its justification. The system will also apply its own methods to incoming information for evaluating whether or not a piece of information is true. From this perspective, knowledge construction is far less a matter of individuals. Rather, it is the application of a specific code that a social system has developed and that essentially guides the behavior of its members. In this way, it harnesses the individual expertise of its members for creating emergent knowledge.

Regarding our fundamental questions with respect to knowledge, we conclude from our elaborations that knowledge is not something that can be universally defined, but instead it is what a specific knowledge-related system accepts. In mass collaboration scenarios, social systems are communities that process and construct knowledge. What is accepted in those groups strongly depends on the criteria for truth and justification that exist in these groups (e.g., the social system of Wikipedia rejects information without any reference, as the system requires contents to be verifiable and from reliable sources). For example, these criteria may be completely different in a community of doctors, in patient forums, or in other platforms. In the case of Wikipedia, verifiability and neutral point of view are the most crucial variables in this regard, and in patient forums, it may be subjectivity and personal experiences. Concerning the question of *who creates* knowledge, the systemic perspective clearly argues that it is the system that shapes the actions of its members. By applying its code, the social system enables users to become epistemic agents and allows the collaborative construction of knowledge. If people participate in different knowledge-related communities, their activities would be expected to differ as a function of the different social system.

The question then, *who possesses* knowledge, brings us back to the debate between classic epistemology and more recent theories. Hardwig (1985) proposed that the community is the bearer of knowledge in such cases (see also Faulkner, 2006), whereas Popper (1972) grants to thought contents an objective nature that is independent of anybody's mind. From the systemic perspective, we would argue that knowledge is contained in the communication that constitutes the social system. In mass collaboration scenarios on the Internet, this communication may become manifest in shared digital artifacts, as artifacts condense the interplay between the social system and cognitive systems which took place in mutual stimulation, thus reflecting the coevolution of both systems (Cress & Kimmerle, 2008).

Our perspective differs from traditional accounts in that we introduce a systemic-constructivist concept of knowledge and put emphasis on the code of a system. Some implications arise from this point of view that may stimulate the debate in the learning sciences: In a nutshell, our approach proposes that novices should be able to create information content of high quality—or knowledge—if the social system offers the proper conditions. The notion that knowledge construction may be accomplished by nonexperts such as students has been put forward before (e.g., Bereiter & Scardamalia, 2010). We put emphasis on the latter part of the proposal, however, on the proper conditions or the "code" of the social system. From this perspective, the question as to what constitutes a system's code arises immediately. More precisely, what is a system's definition of knowledge? And what is required in order to accept a certain proposition as knowledge? Hence, for a system that strives to enable construction of knowledge, a focus on these questions would be crucial and a discussion fruitful. Also from this view, it becomes immediately obvious that traditional education's code is *not* in essence one that leads to knowledge construction. Instead, the present common code tackles primarily the issues of teaching and learning. More precisely, the question is not what knowledge is, but whether or not (or how) it can be imparted, along with the question as to whether or not and how it may be effectively encoded and retrieved. As early as 1999, Scardamalia and Bereiter argued in their knowledge-building account for a novel understanding of schools as places where knowledge construction should take place (see also Paalova & Hakkarainen, 2005). The idea was that schools should prepare students for their lives in a knowledge society in which they should take responsibility for this common good (i.e., knowledge; see also Damşa, Kirschner, Andriessen, Erkens, & Sins, 2010). Our approach further stresses that for successfully achieving this goal, reflection about the code, and in turn reflection about the conditions imposed by a system, is downright necessary.

References

Adler, J. (2010). Epistemological problems of testimony. In Edward N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Winter 2010 ed.). Retrieved from http://plato.stanford.edu/entries/testimony-episprob/

Alkin, M. C. (1992). *Encyclopedia of educational research* (6th ed.). New York, NY: Macmillan.

Alston, W. P. (1988). The deontological conception of epistemic justification. *Philosophical Perspectives, 2*, 257–299.

Ballard, P. B. (1913). Oblivescence and reminiscence. *British Journal of Psychology, 1*(No. 2, Monograph Supplements), Preface-82.

Bar-Tal, D., & Kruglanski, A. W. (1988). *The social psychology of knowledge*. Cambridge, England: Cambridge University Press.

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge, England: Cambridge University Press.

Bereiter, C. & Scardamalia, M. (2010). Can children really create knowledge? *Canadian Journal of Learning and Technology, 36*(1). Retrieved from http://www.cjlt.ca/index.php/cjlt/article/view/585/289

Boghossian, P. A. (2006). *Fear of knowledge: Against relativism and constructivism*. Oxford, England: Clarendon.

Caramazza, A., McCloskey, M., & Green, B. (1981). Naïve beliefs in "sophisticated" subjects: Misconceptions about the trajectories of objects. *Cognition, 9*, 117–123.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with wikis. *International Journal of Computer Supported Collaborative Learning, 3*, 105–122.

Damşa, C. I., Kirschner, P. A., Andriessen, J. E. B., Erkens, G., & Sins, P. H. M. (2010). Shared epistemic agency: An empirical study of an emergent construct. *The Journal of the Learning Sciences, 19*, 143–186.

David, M. (2013). The correspondence theory of truth. In Edward N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2013 ed.). Retrieved from http://plato.stanford.edu/entries/truth-correspondence/

Dienes, Z., & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioral and Brain Sciences, 22*, 735–808.

Dunn, J. C. (2004). Remember—know: A matter of confidence. *Psychological Review, 2004*(111), 524–542.

Ebbinghaus, H. (1964). *Memory* (H. A. Ruger & C. E. Bussenius, Trans.). New York, NY: Dover (Original work published 1885).

Erdelyi, M. H. (2010). The ups and downs of memory. *American Psychologist, 65*, 623–633.

Faulkner, P. (2006). Understanding knowledge transmission. *Ratio, 19*, 156–175.

Feldman, R., & Conee, E. (1985). Evidentialism. *Philosophical Studies, 48*, 15–34.

Fiedler, K., Russer, S., & Gramm, K. (1993). Illusory correlations and memory performance. *Journal of Experimental Social Psychology, 29*, 111–136.

Fleck, L. (1935). *Entstehung und Entwicklung einer wissenschaftlichen Tatsache. Einführung in die Lehre vom Denkstil und Denkkollektiv* [The genesis and development of a scientific fact]. Basel, Switzerland: Schwabe.

Gardiner, J. M. (1988). Functional aspects of recollective experience. *Memory & Cognition, 16*, 309–313.

Gettier, E. L. (1963). Is justified true belief knowledge? *Analysis, 23*, 121–123.

Giere, R. N., & Moffatt, B. (2003). Distributed cognition: Where the cognitive and the social merge. *Social Studies of the Science, 33*, 301–310.

Gigerenzer, G. (2004). Fast and frugal heuristics: The tools of bounded rationality. In D. J. Koehler & N. Harvey (Eds.), *Blackwell handbook of judgment and decision making* (pp. 62–88). Malden, MA: Blackwell.

Gilovich, T., Griffin, D., & Kahnemann, D. (2002). *Heuristics and biases: The psychology of intuitive judgment*. Cambridge, England: University Press.

Goldman, A. (1979). What is justified belief? In G. Pappas (Ed.), *Justification and knowledge*. Boston, MA: D. Reidel.

Goldman, A. (1987). Foundations of social epistemics. *Synthese, 73*, 109–144.

Goldman, A. (2010). Systems-oriented social epistemology. In T. Gendler & J. Hawthorne (Eds.), *Oxford studies in epistemology (vol. 3).* Retrieved from http://fas-philosophy.rutgers.edu/goldman/Systems-Oriented%20Social%20Epistemology.pdf

Goldman, A., & Blanchard, T. (2010). Social epistemology. In Edward N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Summer 2010 ed.). Retrieved from http://plato.stanford.edu/entries/epistemology-social/

Greco, J. & Turri, J. (2011). Virtue epistemology. In Edward N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Spring 2011 ed.). Retrieved from http://plato.stanford.edu/entries/epistemology-virtue/

Greenwald, A. G. (1975). Consequences of prejudice against the null hypothesis. *Psychological Bulletin, 82*, 1–20.

Griffith, A. K., & Preston, K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching, 29*, 611–628.

Gruber, T. (2011). *Gedächtnis—Lehrbuch Basiswissen Psychologie*. Wiesbaden, Germany: VS-Verlag für Sozialwissenschaften.

Hardwig, J. (1985). Epistemic dependence. *The Journal of Philosophy, 82*, 335–349.

Higgins, E. T., & Rholes, W. S. (1978). "Saying is believing": Effects of message modification on memory and liking for the person described. *Journal of Experimental Social Psychology, 14*, 363–378.

Hinsz, V. B., Tindale, R. S., & Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin, 121*, 43–64.

Hirst, W., & Manier, D. (2008). Towards a psychology of collective memory. *Memory, 16*, 183–200.

Ichikawa, J. J. & Steup, M. (2014). The analysis of knowledge. In Edward N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Spring 2014 ed.). Retrieved from http://plato.stanford.edu/entries/knowledge-analysis/

Kerr, N. L., MacCoun, R. J., & Kramer, G. P. (1996). Biases in judgment: Comparing individuals and groups. *Psychological Review, 103*, 687–719.

Kimmerle, J., Cress, U., & Held, C. (2010). The interplay between individual and collective knowledge: Technologies for organisational learning and knowledge building. *Knowledge Management Research & Practice, 8*, 33–44.

Kimmerle, J., Gerbing, K.-K., Cress, U., & Thiel, A. (2012). Exchange of complementary and alternative medical knowledge in sport-related Internet fora. *Sociology of Sport Journal, 29*, 348–364.

Kimmerle, J., Moskaliuk, J., Cress, U., & Thiel, A. (2011). A systems theoretical approach to online knowledge building. *AI & Society: Journal of Knowledge, Culture and Communication, 26*, 49–60.

Kimmerle, J., Moskaliuk, J., Harrer, A., & Cress, U. (2010). Visualizing co-evolution of individual and collective knowledge. *Information, Communication and Society, 13*, 1099–1121.

Kimmerle, J., Moskaliuk, J., Oeberst, A., & Cress, U. (2015). Learning and collective knowledge construction with social media: A process-oriented perspective. *Educational Psychologist, 50*, 120–137.

Kitcher, P. (1990). The division of cognitive labor. *The Journal of Philosophy, 87*, 5–22.

Klemke, E. D. (1979). Karl Popper, objective knowledge, and the third world. *Philosophia, 9*, 45–62.

Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor? *Journal of Management, 20*, 403–437.

Knorr-Cetina, K. (1981). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science*. New York, NY: Pergamon Press.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Kusch, M. (2002a). Testimony in communitarian epistemology. *Studies in History and Philosophy of Science, 33*, 335–354.

Kusch, M. (2002b). *Knowledge by agreement: The programme of communitarian epistemology*. Oxford, England: University Press.

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth in knowledge*. London, England: Cambridge University Press.

Larson, J. R., Jr., & Christensen, C. (1993). Groups as problem-solving units: Toward a new meaning of social cognition. *British Journal of Social Psychology, 32*, 5–30.

Lehrer, K. (1987). Personal and social knowledge. *Synthese, 73*, 87–107.

Lindner, I., Echterhoff, G., Davidson, P. S. R., & Brand, M. (2010). Observation inflation: Your actions become mine. *Psychological Science, 21*, 1291–1299.

Luhmann, N. (1984). *Soziale Systeme. Grundriß einer allgemeinen Theorie* [Social systems. Outline of a general theory]. Frankfurt am Main, Germany: Suhrkamp.

Luhmann, N. (1990). *Die Wissenschaft der Gesellschaft* [Science as a social system]. Frankfurt am Main, Germany: Suhrkamp.

Maier, J., & Richter, T. (2014). Verstehen multipler Texte zu kontroversen wissenschaftlichen Themen: Die Rolle der epistemischen Validierung. *Unterrichtswissenschaft, 42*, 24–38.

Mandl, H. & Spada, H. (1988). *Wissenspsychologie* [The Psychology of Knowledge]. Weinheim, Germany: Beltz.

Matthiessen, H. O., & Willaschek, M. (2009). Epistemische Rechtfertigung. In H. J. Sandkühler (Ed.), *Enzyklopädie Philosophie* (3rd ed.). Hamburg, Germany: Meiner.

Maturana, H. R., & Varela, F. J. (1987). *The tree of knowledge: The biological roots of human understanding*. Boston, MA: New Science Library/Shambhala Publications.

Moskaliuk, J., Kimmerle, J., & Cress, U. (2009). Wiki-supported learning and knowledge building: Effects of incongruity between knowledge and information. *Journal of Computer Assisted Learning, 25*, 549–561.

Moussavi, F., & Evans, D. A. (1993). Emergence of organizational attributions: The role of a shared cognitive schema. *Journal of Management, 19*, 79–95.

Oeberst, A. (2012). If anything else comes to mind… better keep it to yourself? Delayed recall is discrediting—unjustifiably. *Law and Human Behavior, 36*, 266–274.

Oeberst, A., & Blank, H. (2012). Undoing suggestive influence on memory: The reversibility of the misinformation effect. *Cognition, 125*, 141–159.

Oeberst, A., Halatchliyski, I., Kimmerle, J., & Cress, U. (2014). Knowledge construction in Wikipedia: A systemic-constructivist analysis. *Journal of the Learning Sciences, 23*, 149–176.

Paalova, S., & Hakkarainen, K. (2005). The knowledge creation metaphor—An emergent epistemological approach to learning. *Science & Education, 14*, 535–557.

Pappas, G. (2009). Internalist vs. externalist conceptions of epistemic justification. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Spring 2009 ed.). Retrieved from http://plato.stanford.edu/entries/justep-intext/

Peressini, A. (2008). Proof, reliability, and mathematical knowledge. *Theoria, 69*, 211–232.

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model of persuasion. *Advances in Experimental Social Psychology, 19*, 123–205.

Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures*. New York, NY: Viking.

Pohl, R. F. (2004). *Cognitive illusions: A handbook on fallacies and biases in thinking, judgement and memory*. Hove, England: Psychology Press.

Popper, K. R. (1968). Epistemology without a knowing subject. *Studies in Logic and the Foundations of Mathematics, 52*, 333–373.

Popper, K. R. (1970). *Die offene Gesellschaft und ihre Feinde* [The open society and its enemies]. Bern, Switzerland: Francke.

Popper, K. R. (1972). *Objective knowledge: An evolutionary approach*. Oxford, England: Clarendon.

Popper, K. R. (1978). *Three worlds: The Tanner lecture on human values.* Lecture delivered at the University of Michigan, April 7, 1978. Retrieved from http://tannerlectures.utah.edu/_documents/a-to-z/p/popper80.pdf

Putnam, H. (1975). The meaning of "meaning". *Minnesota Studies in the Philosophy of Science, 7*, 131–193.

Reber, R., & Unckelbach, C. (2010). The epistemic status of processing fluency as source for judgments of truth. *Review of Philosophical Psychology, 1*, 563–581.

Resnick, L. B., Levine, J. M., & Teasley, S. D. (Eds.). (1991). *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association.

Richter, T. (2003). *Epistemologische Einschätzungen beim Textverstehen* [Epistemological evaluations in text understanding]. Lengerich, Germany: Pabst.

Russell, B. (1910). Knowledge by acquaintance and knowledge by description. *Proceedings of the Aristotelian Society, 11*, 108–128.

Salomon, G. (Ed.). (1993). *Distributed cognitions*. Cambridge, England: Cambridge University Press.

Scardamalia, M. & Bereiter, C. (2010). A brief history of knowledge building. *Canadian Journal of Learning and Technology, 36*(1). Retrieved from http://www.cjlt.ca/index.php/cjlt/article/view/574/276

Schiffer, S. (1996). Contextualist solutions to skepticism. *Proceedings of the Aristotelian Society, New Series, 96*, 317–333.

Schroeder, S., Richter, T., & Hoever, I. (2008). Getting a picture that is both accurate and stable: Situation models and epistemic validation. *Journal of Memory and Language, 59*, 237–255.

Shaw, J., & Porter, S. (2015). Constructing rich false memories of committing crime. *Psychological Science.* Advance online publication. doi:10.1177/0956797614562862

Sperling, M., & Schmidt, T. (2009). *Allgemeine Psychologie kompakt—Wahrnehmung, Aufmerksamkeit, Sprache, Denken*. Weinheim, Germany: Beltz.

Sporer, S. L., Penrod, S. D., Read, J. D., & Cutler, B. L. (1995). Choosing, confidence, and accuracy: A meta-analysis of the confidence-accuracy relation in eyewitness identification studies. *Psychological Bulletin, 118*, 315–327.

Steck, P., Hermanutz, M., Lafrenz, B., Schwind, D., Hettler, S., Maier, B., & Geiger, S. (2010). Die psychometrische Qualität von Realkennzeichen *[Psychometric characteristics of the criteria based content analysis]*. Retrieved from http://serwiss.bib.hs-hannover.de/frontdoor/index/index/docId/263

Steffens, M. C., & Mecklenbräuker, S. (2007). False memories. Phenomena, theories, and implications. *Journal of Psychology, 215*, 12–24.

Thompson, L., & Fine, G. A. (1999). Socially shared cognition, affect, and behavior: A review and integration. *Personality and Social Psychology Review, 3*, 278–302.

Tulving, E. (1985a). How many memory systems are there? *American Psychologist, 40*, 385–398.

Tulving, E. (1985b). Memory and consciousness. *Canadian Psychology, 25*, 1–12.

Tulving, E. (1987). Multiple memory systems and consciousness. *Human Neurobiology, 6*, 67–80.

Tulving, E. (1989). Memory: Performance, knowledge, and experience. *Journal of Cognitive Psychology, 1*, 3–26.

Vahid, H. (1998). Deontic vs. nondeontic conceptions of epistemic justification. *Erkenntnis, 49*, 285–301.

Vicente, K. J., & Brewer, W. F. (1993). Reconstructive remembering of the scientific literature. *Cognition, 46*, 101–128.

von Foerster, H. (2003). *Understanding understanding: Essays on cybernetics and cognition*. New York, NY: Springer.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wegner, D. M., Erber, R., & Raymond, P. (1991). Transactive memory in close relationships. *Journal of Personality and Social Psychology, 81*, 923–929.

Wilson, R. A., & Keil, F. C. (1999). *The MIT encyclopedia of the cognitive sciences*. Cambridge, MA: MIT Press.

Womack, C. A. (1993). The crucial role of proof: A classical defense against mathematical empiricism. *Doctoral Dissertation at the Massachusetts Institute of Technology.* Retrieved from http://dspace.mit.edu/handle/1721.1/12678

Wood, J. M., & Nezworski, M. T. (2005). Science as a history of corrected mistakes. *American Psychologist, 60*, 657–658.

From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration

Wai-Tat Fu

Collective Intelligence and Collaboration

Intuitively, one may argue that collective intelligence is more than the sum of the intelligence of the individuals. For example, the classic study by Galton (1907) showed that the collective judgment of a group of individuals could be better than any of the individuals in the group, even when the individuals did not explicitly collaborate with each other. Since then, researchers have been interested in understanding how a group of individuals can become more intelligent when they collaborate to achieve their goals. Consistent with the classic study by Galton, research shows that collective intelligence often does not depend critically on individual intelligence. For example, recent research shows that, regardless of measures of individual intelligence, a group of individuals may appear to be *collectively* more intelligent than any of the individuals as the *diversity* in the group increases. These results suggest that the *composition* of the group and *processes* of information that support the *coordination of distributed cognitive processes* are important for improving massive collaboration. The goal of this chapter is to discuss what and how characteristics of online socio-technological systems can support such coordination, in ways that may potentially increase the collective intelligence of the collaborators.

Traditionally, collaboration can be defined broadly as the process in which individuals work *together* with a shared goal or vision. Online collaboration, however, may occur without explicit coordination or communication among the individuals, nor does it require that individuals work toward a single, common goal. Rather, online socio-technological systems are designed such that they provide the platforms on which individual users can contribute to (emergent) *structures* that help the users to accomplish their goals. Because contribution from individuals

---

W.-T. Fu (✉)
Department of Computer Science, University of Illinois at Urbana-Champaign,
Champaign, IL, USA
e-mail: wfu@illinois.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_7

does not require explicit coordination and communication, these online socio-technological systems can accommodate a massive number of users who, often implicitly, contribute to the structures that allow the shared goal or vision of the systems to be realized. For example, the goal of Wikipedia is to generate knowledge, although the majority of the individuals are contributing by making infrequent minor edits on a small number of pages, which *collectively* contribute to useful structures that allow knowledge to be linked and shared (through hypertexts) for a massive number of users. The collective goal for this kind of online massive collaboration is therefore often long term or abstract and does not require explicit coordination and communication among the individuals. In contrast to traditional collaboration, the success of online massive collaboration hinges on features that support the construction of emergent structures that are useful for the shared goal or vision of the online socio-technical systems.

To understand what makes such online massive collaboration successful, one may need to focus on how well each individual is able to coordinate their cognitive processes through the features and functions provided by the socio-technical systems. The key is to understand how collaboration process can improve the quality of the collective outcome (i.e., emergent structures) in the systems, thereby increasing the collective intelligence of the systems (and the individual users). While individual intelligence is often measured by how well the individual can make use of his or her knowledge and cognitive skills to accomplish a cognitive task (e.g., solving an algebra problem), there is still a general lack of a quantifiable measure of collective intelligence of a group of individuals as they engage in such online massive collaboration. The current chapter will focus on the nature of cognitive computations in individuals and in groups. In particular, the chapter will focus on the central role of *cognitive search* in individual cognition and discuss how cognitive search may also play a central role in collective intelligence exhibited in online massive collaboration. The chapter will then provide examples of information systems that support collective intelligence and argue from a theoretical standpoint the design principles that make these systems more efficient and capable of facilitating massive online collaboration.

Foundation

A cognitive computational system is defined generally as a *control system* that determines what behavior should be taken in a given environment to achieve a goal. A system that plays chess has a clear goal—to win; and in order to do that, it has to decide on a sequence of moves based on its assessment of the environment (e.g., the chess positions on the board) to achieve that goal. The control system can have multiple components (memory, rules, planner, etc.) to determine what is the best move at any given moment. All computations inside the control system that are conducted to generate *goal-directed behavior* are considered *cognitive computations*. Most AI systems and human cognition are functioning as cognitive computational systems.

Local-to-Distal Processing of Symbolic Structures

Cognitive computations involve representations and processes that allow the system to generate goal-directed actions. Cognitive computations involve processing of symbols[1] in the specific contexts that the symbols are situated (Newell, 1994). For example, in the sentence "Berlin is the capital of Germany," each word is a symbol. However, processing each symbol individually is not enough to understand the meaning of the sentence; it also needs to take into account how each word is put together in the sentence such that the meaning of the sentence can be extracted. Symbols are therefore situated in symbol structures that provide the context under which multiple symbols can be processed. Knowledge can be represented as a network of symbol structures, which allow the system to *know* how to process inputs from the environment to generate a response.

An important characteristic of a cognitive computation system is that local processing of a symbol structure is often not enough. In the above example, processing the meaning of each individual word is not enough to understand the sentence. It also needs knowledge about, for example, English grammar, the context under which the sentence is written, and other relevant general knowledge, which allows the system to understand how the words together represent the meaning of the sentence with respect to the general context that the sentence should be interpreted. When the system processes such symbol structures, it will at some point need to detect that there is not enough knowledge in the local symbol structures and decide to utilize some local cues in the symbol structures to guide the system to access distal knowledge in another symbol structures. This local-to-distal processing of symbol structures is an important property of cognitive computations in intelligent systems.

More generally, computations in a symbol system are all local, in the sense that they always occur within a region in the *physical* space (i.e., there is no instantaneous action at a distance). However, the essence of cognitive computations is that they require intelligent processing across symbol structures to derive meaning, in which information needs to be fetched from distal symbol structures, integrate with local symbol structures, such that new symbol structures may be created to inform actions. The fetch of distal information is based on local computation of the proximal symbol structure. A successful fetch process from proximal to distal symbol structures requires knowledge about which distal symbol structures should be fetched (see Fig. 1).

---

[1] Note that "symbols" are broadly defined as representations that relate to other entities. Although the focus is on processing of symbolic structures, it does not imply that this is the only kind of processing. There are other computations that, for example, implement the processing of symbols (e.g., in connectionist networks, in the chemical reactions of neurons, etc.), but this is not the level nor the kind of computation that the current analysis focuses on.

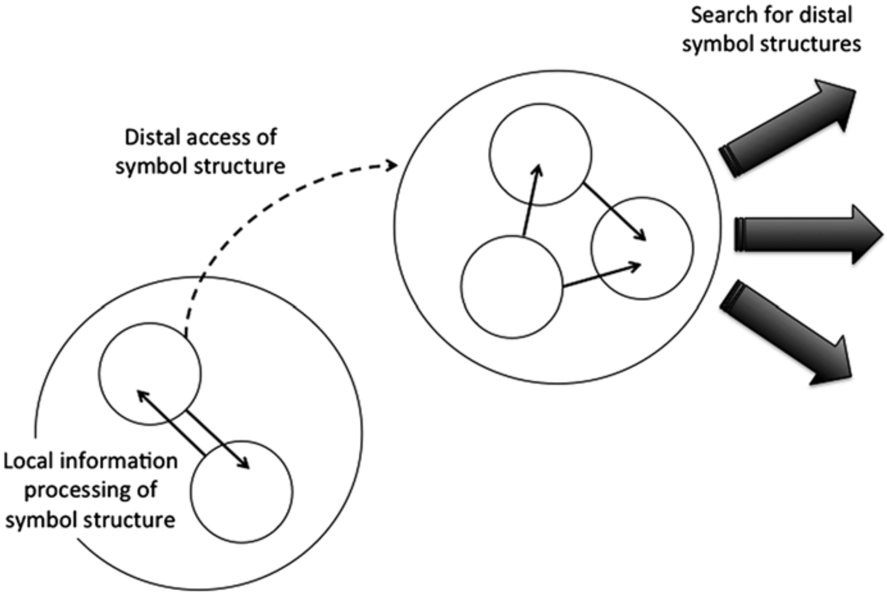


Fig. 1 The local-to-distal access of knowledge when processing symbol structures. When there is uncertainty about distal knowledge, search is necessary

The Central Role of Search in Intelligent Behavior

One way to define the level of intelligence of a system is to measure how much knowledge the system can bring to generate the right response. Bringing knowledge requires cognitive computations that access distal information from local information. As discussed above, when a cognitive computation system is processing a symbol structure, it needs to detect local patterns and access distal knowledge to generate a goal-directed response. However, there is often some level of uncertainty about where to access the distal knowledge. The system will need to engage in *search* to find the right knowledge to apply. This *knowledge search* process is central to the intelligence of the system. It is central because, except in some trivial tasks, the search process influences the extent to which the system can utilize its knowledge to generate a response. In other words, if the search is effective, responses generated by the system will more likely be intelligent.

In addition to knowledge search, the system often needs to engage in *state-space search*, which is also critical for intelligence. This is when a system is searching in the environment space to determine the right course of actions that will allow it to accomplish its goals. For example, when one is playing chess, making a move will lead to a change in the environment (which defines a state space) that influences subsequent moves. State-space search can be done internally, as when a chess player is simulating (by representing the environment internally) how different moves may lead to changes in the chessboard. In that situation, symbol structures are *generated* to represent possible moves such that they can be evaluated, and state-space search determines where and how new structures are generated. Because of the uncertainty involved when making such moves, generation of new symbol structures in state-space search allows the system to look ahead and consider how different actions may lead to different paths in the state space (and how likely these paths will eventually lead to the goal).

Search Control Knowledge and Effective Representations

Having established that search plays a central role in cognitive computations, the next question is how search is related to the level of collective intelligence in socio-technical systems. However, before discussing collective intelligence, I will first describe how the level of intelligence can be defined in individual cognition and how distributed cognition can be combined to generate collective intelligence in socio-technical systems.

As discussed above, in a cognitive computational system, the level of intelligence can be determined by the *efficiency* of the search process. While an efficient knowledge search process allows the system to recognize, locate, and process the necessary symbol structures to generate the best solution given the bounds, an efficient state-space search process allows the system to reach and evaluate more desirable states (and avoid undesirable states) and extract useful information along the way to enrich its knowledge. An important point about intelligent behavior of a cognitive computation system is, however, not determined by how much search is needed to compute a solution. Rather, the intelligence is determined by how much search it does *not* need to compute the same solution.

To understand this idea, one can consider the situation when a system, *A*, performs fewer searches than another system *B* to generate the same solution. To perform fewer searches, *A* needs to be more *selective* in knowledge and state-space search, such that fewer cognitive computations are required to generate the same solution. There are two major ways that a system can accomplish this. First, *A* can have more *search control knowledge*, such that it can more effectively process local symbol structures to infer where the necessary distal knowledge is (more efficient knowledge search) and decides what actions to take to reach states that are more informative and more promising to lead to the goal (more efficient state-space search). Second, the system can have more *efficient representations* (i.e., networks of symbol structures) of the problem or the environment that make knowledge more accessible (can be processed with fewer cognitive computations) or the solution more easily computed. The reason why representations are important is that any problem needs to be internally represented in ways that allow appropriate operations to be applied to them, and some representations will more likely than others to solve a specific problems. For example, when describing objects in the environment, one can represent an object A to be “to the left of” object B, or “attacking” object B (e.g., in chess), etc. Depending on the problem to be solved, some representation can be more efficient than others to generate a solution. In many situations, better representations can also be constructed during the search process, such that the system learns which representations can allow search to be performed more efficiently.

We can broadly categorize search processes that utilize either search control knowledge or better representation to generate a solution as *cognitive search* (as opposed to other forms of search, see Pearl, 1984). Cognitive search allows the system to generate intelligent behavior by more effectively utilizing knowledge to generate a solution, given the limits on cognitive computations. In fact, when comparing the level of intelligence of two systems, one can focus on *how* they perform cognitive search to attain some level of performance. Similarly, when one is interested in measuring how much intelligence a system has gained, one can focus on the cognitive search process to estimate the amount of search that it can reduce to attain the same performance. I will use the example of a simple game "tic-tac-toe"[2] to illustrate this idea below.

An Example: Tic-Tac-Toe

Consider the simple game of tic-tac-toe. The game is considered simple because it has low complexity: the number of possible states and moves to be $3^9 = 19{,}683$ and $9! = 362{,}880$, respectively. While searching through all these possible moves to find the optimal ones is tractable for most machines, the inherent structures of the game environment can be easily exploited to greatly simplify the search process. It is therefore a good example game to show how the *knowledge* that allows an agent to adopt *heuristic search* to perform fewer cognitive computations to obtain good solutions can define the level of *intelligence* of the agent.

Like any well-defined problem, the tic-tac-toe can be expressed as a problem space, in which it has a clear initial state, operators that transition from one state to another, and a well-defined goal state (a win with three-in-a-row). To determine a good move in any given state, an agent needs to *search* in the problem space by (1) generating possible moves, (2) evaluating the moves, and (3) determining when to stop the search process. For example, when generating the first move, any of the nine locations are possible moves. Each of these moves can then be evaluated until the agent decides to stop evaluating and select the best of the evaluated moves.

There are many ways that this process can be simplified such that the amount of search can be reduced. For example, the agent may *know* that the corner moves are symmetrical, and thus for the purpose of the game, they are the same (see left of Fig. 2). Similarly, the four moves in the middle are identical. By representing the problem space differently using knowledge about the identical *functional roles* of these moves, the search process of the first move can be significantly reduced to three possible states (see right of Fig. 2).

---

[2] Sometimes also called Noughts and Crosses; see http://en.wikipedia.org/wiki/Tic-tac-toe.

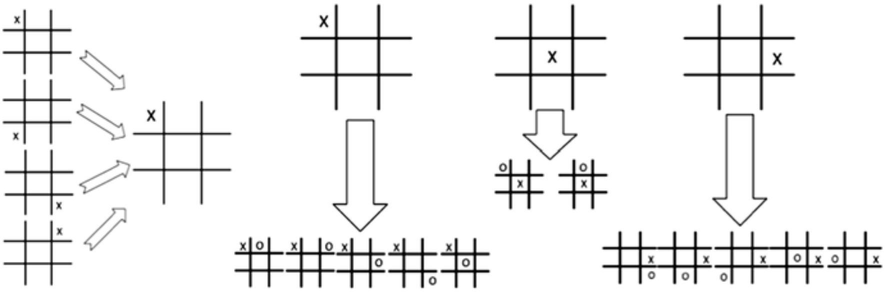


Fig. 2 The functional equivalence of corner states in tic-tac-toe (*left*) and the resulting states in the reduced search space (*right*)

Another piece of knowledge that is useful for the search process is how to evaluate moves. An agent may *know* that moves that lead to more possible win lines are better, and thus for each possible move generated in state n, the agent can calculate a function $H(n)$ to represent the number of possible win lines for that move (see Fig. 3). The value of $H(n)$ can be used to guide the search process—for example, the agent can decide to order the search based on the value of $H(n)$. Given that the center position will lead to four possible win lines and the other two moves will lead to only three win lines, the agent can decide to first search for possible moves after the center position, calculate $H(n)$ for all states again, select the moves that lead to the highest H(n), and so on[3] (see Fig. 3).

Variations of this form of heuristic search are in fact widely used in AI to perform graph traversal in tasks like the tic-tac-toe (e.g., Pearl, 1984) and have been shown to be very efficient in terms of *simplifying* the search process by finding good solutions while reducing the number of possible states to be evaluated. As illustrated by the example above, the key to the efficiency of the heuristic search process is the agent's *knowledge* of the problem structures. The knowledge includes (1) *efficient representations*, the functional equivalence of problem states, and (2) *search control knowledge*, the heuristic function that calculates the distance to the goal, which allows the agents to predict which paths will more likely lead to the winning state.

From Distributed Cognition to Collective Intelligence

Having discussed the characteristics that make a cognitive computation system intelligent, the next question is how the otherwise distributed cognitive systems can collaborate to achieve a goal and how these characteristics apply to determine the level of intelligence of such a *collective cognitive system*. In particular, the discussion will

---

[3] Note that this is similar to the choice of cues based on their validities in decision heuristics like "take-the-best."

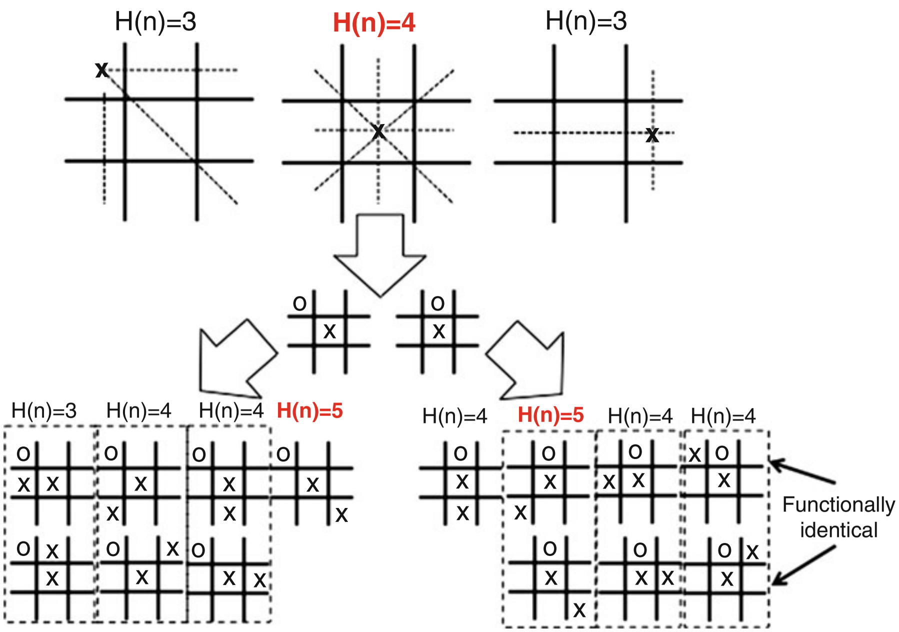


Fig. 3 Calculating the number of win lines (H(*n*)) to guide the search process in tic-tac-toe. The highest value of the first move is H(*n*) = 4 and the second move is H(*n*) = 5

focus on how socio-technical systems should support collective development of (1) efficient representations and (2) effective search control knowledge.

Efficient Representations

As discussed in the example of the tic-tac-toe game, an efficient representation can significantly reduce state-space search as functionally similar states can be categorized and collapsed to reduce the search space. For individual and collective cognitive systems, efficient representations can be developed empirically through experience with the search space and analytically through reasoning or logical inference. However, for collective cognitive systems, an important aspect is that distributed cognition needs to have coherent structures that allow them to construct effective representations collectively. Modern humans, for example, share common languages that allow them to more effectively share their experiences and communicate with each other to construct more sophisticated representations (or knowledge) of our natural and artificial world. In the next section, I will discuss how socio-technical systems have the potential to provide an extra level of structures that facilitate this form of collective construction of representations. For example, online technologies like wiki, tagging, collaborative filtering, or recommender systems allow users to leave "digital traces" that the system can aggregate to generate more effective representations of the information space. An example of such system will be discussed in the next section.

Effective Search Control Knowledge

Search control knowledge is important as it provides guidance to improve the intelligence of the search process. In a collective cognitive system, knowledge may be distributed across individuals, and the search for knowledge may be more challenging than individual cognitive systems, as one needs to know how and where (or who) to find the right knowledge to accomplish their (information) goal. On the other hand, research has shown that there are various forms of "social signals" or cues that allow one to search more effectively as one observes, for example, what others do. These social cues may serve as collective search control knowledge that makes that system more intelligent, in the sense that less search is needed to support the collective cognitive computations required to achieve the system's goal. I will provide an example in the next section.

Case Study: Social Tagging Systems

Social tagging systems allow users to annotate, categorize, and share Web content (links, papers, books, blogs, etc.) using short textual labels called tags (Fu & Dong, 2012). Tags help users in organizing, sharing, and searching for Web content in shared social systems. The inherent simplicity in organizing and annotating content in these systems through "open-ended" tags satisfies a personal and social function. At a personal level, customized tags can be added to a resource based on a specific information goal (e.g., markup for future reading or identifying books for a history library) that will help in organization of resources or future search and retrieval. At the social level, the tags facilitate sharing and collaborative indexing of information, such that social tags act as "way finders" for other users with similar interests to search for relevant information (Fu, 2008, 2012; Fu & Dong, 2012; Fu, Kannampallil, & Kang, 2009; Fu, Kannampallil, Kang, & He, 2010).

Social tagging systems allow multiple users engage in collaborative knowledge exploration, in which users find and evaluate relevant documents related to a topic and assign social tags that allow others to find them. Assigning social tags to documents involves comprehending and extracting of knowledge from the documents, which is then integrated with existing knowledge of the users when social tags are selected and assigned to the documents (Fu et al., 2010). These social tags are then often organized in a list or "tag cloud" such that others can click on them to retrieve documents that have the same tags assigned to them.

A social tagging system is an example of socio-technical systems that support collective intelligence. First, it allows users to collectively categorize information resources (e.g., documents) based on their contents and assign tags to represent these resources. The user-tag-resource structure has the potential to make the representation of knowledge more efficient, in the sense that users can interpret the tags to infer the contents of the information resource, thereby making their search for knowledge more efficient (see Fig. 4).

As shown in Fig. 4, multiple users can assign tags to information resources (documents, Web pages, blogs, etc.). Because these tags will be visible to other users, all users can use these tags to access resources tagged by others. These tags (through semantic interpretation) provide an effective representational structure that allows users to infer the content of the resources. The tags created by each user can therefore accumulate and act as search control knowledge that allows others to

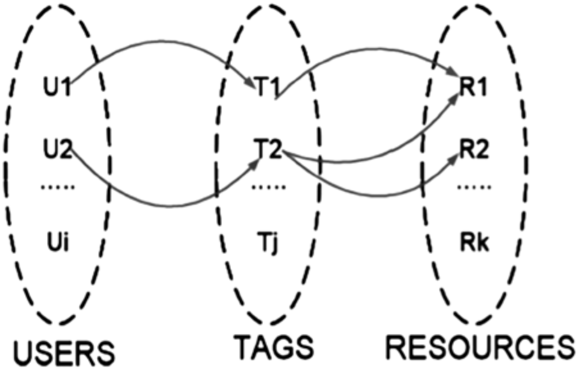


Fig. 4 The user-tag-resource structure of a social tagging system

explore knowledge distributed across information resources. Two important questions are (1) to what extent the user-tag-resource structure can help users to develop efficient representation of the information/knowledge space and (2) how well can users utilize the structure as search control knowledge. I will present two studies that hint at positive answers to these questions.

Developing Efficient Representations

Fu et al. (2010) show that as users collaboratively assign tags to a set of resources, the semantic interpretation of the tags associated with the resources impacts how they comprehend the resources, which in turn influence them to create tags that are semantically similar to existing tags. This finding is consistent with research on semantic priming, in which the semantics (i.e., meaning) of a word will impact the interpretation of later words (Meyer & Schvaneveldt, 1971). More importantly, the findings by Fu et al. (2010) demonstrate that, although users can assign any tags to the resources, the collaborative tagging process will likely converge to a set of tags that are similar in meaning, which helps to lead users to interpret the content of the information resources.

Figure 5 shows the semantic imitation model that predicts how tag choices are influenced by both existing tags and contents of the information resource (a mathematical model can be found in Fu et al., 2009). The model assumes that users will

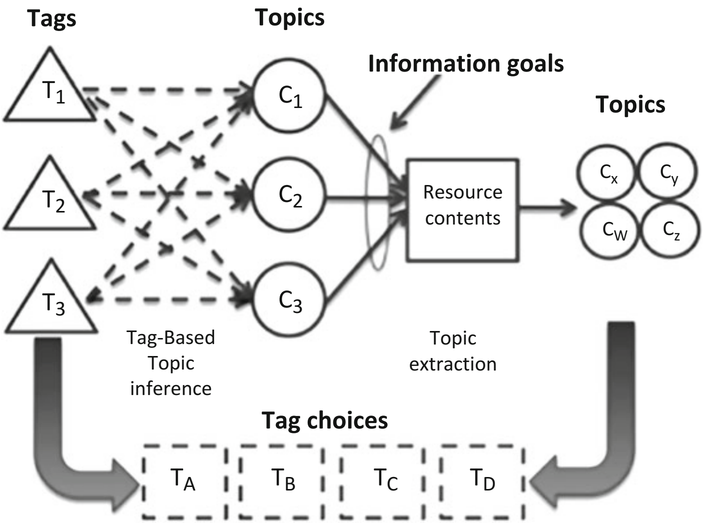


Fig. 5 The semantic imitation model of social tagging by Fu et al. (2010). The model predicts that tag choices will be influenced by the semantics of the existing tags and the content of the information resources, a process known as semantic imitation. The semantic imitation process is argued to be a useful process for the collaborative development of effective representations of the knowledge distributed in the information space

first process existing tags before reading the information resource. These existing tags will invoke mental concepts through a topic inference process. These mental concepts will interact with the information goals of the users to influence the comprehension of the information resource, and different topics will be extracted and mentally represented as new concepts by the users. Tag choices will then be influenced by both the set of concepts invoked by the existing tags and the new concepts extracted from the resource. This model shows good fit to the data obtained from a user study, in which participants were separated into two groups, who were instructed to create tags to a set of resources with or without seeing others' tags. In particular, by comparing the tags created by the two groups, the model predicts correctly that users who can see tags created by others will create tags that tend to converge over time, and the tags are more semantically similar. In addition, information goals moderate the influence the impact of existing tags on tag choices.

Referring back to Fig. 1, the semantic imitation model can be characterized as a sequence of local-to-distal information processes. First, the tag-based topic inference process allows the user to utilize the (local) tags as retrieval cues to access relevant (distal) conceptual knowledge to infer the contents of the resources. Second, the conceptual knowledge *primed* by the tags can be utilized to help the user to comprehend the resources by assisting in the accommodation and assimilation of the newly encoded (local) knowledge into their existing set of (distal) knowledge. The assumption is that the semantic priming of tags facilitates the formation of *coherent situation models* that allow better integration of information during the comprehension process (van Dijk & Kintsch, 1983). Finally, when choosing tags to describe the (local) topics extracted from the resources, the users need to access their (distal) knowledge structures to label the topics.

Characterizing the semantic imitation model as a sequence of local-to-distal access of knowledge can help shed light on how the tagging system is providing more[4] efficient representation for explorative search of knowledge. In contrast to the game of tic-tac-toe, the search space is ill defined in explorative knowledge search—the user may not know what knowledge is relevant, and thus the local-to-distal access is very limited. What makes the user-tag-resource representation efficient for search is that it, to a certain extent, provides the structures that allow the local-to-distal access possible. In addition, similar to the example of tic-tac-toe discussed above, the efficiency of the representation also comes from the reduction of the search space, as the system provides the structures (links between tags, users, and resources) that allow users to explore knowledge more efficiently. The efficiency relies on the fact that users share similar knowledge (and language) structures that allow them to interpret tags and extract knowledge structures in ways that are coherent with each other. The efficient representations make the systems collectively more intelligent—in the sense that users can find the information they need with less search in the knowledge space.

---

[4] In the current context, it is *more* efficient relative to tools that do not provide any meaningful structures for explorative search, such as search engines.

Effective Use of Social Tags as Search Control Knowledge

Fu and Dong (2012) present a computational model of social learning in social tagging and a longitudinal experiment that validates that model. The computational model was constructed to simulate how mental concepts were formed through an assimilation and accommodation process (Piaget, 1975; see also chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" by Cress, Feinkohl, Jirschitzka, J, & Kimmerle, 2016). The goal of the model was to characterize how users learn new conceptual structures as they explored the knowledge space indexed by the social tagging system. It is expected, for example, if the social tags can provide search control knowledge, users should improve their search for relevant information as they progressively learn about various topics during search. Details of the model can be found in Fu and Dong (2012) and Fu et al. (2009).

To validate the model, participants were engaged in an 8-week study, in which they learned about the topics of "antiaging (AA)" and "independence of Kosovo (IK)" online. Participants were given a rough description of the topic, and they gradually acquired knowledge about the topic through an iterative search-and-learn exploration cycle. Participants were instructed to imagine that they wanted to understand the topics and to write a paper and give a talk to a diverse audience. The topics were chosen because the two topics represented two different distributions of the information ecology—while the independence of Kosovo referred to a specific event, information related to it tended to be more specific, and there were more Websites containing multiple pieces of related information relevant to the topic (it will be called a "high-overlap" task); antiaging, on the other hand, was more ambiguous and related to many disjoint concepts such as cosmetics, nutrition, or genetic engineering (it will be called a "low-overlap" task). The study focused on studying how exploratory learning differed in the high-overlap IK task and the low-overlap AA task.

Eight participants were recruited and divided randomly and assigned to one of the tasks, and they were instructed to learn over a period of 8 weeks. Participants were asked to use any search engine to look for information relevant to the topic for 30 min in each of the 8 weeks, and all links clicked were recorded. For Web pages that they found relevant, they were instructed to bookmark them and create tags (short representative words) to describe the contents of the Web pages such that they themselves or their colleagues could use the tags to refind the Web pages more quickly in the future. Participants were asked to think aloud during the task and to provide a verbal summary of Web pages that they found relevant. These verbal utterances were recorded and analyzed later. After the last session, the pages that they bookmarked were printed out, and participants were asked to categorize these Web pages into as many groups as they wanted.

Search performance was characterized by two measures that captured the breadth and depth of search. First, we measured the *branchiness* of search. A branch was characterized by the situation when a participant clicked on a link on a page P and eventually went back and clicked on a different link on the same page P without bookmarking any relevant Web pages. Branchiness was measured by the average number of branches before a relevant Web page was bookmarked. A higher branchiness indicated that more pages were searched before relevant information was found—i.e., more states at the same level of the search tree were evaluated. Second, we measured the number of *search layers*. A search layer was defined as a link-following action without going back. The number of search layers before a relevant Web page was bookmarked reflected the amount of search performed to reach a relevant Web page. The branchiness and number of search layers together measured the complexity of the search tree chosen by the person. It is expected that as search control knowledge improves, search becomes more efficient. As a result, the search tree becomes simpler.

Figure 6 shows the average branchiness and number of search layers for the low-overlap AA task and the high-overlap IK task. Comparing search performance between the two tasks, both branchiness and number of search layers were higher in the AA than the IK task. In the low-overlap AA task, information was more distributed as Web pages relevant to the target topic tended to have little overlap in concepts. Links that lead to these Web pages were in general more difficult to judge whether they would eventually lead to information relevant to the topic, and thus participants had to perform more complex search to find relevant information. For both tasks, both branchiness and search layers decreased over sessions, providing support that participants learned to search more efficiently.

Using this method, the set of Web pages categorized by the human participants were compared to those categorized by the model. The correlation between the two conceptual structures for each participant and model was calculated, and the average was 0.83 (min = 0.62, max = 0.98). The high correlation suggests that the conceptual structures of the models matched those of the human participants well, providing support for the notion that conceptual structures changed to support better search performance across sessions. Results from the empirical study and the model demonstrate how human conceptual structures can incrementally adapt to new information in ways that improve search performance. The results also demonstrate how social tags can help users to acquire search control knowledge during knowledge exploration, in ways such that they learn to interpret the tags and become more efficient in identifying useful information resources.

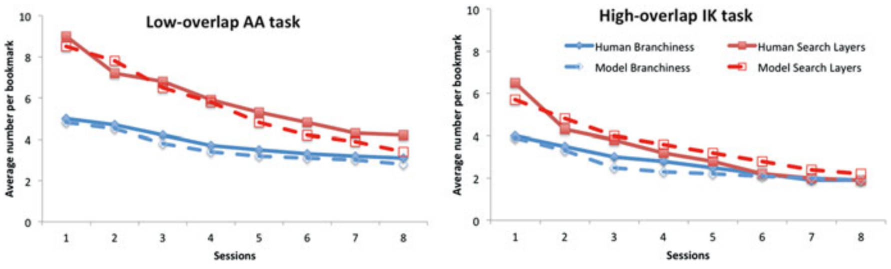


Fig. 6 The average branchiness and search layers per bookmark for the AA task (*left*) and the IK task (*right*)

Conclusion

This chapter begins with the definition of a general cognitive computation system and argues that the level of intelligence of the system can be measured by the extent to which *cognitive search can be more efficient* when knowledge is assembled to accomplish a goal. In massive collaboration, the level of collective intelligence can similarly be defined as the extent to which multiple users can reduce the cognitive search necessary for them to achieve a collective goal. Two important properties that are essential for improving the collective intelligence of such a system were discussed: effective representations and efficient search control knowledge.

I show how a social tagging system can have such properties. First, the user-tag-resource structure allows multiple users to contribute tags to the system to annotate information resources. Studies show that these tags tend to help establish the local-to-distal link to knowledge, making them efficient representations that facilitate explorative knowledge search. Second, users can utilize their general knowledge to incrementally improve their interpretation of social tags, allowing them to more efficiently search for relevant knowledge. This demonstrates that users can acquire control knowledge to guide the search process.

To conclude, the goal of this chapter is to argue from the perspective of a cognitive computation system that supporting cognitive search should be an important design goal for socio-technical systems that support massive collaboration. In particular, a socio-technical system should be designed to allow collaborative construction of structures that support effective representation of the search and information space, and these representations should provide enough search control knowledge for users to successfully explore the information space more intelligently. These two properties should therefore be considered essential features to be evaluated in the design of socio-technical systems, and the extent to which they support cognitive search should be empirically tested to inform how well they can support massive collaboration.

References

Cress, U., Feinkohl, I. Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, H. Jeong, & J. Moskaliuk (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fu, W.-T. (2008). The microstructures of social tagging: A rational model. In *Proceedings of the 2008 ACM Conference of Computer Supported Cooperative Work (CSCW 08)* (pp. 229–238). New York, NY: ACM.

Fu, W.-T. (2012). From Plato to the WWW: Exploratory information foraging. In P. M. Todd & T. Robbins (Eds.), *Cognitive search*. Cambridge, MA: MIT Press.

Fu, W.-T., & Dong, W. (2012). From collaborative indexing to knowledge exploration: A social learning model. *IEEE Intelligent Systems, 27*, 39–46.

Fu, W.-T., Kannampallil, T. G., Kang, R., & He, J. (2010). Semantic imitation in social tagging. *ACM Transactions on Computer-Human Interaction, 17*, 1–37.

Fu, W.-T., Kannampallil, T. G., & Kang, R. (2009). A semantic imitation model of social tag choices. In *Proceedings of the 2009 IEEE International Conference of Social Computing* (Vol. 4) (pp. 66–72). Los Alamitos, CA: IEEE Computer Society.

Galton, F. (1907). Vox populi. *Nature, 75*, 450–451.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227–234.

Newell, A. (1994). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

Pearl, J. (1984). *Heuristics: Intelligent search strategies for computer problem solving*. Boston, MA: Addison-Wesley.

Piaget, J. (1975). *The equilibration of cognitive structures*. Chicago, IL: University of Chicago Press.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies in discourse comprehension*. New York, NY: Academic.

Part III
Cases of Mass Collaboration

Patterns of Meaning in a Cognitive Ecosystem: Modeling Stabilization and Enculturation in Social Tagging Systems

Tobias Ley, Paul Seitlinger, and Kai Pata

Formation of Shared Meaning in Mass Collaboration Environments

Mass collaboration in education makes use of technology for scaling beyond a local context and beyond a small group of students. The idea is that technology frees the learning process from constraints of time and physical place and hence can scale up to large numbers of learners in a highly distributed setting. While initial attempts with using eLearning systems soon led to some disillusionment (Zemsky & Massy, 2004), it is now widely acknowledged that social software holds great potential for mass collaboration in education, as it can support dynamic collective knowledge generation (Dron & Anderson, 2014). Among many others, Dron and Anderson (2014) argue that social software can encourage social and active learning and knowledge creation over the distance. Through active engagement with conflicting and confounding ideas, social software encourages debate and cognitive conflict which is a prerequisite for learning.

There is also a wide agreement that scaling learning is a much more complex issue than just turning face-to-face interactions digital, as it involves changes on a number of dimensions (Ley et al., 2014). In this paper, we focus specifically on one of those dimensions, namely, on the problem of scaling meaning-making in highly distributed technology-mediated settings. The question is how shared understanding emerges in those settings when meaning is not simply bound to a predefined formal course structure or curriculum and learners enter into the learning situation from a number of highly diverse backgrounds. How does, for instance, a common

T. Ley (✉) • K. Pata
Center for Educational Technology, Tallinn University, Tallinn, Estonia
e-mail: tley@tlu.ee; kpata@tlu.ee

P. Seitlinger
Knowledge Technologies Institute, Graz University of Technology, Graz, Austria
e-mail: paul.seitlinger@tugraz.at

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_8

vocabulary come about if there are limited opportunities for direct face-to-face negotiations about its meaning.

In this chapter, we put forward a perspective that looks at learners and their shared artifacts as forming a cognitive ecosystem (Hutchins, 2010). We assume that a dynamic coupling exists between the learners and their shared artifacts. On the one hand, the artifacts influence students' learning. As social software allows cocreation of those artifacts, the artifacts also change their shape and structure which in turn supports or hinders the collaborative process of exploring and deepening the understanding of a particular topic. We look at communities of learners as a distributed cognitive system (Hutchins & Hazlehurst, 1995; see also chapter "From Distributed Cognition to Collective Intelligence: Supporting Cognitive Search to Facilitate Online Massive Collaboration" by Fu, 2016) in which social minds influence each other through mediating structure, and meaning is created by coordinating different structures (internal structures, artifactual structure, and physical structure). To some extent, these emergent structures embody the culture that has developed over the history of that cognitive system, and this culture constrains future behavior of the system and its individuals. For example, individual processes of sensemaking and categorization co-occur with a cultural process of pattern formation, where shared patterns form and individuals adapt to them.

We exemplify our view with results of recent empirical studies we have conducted in the context of social tagging. In social tagging, users of a shared Web environment can introduce freely chosen keywords to describe a resource without relying on a predefined vocabulary. It can be found in many diverse social Web environments (Cress, Held, & Kimmerle, 2013) including environments used for teaching and learning (Gao, 2013; Kuhn et al., 2012; Yew, Gibson, & Teasley, 2006). Social tagging is a typical functionality that supports "emergence" in social software (Dron & Anderson, 2014).

Imagine students get the task to write a short essay about the topic "What are the different ways to make use of Weblogs in university teaching?" Before they start writing, they are asked to make a research on the Web about different ways Weblogs have been used and what the experiences have been. They use a social bookmarking tool in which they assign keywords (tags) to resources they discover in that search. The bookmarking tool allows other students in the group to see the resources discovered by others and the tags that were assigned. Tags that describe particular subjects of study (e.g., "economics") or particular uses of Weblogs (e.g., "reflection," "learning diary") may come up. A tag introduced by one student might trigger another student to search for similar or other types of uses of Weblogs. The tags they use are a reflection of the categories the students learn over time as a result of sensemaking (e.g., Fu & Dong, 2012), but there is also a social process that is going on at the same time. Without an explicit coordination, the group might converge to using particular terms and categories, and this is what we would call a cultural process of pattern formation that is part of the meaning-making system on the group level (Stahl, 2013).

We think it is critical to understand this cultural pattern formation process and its relation to individual learning in mass collaboration. This is because there is a need to better support the generation of meaning in large communities of learners that work with shared artifacts in a shared environment. The main purpose of this chapter is therefore to put forward a cognitive ecosystem view on mass collaboration and explore how meaning emerges in those settings. We present an approach that formalizes this process as a tight coupling between human cognition and the environment, and we demonstrate how patterns of meaning emerge in communities of learners as a result. In each case, we will exemplify our ideas with empirical research that we have conducted in using social tagging technology. In the end, we discuss the implications of a cognitive ecosystem view on mass collaboration in education.

Patterns of Meaning in the Cognitive Ecosystem

Cognition in the Organism-Environment System

In the example of the student group using a social bookmarking system, we would regard the categories that students develop not as purely external (tags), nor as purely internal (mental), but instead as an "action-environment interface" (Barsalou, 2003) providing a mediating function for one unitary and inseparable "organism-environment system" (Järvilehto, 1998). According to Järvilehto (1998) and Clark & Chalmers (1998), a cognitive activity is not something located in the organism, but extends into the environment and takes place on a hybrid network of internal and external entities. And the environment is not something passively surrounding the organism but an active part of the cognitive system leading to the results of behavior. Referring to Albrechtsen, Andersen, Bødker, and Pejtersen (2001), who focus on a Gibsonian ecological psychology view, it is the very mutuality between actor and environment that constitutes the basis for the actor's perception and action. Hence, the primary unit of analysis is neither the actor nor the environment as distinct categories, but the total ecosystem of actors and environment. Similarly, Hollan, Hutchins, and Kirsh (2000) propose that people form a tightly coupled system with their environments, and the latter is part of a hybrid composition of internal and external resources evolved for adaptive problem solving.

For humans, it is not only the biological environment that is relevant, but instead we are embedded into a net of social relations that forms our cultural environment. While being rooted in the structures of our biological embodiment, our capacity of understanding is a result of ongoing interpretation of our environment within consensual action and cultural history (Varela, Thompson, & Rosch, 1991). Bereiter (2002) raises the questions: Where is knowledge if it isn't contained in individual minds? A question that is also considered in chapter "What Is Knowledge? Who Creates It? Who Possesses It? The Need for Novel Answers to Old Questions" by Oeberst, Kimmerle, and Cress (2016) The kind of answer coming from activity and situated cognition theorists runs along the following lines: Knowledge is not lodged in any physical or metaphysical organ. Rather knowledge inheres in social practices and in the tools and artifacts used in those practices.

These interactions of people and the resources in the environment can be considered as an emergent distributed cognitive system (Hollan et al., 2000; Paavola

& Hakkarainen, 2014; Stahl, 2013) where internal resources (memory, attention, executive function) and external resources (the objects, artifacts, and at-hand materials and software) are temporally integrated in goal-directed affordance networks that afford possibilities for adaptive actions (see Barab & Roth, 2006). The knowledge artifacts start functioning as the emergent interactional resources, which can mediate individual learning, group cognition, and community knowledge building (Stahl, 2012). Such interactional resources may be viewed not only as artifacts but as materially embodied entities that are worked on in various "external memory fields" (Donald, 1991) rather than reduced to their conceptual content only (Paavola & Hakkarainen, 2014). During long-term collective knowledge creation practices, shared knowledge artifacts are versioned and iteratively transformed from reified toward sedimented and institutionalized resources, and this can lead to forming cultural knowledge and practices (Paavola & Hakkarainen, 2014).

Collective and Epistemic Distributed Cognition

We may consider the community of learners in a mass collaboration environment as a distributed cognitive system (Hutchins & Hazlehurst, 1995) in which social minds influence each other through mediating structure, and meaning and action potentials are created by coordinating different structures (internal structures, artifactual structure, and physical structure). We want to stress two aspects of distributed cognition (see Fig. 1).

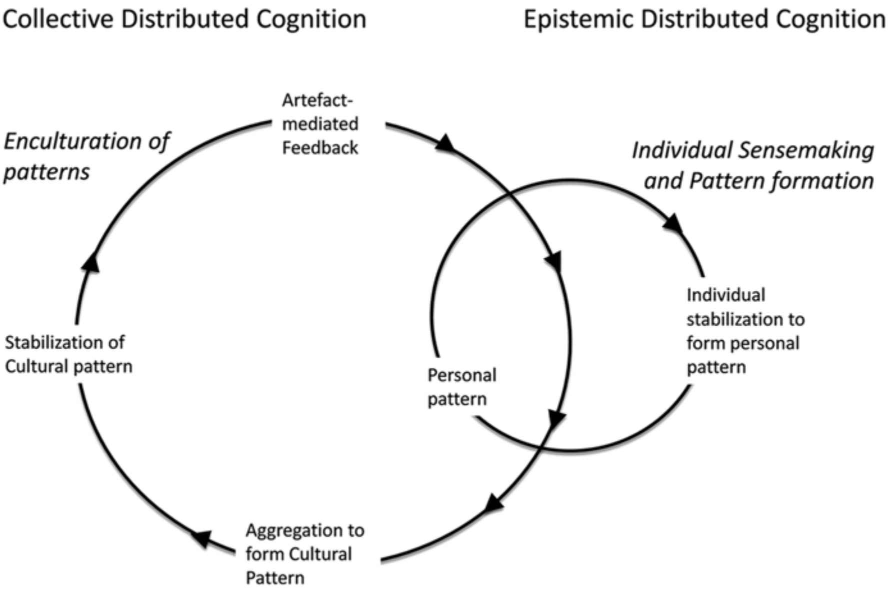


Fig. 1 Collective and epistemic distributed cognition as formation and stabilization of patterns

Epistemic distributed cognition (EDC, right circle) deals with the very activity of knowing and understanding the world one lives in which can only be attributed to individual agents who are the only ones that are endowed with attributes like intentions, beliefs, consciousness, and so on (Pata & Bardone, 2014). EDC builds on the idea that culture and the way we make sense of the environment and plan a course of action mutually influence each other and evolve through a dynamic interplay. In the example of the student group, EDC describes the way that individual students try to make sense of the resources they discover, categorize them, and assign tags to them.

On the other hand, "distributed" may be applied to cognition that relates with collective enaction and enculturation. Collective distributed cognition (CDC) targets what we refer to as ecological enculturation—collective patterns emerging from artifact-mediated EDC (Pata & Bardone, 2014), e.g., the common understanding that the students develop around the use of particular tags. This extends the traditional view of enculturation that highlights it as the process by which a person becomes acquainted with a given culture (or community of practice) (Wenger, 1998) and is related with how EDC is influenced by CDC. Magnani (2009) suggests that human beings act as an integral part of their environment while at the same time actively modifying and constructing this environment. Enculturation therefore refers to the fact that part of the environment can be enculturated, that is, modified so that it becomes potentially meaningful for certain purposes rather than others. And such enculturation would become visible in a social software environment used in the context of mass collaboration.

Patterns of Meaning

In summarizing the previous sections, mediating structure develops in communities of learners in a process of enculturation, and these collective processes shape individual knowing. The question now is how to capture and describe the regularities that emerge as a process of enculturation. Here, we develop the concept of a "pattern" for defining our unit of analysis. We use the term pattern because (1) it captures our view of cognition as a tight coupling between the person and its environment, and (2) it allows us to describe that coupling as an emergent process that is driven both by individual sensemaking and the meaning-making system in the collective (see Fig. 1).

We define a pattern as any regularity that organizes what we see in a consistent, regular manner. Effective problem solutions as well as meanings may be seen as kind of patterns, and culture propagates itself with patterns and pattern systems (Alexander et al., 1977). In the Soviet school of thinking, Ilyenkov (1977) has coined the idea of "ideality." He noted that objects acquire an ideal content for certain activities not as the result of being accessed by an individual mind but by the historically developing activities of communities of practice. The ideal as a pattern exists not in the individual mind but in the collective, as a set of given rules, practices, tools, and artifacts. Patterns are distributed in their nature and couple human cognition and environmental cues. Pattern formation processes apply both to epistemic distributed cognition (EDC) and collective distributed cognition (CDC), as well as to their interaction through coupling in pattern formation (Pata & Bardone, 2014).

Personally, we may put a pattern together from any kind of cues in the environment when we continuously interact with the environment while tackling particular problems or seeing the others doing it. The epistemic distributed cognition in an organism-environment system contains the loop of personal pattern formation as an individual sensemaking and stabilization process. In the example with the students, an individual pattern might be the tags that a student tends to use together with an understanding of the particular meaning that those tags ascribe to the collected resources. These individual patterns stabilize through repeated use, where the probability of repetition and thus, stabilization is mediated by cultural pattern appropriation. A collective or cultural pattern would then be a conceptualization that is shared among the whole group, for example, an agreement on using a particular tag in a certain way.

The notion of a pattern as a dynamic coupling of mental and environmental structures, which supports effective problem solving, shares similarities with the conceptualization of mental categories in the human conceptual system as environment-action interfaces (Barsalou, 2003). According to grounded cognition research (e.g., Kiefer & Barslaou, 2013), a mental category is a dynamic system that allows mapping environmental constellations on goal-directed actions. In case of tagging a resource (e.g., an article), a user is assumed to activate a set of mental categories to make sense of it (Fu & Dong, 2012). These categories then allow mapping semantic features (topics) on word forms (tags) that are sufficient to index the categories and to retrieve the resource in the future (Seitlinger, Ley, & Albert, 2015). Seen from such an angle, patterns in social bookmarking systems are environment-action mappings that emerge, i.e., become encultured through tag-mediated user interactions within the shared environment.

In the following section, we develop the idea of patterns of meaning further. Initially, what we mean by "pattern" remains fairly vague. We use a first empirical study of a student group using a social bookmarking system to merely illustrate what a pattern could be in our view. While the study was conducted in a traditional course setting, we introduced a distributed learning task as commonly found in mass collaboration settings, i.e., a Web search and sensemaking task where students collaborated only via the social bookmarking tool through which they were made aware of what other students were doing. We show how social tags to some extent capture the *enculturation processes of a group of learners* and how the collective patterns that develop as a result of this enculturation constrain and enable individual learning.

Later, we then develop a formal specification of a pattern using connectionist networks, a modeling technique that allows modeling the emergence of patterns in an interconnected network of simple units. The pattern then is a particular configuration of connectivity and activation in that network that connects an agent to its environment and to other agents. This allows us to simulate how *individual* *formation and appropriation of categories that is mediated by communication through shared artifacts leads to a collective enculturation process.*

Toward a Cognitive Ecosystem View: Three Cases of the Study of Social Tagging

Study 1: Stabilizing Patterns on the Collective Level Have an Impact on Individual Learning

In a study that we conducted as part of a university course, we explored how patterns develop and influence individual cognitive processing when smaller groups of students (5–6 persons randomly assigned to each group) use a social bookmarking system (Ley & Seitlinger, 2015). Much like in the example presented in the introduction, we examined how the students developed categories over time as a result of collecting and tagging resources. We observed the categories students developed by looking both at the tags the students used in the system and the associations they produced in a free association test when the tags were presented to them as cues (as a measure of the strength of representation in memory). As it is usually assumed that students engage in a sensemaking task when they iteratively search for resources and produce tags (e.g., Fu & Dong, 2012), we expected that over time students would switch from general (basic-level) to more specific categories, a phenomenon known as the basic-level shift (Rosch et al., 1976).

This first assumption was confirmed as we observed that over time more specific tags were used by the students. And in line with the view that patterns describe a coupling between environmental and internal structures, the strength of memory representations for tags was a function of how much those tags were used in the tagging system: the group of students exhibiting a more pronounced basic-level shift produced more associations to specific tags than the other group.

In that study, we had a further assumption which was related to a group-level variable. We assumed that individual sensemaking (the individual basic-level shift) would be mediated by how quickly and effectively the whole group of students formed shared and stable patterns of categorization. In doing so, we focused on semantic stabilization, which describes a lexical convergence, i.e., a stronger consensus on the use of particular words within the group (e.g., Steels, 2006; Wagner, Singer, Strohmaier, & Huberman, 2014). According to Bollen and Halpin (2009), these stabilization processes can be observed even if no direct interaction between the users of these systems is possible (e.g., people only see their own tags), but it is intensified when people see the tags that others have used.

We had formed two conditions, one which contained those groups of students that more successfully converged to a common vocabulary (high semantic stabilization) and another condition where groups were less successful (low semantic stabilization). Figure 2 shows the results. While in both conditions students used increasingly more specific terms over time, this basic level shift was much

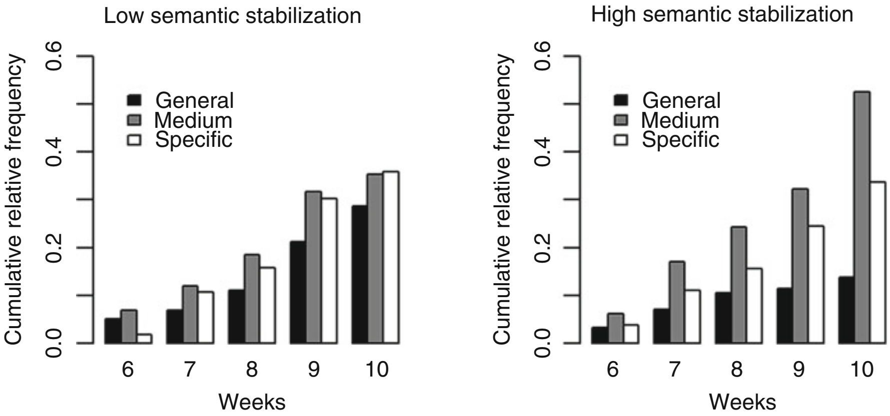


Fig. 2 Relative frequency of tags used on three levels of specificity in the low semantic stabilization condition (*left*) and the high semantic stabilization condition (*right*) (see Ley & Seitlinger, 2015)

more pronounced for those groups with higher degrees of semantic stabilization. This pattern was the same for the association test as well.

We take the results of this study as first evidence that the development of individual categories (that we conceptualize as personal patterns) was mediated by pattern formation processes on the collective level. Individual differentiation of the resources found (both in tag use and in the associations) took place more successfully if semantic stabilization as a form of collective pattern formation had taken place in the group. Hence, we observed a situation in which the formation of cultural patterns on a collective level (the agreed use of particular words) that was mediated by the use of the tagging service had an impact on the differentiation of individual categories.

This first study has illustrated some of our thinking around how categories emerge when students interact through shared artifacts in a social bookmarking environment. Of course, there are a number of limitations to this study, including the question of how a setting of small (partly collocated) groups can be generalized to the situation of a mass collaboration environment. The theoretically more troublesome limitations of this study can be seen in the fact that although we were interested in the emergence of patterns, the design of this study only allowed us to take very simplistic snapshots of the state of the system at various points in time. First, the "patterns" in this first study revealed themselves through the tags that were used and the associations produced when cued for those tags. This is of course a rather simplistic account of the categories that we assumed to have emerged as a result of this activity that mediated both individual sensemaking and the emergence of meaning at the group level.

Second, and maybe even more troublesome, the design only allowed us to take snapshots when we actually wanted to examine how students' interactions (when they encode tags and the content of resources, interpret the meaning of these, and verbalize them) lead to emergent behavior in the system as a whole. The next two studies will therefore address these shortcomings. The second study will introduce a more refined and formal definition of the pattern of meaning that we assumed to emerge as a result of student interaction. And the third study will then allow us to simulate the behavior of the whole cognitive ecosystem.

Study 2: Formalizing Patterns of Meaning in Social Tagging by Means of Connectionist Networks

With this second study, our intention was to introduce a more refined and formal structure of a "pattern" that we have informally defined in the previous section. Here, we regard a pattern as a process that maps environmental structure (i.e., features of the resources students discover, e.g., the fact that a website talks about "Weblogs") on artifactual structure (i.e., the tags they use, e.g., the term "Weblog" they assign to that website in the social bookmarking system). The pattern also includes the mediating mental structure that provides this mapping as an interface between a user's environment and her goal-directed actions (e.g., Barsalou, 2003). Hence, these patterns are a way to model the mapping processes during tagging in form of patterns of associations between environmental, mental, and artifactual entities. In particular, we look at how these patterns evolve as users (1) search for and make sense of new resources and (2) mutually influence each other through artifactual structure when using a social bookmarking system.

To formalize the evolving patterns, we follow the work of Fu and Dong (2012) and apply a clustering model of human categorization. This approach is well suited to capture how people learn from statistical regularities in the environment (i.e., feature correlations) in form of an evolving cluster structure (Love, Medin, & Gureckis, 2004). Similar to the human conceptual system, a clustering model starts simple with only a few categories (clusters) and tries to interpret new environmental information by assigning it to existing categories. Only if the model encounters "surprising" information that does not fit into existing categories, it recruits a new one. Continuing with the social bookmarking example, a student who has mainly bookmarked and tagged resources dealing with the positive impact of Weblogs in university teaching might have developed a structure of clusters that needs refinement (e.g., a new subcluster) to integrate information revealing negative experiences in teaching in such distributed settings.

Applying SUSTAIN to formalize a pattern. Figure 3 shows a categorization network that is based on the clustering model SUSTAIN (Love et al., 2004) and propagates information about a resource *R* (e.g., a website describing the use of Weblogs in a particular course) across different layers of interconnected units. The input layer characterizes *R* along a set of resource dimensions. In the figure, each rectangle symbolizes a particular dimension *i* (e.g., challenges of using Weblogs), the small circles (units) represent potential features on *i* (e.g., loss of control, information overload, etc.), and the black-filled circles indicate activated units, i.e., features

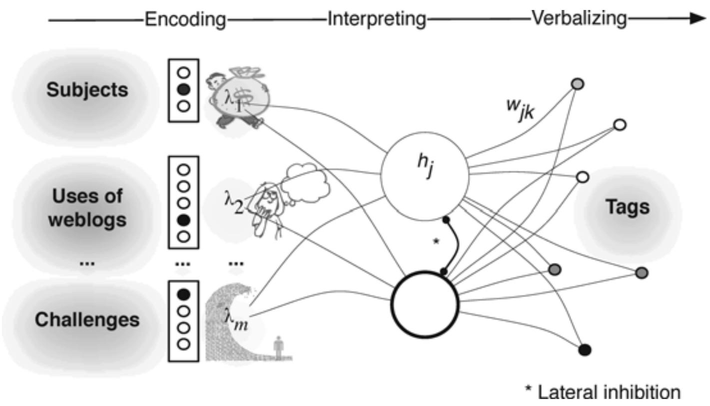


Fig. 3 SUSTAIN network processing information along interconnected layers of input (encoding), hidden (interpreting), and output units (verbalizing)

that are true for the given resource. The activation of each unit is gated by the attentional weight λ_i of the corresponding dimension i, which is learned as the network encounters new resources and reflects the dimension i's relevance for the tagging task. The network interprets R by assigning the gated input pattern to the most similar cluster h_j at the hidden layer. Each cluster has a particular position in the multidimensional space, which represents its members and, thus, slightly changes when the new resource is assigned to it. Specifically, a cluster captures the probability of displaying certain features given that a resource is a member of the cluster. The verbalization of the categorized input takes place through the associations w_{jk}, which spread activation from the chosen cluster to the output units k that represent the tags (e.g., "Weblog," "information overload," "criticism"). Finally, the emerging output activation is turned into a probability distribution from which tags are chosen. Summarizing, the whole network stores distinct patterns of feature-tag mappings by means of a mediating cluster structure, which connects environmental information with responses in form of tags.

We believe that these patterns, which span λ_i, h_j, and w_{jk}, arise as a user tries to make sense of resources and interacts with other users through tags. Before applying SUSTAIN to model and simulate this form of cognition being distributed across people, tags, and resources, we checked for its validity in the context of social bookmarking systems. While the model provides a good account of human category learning to be observed in laboratory experiments (e.g., Love et al., 2004) and neuroimaging studies (e.g., Davis, Love, & Preston, 2011; Love & Gureckis, 2007), it is not clear whether it accounts for social tagging too, i.e., categorization under natural conditions (Glushko, Maglio, Matlock, & Barsalou, 2008). To explore this question of generalizability, we tried to predict real tagging behavior in large-scale social tagging datasets by means of *3Layers* (Seitlinger, Kowald, Trattner, & Ley, 2013) that is a tag recommendation model based on ALCOVE (Kruschke, 1992) that – in contrast to SUSTAIN – forms an exemplar at the hidden layer for each encountered resource.

Empirical validation of a SUSTAIN-based pattern formalization. The evaluation of tag predictions is usually performed offline by means of a large-scale social tagging dataset (e.g., Jäschke, Marinho, Hotho, Schmidt-Thieme, & Stumme, 2007). For a given user, a particular portion (e.g., 80 %) of her collected bookmarks is used to form a training set and to observe her tagging behavior. Based on the training set, a user model is built in order to predict the tag assignments in the test set, which includes the remaining portion (e.g., 20 %) of the user's bookmarks. Then, the observed and predicted tag assignments are compared by means of standardized evaluation metrics, such as *recall* (the number of correctly predicted tags divided by the number of true tags), *precision* (number of correctly predicted tags divided by the number of predicted tags), and the *F*-score (the weighted harmonic mean of *precision* and *recall*).

We used a dataset of *Delicious* bookmarks of Wikipedia articles (for a more detailed description, see Seitlinger et al., 2013). Each article was described by a subset of 24 Wikipedia top-level categories (e.g., "social science") that provided the nominal resource dimensions. The different bookmarks in the training set, in particular, the bookmarks' categories, were used to train *3Layers* with respect to the user-specific attentional weights λ_i as well as the user-specific structure of clusters h_j. In this study, the associations w_{jk} were simply estimated based on the co-occurrence frequency of cluster j and tag k in the user's training set. The results are shown in Fig. 4 where the performance of *3Layers* is compared with a well-established tag recommender based on latent Dirichlet allocation (LDA) (Krestel, Fankhauser, & Nejdl, 2009). Both in terms of *precision*/*recall* (left panel) and the *F*-score (right panel), 3Layers reaches higher estimates than the LDA algorithm ($F_{1,1966} = 17.38$, $p < 0.001$).

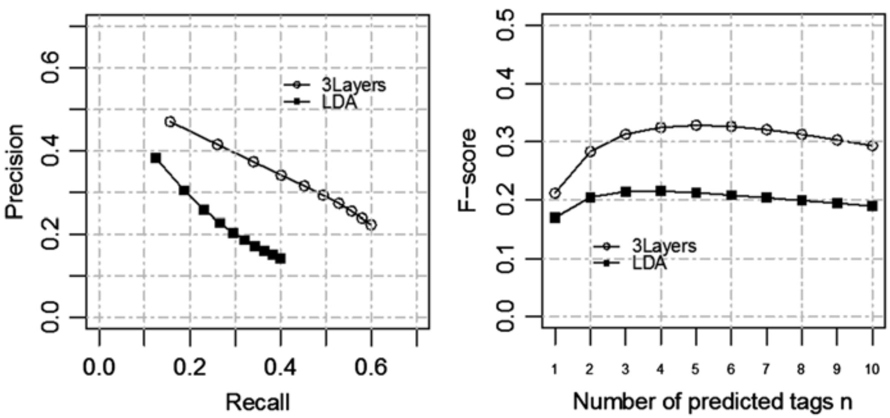


Fig. 4 Accuracy of tag predictions based on a connectionist network (3Layers) and a topic model (LDA) in terms of precision/recall and the F-score. (*Note*: All three metrics are calculated for a varying number n (1–10) of predicted tags resulting in 10 points per line)

From these results, we conclude that the model also accounts for categorization behavior under natural conditions and seems to provide a valid connectionist formalization of user-specific patterns. In a next step, we applied this formalization in order to model the formation of patterns as a socio-cognitive process distributed across users, resources, and artifacts. The goal of Study 3 was to represent artifact-mediated influences between users of social tagging functionality in form of a community of SUSTAIN networks, which also interacted through artifacts, and to use this multi-agent representation to simulate the emergence of stable patterns.

Study 3: The Emergence of Patterns of Meaning in Communities of Learners

In a social bookmarking system, tags left by some users influence others' browsing behavior (e.g., Kang, Fu, & Kannampallil, 2010) that in turn shapes their thoughts and associations to the items (e.g., Held, Kimmerle, & Cress, 2012; chapter "Mass Collaboration as Coevolution of Cognitive and Social Systems" by Cress, Feinkohl, Jirschitzka, & Kimmerle, 2016). From this follows a dynamic interplay between mental and artifactual structure because the shaped thoughts also influence future tag assignments. This interplay is assumed to be at the heart of the emergence of meaning in social tagging. According to Bollen and Halpin (2009) and Halpin, Robu, and Shepherd (2007), the emergence of stable patterns, e.g., of consensus in tagging resources, is also coordinated by artifactual structure (e.g., tag clouds and recommendations) that influences the users' mental structure (e.g., aspects of the meaning attributed to the things to which the tags refer).

We assume that the patterns and their emergence can be revealed by modeling the processes by which these different structures get coupled. The pattern comprises the thing-meaning-form associations that emerge in a discursive process. In such a discourse, individuals try to align socially shared word forms with their interpretations of things in the environment (e.g., Puglisi, Baronchelli, & Loreto, 2008). According to semiotic assumptions about an evolving intersubjectivity (shared understanding, e.g., Arroyabe, 1984) as well as empirical studies on peoples' motives to imitate each other (e.g., Wisdom & Goldstone, 2011), it can be assumed that alignment takes place because people aim at increasing intersubjectivity: people reinforce the behavior of others if this behavior indicates that the others talk about similar things (see also Hutchins and Johnson (2009) on reinforcement learning and its impact on the emergence of human language).

Emergent phenomena that involve socio-cognitive and material aspects have been studied in psychology applying a community of networks (Hutchins & Hazlehurst, 1995) or talking net (Van Overwalle & Heylighen, 2006) approach (for a review see Hutchins & Johnson, 2009). Each individual of the community is modeled as a connectionist network that learns to represent and symbolize environmental regularities. The development of the mental structure that allows for the representation and symbolization is influenced by the symbolizations (artifacts) of other networks that change environmental regularities and provide additional feedback. Hence, the community of network approach implements the distributed cognition assumption that individuals coordinate their development of representations by means of artifactual structure that "is a bridge between internal structures" (Hutchins & Hazlehurst, 1995, p. 163).

Therefore, we applied the community of network approach and simulated a community of SUSTAIN networks that processed and tagged several resources (again Wikipedia articles), were influenced by the tags assigned by previous networks (e.g., through tag clouds and recommendations), and developed particular mental structures (e.g., attentional weights, clusters, and word associations). The goal was to simulate the emergence of stable patterns, i.e., semantic stabilization (see Study 1). Our measure for semantic stabilization was derived from Halpin et al. (2007) who looked at particular resources that were bookmarked and tagged several times and observed that the tag frequency distribution that was associated with those resources stabilizes very quickly. After a few bookmarks, the difference between the distribution at time t and time t + *x*, which is measured by the Kullback-Leibler distance, gets very small.

Figure 5 illustrates our community of network approach applied to social tagging: At time t_1, user x (an individual SUSTAIN network) encounters a particular resource R_a. In a process described above, user x categorizes R_a and assigns a set of personal tags TAS_x to it (see circled number 1). TAS_x changes the tag distribution associated with R_a of which the seven most popular tags (MPT) of R_a are visible for all users (number 2). The displaying of MPT in the environment represents the artifactual structure through which the community influences its members. In the next time step t_2, user y (another individual SUSTAIN network) encounters the same resource R_a, categorizes and tags it (number 3) with individual tags TAS_y, which in turn

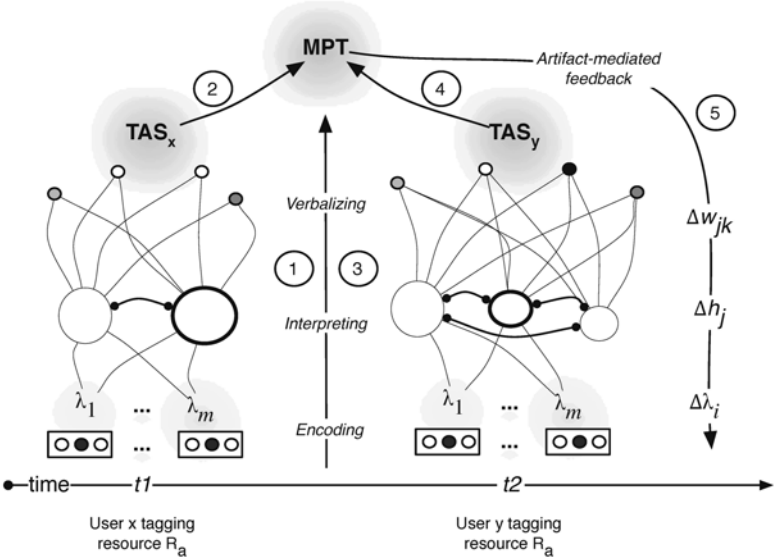


Fig. 5 Community of network approach to simulate stabilization in social tagging

influence MPT (number 4). We assume that MPT provides an artifact-mediated feedback that slightly changes user y's mental structure to a certain amount (see the delta symbols at number 5) through a process described in the following.

We regard the act of tagging as retrieval from (semantic-lexical) memory. Research on human memory shows that people tend to strengthen the associations just activated through a learning process called output encoding (e.g., Rizzuto & Kahana, 2001). In the current simulation, we implemented the assumption that MPT mediates this output encoding in such a way that changes in mental structure ($\Delta\lambda_i$, Δh_j, and Δw_{jk}) are greater the higher the overlap between TAS and MPT is.

We conducted 100 simulation runs, each comprising 50 users and 300 resources. Figure 6 shows the average results of stabilization in terms of the Kullback-Leibler divergence (KLD) and indicates a process similar to the empirical one observed by Halpin et al. (2007): The tag distribution of a given resource changes strongly at early points in time (as indicated by high KLD values) but converges on a stable state after only a few bookmarks.

We conclude that the socio-cognitive process illustrated in Fig. 5, by which different individuals coordinate the development of patterns (comprising λ_i, h_j, and w_{jk}), provides a valid model of complex dynamics in social tagging resulting in stabilization. From a more general perspective, we believe that the community of network approach embedded into distributed cognition provides a powerful theoretical and computational framework to increase our understanding of emergent phenomena in mass collaboration. In the past, this approach has been successful to reconstruct aspects of human language development (e.g., Hutchins & Johnson, 2009) as well as key phenomena of social influence, such as opinion formation or spreading of stereotypes (Van Overwalle & Heylighen, 2006). The current results of Study 3 imply that it can also contribute to our understanding of key phenomena in social tagging and probably in mass collaboration in general.

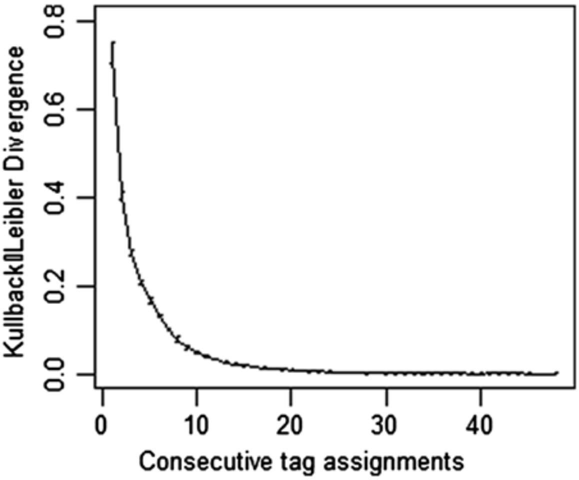


Fig. 6 Simulated stabilization in social tagging measured by the Kullback-Leibler divergence (relative entropy)

Insights from the Studies for a Cognitive Ecosystem View

Taking the perspective of a cognitive ecosystem means to view technology not only as a means for learning at a distance or increasing the reach of learning to larger masses of people. Instead, this view suggests that technology itself takes an active part in the learning process. The use of a particular technology in the context of mass collaboration that allows easy sharing of resources and interpretations around them (e.g., the social bookmarking system) makes it possible that far greater numbers of people can participate in and contribute to meaning-making processes than in a face-to-face setting.

The perspective of a cognitive ecosystem assumes a tight coupling between humans and the artifacts they create. As a result, human sensemaking is mediated by cultural patterns that evolve as a result of collective activity. Figure 7 shows our understanding of collective and epistemic distributed cognition as it relates to social tagging as a highly dynamic interactive process. Individual sensemaking happens through the learning of categories that guide encoding, interpreting, and verbalizing as formalized by our SUSTAIN model (e.g., the categories and tags that learners use to make sense of the encountered bookmarks). Stabilization on the individual level happens by repeated engagement with these categories. At the same time, the social bookmarking system aggregates tags, and this contributes to the formation of cultural patterns (e.g., semantic stabilization in the use of tags). Individual categories are then influenced and reinforced by those cultural patterns through artifact-mediated feedback (e.g., the most popular tags visualized by the system).

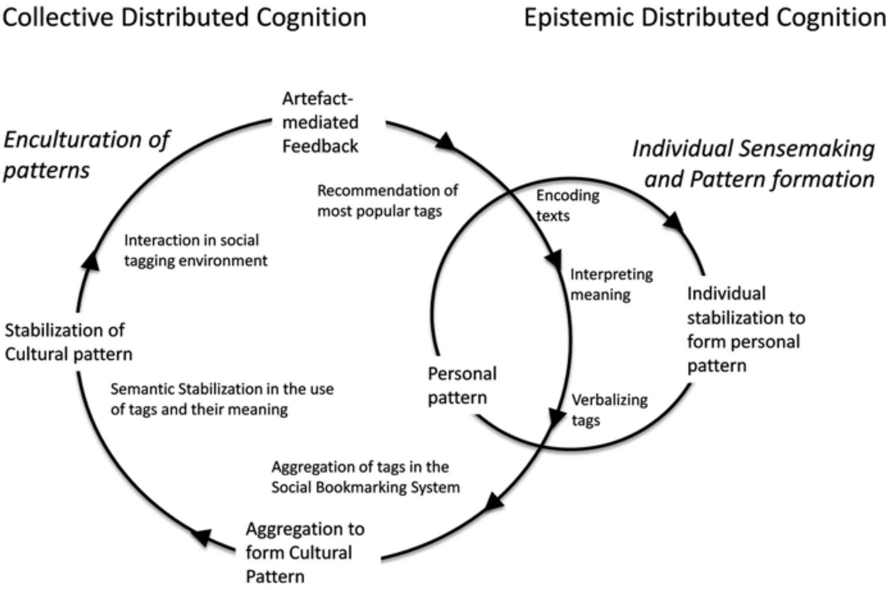


Fig. 7 Coupling in pattern formation between collective and epistemic distributed cognition

The three studies we have reported above have contributed some key insights around this understanding. In Study 1, we found that *individual stabilization co-occurs with processes of enculturation*. Students that used social tagging technology formed stronger associations for specific concepts when semantic stabilization was more pronounced on the group level. In Study 2, we showed that *artifact-mediated activity leads to formation and stabilization of individual patterns*. By training a connectionist network that learns categories from individual tagging behavior, we were able to predict interpretation and verbalization of new tags by those same individuals. Finally, in Study 3, we showed how *collective stabilization is a result of individual pattern formation and artifact-mediated social feedback*. In this study, we showed how semantic stabilization in social tagging can be modeled as a process of individual sensemaking (interpreting and verbalizing tags) and the feedback through most popular tags displayed in a social bookmarking environment.

Certainly, the studies we have reported here are only initial steps into understanding mass collaboration as an artifact-mediated cognitive ecosystem. While we have based our approach on a validated model of human categorization (SUSTAIN), Studies 2 and 3 have used a simulation approach to validate the adaptation of the model to a situation of social tagging. Clearly, additional validation studies are necessary that would relate predictions of the model to observed behavior and also compare this approach to potential alternatives. The purpose of the present chapter has been to operationalize some of the assumptions of dynamic coupling and emergence. We believe that this perspective needs new models and new methods that truly reflect the dynamic and interactive character of the assumed system with its constant feedback. We have presented connectionist models and simulation studies to complement purely experimental research designs that are necessarily limited in their attempt to identify cause and effect relationships through analyzing social interaction as isolated events (see Wisdom and Goldstone (2011) for a similar argument).

Implications for Mass Collaboration in Education

What follows from this view of meaning-making as a pattern formation process in the cognitive ecosystem for the design of mass collaboration environments? A development that has recently received a lot of attention in mass collaboration in education is the movement toward massive open online courses (MOOCs). In MOOCs, learners come from different contexts and have different open goals, and they use, share, and create digital contents (Gillet, 2013) that could open new potentials for collective meaning-making. Many of the mainstream xMOOC platforms stemming from open courseware just continue directing massive numbers of learners along predefined learning paths and resources to perform individual assignments. Due to big numbers of learners, xMOOCs rather do not make use of the different perspectives the learners bring to the courses, and collective meaning-making potential is unused. Alternatively, connectivist MOOCs (cMOOCs) that support learning with personal social learning environments emphasize making connections between learners with similar interests. The problem in cMOOCs is discovering from the mass these resources and learning partners that allow meaning-making that is of interest to particular learners.

Both MOOC approaches require mechanisms to promote collective meaning-making, and Dron and Anderson (2014) have proposed "set-based learning" to address this issue where a set is defined by intentional engagement around a topic. The set may be a set of students who have similar preferences to courses they take in MOOCs; also a set may be defined based on what resources students share and create at MOOCs. Much set-based learning occurs "just in time," concerned with finding out something of value to the learner now, rather than a continuing path. The set will represent a range of perspectives and views of the subject, which together will offer diverse opportunities to connect existing knowledge to new discoveries. Learners in the set will not necessarily discover each other but are learning in a mutually shared collective distributed cognitive field.

In MOOCs, these sets would be the setting where patterns of meaning emerge among the participating students, much in the same way as we observed it in the classroom setting of our first study. Some of these patterns may be amplified by means of technology. The recommender technology that is based on most popular tags is one example of such a feedback mechanism. However, current MOOCs do not yet provide support in discovering the sets, identifying patterns and amplifying them by providing feedback. So we see some of the technology that becomes possible by means of modeling the cognitive ecosystem as a way to promote set-based learning in MOOCs.

If we take the view that technology plays an active role in amplifying some of the interpretations among the community of learners that evolve in the cognitive ecosystem, then it is important to consider how technology actually represents or models those interpretations. In this chapter, we have suggested connectionist networks as a means to model the process of understanding in line with a cognitive ecosystem view. We find these particularly appropriate because they formalize patterns as the coupling in the organism-environment systems, and it is possible to model a pattern formation and stabilization processes. Recommender technology built upon connectionist networks (e.g., Seitlinger et al., 2013) would therefore especially support *knowledge creation* (see Paavola and Hakkarainen (2005) for three metaphors of learning) in mass collaboration.

In contrast, the use of symbolic knowledge representation (as found in the use of semantic Web technology in MOOCs, e.g., Shatnawi, Gaber, & Cocea, 2014) tries to predefine particular learning goals and paths. It is therefore more related to the *knowledge acquisition* metaphor of learning. Accordingly, we see the recent widespread trend to apply the use of social network analysis to learning environments in mass collaboration (see, e.g., Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2013; Rabbany, Elatia, Takaffoli, & Zaïane, 2013; chapter "Applying Network Models and Network Analysis Techniques to the Study of Online Communities" by Hoppe, Harrer, Göhnert, & Hecking, 2016; chapter "Theoretical and Empirical Analysis of Networked Knowledge" by Halatchliyski, 2016) as related to the *participation* metaphor of learning.

Conclusions and Outlook

Mass collaboration environments in education are characterized by a highly distributed setting where learner interactions are mediated by means of different types of tools and artifacts. In this chapter, we have shown that if learning in those settings should take place, then we need to ensure that shared patterns of meaning emerge. We have demonstrated that social tagging can be used as a technology to study and support this pattern formation process. We have studied connectionist networks as a way to formalize this pattern formation process as they track the formation of categories over time as learners interact with resources and tags. These networks can also be used to recommend tags as a way to amplify emerging patterns that have evolved in the community.

Viewed from a material-semiotic perspective (e.g., Law, 2007), however, we should also take a critical look at the formation of patterns, such as thing-meaning-form associations, which tend to stabilize quickly in social information systems (see Halpin et al., 2007; Wagner et al., 2014; and Study 3), sometimes even without recommendations of tags (e.g., Bollen & Halpin, 2009). The emergence of patterns may also be regarded as a discourse (in a post-structuralist sense), i.e., a process by which a particular understanding of reality comes into being. Each discourse defines conditions of epistemic possibility and "cannot recognize certain kinds of realities" (Law, 2007, p. 151). Hence, there may be a strong need for technology that supports a multi-discursive ordering, i.e., leaves room for the emergence of distinct patterns to help people developing integrative viewpoints (such as those we have proposed in relation to set-based learning in MOOCs). If technology only aims at stabilizing patterns, we may run the risk of realizing mass collaboration where people get stuck in crystallized and consensual understandings of reality.

References

Albrechtsen, H., Andersen, H. H. K., Bødker, S., & Pejtersen A. M. (2001). Affordances in activity theory and cognitive systems engineering. Roskilde, Denmark: Forskningscenter Risoe. Risoe-R; No. 1287(EN).

Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Friksdahl-King, I., & Angel, S. (1977). *A pattern language: Towns, buildings, construction*. New York, NY: Oxford University Press.

Arroyabe, E. (1984). *Semiotik und Literatur: Philosophische Probleme der Literatur*. Bonn, Germany: Bouvier.

Barab, S., & Roth, W. M. (2006). Intentionally-bound systems and curricular-based ecosystems: An ecological perspective on knowing. *Educational Researcher, 35*, 3–13.

Barsalou, L. W. (2003). Situated simulation in the human conceptual system. *Language and Cognitive Processes, 18*, 513–562.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ: Lawrence Erlbaum Associates.

Bollen, D., & Halpin, H. (2009). An experimental analysis of suggestions in collaborative tagging. *Web Intelligence and Agent Systems, 11*, 41–53.

Clark, A., & Chalmers, D. J. (1998). The extended mind. *Analysis*, 58, 10–23.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cress, U., Held, C., & Kimmerle, J. (2013). The collective knowledge of social tags: Direct and indirect influences on navigation, learning, and information processing. *Computers & Education, 60*, 59–73. doi:10.1016/j.compedu.2012.06.015.

Davis, T., Love, B. C., & Preston, A. R. (2011). Learning the exception to the rule: model-based fMRI reveals specialized representations for surprising category members. *Cerebral Cortex, 22*, 260–273.

Donald, M. (1991). *Origins of the modern mind: Three stages in the evolution of culture and cognition*. Cambridge, MA: Harvard University Press.

Dron, J., & Anderson, T. (2014). *Teaching crowds: Learning and social media*. Athabasca, Alberta, Canada: Athabasca University Press.

Fu, W.-T. (2016). From distributed cognition to collective intelligence: Supporting cognitive search to facilitate online massive collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Fu, W.-T., & Dong, W. (2012). Collaborative indexing and knowledge exploration: A social learning model. *IEEE Intelligent Systems*, *27*, 39–46. Retrieved from http://doi.ieeecomputersociety.org/10.1109/MIS.2010.131

Gao, F. (2013). A case study of using a social annotation tool to support collaboratively learning. *The Internet and Higher Education, 17*, 76–83. doi:10.1016/j.iheduc.2012.11.002.

Gillet, D. (2013). Personal learning environments as enablers for connectivist MOOCs. *Proceedings of the 12th International Conference on Information Technology Based Higher Education and Training (ITHET), Oct 2013* (pp. 1–5). Antalya, Turkey: IEEE.

Glushko, R. J., Maglio, P. P., Matlock, T., & Barsalou, L. W. (2008). Categorization in the wild. *Trends in Cognitive Science, 12*, 129–135. doi:10.1016/j.tics.2008.01.007.

Halatchliyski, I. (2016). Theoretical and empirical analysis of networked knowledge. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Halatchliyski, I., Moskaliuk, J., Kimmerle, J., & Cress, U. (2013). Explaining authors' contribution to pivotal artifacts during mass collaboration in the Wikipedia's knowledge base. *International Journal of Computer-Supported Collaborative Learning, 9*, 97–115. doi:10.1007/s11412-013-9182-3.

Halpin, H., Robu, V., & Shepherd, H. (2007). The complex dynamics of collaborative tagging. In C. Williamson & M. E. Zurko (Eds.), *Proceedings of the 16th International Conference on World Wide Web* (pp. 211–220). New York, NY: ACM Press.

Held, C., Kimmerle, J., & Cress, U. (2012). Learning by foraging: The impact of individual knowledge and social tags on web navigation processes. *Computers in Human Behavior, 28*, 34–40.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction, 7*, 174–196. doi:10.1145/353485.353487.

Hoppe, H. U., Harrer, A., Göhnert, T., & Hecking, T. (2016). Applying network models and network analysis techniques to the study of online communities. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Hutchins, E. (2010). Cognitive ecology. *Topics in Cognitive Science, 2*, 705–715.

Hutchins, E., & Hazlehurst, B. (1995). How to invent a lexicon: The development of shared symbols in interaction. In N. Gilbert & R. Conte (Eds.), *Artificial societies: The computer simulation of social life* (pp. 157–189). London, England: UCL Press.

Hutchins, E., & Johnson, C. M. (2009). Modeling the emergence of language as an embodied collective cognitive activity. *Topics in Cognitive Science, 1*, 523–546.

Ilyenkov, E. (1977). *Problems of dialectical materialism* (Translated by A. Bluden). Retrieved from http://www.marxists.org/archive/ilyenkov/works/ideal/ideal.htm

Järvilehto, T. (1998). The theory of the organism-environment system: I. Description of the theory. *Integrative Physiological and Behavioral Science, 33*, 321–334. doi:10.1007/BF02688700.

Jäschke, R., Marinho, L. B., Hotho, A., Schmidt-Thieme, L., & Stumme, G. (2007). Tag recommendations in folksonomies. In J. N. Kok, J. Koronacki, R. L. de Mántaras, S. Matwin, D. Mladenic, & A. Skowron (Eds.), *Knowledge Discovery in Databases: PKDD 2007, 11th European Conference on Principles and Practice of Knowledge Discovery in Databases, Warsaw, Poland, September 17–21, 2007, Proceedings* (Vol. 4702, pp. 506–514). Heidelberg, Germany: Springer.

Kang, R., Fu, W.-T., & Kannampallil, T. G. (2010). Exploiting knowledge-in-the-head and knowledge-in-the-social-web: Effects of domain expertise on exploratory search in individual and social search environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI'10* (pp. 393–402). New York, NY: ACM Press.

Kiefer, M., & Barslaou, L. W. (2013). Grounding the human conceptual system in perception, action, and internal states. In W. Priz, M. Beisert, & A. Herwig (Eds.), *Action science: Foundations of an emerging discipline* (pp. 381–407). Cambridge, MA: MIT Press.

Krestel, R., Fankhauser, P., & Nejdl, W. (2009). Latent dirichlet allocation for tag recommendation. In *Proceedings of the third ACM conference on Recommender systems* (pp. 61–68). New York, NY: ACM-Press.

Kuhn, A., McNally, B., Schmoll, S., Cahill, C., Lo, W.-T., Quintana, C., & Delen, I. (2012). How students find, evaluate and utilize peer-collected annotated multimedia data in science inquiry with zydeco. In *Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems—CHI'12* (pp. 3061–3070). New York, NY: ACM Press. doi:10.1145/2207676.2208719

Law, J. (2007). Actor network theory and material semiotics. In B. S. Turner (Ed.), *The new Blackwell companion to social theory* (pp. 141–158). Chichester, England: Wiley-Blackwell.

Ley, T., Cook, J., Dennerlein, S., Kravcik, M., Kunzmann, C., Pata, K., … Trattner, C. (2014). Scaling informal learning at the workplace: A model and four designs from a large-scale design-based research effort. *British Journal of Educational Technology*, *45*, 1036–1048. doi:10.1111/bjet.12197

Ley, T., & Seitlinger, P. (2015). Dynamics of human categorization in a collaborative tagging system: How social processes of semantic stabilization shape individual sensemaking. Computers in Human Behavior, 51, 140–151. doi:10.1016/j.chb.2015.04.053.

Love, B. C., & Gureckis, T. M. (2007). Models in search of a brain. *Cognitive, Affective, & Behavioral Neuroscience, 7*, 90–108.

Love, B. C., Medin, D. L., & Gureckis, T. M. (2004). SUSTAIN: A network model of category learning. *Psychological Review, 111*, 309–332.

Magnani, L. (2009). *Abductive cognition. The epistemological and eco-cognitive dimensions of hypothetical reasoning*. Berlin, Germany: Springer.

Oeberst, A., Kimmerle, J., & Cress (2016). What is knowledge? Who creates it? Who possesses it? The need for novel answers to old questions. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Paavola, S., & Hakkarainen, K. (2005). The knowledge creation metaphor: An emergent epistemological approach to learning. *Science & Education, 14*, 535–557. doi:10.1007/s11191-004-5157-0.

Paavola, S., & Hakkarainen, K. (2014). Trialogical approach for knowledge creation. In S. C. Tan, H. J. So, & J. Yeo (Eds.), *Knowledge creation in education* (Springer education innovation book series). Singapore: Springer.

Pata, K., & Bardone, E. (2014). Promoting distributed cognition at MOOC ecosystems. In P. Zaphiris & A. Ioannou (Eds.), *Learning and collaboration technologies. Designing and developing novel learning experiences. First International Conference, LCT 2014, Held as Part of HCI International 2014, Heraklion, Crete, Greece, June 22–27, 2014* (pp. 204–215). Heidelberg, Germany: Springer. doi:10.1007/978-3-319-07482-5_20.

Puglisi, A., Baronchelli, A., & Loreto, V. (2008). Cultural route to the emergence of linguistic categories. *Proceedings of the National Academy of Sciences of the United States of America, 105*, 7936–7940.

Rabbany, R., Elatia, S., Takaffoli, M., & Zaïane, O. R. (2013). Collaborative learning of students in online discussion forums: A social network analysis perspective. In A. Peña-Ayala (Ed.), *Educational data mining* (pp. 441–466). Heidelberg, Germany: Springer.

Rizzuto, D. S., & Kahana, M. J. (2001). An autoassociative neural network model of paired-associate learning. *Neural Computation, 13*, 2075–2092.

Rosch, E. H., Mervis, C. B., Gray, W. D., Johnson, D. M., Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8*, 382–439.

Seitlinger, P., Kowald, D., Trattner, C., & Ley, T. (2013). Recommending tags with a model of human categorization. In *Conference on Information and Knowledge Management, CIKM'13, Oct. 27–Nov. 1, 2013, San Francisco, CA, USA* (pp. 2381–2386). New York, NY: ACM Press. doi:10.1145/2505515.2505625

Seitlinger, P., Ley, T., & Albert, D. (2015). Verbatim and semantic imitation in indexing resources on the Web: A fuzzy-trace account of social tagging. *Applied Cognitive Psychology, 29*, 32–48. doi:10.1002/acp.3067.

Shatnawi, S., Gaber, M. M., & Cocea, M. (2014). Automatic content related feedback for MOOCs based on course domain ontology. In *Intelligent data engineering and automated learning–IDEAL 2014* (pp. 27–35). Cham, Switzerland: Springer.

Stahl, G. (2012). Traversing planes of learning. *International Journal of Computer-Supported Collaborative Learning, 7*, 467–473. doi:10.1007/s11412-012-9159-7.

Stahl, G. (2013). Learning across levels. *International Journal of Computer-Supported Collaborative Learning, 8*, 1–12. doi:10.1007/s11412-013-9169-0.

Steels, L. (2006). Collaborative tagging as distributed cognition. *Pragmatics and Cognition, 14*, 287–292.

Van Overwalle, F., & Heylighen, F. (2006). Talking nets: A multi-agent connectionist approach to communication and trust between individuals. *Psychological Review, 113*, 606–627.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Wagner, C., Singer, P., Strohmaier, M., & Huberman, B. (2014). Semantic stability and implicit consensus in social tagging streams. *IEEE Transactions on Computational Social Systems, 1*, 108–120.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, England: Cambridge University Press.

Wisdom, T. N., & Goldstone, R. L. (2011). Innovation, imitation, and problem-solving in a networked group. *Nonlinear Dynamics, Psychology, and Life Sciences, 15*, 229–252.

Yew, J., Gibson, F. P., & Teasley, S. D. (2006). Learning by tagging: The role of social tagging in group knowledge formation. *MERLOT Journal of Online Learning and Teaching*, *2*, 275–285. Retrieved from http://jolt.merlot.org/vol2no4/yew.pdf

Zemsky, R., & Massy, W. F. (2004, July 09). Why the e-learning boom went bust. *The Chronicle of Higher Education.* Retrieved from http://chronicle.com

Individual Versus Collaborative Information Processing: The Case of Biases in Wikipedia

Aileen Oeberst, Ulrike Cress, Mitja Back, and Steffen Nestler

Collective Biases in Mass Collaboration

The Internet has revolutionized the search for information. Not only does it facilitate the access to myriad (remote) sources of information, it even creates novel sources of information. As Web 2.0 technologies have enabled ordinary users to become producers of content, new phenomena such as mass collaboration have emerged. The online encyclopedia Wikipedia is one of the most successful examples of mass collaboration. Here, a multitude of volunteers is constantly involved in thoroughly searching and compiling information on innumerable topics and events, an effort that exceeds all previous attempts to cover the world's knowledge.[1] Interested users may retrieve information about all kinds of issues, and the fact that Wikipedia is among the ten most frequently retrieved pages on the web (www.alexa.com) indicates that they do so. This raises new questions for research.

A vast amount of psychological research, for instance, demonstrates that individual information processing is often biased (e.g., Fischhoff, 1975; Kahneman & Tversky, 1972; Lord, Ross, & Lepper, 1979; Nickerson, 1998; Ross & Sicoly, 1979; Tajfel & Turner, 1979; Tversky & Kahneman, 1974; see Pohl, 2004, for an overview about most information processing biases). Therefore, the question arises whether individual biases translate into collective biases in the process of mass collaboration. Mass collaboration, in this context, is conceptualized as the joint work of many individuals on the same artifact. Much research into mass collaboration

---

[1] http://en.wikipedia.org/wiki/Wikipedia:Size_comparisons#cite_note-1 [2014-05-07]

A. Oeberst (✉) • U. Cress
Leibniz-Institut für Wissensmedien, Knowledge Construction Lab, Tuebingen, Germany
e-mail: a.oeberst@iwm-tuebingen.de; u.cress@iwm-tuebingen.de

M. Back • S. Nestler
Section of Psychological Assessment and Personality Psychology, Department of Psychology, University of Muenster, Muenster, Germany
e-mail: mitja.back@uni-muenster.de; steffen.nestler@uni-muenster.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_9

points to its benefits and potential (e.g., Benkler, 2006; Cohn; 2008; Giles, 2005; Gowers & Nielsen, 2009; Kanefsky, Barlow, & Gulick, 2001; Kittur & Kraut, 2008; see also Cress, Moskaliuk, & Jeong, 2016) even almost as if there were the implicit assumption that (mass) collaboration always has positive effects. Could this likewise be the case when it comes to biases in information processing?[2]

It is the main goal of the chapter presented here to clarify whether individual biases translate into collective biases or whether they might level out in the process of collaboration. We deal with mass collaboration in the context of memory construction, and we will make use of the online encyclopedia Wikipedia as one example of such collaborative memory construction. Our main research question is whether biases known from research on individuals (here, hindsight bias, in-group bias) are likewise found in Wikipedia. The answer not only sheds light on the relation between individual and collaborative information processes. It is also highly relevant, as Wikipedia is among the most frequently retrieved pages on the web and constitutes a source of information for millions of users. If it is biased, it in turn might bias a broad audience.

The chapter is structured as follows: We will first briefly characterize Wikipedia and then describe each bias identified separately. Next we will outline empirical evidence for the occurrence of the bias on the individual level as well as in Wikipedia. Finally, we will discuss the potential preconditions for collective biases, possible countermeasures, and the relation between individual and collaborative biases.

Wikipedia as a Platform for Mass Collaboration

The “free encyclopedia” Wikipedia is one of the most recent and most impressive examples of the potential of collaboration. Exclusively written by volunteers, Wikipedia exceeds traditional encyclopedias in quantity and topicality (Danowski & Voss, 2005) but can also compete with them with regard to accuracy (Giles, 2005; see also Nielsen, 2014). Articles can be created and edited by anyone, and editing covers the whole range from adding novel information, revising existing text, to deleting text. Based on a wiki technology, every version of the article is stored separately, allowing for fast and easy tracking of the revision history as well as restoring prior versions (e.g., if one author wishes to undo previous edits). Each article is accompanied by a talk page that makes exchange among the authors possible. Here, questions and feedback are posted, revisions are explained, and controversies are discussed (e.g., Viégas, Wattenberg, Kriss, & van Ham, 2007).

---

[2] We would like to point out that the present chapter employs a classically cognitive-psychological perspective (contrary to chapter “Mass Collaboration as Co-Evolution of Cognitive and Social Systems” by Cress, Feinkohl, Jirschitzka, & Kimmerle, 2016 and chapter “What is Knowledge? Who Creates it? Who Possesses it? The Need for Novel Answers to Old Questions” by Oeberst, Kimmerle, & Cress, 2016 that are based on radical constructivism), as it aims at investigating whether phenomena in information processing (here, biases) that have been demonstrated for individuals can be documented in collaboratively authored articles under Wikipedia’s guidelines as well.

Although anyone can edit Wikipedia, of course not everyone does. Many studies document that the lion's share of editing is done by a limited number of users (e.g., Kittur, Chi, Pendleton, Suh, & Mytkowicz, 2007). Kittur and Kraut (2008), however, registered an average number of about 50 authors per article (in the English Wikipedia), and this number is easily multiplied when it comes to articles of broad importance and high topicality. Examples of this can be observed for consequential catastrophes (e.g., the nuclear disaster in Fukushima, Keegan, Gergle, & Contractor, 2011; Oeberst, Halatchliyski, Kimmerle, & Cress, 2014) or current political and societal developments (e.g., the Arab spring, Ferron & Massa, 2011; Massa & Scrinzi, 2012). It is for this reason that Wikipedia was proposed to be a "global memory place" (Pentzold, 2009), which may offer a "first draft of history" (Rosenzweig, 2006, p. 136). More importantly, this publicly available draft contains representations of events that have been socially negotiated, which may thus be interpreted as collective memories (Irwin-Zarecka, 1994, cited by Hirst & Manier, 2008; Olick, 1999).

But how can social negotiation under such circumstances work effectively? Unknown to many, Wikipedia requires authors to adhere to a number of basic rules,[3] which indeed guide contributions effectively (e.g., Forte & Bruckman, 2008; Oeberst et al., 2014; Viégas et al., 2007; Viégas, Wattenberg, & Dave, 2004; Viégas et al., 2007). Most important in the present context are the following three rules: (1) verifiability,[4] (2) no original research,[5] and (3) neutral point of view (NPOV).[6] They require authors (1) to contribute only information that is verifiable (and preferably coming from reliable sources),[7] (2) to contribute *recognized* knowledge (thereby refraining from being a place for novel ideas, theories, and thoughts), and (3) to present the information from a neutral point of view, which not only refers to unbiased language but also implies a representation of "all significant viewpoints that have been published by reliable sources, in proportion to the prominence of each viewpoint." All these rules obviously aim at preventing not only the insertion of personal opinions but any sort of bias. However, are the rules effective in that regard?

Despite the clearly positive evaluations regarding the accuracy and quality of information contained in Wikipedia (Giles, 2005; see also Fallis, 2008; Magnus, 2009), there is evidence of some general biases in Wikipedia that result from a self-selection process of the authors. Obviously, not all kinds of people embrace alike the idea of Wikipedia or spend (considerable amounts of) time to edit its articles. Rather, active editors seem to share certain characteristics that shape their editing. The Wikipedian community itself, for instance, is aware of a "systemic bias": Most of the active authors in Wikipedia share a certain social and cultural background

---

[3] http://en.wikipedia.org/wiki/Wikipedia:List_of_policies#Content [2015-01-07]

[4] http://en.wikipedia.org/wiki/Wikipedia:Verifiability [2015-01-07]

[5] http://en.wikipedia.org/wiki/Wikipedia:No_original_research [2015-01-07]

[6] http://en.wikipedia.org/wiki/Wikipedia:Neutral_point_of_view [2014-05-07]

[7] http://en.wikipedia.org/wiki/Wikipedia:Verifiability#What_counts_as_a_reliable_source [2015-01-07]

that leads to an "imbalanced coverage of subjects on Wikipedia,"[8] with certain cultures and topics being clearly underrepresented (e.g., Bellomi & Bonato, 2005; Callahan & Herring, 2011; Hecht & Gergle, 2009, 2010; Royal & Kapila, 2009). Wikipedians are not only aware of this, however, but actively strive to overcome this bias (e.g., Livingstone, 2010; see also Wikipedia projects[9]).

Overall, these studies suggest that Wikipedia is not free from bias. Of course, it must be acknowledged that Wikipedia's guidelines are not about topic coverage. But precisely because of this, it is a perfect example of a bias that cannot be prevented by the guidelines of Wikipedia that is provided: An article may contain only verifiable information from reliable sources and be presented from a neutral point of view but even so represent bias—merely due to the fact that the article exists (and articles about other topics do not). In simplified terms, one might summarize that bias can result from the very selection of topics that are elaborated upon. In the following section, we want to go into detail about two biases that result from the selection of information per topic rather than selection of a topic itself. What might not seem obviously biased at first glance can indeed occur as bias in very subtle forms and go unnoticed—particularly if all authors share the same bias. We will now turn to each bias separately within the context of existing research that is mainly restricted to individuals. Then, we will present and discuss empirical evidence for each bias in Wikipedia.

Hindsight Bias

Hindsight bias refers to the tendency to overestimate the likelihood, inevitability, and foreseeability of an outcome once it is known (Blank, Nestler, von Collani, & Fischer, 2008; Fischhoff, 1975). For elections, for instance, it has been repeatedly shown that people perceive the actual outcome of the election as more likely, inevitable, and foreseeable than they actually did in foresight. That is, they have the feeling that it "must have happened" that way and that they "knew it all along." Sometimes, they even have a faulty memory of their own forecasting as having been more close to the actual outcome.

The hindsight bias is a robust (Guilbault, Bryant, Brockway, & Posavac, 2004) and widespread (Pohl, Bender, & Lachmann, 2002) phenomenon, which is difficult to avoid (Roese & Vohs, 2012) and of which people are largely unaware (Pohl & Hell, 1996). Hence, even if people know about hindsight bias or are explicitly warned or even motivated to avoid it, they rarely succeed (e.g., Fischhoff, 1977; Kamin & Rachlinski, 1995; Smith & Greene, 2005). To date, there have been a number of explanations that have been put forward to account for hindsight bias. In

---

[8] http://en.wikipedia.org/wiki/Wikipedia:Systemic_bias [2014-12-18]

[9] http://en.wikipedia.org/wiki/Wikipedia:WikiProject_Countering_systemic_bias in the English Wikipedia and http://de.wikipedia.org/wiki/Wikipedia:WikiProjekt_Diskriminierungsfreie_Wikipedia in the German Wikipedia [2015-01-12]

the context of events, hindsight bias can be explained by the *causal model theory* (CMT; Nestler, Blank, & von Collani, 2008). CMT assumes that people are generally motivated to understand their world and that they want to know why an event occurred or why something turned out the way it did. To this end, they search for the antecedents that may explain the occurrence or the outcome. Crucially, knowledge of the outcome narrows their search (and evaluation) of antecedents. After all, they especially want to know why this particular event occurred. Thus, they ignore all the antecedents that would have spoken *against* the occurrence of this event. The causal model that results from a one-sided search is much more simple and straightforward than a causal model which results from not knowing what the outcome would have been. This situation leads to the tendency to believe that the event was highly likely, if not inevitable, and one may even come to the conclusion that this has always been the case and, thus, that one had foreseen it.

"Collective" Hindsight Bias in Wikipedia

Against this background, it becomes clear that hindsight bias may go undetected even when participants adhere to Wikipedia's rules. Each unit of information that is inserted may well be verifiable and come from respected sources and may even be presented in a neutral and unbiased way. A biased article may still result, as the *selection* of information is biased. Moreover, as people are usually unaware of this bias, they can hardly control for it (Fischhoff, 1977; Kamin & Rachlinski, 1995; Smith & Greene, 2005). Hence, it is reasonable to assume that hindsight bias does not only show up in individual processing but would nevertheless be mirrored in collaboratively authored Wikipedia articles, even though they require adherence to the rules mentioned above.

To date, the overwhelming majority of research on hindsight bias has investigated individuals only. A few exceptions examined hindsight bias in small groups and compared it to hindsight bias in individuals (Bukszar & Conolly, 1988; Choi, Koo, & Choi, 2007; Stahlberg, Eller, Maass, & Frey, 1995). Their results were mixed, however. Sometimes, groups and individuals did not differ in their bias (Bukszar & Conolly, 1988; Choi et al., 2007; Stahlberg et al., 1995). Sometimes groups were less biased than individuals (Stahlberg et al., 1995), and sometimes they showed greater bias than individuals (Choi et al., 2007). In sum then, groups also showed hindsight bias, but it remains unclear whether groups are likely to be biased to the same extent as individuals.

It must be pointed out, however, that the setting for these studies still differs from the Wikipedia context in a number of aspects: First, the small group studies involved only 3–4 people. Second, these people had face-to-face contact and a limited amount of time. Third, there were no guiding rules such as those for Wikipedia. Finally, the participants' responses were recorded solely for scientific inquiry but had no other consequences. In the case of Wikipedia, by contrast, a person's behavior becomes publicly available and may thus eventually shape the view of a broad audience.

Moreover, the authors are urged to strive for the most accurate and appropriate representation of an event possible, whereby they not only have to take Wikipedia's guidelines into account but also the input of tens and hundreds of others when pursuing this goal.

In summary, our theoretical considerations suggest that a hindsight bias in Wikipedia may exist. Strictly speaking, the existing results from studies with small groups are not only mixed, but they cannot be generalized to the Wikipedia setting of mass collaboration. We therefore conducted two studies in our labs to examine whether hindsight bias is in fact present in Wikipedia articles (Oeberst, von der Beck, & Nestler, 2014a).

For each of the two studies, we selected several events; for each of which, a Wikipedia article had already existed *prior* to the occurrence of the event in question (e.g., the article "Fukushima Daiichi Nuclear Power Plant" that existed prior to the nuclear disaster). Some of the same events are used in both of the two studies. For each event, we retrieved three different article versions (see Fig. 1): (1) the last version that had existed prior to the event (t_1), (2) the first version that existed after the event happened (t_2), and the article version that existed 8 weeks after the event had taken place (t_3). The reasoning for this time interval was that the construction of a causal model (and thus its insertion into the article) needed time and elaboration (Nestler et al., 2008).

Each version of each article was then analyzed with regard to "the extent to which it suggested that the event was likely to happen and/or that it was foreseeable" (one rating; main dependent variable).

In Study 1, we analyzed the articles of 17 different events in the German Wikipedia (e.g., the nuclear disaster of Fukushima, the Tulip Revolution in Kyrgyzstan, the collapse of the municipal archive in Cologne, the victory of Mahmud Ahmadinedschad). To this end, each of the 51 article versions was coded by two raters. They achieved sufficient agreement in their ratings (Cohen's Kappa >0.80) regarding the main dependent variable (see above). The main result of this study was the significant increase in the ratings over time. Specifically, the article versions that existed 8 weeks after the event took place contained content which

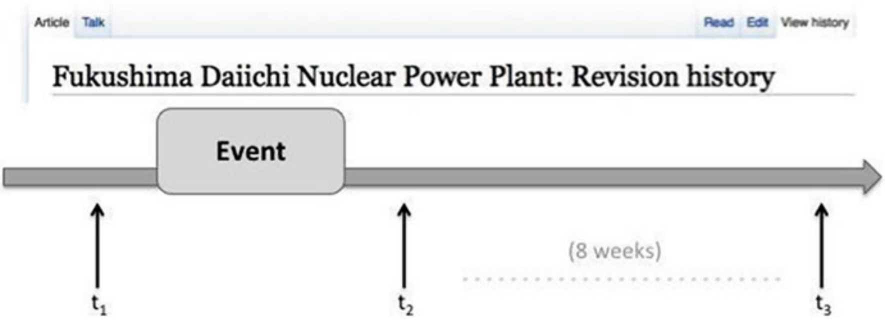


Fig. 1 Retrieved article versions for each event

suggested to a significantly higher degree when compared to the foresight version (t_1) that the specific event had been likely to happen. To illustrate this finding, let us have a look at one of the articles for which the maximum change in ratings was obtained from the t_1 to the t_3 article version: the Nuclear Power Plant of Fukushima. While the article is too long to analyze in detail here, a comparison of the tables of contents of the two article versions may shed some light on possible hindsight distortions: Whereas the t_1 version only referred to (1) accidents and (2) reactor data, the t_3 article version not only contained a description of the recent disaster (3) but also referred to (4) risks of this type of power plant, (5) construction deficits of Fukushima Daiichi, (6) lacking protection for earthquakes and tsunamis, and (7) hushed failures and lacking controls. Most importantly, much of the information presented within these paragraphs had been known prior to the event. Crucially for our analysis, however, this information was inserted only later, after the disaster had taken place. This clearly made the t_3 version of the article much more suggestive of the notion that the disaster was, in fact, highly likely and actually foreseeable. It thus demonstrates how information is evaluated differently in hindsight and how event-consistent information is given more weight than in foresight. This is precisely the underlying mechanism of hindsight bias (Carli, 1999; Nestler et al., 2008).

It also explains why the t_2 article versions did not significantly differ from the foresight version (t_1) with regard to the perceived likelihood and foreseeability of the event: Here, the event was mostly merely announced. Mere knowledge of the event, however, does not suffice for hindsight bias to occur (Yopchick & Kim, 2012). Rather, the provision of a causal explanation into which the occurrence of the event was embedded was necessary to increase the suggestiveness of the event's probability/inevitability/foreseeability in the article. This was confirmed by regression analyses (Oeberst, Halatchliyski, Kimmerle, & Cress 2014), which identified the presence of an explanation as a significant predictor of the t_3 rating and is in line with causal model theory (Nestler et al., 2008).

These findings thus provide a first hint of the presence of hindsight distortions in Wikipedia. Only after an event had already occurred (and was explained) did the articles seem to suggest that this particular event had been likely all along. It must be pointed out, however, that this finding is based on averages. Although we did find a significant increase over all articles, there were a substantial number of articles (6 out of 17), for which we did not find any significant changes in the ratings for the t_1 to the t_3 articles. Hence, we found only partial support for our hypothesis. Our results clearly do *not* suggest that all Wikipedia articles succumb to the hindsight bias. To shed more light on this issue, we chose events from different categories in Study 2.

A final aspect that is worth mentioning with regard to Study 1 is that we obtained only one single instance of a concrete phrase that was rated as indicator of hindsight distortions (i.e., sentences saying that the event was likely, inevitable, foreseeable or the reverse). Put differently, even those article versions that had been rated as highly suggestive of the probability/inevitability/foreseeability of the event did not contain explicit formulations suggesting the event to be likely or foreseeable or alike.

That is, we did not find explicit sentences such as "The event was inevitable/foreseeable." The impression of the raters that an article was highly suggestive of the probability/inevitability/foreseeability of the event resulted instead from detailed elaborations on causal arguments for the events' occurrence and from an ignorance of antecedents, which would have simultaneously spoken against the event's occurrence.

Study 2 aimed at replicating and extending the findings from Study 1. The basic procedure was the same as in Study 1 with the following exceptions: First, we selected events from six different event categories: elections (e.g., president election in Iran), official decisions (e.g., the declaration of independence of Kosovo), personal decisions (e.g., resignation of the German Federal President Köhler), scientific discoveries (e.g., evidence for the Higgs boson), sports events (e.g., the victory of Usain Bolt in the 100 m at the Olympic Games in 2012), and disasters (e.g., the accident at the Shushenskaya Dam in Russia). Second, we selected (a) widely known events and (b) unknown events for each category. This was done to exclude a simple alternative explanation for the results of Study 1, namely, that the raters discovered a bias because they had known about the event and exhibited their own bias in their ratings. In Study 2, we ruled out this possibility by providing only the t_1 article versions of the unknown events before providing raters with the other two article versions and thus information about the event which had occurred. Third, we extended the number of raters to ten in order to enhance the reliability of our findings. Taken together, we had ten raters code three article versions (t_1, t_2, t_3) for each of the 30 events.

The major dependent variable was, again, to what extent an article version suggested that the event was likely to happen and/or foreseeable (e.g., the election of Ahmadinedschad as president of Iran). In the case of the unknown events in the t_1 version, raters coded whether the article suggested that a particular event was likely to happen in the future. If this happened to be another event than the one in question (that actually occurred), the ratings were later recoded. For example, if someone found the article about an unpopular election to be suggestive of a victory of Person X and gave it a rating of "5" but actually Person Y won the election, the rating was recoded to "1," as this indicated that the article was *not* suggestive of a victory of Person Y.

Inter-rater agreement was sufficient to high (ICCs >0.70). The first interesting finding was that the ratings did not differ between known and unknown events. This suggests that the raters' knowledge about the events did not affect their ratings. Beyond that, however, we obtained a significant interaction between article version and event category, and it became evident that the pattern observed in Study 1 was replicated but only in one event category: disasters. Here, the t_3 versions, again, suggested that the event in question was perceived as likely to happen when compared to the t_1 version, which did not differ from the t_2 version. For all other event categories, in contrast, there was not even a descriptive increase in the ratings.

Hence, we could replicate and specify the findings from Study 1. We obtained evidence for hindsight distortions, but these were limited to one class of events: disasters. For the majority of events and event classes, however, this was not the case. Therefore, it must be stressed that hindsight distortions are certainly not a general phenomenon in Wikipedia articles. Nevertheless, we did obtain evidence for "collective" hindsight distortions in one of the worlds' largest collections of knowledge. Disasters and catastrophes are particularly sensitive events. Not only do they have dramatic consequences and are therefore closely linked to questions of responsibility, guilt, and repercussions (e.g., Harley, 2007). But they are also of great interest to a broad audience. That is, they not only attract a disproportionate number of users to contribute to the article (Keegan, Gergle, & Contractor, 2011; Oeberst et al., 2014), but they also stimulate a heightened readership. The Fukushima article, for instance, was retrieved more than 130,000 times in May 2011 alone (the time frame into which our t_3 article version falls[10]). Of course, this holds mainly for disasters of worldwide relevance. Nevertheless, in these cases, it becomes more than clear that Wikipedia is a frequently retrieved source of information. It also indicates that greater involvement (i.e., more authors) does not necessarily lead to more accurate (i.e., less biased) articles. Kittur and Kraut (2008) found a positive relationship between the number of authors and article quality. If all of the many authors succumb to hindsight bias, however, as is suggested by the pervasiveness and robustness of the bias (e.g., Guilbault et al., 2004; Roese & Vohs, 2012), and if people are largely unaware of it (Pohl & Hell, 1996), more authors might not make for better quality.

In sum then, even if it is only Wikipedia articles about disasters that contain traces of hindsight bias, it is particularly these articles that reach the greatest audience. Even if hindsight distortions are not a universal problem in Wikipedia, there is evidence for them, and they might shape the views of millions of users (e.g., Oeberst, von der Beck, & Nestler, 2014b).

It must be acknowledged, however, that field studies can lack the internal validity of experimental research. In experiments, information can be carefully controlled and manipulated, and as a result, participants' biased responses can be more clearly traced. In the future, we will complement the current field studies with lab studies in which the participants' task will be to (collaboratively) write articles.

Taken together, we interpret our results as preliminary empirical evidence for hindsight bias on a collective level. Our findings thus expand upon prior research into hindsight bias that has dealt mainly with individuals and sometimes with small groups. Also, our findings extend prior research on collaboration and on information quality in Wikipedia. As pointed out earlier, hindsight bias may occur in spite of Wikipedia's guidelines and exist in an article that is well researched, elaborated, and presented in a neutral fashion. It might even be possible that collaboration *enhances* the resultant bias. We will come back to this issue at the end of this chapter. First, however, we want to elaborate on another kind of bias—in-group bias—and its possible manifestation in Wikipedia.

---

[10] Source: http://stats.grok.se. This number includes the Internet traffic to the newly created article "Nuclear disaster of Fukushima Daiichi" to which the elaborations regarding the disaster migrated.

In-Group Bias

In contrast to the rather generally biased perceptions and evaluations of events in hindsight, the *in-group bias* refers to systematic distortions that result from group membership. Specifically, it stands for a systematically more positive perception and representation of information that concerns the group(s) one belongs to (Sahdra & Ross, 2007; Tajfel & Turner, 1979). In international conflicts, for instance, people tend to view their own nation and its actions as less responsible (Baumeister & Hastings, 1997; Bilali, 2013; Bilali, Tropp, & Dasgupta, 2012; Doosje & Branscombe, 2003; Silverstein & Flamenbaum, 1989) and as more justified (e.g., Levin, Henry, Pratto, & Sidanius, 2003; Liu et al., 2009; Tarrant, Branscombe, Warner, & Weston, 2012). Also, in individuals' representation of history, favorable information regarding one's own group is systematically better remembered than negative information, such as in incidents where the in-group caused harm to others (Sahdra & Ross, 2007). But again, the question arises as to whether this bias, which has been robustly and repeatedly documented for individuals (see Hewstone, Rubin, & Willis, 2002 for an overview), is mirrored in collaboratively authored Wikipedia articles that explicitly aim to represent accurate world knowledge. After all, this is one point that directly relates to the neutral point of view guideline of Wikipedia. It is more common in cases of intergroup conflict that those involved will be more aware of an opposing point of view (the perspective of the other group) than in cases of hindsight bias. Nevertheless, it may very well be the case that the out-group perspective is presented but in a manner that still communicates in-group favoritism (Fiedler & Semin, 1988). A number of studies have shown that the simple use of different word forms (e.g., nouns, verbs, adjectives) shapes the representations of the people who are described and eventually may communicate bias (Arcuri, Maass, & Portelli, 1993; Maass, Salvi, Arcuri, & Semin, 1989; Schmid, 1999; Werkman, Wigboldus, & Semin, 1999; Wigboldus, Semin, & Spears, 2000). For instance, there is a difference whether one says "A attacked B" or "A is aggressive" for the latter implies to a greater extent a stable trait that will likely shape A's behavior in the future as well. Research on the linguistic intergroup bias has demonstrated systematically different uses of words for in-group and out-group members: Whereas negative behavior of an in-group member is more likely described in concrete (less stable) terms (i.e., verbs), the same behavior is described more abstractly (e.g., with adjectives) when performed by an out-group member. For positive behaviors, in contrast, the reverse is found.

An interesting and very useful feature of Wikipedia in this regard is that Wikipedia exists in several languages (www.wikipedia.org). These are not translations of some "master version" but rather unique articles (Hecht & Gergle, 2010; Stvilia, Al-Faraj, & Yi, 2009), which are predominantly constructed by members sharing that language as a mother tongue—at least for most languages other than English (Callahan & Herring, 2011; Kolbitsch & Maurer, 2006). Hence, different representations regarding the same topic or event (e.g., Israeli-Palestinian conflict) exist in different languages (e.g., Hebrew, Arab, English, etc.). Moreover, the different language versions of Wikipedia employ very similar guidelines for contribution. Thus, collective representations of both conflicting parties, for instance, can be compared to one another (e.g., Hebrew vs. Arab). Wikipedia is in this way perfectly suitable for investigating the question of whether there is an in-group bias in representations of intergroup conflicts.

In-Group Bias in Wikipedia

As mentioned earlier, in-group favoritism can be displayed in content coverage. In Wikipedia, a preference for topics of the in-group has been documented (Hecht & Gergle, 2009). Callahan and Herring (2011), for instance, compared Wikipedia articles about popular American and Polish people in the English and Polish Wikipedia. Despite generally longer articles in the English Wikipedia, it was found that elaborations on people from the contributor's own nation exceeded those on people from the other nation. Beyond that, Polish people in the English Wikipedia were presented much more critically than in the Polish Wikipedia. This provides some first evidence for an in-group bias in Wikipedia. But this is only very tentative evidence, as this effect could be due to information imbalance: it is likely that there is more information available to people of the same nation (and language) than to people of other languages. It might therefore not be an effect of interest or preference but rather information constraints due to language.

Some more direct empirical support for in-group bias was provided by Rogers and Sendijarevic (2013), who compared the article about the Srebrenica massacre in the English, Danish, Serbian, Bosnian, and Croatian Wikipedia. They reported elaborations favoring the in-group with regard to causality and blame. Unfortunately, however, the study offers only descriptive and qualitative results for a single case. In addition, the analysis was exploratory in nature—lacking any theoretical background or hypothesis, which also applies to the study by Callahan and Herring (2011).

Nevertheless, the findings of both studies hint toward a possible in-group bias at the collective level. In order to take these results further, and to answer our research question, we conducted a study in our lab with the objectives of (1) investigating in-group favoring in elaborations upon a variety of conflicts rather than limiting the investigation to one event and (2) providing a quantitative test of a specific hypothesis that derives from social identity theory. In the following, we will outline the reasoning and approach of our study as well as the tool we used.

The social identity approach as well as the empirical evidence for the in-group bias would suggest that representations of international conflicts (e.g., Ukraine crisis) are positively biased toward the in-group. That is, one would expect the Ukrainian Wikipedia article to present the Ukraine and its role in the conflict in a more favorably than Russia and its role, whereas the reverse would be expected of the Russian Wikipedia article. From this, it can be hypothesized that the articles of the two parties involved in a conflict would differ more from one another in their

Fig. 2 Compared article versions

representation of the same event (black arrow in Fig. 2) than each conflict party's version would differ from an uninvolved language version (dark gray arrow in Fig. 2) or if two uninvolved language versions were compared to one another (light gray arrow in Fig. 2).

Of course, the comparison of different language versions poses the challenge that coders are not capable of every language. For the present study, we therefore made use of a tool that estimates the similarities among articles based on links to other Wikipedia articles (www.manypedia.com, Massa & Scrinzi, 2012). Manypedia provides an indicator of *concept similarity* for two Wikipedia articles from different language versions about the same event. *Concept similarity* is based on the percentage of links to other Wikipedia articles which different language versions of the same Wikipedia article (e.g., the Arab and the Hebrew article about the Israeli-Palestinian conflict) share (Hecht & Gergle, 2010). The underlying rationale is that if two articles on the same concept define the concept in highly similar ways, they should link to nearly the same articles. On the other hand, if there is great discrepancy, the percentage of shared links to other concepts should be significantly lower. We expected the different language versions of the involved conflicting parties (e.g., Hebrew vs. Arab for the Six-Day War 1967) to be less similar than the different language versions of one conflict party and an uninvolved party (e.g., Hebrew vs. German) and less similar than two language versions that were uninvolved in the conflict (e.g., German vs. English; see Fig. 2). We tested this hypothesis by conducting comparisons with Manypedia for a total of 37 international conflicts (e.g., the Six-Day War, the massacre of Srebrenica, Vietnam War).

As expected, we found that articles of the two involved populations on the same event were the least similar (Oeberst, 2014). Significantly greater similarity was observed among the Wikipedia articles of one involved and one uninvolved nation.

Also, similarity among the Wikipedia articles of two uninvolved nations was significantly greater than similarity among the two involved. Consequently, the study suggests that the representations of the same event differ the most between the two parties that are involved in the conflict. Although this is consistent with our hypothesis, it is necessary to point out a few limitations of this study. First, it must be stressed that the concept similarity measure is only a rough indicator of the article contents. Actual content analyses are of course necessary in order to further validate our findings. Second, it must be acknowledged that while the presence of an in-group bias in each involved language version would imply a difference between the two versions, this is not necessarily true. After all, the difference we obtained may eventually be found to be based on aspects other than in-group bias. This provides another argument for further studies that take a closer look into the genuine contents of an article and specifically into the way each party represents their points of view. Nevertheless, the present findings are consistent with previous ones. Moreover, they are the first systematic evidence that is based on multiple conflicts.

Summary, Discussion, and Outlook

"Collective" Biases in Wikipedia

The chapter presented here aimed to answer the question of whether biases we know from individual information processing translate into collaborative or even collective biases in Wikipedia articles. To this end, we summarized the existent evidence with regard to hindsight bias and in-group bias. Although the number of studies is still sparse, all studies show that both the hindsight bias and the in-group bias are neither prevented by mass collaboration nor by the fact that persons contribute to publicly available accounts of what is supposed to be world knowledge (instead of responding anonymously in the lab without any consequences associated). Obviously, more research is needed to get a sound empirical basis for valid conclusions. Nevertheless, we think that a number of aspects seem noteworthy even at this early point.

First, we found evidence for a collective bias *despite* Wikipedia's rules. Even though the majority of articles was *not* biased (with regard to hindsight bias), the existence of a bias in *some* articles clearly indicates that Wikipedia's current rules are not sufficient for preventing biases. It is important to note, however, that both biases—hindsight bias and in-group bias—may result (among other things) from the *selection* of information: people preferably select information that is consistent with an outcome (vs. outcome inconsistent information) as well as information that throws a more positive light on their own group (vs. negative information). And whereas one unit of information that is contributed may very well conform to Wikipedia's rules—in that it is "recognized" (i.e., from a reliable source), verifiable (e.g., by the insertion of a reference), and neutrally presented—the sum of all units of information (i.e., the whole article) may nevertheless be biased if it consists only (or mainly) of one-sided information (e.g., outcome-consistent or in-group favoring). A good example for this is the Wikipedia article about the nuclear power plant of Fukushima. External experts judged it to be not only accurate but also written in a balanced and neutral manner ("better than the average media reports at that time"), and for the same reason, the article was awarded the Zedler Price. Nevertheless, it turned out to be one of those articles that displayed the greatest hindsight bias. Consequently, the answer to the question of whether a bias we know from individual information processing might be present in the Wikipedia presumably depends on whether the bias results from mechanisms other than detected by Wikipedia's rules. Biases that are based (in part) on *selective* information processing have a good chance of being mirrored in Wikipedia.

Two further aspects that are likely to play a role with regard to the question of whether a certain individual bias translates into a "collective bias" in Wikipedia are (a) the extent to which a bias is shared among the authors and (b) the extent to which authors are aware of this bias and able (and willing) to avoid it. Recall that the research on hindsight bias suggests that it is widespread and that people are largely unaware of it and have tremendous difficulties avoiding it. Similarly, it is plausible to assume that an in-group bias regarding one's own ethnic group is widespread among members of this group (although there might be interindividual differences depending on the degree of social identification).[11] The in-group bias, however, can be a consideration at different group levels: Think of a conflict, for instance, that exists among members of the same country (or language-sharing community, e.g., civil wars). An article in Wikipedia in their common language would more likely attract authors from both subgroups. In this situation, it would not be the case that the same bias is shared among all authors. Rather, the authors would hold even contrary views. Under such circumstances, the result may depend on group composition (Schulz-Hardt, Frey, Lüthgens, & Moscovici, 2000) and the social decision scheme applied (e.g., majority wins rule; Kerr, MacCoun, & Kramer, 1996). But it is possible that collaboration might then result in a balanced article that is free from any bias, because it presents every viewpoint and thus overcomes selective (i.e., one-sided) information processing. This insight could eventually be also useful to counter biases that are shared within a language community. After all, balanced articles might result if collaboration is extended to out-group members. Imagine authors from both conflicting parties of two different language communities working collaboratively on *one* article about the conflict. Could this result in a balanced representation of the conflict? Or is there a better way to deal with cultural

---

[11] It is important to note, however, that the case of language versions of Wikipedia is a special one since the same language is sometimes spoken in different countries. This does not only preclude comparisons of different cultural viewpoints on conflicts between countries sharing a language (e.g., the Independence War between the USA and Britain). More importantly, it makes clear that one language version of Wikipedia is not only written by people from one culture. Particularly for languages such as English, Arab, Spanish, and French, which are spoken in many countries, the possibility is high that the authors come from different countries (and for English, for instance, even nonnative speakers are prevalent).

differences in the representation of events? This question touches upon issues for international textbook research and particularly the question of how historical as well as current events can be presented in a manner free of bias in order to foster unbiased representations by students.

The Relation between Individual and Collaborative Biases: Is There an Enhancing Effect of Collaboration?

Above, we suggested that a bias presumably needs to be shared by a vast majority of the authors writing a Wikipedia article in order to expect individual biases to enter the article as well. We also provided some evidence for the notion that individual biases are indeed present at the "collective" level as well. The interesting question, however, is, how do the individual and the collective biases, if present, compare to one another? Are they of similar magnitude? Or does collaboration, in fact, attenuate or enhance the bias? The greatest theoretical support from prior research actually confirms the notion that collaboration may amplify the bias: From the research on *group polarization*, it is known that exchange among like-minded people polarizes (see Isenberg, 1986, for an overview). That is, groups which have an initial tendency (e.g., to be risky) tend to become more extreme in that tendency (e.g., more risky) after discussion. Essentially, this effect is driven by two factors (Isenberg, 1986). First, the exchange of arguments in favor of the tendency (e.g., in favor of the more risky option) provides individuals with novel arguments that further support their prior tendency and thus results in an even stronger tendency. The second factor has to do with social comparisons among individuals: People are motivated to present and view themselves in a socially desirable way (e.g., to be risky). To this end, they attend to how others present themselves and adjust their own self-presentation accordingly—often even in a somewhat more favorable light (e.g., more risk seeking). When all members of a group engage in the same comparison process, this results in an average shift (all become riskier).

The same might take place when participants are socially negotiating an appropriate representation of an event for Wikipedia (e.g., a disaster, an international conflict). Regarding the in-group bias, the initial tendency to favor one's in-group might become stronger after discussing—and collaboratively authoring an article about—an international conflict with other in-group members. Even if social comparisons might play a smaller role here, the preferred exchange of information that favors the in-group might persuade the authors toward a greater bias. Likewise, authors holding a hindsight bias are most likely to exchange information that supports this view (e.g., that an event was inevitable and/or foreseeable), which again might strengthen their impression that this event was indeed inevitable/foreseeable. People might also be motivated to present themselves as having foreseen some event—as that foresight indicates how knowledgeable they are (e.g., Louie, 2005; Pezzo, 2011). Hence, social comparisons may come into play and contribute to group polarization.

Prior research demonstrates that group polarization is not bound to face-to-face communication but is found in computer-mediated communication as well (Sia, Tan, & Wei, 2002; Spears, Lea, & Lee, 1990; see also Bordia, 1997). A first hint in the same direction comes from a study that showed an increased bias in readers of biased articles (Oeberst, von der Beck, & Nestler, 2014b). Given that readers easily turn into authors, one might picture a spiral of bias that results from the reading and contributing of many persons who mutually validate each other.

Such an additional bias emerging from collaboration would truly represent a negative consequence of (mass) collaboration. From the findings we have referred to in this chapter, we may only conclude that collaboration does not (entirely) eliminate bias (at least not hindsight bias and in-group bias at the language level, as we found evidence for both in Wikipedia). We do not know yet, however, whether the bias we discovered is similar, reduced, or amplified in magnitude to that of individuals' biases. A distinctively less positive light would be shed on collaboration if it were demonstrated that this process amplified bias. We are currently running and planning studies in which we pursue this question by comparing articles which have been written collaboratively with articles which have been written by single authors.

Potential Countermeasures

Whatever the relation between individual and collective bias may be, an unbiased Wikipedia (or any other collaborative artifact) is certainly preferable. But is this possible to achieve? From prior research, countermeasures have been found that have effectively reduced or even eliminated hindsight bias as well as in-group bias in individuals: Actively elaborating on how the same antecedents might have led to a different outcome, for instance, may substantially reduce or even prevent hindsight bias (e.g., Arkes, Faust, Guilmette, & Hart, 1988; see also Roese & Vohs, 2012). Likewise, recategorizing groups and subsuming the in-group and the outgroup into the same superordinate group may effectively reduce in-group bias (Dovidio, Gaertner, Hodson, Houlette, & Johnson, 2005). The questions still remain not only as to whether these techniques would likewise be effective in the context of (mass) collaboration but also as to how these techniques could actually be implemented. After all, Wikipedia is a self-organized community. Interventions of any sort therefore cannot be simply implemented but instead would have to be wanted and fostered by the community itself. Before this step could be taken, however, several other research questions would need to be answered. Many more possibilities open up if we look at other contexts besides Wikipedia. Tools for knowledge construction, such as wikis and others, are employed also in formal education (e.g., Scardamalia & Bereiter, 1994, 1999), and in that context, collaboration takes place on smaller scale. While there is no theoretical argument that the processes should differ (e.g., group polarization is not assumed to depend upon group size), the smaller setting may more easily allow for the implementation of interventions, which, in turn, may also sensitize for biases in other contexts.

Conclusion

Collaboration certainly has a lot of positive effects, as has been repeatedly demonstrated. What is presented here, however, makes clear that certain biases we find at the individual level are not eliminated by collaboration. Our studies provide some first evidence for the notion that individual biases may actually translate into "collective biases" as they exist in collaboratively authored Wikipedia articles. Moreover, we cannot rule out yet that collaboration possibly even enhances bias in the process of social negotiation, such as that which characterizes the struggle for an appropriate representation of events in Wikipedia. In consideration of the fact that Wikipedia articles are read by millions of people and thus are likely to shape the views of a broad audience, we would urge for more research that goes beyond the study of individual bias. More research investigating the employment of wikis or similar technologies in formal educational settings, especially with regard to biases, and the possibilities for their reduction or elimination would be desirable.

References

Arcuri, L., Maass, A., & Portelli, G. (1993). Linguistic intergroup bias and implicit attributions. *British Journal of Social Psychology, 32*, 277–285.

Arkes, H. R., Faust, D., Guilmette, T. J., & Hart, K. (1988). Eliminating the hindsight bias. *Journal of Applied Psychology, 73*, 305–307.

Baumeister, R. F., & Hastings, S. (1997). Distortions of collective memory: How groups flatter and deceive themselves. In J. W. Pennebaker, D. Paez, & B. Rim (Eds.), *Collective memory of political events: Social psychological perspectives* (pp. 277–293). Mahwah, NJ: Lawrence Erlbaum.

Bellomi, F., & Bonato, R. (2005). Network analysis for Wikipedia. In *Proceedings of the First International Wikimedia Conference Wikimania.* Retrieved from http://www.uvm.edu/~pdodds/files/papers/others/2009/bellomi2009a.pdf

Benkler, Y. (2006). *The wealth of networks*. New Haven, CT: Yale University Press.

Bilali, R. (2013). National narrative and social psychological influences in Turk's denial of the mass killings of Armenians as genocide. *Journal of Social Issues, 69*, 16–33.

Bilali, R., Tropp, L. R., & Dasgupta, N. (2012). Attributions of responsibility and perceived harm in the aftermath of mass violence. *Peace and Conflict: Journal of Peace Psychology, 18*, 21–39.

Blank, H., Nestler, S., von Collani, G., & Fischer, V. (2008). How many hindsight biases are there? *Cognition, 106*, 1408–1440.

Bordia, P. (1997). Face-to-face versus computer-mediated communication: A synthesis of the experimental literature. *The Journal of Business Communication, 34*, 99–120.

Bukszar, E., & Conolly, T. (1988). Hindsight bias and strategic choice: Some problems in learning from experience. *Academy of Management Journal, 31*, 628–641.

Callahan, E. S., & Herring, S. C. (2011). Cultural bias in Wikipedia content on famous persons. *Journal of the American Society for Information Science and Technology, 62*, 1899–1915.

Carli, L. L. (1999). Cognitive reconstruction, hindsight, and reactions to victims and perpetrators. *Personality and Social Psychology Bulletin, 25*, 966–979.

Choi, I., Koo, M., & Choi, J. A. (2007). Individual differences in analytic versus holistic thinking. *Personality and Social Psychology Bulletin, 33*, 691–705.

Cohn, J. P. (2008). Citizen science: Can volunteers do real research? *BioScience, 58*, 192–197.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Cress, U., Moskaliuk, J., & Jeong, H. (Eds.). (2016). *Mass collaboration and education*. Cham, Switzerland: Springer.

Danowski, P., & Voss, J. (2005). Das Wissen der Welt—die Wikipedia [The world's knowledge—Wikipedia]. In B. Lutterbeck, R. A. Gehring, & M. Bärwolff (Eds.), *Open Source Jahrbuch 2005:Zwischen Softwareentwicklung und Gesellschaftsmodell* (pp. 393–408). Berlin, Germany: Lehmanns.

Doosje, B. E. J., & Branscombe, N. R. (2003). Attributions for the negative historical actions of a group. *European Journal of Social Psychology, 33*, 235–248.

Dovidio, J. F., Gaertner, S. L., Hodson, G., Houlette, M. A., & Johnson, K. M. (2005). Social inclusion and exclusion: Recategorization and the perception of intergroup boundaries. In D. Abrams, M. A. Hogg, & J. M. Marques (Eds.), *The social psychology of inclusion and exclusion* (pp. 245–264). New York, NY: Psychology Press.

Fallis, D. (2008). Toward an epistemology of Wikipedia. *Journal of the American Society for Information Science and Technology, 59*, 1662–1674.

Ferron, M., & Massa, P. (2011). Collective memory building in Wikipedia: The case of North African uprisings. *Proceedings of the Wikisym.* Retrieved from http://www.slideshare.net/phauly/collective-memory-building-in-wikipedia-the-case-of-north-african-uprisings

Fiedler, K., & Semin, G. R. (1988). On the causal information conveyed by different interpersonal verbs: The role of implicit sentence context. *Social Cognition, 6*, 21–39.

Fischhoff, B. (1975). Hindsight≠foresight: The effect of outcome knowledge on judgment under uncertainty. *Journal of Experimental Psychology. Human Perception and Performance, 1*, 288–299.

Fischhoff, B. (1977). Perceived informativeness of facts. *Journal of Experimental Psychology. Human Perception and Performance, 3*, 349–358.

Forte, A., & Bruckman, A. (2008). Scaling consensus: Increasing decentralization in Wikipedia governance. In *Proceedings of the 41st Annual Hawaii International Conference on System Sciences (HICSS'08).* Washington, DC: IEEE.

Giles, J. (2005). Internet encyclopaedias go head to head. *Nature, 438*, 900–901.

Gowers, T., & Nielsen, M. (2009). Massively collaborative mathematics. *Nature, 461*, 879.

Guilbault, R. L., Bryant, F. B., Brockway, J. H., & Posavac, E. J. (2004). A meta-analysis of research on hindsight bias. *Basic and Applied Social Psychology, 26*, 103–117.

Harley, E. M. (2007). Hindsight bias in legal decision making. *Social Cognition, 25*, 48–63.

Hecht, B., & Gergle, D. (2009). Measuring self-focus bias in community-maintained knowledge repositories. In *Proceedings of the 4th International Conference on Communities and Technologies* (pp. 11–20). New York, NY: ACM.

Hecht, B., & Gergle, D. (2010). The tower of Babel meets web 2.0: user-generated content and its applications in a multilingual context. In *CHI '10 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 291–300). New York, NY: ACM.

Hewstone, M., Rubin, M., & Willis, H. (2002). Intergroup bias. *Annual Review of Psychology, 53*, 575–604.

Hirst, W., & Manier, D. (2008). Towards a psychology of collective memory. *Memory, 16*, 183–200.

Isenberg, D. J. (1986). Group polarization: a critical review and meta-analysis. *Journal of Personality and Social Psychology, 50*, 1141–1151.

Kahneman, D., & Tversky, A. (1972). Subjective probability: A judgment of representativeness. *Cognitive Psychology, 3*, 430–454.

Kamin, K. A., & Rachlinski, J. J. (1995). Ex post ≠ ex ante: Determining liability in hindsight. *Law and Human Behavior, 19*, 89–104.

Kanefsky, B., Barlow, N. G., & Gulick, V. C. (2001). Can distributed volunteers accomplish massive data analysis tasks? In *Proceedings of the 32nd Annual Lunar and Planetary Science Conference,* 1272

Keegan, B., Gergle, D., & Contractor, N. (2011). Hot off the wiki: Dynamics, practices, and structures in Wikipedia's coverage of the Tōhoku catastrophes. In *Proceedings of the 7th International Symposium on Wikis and Open Collaboration (WikiSym'11)* (pp. 105–113). New York, NY: ACM Press.

Kerr, N. L., MacCoun, R., & Kramer, G. P. (1996). Bias in judgment: Comparing individuals and groups. *Psychological Review, 103*, 687–719.

Kittur, A., Chi, E. H., Pendleton, B. A., Suh, B., & Mytkowicz, T. (2007, April). Power of the few vs. wisdom of the crowd: Wikipedia and the rise of the bourgeoisie. In *25th Annual ACM Conference on Human Factors in Computing Systems (CHI),* San Jose; CA.

Kittur, A., & Kraut, R. E. (2008). Harnessing the wisdom of crowds in Wikipedia: Quality through coordination. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (pp. 37–46). New York, NY: ACM Press.

Kolbitsch, J., & Maurer, H. (2006). The transformation of the web: How emerging communities shape the information we consume. *Journal of Universal Computer Science, 12*, 187–213.

Levin, S., Henry, P. J., Pratto, F., & Sidanius, J. (2003). Social dominance and social identity in Lebanon: Implications for support of violence against the West. *Group Processes & Intergroupt Relations, 6*, 353–368.

Liu, J. H., Hanke, K., Fischer, R., Huang, L., Adams, G., Wang, F., … Lonner, W. J. (2009). In-group favoritism in international justice concerns: Power, involvement, and attitudes toward the Iraq War and the cross straits relationship in five societies. *Basic and Applied Social Psychology, 31*, 148–159.

Livingstone, R. M. (2010). Let's leave the bias to the mainstream media: A Wikipedia community fighting for information neutrality. *M/C Journal, 13(6)*. Retrieved from http://journal.media-culture.org.au/index.php/mcjournal/article/viewArticle/315

Lord, C., Ross, L., & Lepper, M. (1979). Biased assimilation and attitude polarization: The effects of prior theories on subsequently considered evidence. *Journal of Personality and Social Psychology, 37*, 2098–2109.

Louie, T. A. (2005). Hindsight bias and outcome-consistent thoughts when observing and making service provider decisions. *Organizational Behavior and Human Decision Processes, 98*, 88–95.

Maass, A., Salvi, D., Arcuri, L., & Semin, G. R. (1989). Language use in intergroup context. *Journal of Personality and Social Psychology, 57*, 981–993.

Magnus, P. D. (2009). On trusting Wikipedia. *Episteme, 6*, 74–90.

Massa, P., & Scrinzi, F. (2012). Manypedia: Comparing language points of view of Wikipedia communities. In *Proceedings of the 8th International Symposium on Wikis and Open Collaboration (WikiSym'12), Linz, Austria.* Retrieved from http://www.gnuband.org/files/papers/manypedia_006_wikisym_2012_cameraready.pdf

Nestler, S., Blank, H., & von Collani, G. (2008). Hindsight bias doesn't always come easy: Causal models, cognitive effort and creeping determinism. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 34*, 1043–1054.

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology, 2*, 175–220.

Nielsen, F. Å. (2014). Wikipedia research and tools: Review and comments. *Working Paper.* Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2129874

Oeberst, A. (2014, July). Ingroup bias in international conflicts—also in Wikipedia? Talk presented at the *Self and Identity Preconference of the European Association of Social Psychology*, Amsterdam, The Netherlands.

Oeberst, A., Halatchliyski, I., Kimmerle, J., & Cress, U. (2014). Knowledge construction in Wikipedia: A systemic-constructivist analysis. *Journal of the Learning Sciences, 23*, 149–176.

Oeberst, A., Kimmerle, J., & Cress, U. (2016). What is knowledge? Who creates it? Who possesses it? The need for novel answers to old questions. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Oeberst, A., von der Beck, I., & Nestler, S. (2014a). Hindsight Bias 2.0. Are representations of events in Wikipedia distorted? *Poster presented at the European Association of Social Psychology, Amsterdam.*

Oeberst, A., von der Beck, I., & Nestler, S. (2014b). Reading about explanations enhances perceptions of inevitability and foreseeability. A cross-cultural study with Wikipedia articles. *Cognitive Processing, 15*, 343–349.

Olick, J. K. (1999). Collective memory: The two cultures. *Sociological Theory, 7*, 333–348.

Pentzold, C. (2009). Fixing the floating gap: The online encyclopaedia Wikipedia as a global memory place. *Memory Studies, 2*, 255–272.

Pezzo, M. V. (2011). Hindsight bias: A primer for motivational researchers. *Social and Personality and Psychology Compass, 5*, 665–678.

Pohl, R. F. (2004). *Cognitive illusions: A handbook on fallacies and biases in thinking, judgement and memory*. Hove, England: Psychology Press.

Pohl, R. F., Bender, M., & Lachmann, G. (2002). Hindsight bias around the world. *Experimental Psychology, 49*, 270–282.

Pohl, R. F., & Hell, W. (1996). No reduction in hindsight bias after complete information and repeated testing. *Organizational Behavior and Human Decision Processes, 67*, 49–58.

Roese, N. J., & Vohs, K. D. (2012). Hindsight bias. *Perspectives in Psychological Science, 7*, 411–426.

Rogers, R., & Sendijarevic, E. (2013). Neutral or national point of view? A comparison of Srebrenica articles across Wikipedia's language versions. In R. Rogers (Ed.), *Digital Methods*. Cambridge, MA: MIT Press.

Rosenzweig, R. (2006). Can history be open source? Wikipedia and the future of the past. *The Journal of American History, 93*, 117–146.

Ross, M., & Sicoly, F. (1979). Egocentric biases in availability and attribution. *Journal of Personality and Social Psychology, 37*, 322–336.

Royal, C., & Kapila, D. (2009). What's on Wikipedia, and what's not…?: Assessing completeness of information. *Social Science Computer Review, 27*, 138–148.

Sahdra, B., & Ross, M. (2007). Group identification and historical memory. *Personality and Social Psychology Bulletin, 33*, 384–395.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *Journal of the Learning Sciences, 3*, 265–283.

Scardamalia, M., & Bereiter, C. (1999). Schools as knowledge building organizations. In D. Keating & C. Hertzman (Eds.), *Today's children, tomorrow's society: The developmental health and wealth of nations* (pp. 274–289). New York, NY: Guilford.

Schmid, J. (1999). Pinning down attributions: The linguistic category model applied to wrestling reports. *European Journal of Social Psychology, 29*, 895–907.

Schulz-Hardt, S., Frey, D., Lüthgens, C., & Moscovici, S. (2000). Biased information search in group decision making. *Journal of Personality and Social Psychology, 78*, 655–669.

Sia, C.-L., Tan, B. Y., & Wei, K.-K. (2002). Group polarization and computer-mediated communication: Effects of communication cues, social presence, and anonymity. *Information Systems Research, 13*, 70–90.

Silverstein, B., & Flamenbaum, C. (1989). Biases in the perception and cognition of the actions of enemies. *Journal of Social Issues, 45*, 51–72.

Smith, A. C., & Greene, E. (2005). Conduct and its consequences: Attempts at debiasing jury judgments. *Law and Human Behavior, 29*, 505–526.

Spears, R., Lea, M., & Lee, S. (1990). De-individuation and group polarization in computer-mediated communication. *British Journal of Social Psychology, 29*, 121–134.

Stahlberg, D., Eller, F., Maass, A., & Frey, D. (1995). We knew it all along: Hindsight bias in groups. *Organizational Behavior and Human Decision Processes, 63*, 46–58.

Stvilia, B., Al-Faraj, A., & Yi, Y. (2009). Issues of cross-contextual information quality evaluation. The case of Arabic, English, and Korean Wikipedias. *Library and Information Research, 31*, 232–239.

Tajfel, H., & Turner, J. (1979). An integrative theory of inter-group conflict. In J. A. Williams & S. Worchel (Eds.), *The social psychology of inter-group relations* (pp. 33–47). Belmont, CA: Wadsworth.

Tarrant, M., Branscombe, N. R., Warner, R. H., & Weston, D. (2012). Social identity and perceptions of torture: It's moral when we do it. *Journal of Experimental Social Psychology, 48*, 513–518.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.

Viégas, F. B., Wattenberg, M., Kriss, J., & van Ham, F. (2007). Talk before you type: Coordination in Wikipedia. In *Proceedings of the 40th Annual Hawaii International Conference on System Sciences (HICSS'07)*. Washington, DC: IEEE.

Viégas, F. B., Wattenberg, M., & Dave, K. (2004). Studying cooperation and conflict between authors with *history flow* visualizations. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 575–582). New York, NY: ACM Press.

Werkman, W. M., Wigboldus, D. H., & Semin, G. R. (1999). Children's communication of the linguistic intergroup bias and its impact upon cognitive inferences. *European Journal of Social Psychology, 29*, 95–104.

Wigboldus, D. H., Semin, G. R., & Spears, R. (2000). How do we communicate stereotypes? Linguistic bases and inferential consequences. *Journal of Personality and Social Psychology, 78*, 5–18.

Yopchick, J. E., & Kim, N. S. (2012). Hindsight bias and causal reasoning: A minimalist approach. *Cognitive Processing, 13*, 63–72.

Toward Participatory Discovery Networks: A Critique of Current Mass Collaboration Environments and a Possible Learning-Rich Future

R. Benjamin Shapiro

Introduction

Over the past few years, participation in online environments for mass collaboration and learning has grown dramatically. These environments support a diverse array of interactions and practices between participants and their peers, disciplinary content, and environment designers and facilitators. Academic research scientists, commercial enterprises, and hobbyists have created these environments, variably, to enable academics to advance research in the natural sciences, to support teaching and learning, and to support recreational play.

The purpose of this paper is to use key findings from the learning sciences literature to critically examine these existing environments and then to theorize about what the next generation of such environments could be like if informed by the learning literature and successes and failures of current environments. I believe that such examination and speculation are necessary because, as I shall show below, some of the most visible mass collaboration and learning environments do not reflect current research-based understandings of learning. Moreover, these environments might become more effective for mass collaboration if they incorporated design insights from learning theory because doing so could empower participants to collaborate on more ambitious problems. Finally, the growing popularity of such environments is an opportunity for learning scientists to grow their impact on everyday learning by assisting in the design of next generation online collaboration and learning environments.

R.B. Shapiro (✉)
ATLAS Institute and Department of Computer Science,
University of Colorado Boulder, CO, USA
e-mail: ben.shapiro@colorado.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_10

Findings from Research on Learning

Decades of research on learning have produced a remarkable range of insights into how people learn. In particular, studies within schools, workplaces, and informal settings have enabled us to understand how learning environment designs can best enable learning. They also permit us to think about learning in ways that transcend historical framings that can impede environment design, such as by shifting from thinking of learning as a process of incorporating external symbols and meanings into the mind (and in which teachers transmit these ideas to students), to a socially situated process through which knowledge is constructed in joint activity. In this section, I wish to highlight key findings from education research that are especially relevant to the design of online collaborative environments. This section is not intended to be an exhaustive summary of work on online learning environments. Instead, it is intended to enumerate concepts that are useful in design and have discriminant utility, i.e., those that enable comparison and critique of extant mass collaboration environments.

Decades of research on learning show that learners can learn best when learning environments:

- Connect to learners' personal interests, offering opportunities for participation well matched to learners' prior skills, and their intrinsic motivation to develop new expertise (Collins, Joseph, & Bielaczyc, 2004; Edelson & Joseph, 2004; Hidi & Renninger, 2006; Krapp, 1999; Zusho, Pintrich, & Coppola, 2003).
- Afford opportunities for learners to express, challenge, and refine their own and others' ideas (Brown & Campione, 1996; Hutchison & Hammer, 2010; Scardamalia & Bereiter, 1994).
- Offer a mix of guided and ill-structured activity, including room to fail (Bransford & Schwartz, 1999; Kapur, 2006; Kapur & Bielaczyc, 2012; Kirschner, Sweller, & Clark, 2006; Koedinger, Pavlik, McLaren, & Aleven, 2008).
- Encourage collaborative problem-solving together with peers who have complementary or more expert knowledge (Moll & Whitmore, 1999; Vygotsky, 1980).
- Enable learners to observe experts' practices and see connections between their own beginner activities, those of experts, and the broader purposes of the context in which they work. This mutual observability of practice should be coupled to mechanisms that enable deepening ("centripetal") participation in the expert practices of a community (Lave & Wenger, 1991).

None of these findings are new, and many have long been considered best practices for e-learning environments (McCombs & Vakili, 2005). These are design principles for effective learning that apply to most—perhaps all—disciplinary domains. Yet many of them are absent in the apparent design of the most visible environments for online mass collaboration and learning. I wish now to use these pedagogical design principles to critique and compare several genres of online mass collaboration and/or learning environments. These are MOOCs, science crowd-sourcing systems, massively multiplayer online (MMO) games, and the burgeoning maker community. I have chosen these environments in particular because of the large amounts of policy and media attention and financial investment that they have garnered in recent years and because, as I show later in this chapter, their combination offers unprecedented opportunity to combine learning, public service, and scientific research.

Massively Open Online Courses

Massively open online courses (MOOCs) have generated enormous attention over the past few years. In their most common implementations, they are online transpositions of lecture-heavy, collaboration-light university courses. Most aggressively popularized by start-ups Coursera and Udacity and the joint MIT-Harvard nonprofit edX, MOOCs have received extensive coverage in the popular press. A 2012 *New York Times* headline declared that same year the "Year of the MOOC." The MOOC formula is to enroll thousands (or tens of thousands) of participants in a no-cost course that consists of prerecorded lectures, machine-graded homework problems, and online discussion forums. In short, MOOCs take the impersonal format of a large college lecture and further reduce student-instructor interactivity but enable anybody to participate for free from anywhere.

Though laudable as attempts to expand access to university teaching, MOOCs have been largely unsuccessful as environments for mass learning, failure that has not been lost on some of the format's strongest proponents. Compare this 2012 Wired description of an interview with Udacity founder Sebastian Thrun:

> He's thinking big now. He imagines that in 10 years, job applicants will tout their Udacity degrees. In 50 years, he says, there will be only 10 institutions in the world delivering higher education and Udacity has a shot at being one of them. Thrun just has to plot the right course. (Leckart, 2012)

with this quote of Dr. Thrun from 2013 in the Chronicle of Higher Education:

> A medium where only self-motivated, Web-savvy people sign up, and the success rate is 10 percent, doesn't strike me quite yet as a solution to the problems of higher education. (Kolowich, 2013)

This sense of despair is well justified by research on MOOCs thus far. Studies of MOOCs thus far have revealed that over 90 % of participants drop out (Jordan, 2014; Yang, Sinha, Adamson, & Rose, 2013). Many claim that participants in MOOCs feel socially isolated (Gasevic, Kovanovic, Joksimovic, & Siemens, 2014; Mora et al., 2014; Rothkrantz, 2014),[1] and high dropout rates indicate that MOOCs are not yet a viable substitute for other kinds of education. Further, MOOCs are not reaching disadvantaged populations of learners who lack access to more traditional educational opportunities: nearly 80% of participants already have post-secondary

---

[1] Though widely noted in published works, it is difficult to find primary source data supporting this claim.

degrees (Christensen et al., 2014). Though Thrun and other MOOC magnates have been surprised by these results, we should not be. Rather, MOOCs are, by their designed nature, *structurally deficient* as learning environments, patently unfit for the educational democratization for which they are nominally intended. So much is obvious from even cursory scrutiny using the pedagogical design principles described above:

Though voluntary MOOCs are responsive to learners' personal interests (one can take an MOOC on nearly any topic that one desires), they typically meet none of the other criteria that I enumerated above. Like other lecture-based teaching and learning, MOOCs are about the transmission of knowledge from expert teachers to beginners. They are not spaces that engender the explication, challenge, and refinement of personal ideas and epistemologies (Hammer, Sherin, & Kolpakowski, 1991) by learners. The asymmetric communication bandwidth in MOOCs flows strongly from lecturer to audience, with few opportunities for teachers to observe, interpret, and respond to students' ideas or for learners to do the same with their peers.

Similarly, the autograder-friendly character of MOOC work is at odds with the Vygotskian practice of enabling learners to work within their zones of proximal development through the support of more knowledgeable peers, including peers who have complementary knowledge. Though some MOOCs include group work many do not, which hampers their quality as learning environments and fosters the sense of isolation that besets participants, often catalyzing dropout (Baggaley, 2013; Gütl, Rizzardini, Chang, & Morales, 2014; Rosé et al., 2014). MOOCs' scale and the intrinsic open-endedness of group conversations make it difficult for instructors to facilitate group conversations and for automated tools to play this facilitative role.

In order to satisfy their need for easy (and often automated) grading, most MOOCs pose problems to learners for which there are *a priori* known right answers; they cannot yet facilitate creative modes of student participation and expression. Moreover, they expect individuals to solve those problems individually in order to receive individual grades. These facets, combined with mass scale—and proportionally less time for instructors to offer responsive guidance to learners—seem to militate against open-ended, ill-structured, creative problem-solving. As the assessment of open-ended, creative, collaborative work is more difficult, requiring prudent judgment in addition to standardized criteria, it is a poor fit to the MOOC format.

Despite these shortcomings, the emergence and popularity of MOOCs do signal exciting possibilities for the future of online learning. First, they showcase the possibility of using the web to bring together subject-matter experts with topically interested members of the public for joint participation in activity that is explicitly pedagogical. Hundreds of thousands of people virtually congregating with the deliberate purpose of learning is unprecedented and remarkable in this way. The explosion of the MOOC phenomenon is a watershed event for public engagement in education. It demonstrates three important things:

1. That there is a massive public demand for expert-led learning of academic ideas. Rigorous higher education has become popular entertainment.

2. That far from relishing ivory tower seclusion, many academics are eager to experiment with new ways to share what they know with the public.
3. That university administrators, venture capitalists, and the popular press are all willing to endorse, sponsor, and advertise these experiments in mass learning, even before their efficacy is well understood.

What remains to be discovered is how to mobilize this enthusiasm in ways that are pedagogically rich. MOOCs are still new and are likely to improve over time. Later in this chapter, I discuss one vision for their learning-rich future evolution.

Crowdsourcing Science

Another form of mass academic participation has flourished roughly in parallel with MOOCs: science crowdsourcing games. Like MOOCs, these environments bring together highly expert academics with large numbers of the interested public for online interaction with academic content. For example, just as one can take Motonari Uesugi's edX course, The Chemistry of Life (edX, 2015), one can also play Foldit to problem-solve protein-folding puzzles.

However, while these media have striking *topical* parallels, the academic intentions behind them, and the probable learning outcomes of them, could not be more dissimilar. Whereas MOOCs are *intended* as learning environments, crowdsourcing games are piecework labor environments. Whereas the academic intention behind making a MOOC is to benefit the public through education, the academic intention in crowdsourcing games is primarily for scientists to benefit themselves through free or cheap labor. In other words, a Coursera course about molecular biology is intended as a resource for the public to learn about molecular biology, but Foldit uses the public to enable scientists to do better molecular biology, with only incidental investment in public understanding of biology. The topic may be similar, but the intentions and likely outcomes could not be more different.

Consider the example of Galaxy Zoo, a member of the highly successful Zooniverse family of crowdsourcing sites. Professional scientists created Galaxy Zoo because they needed help labeling features of Hubble Space Telescope imagery. Specifically, they needed to know if photographed galaxies were spiral shared or not and, if so, what direction they spiraled in. This labeling could be applied through computer vision moderately well but not well enough to conduct the astrophysical study that the scientists intended. A graduate student refused to do the labeling himself (and threatened to quit if forced to); instead, he built a website so that volunteers could analyze the data for him (Fortson, 2011). Over 900,000 data points were provided by Galaxy Zoo users between 2007 and 2009. And as of March 10, 2015, about 127 papers appear in Google Scholar containing the term "Galaxy Zoo" in the title. So scientists are learning things. But are the volunteers learning astrophysics?

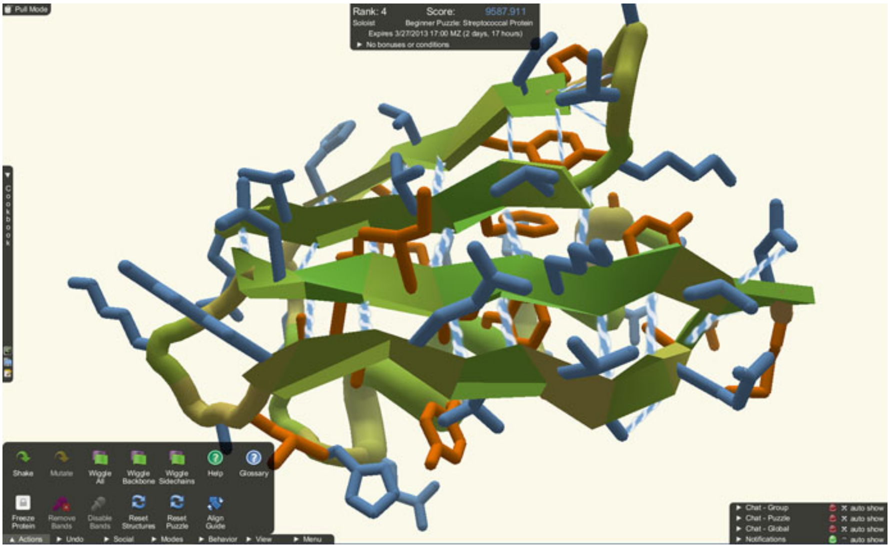


Fig. 1 Foldit interface

On this, we have much less evidence. No study to date has investigated what Galaxy Zoo participants actually learn about astrophysics or astronomy through participation in crowdsourcing tasks. This is consistent with a general lack of rigorous research on what participants actually learn about the target domains they are doing crowd work for. But what we do know—largely anecdote—is uninspiring. Consider the following: Foldit is one of the most highly acclaimed science crowdsourcing puzzle games. Foldit volunteers manipulate domain-native representations of molecular biology (see Fig. 1) in order to solve protein-folding puzzles that are computationally expensive but well suited to the human perceptual system. This approach has been very scientifically successful, rapidly solving long-standing scientific problems (Khatib et al., 2011) and resulting in papers that credit players as coauthors. But what do players learn from this participation? Doreen DeSorbo, one of Foldit's top 20 players, is quoted in a CNN report (Gross, 2012) as describing her (lack of) understanding of the meaning behind the game's user interface as follows: "They're all orange and blue thingies to me… That's the way it is and that's the way it's going to be." This is a reality quite apart from the claims of Foldit creators that they have "basically shown that it is possible to create experts in [molecular biology] purely through game play" (Zoran Popovic, as quoted in Toppo, 2012).

Clearly, one player, even a top player, interviewed by a reporter does not constitute reliable evidence of how well these systems function as learning environments. So we cannot say how well Galaxy Zoo enables learning of astrophysics or Foldit enables learning of molecular biology. But if we heuristically evaluate the design of these environments through the critical lens of learning sciences research, we can conclude that the structure of Galaxy Zoo (and similar environments) is in many ways the opposite of what one would construct if one applied good pedagogical design principles. The Galaxy Zoo tasks provide no room for learners to express, challenge, or refine their conceptual models of astrophysics, but then, it also does not invite them to develop or apply any either. It requires only a functioning, human perceptual system. It asks only, "Does this galaxy image look like a spiral? If so, is it clockwise or counterclockwise?" It does not require more conceptual sophistication than shape identification. Why one would care about the spirality of galaxies is beside the point. A Galaxy Zoo scientist need not care that participants understand the whys and hows of their science any more than they care whether their computers do; the human participants are human computers, not coinvestigators (Quinn & Bederson, 2011).

Galaxy Zoo offers no mechanism whereby a user can share his or her label of a galaxy with another participant. Whereas in other contexts, participants might do so in order to reason through hard problems together, they cannot here. Putting aside momentarily the question of whether there is even reasoning to be discussed (as opposed to gestalt shape formulation), this is not possible because the Galaxy Zoo creators believe that such discussion might harm their science. The reason for this is that the Galaxy Zoo scientists' first concern is to maximize data quality; they want each label to be independent and fear that collaboration could add bias to their volunteer-provided data set (Fortson, 2011). This stance has been experimentally relaxed over the past few years, as the project has experimented with varying the number of samples they collect per image, reducing the number of samples needed proportionately to the confidence they have in the labels they collect based on participants' prior work quality (Kamar, Hacker, & Horvitz, 2012). Nonetheless, the prohibition on collaborative labeling remains and with it, the possibility for rich, peer-supported, and personally responsive learning.

The above critique pertains to crowdsourcing systems like Galaxy Zoo as they currently exist and in how they are crafted by their scientist creators as stand-alone mass collaboration environments. Some educators *have* succeeded in using these systems as instructional resources in more intentionally pedagogical environments, such as in classrooms (Farley, 2013), where Foldit has been used to introduce students to visual representation in molecular biology, and in a MOOC (Seaton et al., 2014), where Foldit puzzles were a problem set and students competed for high scores. These examples show how crowdsourcing puzzle games can be combined with two different teaching genres, the traditional course and the online MOOC, in order to support learning. We do not yet know how couplings between online crowdsourcing systems and other learning environments (e.g., school classrooms) can lead to deeper learning than participating in crowdsourcing alone or can enable more powerful scientific crowdsourcing (drawing upon participants' disciplinary knowledge could support more sophisticated kinds of data collection and analysis).

One approach to drawing connections between crowdsourcing and participants' daily lives is called *citizen science*. Citizen science is a slightly different model for scientific crowdsourcing than puzzle games: like other science crowdsourcing projects, citizen science projects still "involve nonscientists in scientific investigations in which a range of individuals gather data for use by scientists to investigate questions of research importance" (Trumbull, Bonney, Bascom, & Cabral, 2000). As with crowdsourcing projects like Galaxy Zoo, it is rare for citizen science project participants to move beyond data collection and into experimental design and data analysis (Trautmann, Shirk, Fee, & Krasny, 2012). Citizen science and Galaxy Zoo/Foldit-like environments differ, however, in that citizen science, volunteers typically gather data from the physical world around themselves and are encouraged to do so in collaboration with others. Because citizen science projects are usually anchored in participants' communities (e.g., counting bird species in their backyards), they offer a personal relevance that may not inhere in other forms of crowdsourcing. Moreover, by encouraging collaboration, they may offer latitude for richer conversations about science than in crowdsourcing environments that strive for statistical independence through isolation of participants' contributions. Trumbull et al. (2000) analyzed the content of letters written by participants in the Seed Preference Test citizen science project and found strong evidence that participants engaged in scientific thinking processes. However, the majority of participants in Trumbull et al.'s study had bachelors or masters degrees, and the study's methods do not permit assessment of the extent to which participants developed scientific habits of mind through participation or were applying skills that they had previously developed. Another study of citizen science participants' learning and attitude changes over time found "no statistically significant change in participants' attitudes toward science or the environment, or in participants' understanding of the scientific process," though did find a small, significant increase in participants' knowledge of bird biology (Brossard, Lewenstein, & Bonney, 2005). Though connected to participants' personal lives, neither of the two studies just cited investigated how connections between citizen science and purposely constructed learning environments—such as school classrooms—can enable rich learning about science. In chapter "Citizen Science: Connecting to Nature through Networks" of this volume, Barron, Martin, Mertl, and Yassine (2016) describe 4 years of practice by one teacher who forged connections between citizen science and inquiry practices in (and beyond) his classroom. Much more such research is needed, including design-based research into possibilities for connecting crowdsourcing and learning across settings and media.

Commercial Entertainment Video Games

Entertainment video games are a massive industry. The industry collects annual revenues on the order of $100 billion (Van Der Meulen & Rivera, 2013) from approximately one billion gamers (Takahashi, 2013). The average gamer plays for 8 h per week (Entertainment Software Rating Board, n.d.). Ninety-seven percent of American youth are gamers (Lenhart et al., 2008).

Commercial entertainment games are enormously prolific sites for mass collaboration, both within game play and in virtual communities that develop around games. Like MOOCs and volunteer crowdsourcing systems, entertainment games draw participants who join by choice, whether for the visceral and aesthetic experience of slaying colorful monsters (e.g., World of Warcraft, also known as WoW), the chance to explore alternative histories (e.g., the Civilization series), the thrill of besting competitors (e.g., Starcraft), or the communal pleasure of joining a stable player group for nightly online gatherings of playing and (Chen, 2012).

The power of entertainment games to offer rich learning experiences is well established (Gee, 2007; Squire, 2011). Most good games enable players to take on a fictional role and make choices over time that enable them to achieve goals that are either self-imposed or suggested by the game environment, such as through a narrative. They afford learning through offering players meaningful choices to achieve these goals (Gee, 2004; Shapiro, Squire, & The Educational Research Integration Area, 2011). Games frequently offer a mix of well-guided practice (such as through in-game tutorials) and open-ended exploration with ample room for failure and iteration (Litts & Ramirez, 2014).

Beyond the learning affordances of game mechanics that individual players interact with (Gee, 2004), many games and game communities have become mass collaborations between mixed-ability groups of players who work together to succeed at team challenges or to help novice individual players to learn their way around games (Chen, 2012). Players frequently explain their thinking about how game systems work or about why they have constructed particular strategies in light of those game systems. To do so, they enact rich, quasi-scientific discourses around games, arguing in minute empirical detail about causes, effects, and mechanisms for in-game processes (Steinkuehler & Duncan, 2009), co-construct detailed spreadsheets of game element properties (e.g., Team Liquid, 2014), and author detailed, step-by-step tutorials to help peers to master specific game skills (Tabarnak, 2014). Thus, while not publicly positioned as educational environments, commercial games instantiate all of the learning environment design characteristics outlined above.

Nonetheless, educational games are not suitable replacements for traditional schooling. There are several reasons for this. First, though games like World of Warcraft can offer players rich ways of participating in scientific practices and discourses, the content of WoW is an imaginary landscape, not the universe that we inhabit. Most educators and educational policy makers have both process/skill goals and content learning goals for students. Even the Next Generation Science Standards, which is unprecedented in its focus on skills and practices, contains extensive descriptions of specific ideas that students should learn. While WoW player communities are loaded with process and practice, little of the content of the WoW universe would satisfy educators' expectations. Second, many successful examples of using games to enable learning by students situate gaming inside of a carefully crafted curriculum and classroom culture. Barab, Thomas, Dodge, Carteaux, and Tuzun (2005) describe the inseparability of the educational game Quest Atlantis from its accompanying curriculum, how the learning outcomes intended by the authors (as designers) cannot be achieved through game play alone, and how creating a curriculum that could be adapted to different local contexts was a crucial aspect of their design work. DeVane, Durga, and Squire (2010) successful classroom use of Civilization to enable learning about economic systems dynamics was utterly dependent upon teachers' facilitation of classroom conversations about in-game phenomena. Third, public schools should be committed to enabling all students to be successful, regardless of those students' backgrounds and special needs. Doing so often requires extensive adaptation of classroom curriculum tools and materials. Many video games are not accessible to people with physical and intellectual disabilities and are prohibitively difficult for teachers to modify themselves. Therefore, while games are powerful learning environments, they do not substitute for schools, so much as augment and expand the kinds of experiences that can be provided within schools. Much future research and innovative practice will likely involve new models for fusing game-based learning with classroom pedagogies.

Makerspaces and the Maker Movement

Makerspaces (also sometimes known as hackerspaces) are rapidly emerging as physical sites of face-to-face collaboration around the design and engineering of creative, tangible products. These spaces vary dramatically in size, from small 50 m^2 rooms to gigantic warehouses, but all include communal tools and work surfaces for participants to use on their projects. People use these spaces to craft projects ranging from airplane tie-downs to gigantic rideable robots, taking advantage of shared tools and the knowledge of others who also use the spaces. Makerspaces are springing up all over the world, with one directory (Hackerspaces.org, 2015) listing 1886 such spaces around the globe as of February 2015. Some makerspaces are nonprofits, others are commercial enterprises, and still others exist as resources within larger organizations, such as within public library systems as private resources for the employees of companies (Nathan, 2011), for students and faculty at particular universities (BTU Lab, 2015; Tufts Maker Network, n.d.), at museums (Brahms, 2014), and even within primary and secondary schools. Academic researchers are just beginning to understand the collaborative dynamics of these spaces, including how they promote knowledge sharing by participants (Sheridan et al., 2014).

The rapid global emergence of makerspaces is linked to the explosion of the *maker movement*, which encourages people to creatively express themselves through designing, crafting, and engineering new physical products. Activity within makerspaces is a rich mixture of design and engineering, and much of participants' learning about design and engineering happens informally, through networks of mutual observation and collaboration. Initially a grassroots assemblage of people sharing projects and techniques with one another online, in local Maker Faires, and in makerspaces, the movement has now gotten recognition in education policy circles as a possible vehicle for improving STEM education (Peppler & Bender, 2013). President Obama has hosted a series of White House Maker Faires and linked participation in the movement to historical accomplishments and aspirational goals for an innovative society:

> This is a country that imagined a railroad connecting a continent, imagined electricity powering our cities and towns, imagined skyscrapers reaching into the heavens, and an

> Internet that brings us closer together. So we imagined these things, then we did them. And that's in our DNA. That's who we are. We're not done yet. And I hope every company, every college, every community, every citizen joins us as we lift up makers and builders and doers across the country. (Obama, 2014)

Similar government support for Making is emerging internationally as well, such as in India (Fok, 2014) and China (Larson, 2014; Parker, 2014).

The maker movement demonstrates a new model for how mass collaboration and mass learning can be distributed across online and in-person participation. Participants together produce both physical and virtual artifacts, supporting each others' learning by drawing upon the knowledge, tools, and monetary resources of physical and virtual communities.

For example, Project Hexapod (http://www.projecthexapod.com/) is a collaborative effort to construct a rideable hexapod robot named Stompy. It will eventually be large enough for passengers to ride it as it walks *over* cars on city streets. The project is physically based in a Somerville, MA, USA, makerspace called Artisan's Asylum. Project members crowdsourced $97,817 for the project using Kickstarter and have used those funds to buy materials as well as to offer formal courses to local donors, offering structured education in various engineering techniques necessary for the construction of Stompy. Materials from these courses are posted online so that they can benefit others with similar construction goals (Cody, 2012). In addition to within courses, team members learn together through informal inquiry, experimenting with various engineering designs and fabrication processes as they work toward a functional robot. As they do so, they post detailed blog posts sharing what they've discovered, and how they have discovered it, so that others can learn from their efforts. For example, Cavalcanti (2014) documents changes to fabrication techniques (from grinding to chemical removal) and project designs (from bushings to bearings) that eased the construction and reliability of leg joints. The project's blogging becomes a mechanism for documenting the team's work but also for sharing knowledge about engineering that can enable others elsewhere to learn from the team's struggles and successes. Moreover, the work of *making* Stompy enables the Project Hexapod team members to deepen their knowledge of engineering design. This knowledge, in turn, becomes a resource for the whole of the Artisan's Asylum community, where, like in other makerspaces (Sheridan et al., 2014), members routinely help one another to master tools and techniques for a variety of projects.

Project Hexapod illustrates how even projects that are primarily local collaborations, taking place within the walls of neighborhood makerspaces, are nonetheless linked to broad networks. The project's funding came from a global pool of 1571 Kickstarter backers. The project's website (http://projecthexapod.com) offers extensive documentation that could inform makers anywhere working on similarly large-scale robotic projects. This content is an addition to the enormous amount of maker projects and tutorials that are easily found online, covering applications that include aquaculture (Dirksen, 2012), gardening (DiSalvo, Fries, Lodato, Schechter, & Barnwell, 2010), and art (Mitchell, 2013).

Thus, efforts like Project Hexapod really reflect collaborations at two levels: The first is around the objects of the projects themselves (in this case, a gigantic rideable six-legged machine named Stompy). The second is the much more massive collaboration of the maker movement itself, including the production of norms, ideologies, tools, and communities for learning and production. These two levels are bridged by the meta-production of tutorial materials that describe how the products of the first level were made; makers frequently produce tutorials that enable others to reproduce their work, thereby contributing to an open source, *share and share alike* ethos that is central to the maker movement. That is, the normative practice of work process documentation and tutorial authoring creates a mechanism for the perpetuation of the maker movement itself. In continuing to publishing and using tutorials for and by each another, makers (massively) collaborate on the production of a movement that enables—and is larger than—any particular project or makerspace.

Maker Movement as Learning Environment

The emergent structure of the maker movement is remarkably well aligned with the learning environment design principles enumerated earlier.

Participation in maker spaces, and making more generally, is entirely volitional, and the ways that people participate are tied to their personal interests. Makers make because they want to. Moreover, there are numerous entry points to making that can anchor the beginnings of participation in a very wide range of other personal interests, including knitting and sewing of textiles (Buechley, Peppler, Eisenberg, & Kafai, 2013), gardening (Frueh, n.d.), and child care (Romano, 2013). A number of Maker Faires, organized by the publisher O'Reilly and Associates and held around the globe, are public festivals of making, where a carnival-like atmosphere enables members of the public to interact with a massive number of maker projects. These Faires serve existing makers (who gain a broad audience for their projects and their culture) as well as function as advertising, raising public awareness of the movement and potentially sparking interest by members of the public in deeper participation.

Making is a social endeavor, one in which makers frequently share their ideas with one another, get feedback on them, refine their approaches, and sometimes publish evidence of this process. For example, a participant in Sheridan et al. (2014) describes how participating in the Sector67 makerspace enabled him to refine his circuit design technique through feedback from peers:

> I was trying to do an electronics project that I hadn't done before, working with like microcontrollers and building up some power electronics … [When you] do some of those things in a vacuum, you can get away with doing the wrong thing for way too long. (quote from Sheridan et al., 2014)

Makerspaces offer participants room for learning in both guided and ill-structured activity. While members of such spaces may design and build whatever and however they want, they also frequently participate in peer teaching. Artisan's Asylum, the largest makerspace in the USA, lists dozens of courses on its website (http://artisansasylum.com/current-classes/), covering a range of topics including bicycle building, stone setting (for jewelry), and the use of table saws. These practices also exist online, with maker tutorials (such as those on Instructables.com or Sparkfun.com) offering step-by-step guidance in how to replicate another maker's project and then inviting users to share their own projects with the community.

Finally, makerspaces offer learners ample opportunity to observe the practices of more expert participants. One of the primary reasons that people join makerspaces is to use the expensive, loud, space-consuming tools that are in abundance there. These tools serve as educational affinity spaces, drawing in people who know how to use things like plasma cutters together with those who want to learn to use plasma cutters and enabling the latter to learn through mentorship from the former. Likewise, online project documentation for ambitious efforts like Stompy offers beginners the chance to peripherally observe a highly complex and very ambitious project unfold. Sites like projecthexapod.com, with frequent links to the Artisan's Asylum website embedded in documentation of how Stompy is being constructed, then offer a pathway to more central participation through joining the makerspace and taking part in the project.

While projecthexapod.com is an entire website dedicated to a single project, documentation of, and other resources to support, maker projects frequently occurs on websites that are not single-project specific. For example, Instructables.com is a commercial site where makers write public tutorials for others; Thingiverse is a popular site for people to post models (3D drawings) of 3D printable objects; the site is owned and maintained by MakerBot, a company that sells 3D printers to the maker community. Likewise, SparkFun and Adafruit, commercial vendors of electronic components that are frequently used in maker projects, integrate tutorial materials with their electronic storefronts. These sites, as well as myriad blogs, serve as repositories for makers' knowledge and enable connections between makers, either working alone or in makerspaces, whereby innovations created in one space diffuse into others.

Participatory Discovery Networks

The above analyses describe how various online and face-to-face mass collaboration genres do and do not exhibit different characteristics that can make for powerful learning environments. Each of the genres described has different strengths and weaknesses. For example, crowdsourcing systems illustrate how mass publics can participate in scientific discovery while simultaneously occupying roles so marginal that they do not afford deep learning. In contrast, MMO games can support deep peer-supported apprenticeship for learning, though thus far this learning has been about the properties of imaginary digital worlds, not systems in the physical world. MOOCs show that there is a public appetite for learning about academic topics but that the lack of social contexts for peer support for learning and knowledge production can severely hamper participation and impact.

The future of online mass collaboration and learning environments likely lies in environments that capture the best properties of these systems; these environments will:

- Fully embrace volunteers as *learners*.
- Enable learning about disciplinary ideas, including inquiry and production process.
- Offer pathways from novice to expert participation, including from data entry to data analysis, scientific fact production, publication, and research problem formulation.
- Integrate online and in-person learning communities.

They will do these things by recombining the learning environment design principles enumerated early in this chapter with some of the designed characteristics of entertainment games, MOOCs, crowdsourcing systems, and the maker movement.

The term "mass collaboration environment" seems a poor choice for this class of systems: while some will likely be massive and all will include collaboration, neither is the express purpose of these environments. Collaboration on a massive scale is not the end but rather the means to enabling diverse, interconnected communities of people to participate in scientific discovery. I purpose that such environments should be instead called Participatory Discovery Networks (PDNs).

To illustrate some possibilities for PDNs to foment radical new forms of learning and scientific discovery, I offer a hypothetical description of what a PDN might be like. This description is intended as a thought experiment, an illustration of what the future of mass collaboration could be like.

Body Makers

What if we could create a mass collaborative learning environment that could improve medical diagnosis in developing nations while also enabling members of the public to learn about engineering, biology, and medicine? This might seem far-fetched, but prior successes in online game play, MOOCs, and making show that it might be possible. Here I present a specific problem, one that is ripe for mass collaboration, and describe how an imaginary PDN, called Body Makers, could address it.

The Problem

Ultrasound, Computed Axial Tomography (CAT or CT), and Magnetic Resonance Imaging (MRI) scans enable doctors to spot pathologies that would otherwise be invisible. But most doctors do not have the expertise to read ultrasound, CT, or MRI images themselves and depend upon specialists, radiologists, to interpret images in order to make diagnoses. These technologies and collaborative medical practices have enabled dramatic improvements in wealthy nations' abilities to detect and treat disease.

Unfortunately, this technology and this expertise are inequitably distributed. Three quarters of the world's population has no access to medical imaging (Granot, Ivorra, & Rubinsky, 2008; Maru et al., 2010). This is both a hardware and a human resources problem: developing nations lack both imaging hardware and the expertise to use it. Medial specialists from wealthy nations sometimes make aid trips to developing nations to assist with diagnosis in times of tragedy (American College of Radiology, n.d.; Short, 2014), but they must use equipment that is far less capable than what exists in their home countries, and in any case, their contributions do not enable sustainable improvement in local medical practice.

Sustainable change will require new kinds of imaging hardware, including equipment that is more robust in harsh environmental conditions, functions with intermittent electricity, and can be used by nonspecialists, all while protecting patients and clinicians from excess radiation. Very little such equipment is made today (Maru et al., 2010). Simultaneously, clinicians on the ground need help to interpret the images that result from using these systems. Visits by foreign doctors fulfill temporary interpretive needs, but lasting improvements in case will require ongoing support, whether through training local specialists or creating mechanisms for persistent long-distance assistance.

What Could Be

What if there was a hybrid online-meatspace environment where participants with different skills and goals collaborated to design, build, test, and refine durable, low-cost biomedical imaging equipment and then to analyze images captured with this equipment to assist doctors in developing nations with medical diagnosis and treatment? Imagine the following vignette:

Dr. Narcisse, a physician in Haiti, is worried about his patient Sophie. At first, she seemed like a simple case of diabetes, but her response to treatment has progressively worsened. Could it be a pancreatic cancer? He decides that she needs a CT scan and refers her to Haiti Communitere, which runs a makerspace in Port au Prince (Dauster, 2013*). The makerspace has a CT scanner that its members built through a virtual collaboration with makers in other countries. One of the local builders of the ultrasound machine scans Sophie's abdomen and uploads the imagery and Sophie's anonymized case history into the Body Makers online community. Once there, a virtual community of medical students, radiology residents, doctors seeking continuing medical education, and interested volunteers analyze the images, arguing over what they see and together crafting a shared diagnosis and recommended treatment plan. Their work is scrutinized and verified by veteran participants, including volunteers working at home as well as radiology residents and expert attending radiologists as part of daily hospital-based resident education. Once verified, this diagnosis and treatment plan is sent back to Dr. Narcisse to guide his treatment of Sophie.*

With Sophie's permission, her case, like hundreds of others, becomes part of a library of case histories that are available for participants to use as resources while analyzing new cases but also become available for creators of MOOCs and educational games to use as content for new learning environments. For example, one team of researchers creates Contours, a game for anatomy education that challenges players to label organs on 3D reconstructions of CT and MRI data and then to spot pathologies in those images. Body Makers data about which cases were easy or hard for participants to converge on in analysis informs the development of sequences of game levels that gradually escalate in difficulty. Elsewhere, a MOOC on anatomy and physiology uses case histories and Body Makers images to explain how different biological processes are disrupted as disease develops. These new developments are bidirectionally linked, so content does not only flow out of the system: participants in Body Makers can find additional participatory experiences related to their current cases (e.g., an educational game about the physiological system under scrutiny) that can enable them to shape their own just-in-time improvement of their skills.

This story might seem far-fetched, but nearly every facet of this socio-technical system already exists. As described above, makerspaces already exist all over the world, and participants in them routinely swap project plans with one another. The makerspace in Port au Prince already exists. Participants in crowdsourcing projects like EyeWire (https://eyewire.org/) already work together to map intricate anatomical structures. And, perhaps most surprisingly, hobbyists have already created their own homebrew CT scanners in their garages (Krasnow, 2013) and in their local makerspaces (Jansen, 2013). Figure 2 shows the current state of this open source (Jansen, 2014) work, which is not ready for use with humans, but is a shocking illustration of future potential.

The above vignette weaves together and extends several existing genres for mass collaboration, including MOOCs, crowdsourcing, entertainment games, and the maker movement. It offers a glimpse of how we might expand the impact of crowdsourcing games by explicitly enabling learning through peer mentoring, debate, and other social interactions present in commercial entertainment games. It also shows how crowdsourcing environments might offer pathways for knowledge and

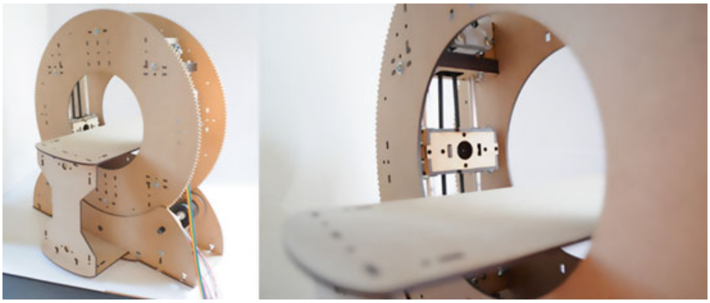


Fig. 2 Hobbyist CT scanner, made in a makerspace

community development by amateurs: they can use MOOCs, games, and long-term participation in Body Makers argumentation to simultaneously grow knowledge and authority (such as gaining the ability to certify others' analyses) within the Body Makers analysis community. Rather than being permanently relegated to the margins of the crowdsourcing enterprise, participants in the vignette have room for centripetal participation (Lave & Wenger, 1991). The vignette also illustrates how mass collaborations can span multiple kinds of mass collaboration system (e.g., the maker movement and crowdsourcing games), in order to achieve outcomes that are not possible in any single genre alone. By creating linkages between makers' expertise (e.g., in engineering) into biology and medicine, new PDNs like Body Makers could enable the collective production of massive social impact.

Conclusion

Current mass collaboration environments only scratch the surface of what might be possible were these environments informed by solid research on how people learn and how designed environments can best support learning. By recombining learning research with the characteristics of existing environments (e.g., MOOCs, crowdsourcing games, and the maker movement), new kinds of production, enabled by far richer learning, might be possible. To build these, we will need to think more systematically about how to design trajectories for deeper participation and learning within them.

The environment design principles laid out early in this chapter may offer useful heuristics for the creation of new environments that embrace participants not only as collaborators but also as learners. These principles are instantiated in the hypothetical Body Makers Participatory Discovery Network just described. But Body Makers itself is meant as a thought experiment, an elaboration of what-if conjectures about how existing mass collaboration environments might grow together in the future. Moreover, the physical, virtual, and intellectual boundary spanning that environments like Body Makers would offer learning sciences opportunities for studying new ways and kinds of learning and for collaborating with game developers and other technologists in design-based research. Future environments may take drastically different concrete forms than the one I describe, but decades of learning research suggest that these environments are most likely to be successful if the environment design principles I've laid out are central to their creation. Moreover, the physical, virtual, and intellectual boundary spanning of environments like Body Makers would offer learning sciences researchers opportunities for studying new ways and kinds of learning and for collaborating with game developers and other technologists in design-based research. These collaborations will likely lead to the discovery of new learning environment design principles, which could have pedagogical and technological ramifications far beyond mass collaboration.

Acknowledgements This chapter was written with support from the National Science Foundation (Award IIS-1227530) and was greatly helped by conversations with Michael Ferris, David Hatfield, Kurt Squire, and Richard Halverson.

References

American College of Radiology. (n.d.). *Haiti radiology relief*. Retrieved March 14, 2015, from http://www.acr.org/Membership/Volunteering/International-Outreach/Haiti-Relief

Baggaley, J. (2013). MOOC rampant. *Distance Education, 34*, 368–378.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development, 53*, 86–107.

Barron, B., Martin, C. K., Mertl, V., & Yassine, M. (2016). Citizen science: Connecting to nature through networks. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International Publishing.

Brahms, L. J. (2014). *Making as a learning process: Identifying and supporting family learning in informal settings* (Unpublished doctoral dissertation). University of Pittsburgh, Pittsburgh, PA. Retrieved March 7, 2015, from http://d-scholarship.pitt.edu/21525/1/L_Brahms_ETD_2014.pdf

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24*, 61–100.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education, 27*, 1099–1121.

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning* (pp. 289–326). Mahwah, NJ: Lawrence Erlbaum Associates.

BTU Lab. (2015). Retrieved March 7, 2015, from http://www.btulab.com/

Buechley, L., Peppler, K., Eisenberg, M., & Kafai, Y. (Eds.). (2013). *Textile messages: Dispatches from the world of e-textiles and education*. New York, NY: Peter Lang.

Cavalcanti, G. (2014, January 26). *Stompy build progress!* [Web log post]. Project Hexapod. Retrieved March 7, 2015, from http://projecthexapod.com/blog/stompy-build-progress/

Chen, M. (2012). *Leet noobs: The life and death of an expert player group in World of Warcraft*. New York, NY: Peter Lang.

Christensen, G., Steinmetz, A., Alcorn, B., Bennett, A., Woods, D., & Emanuel, E. (2013, November 6). *The MOOC phenomenon: Who takes massive open online courses and why?* Retrieved March 10, 2015, from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2350964

Cody, D. (2012). *Controls overview: Project Stompy the hexapod*. Retrieved March 7, 2015, from http://projecthexapod.com/blog/wp-content/uploads/2012/05/Controls_Overview_20120501.pdf

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the Learning Sciences, 13*, 15–42.

Dauster, J. (2013, February 13). *Making a Makerspace in Haiti* [Web log post]. Retrieved March 14, 2015, from http://makezine.com/2013/02/13/making-a-makerspace-in-haiti/

DeVane, B., Durga, S., & Squire, K. (2010). 'Economists who think like ecologists': reframing systems thinking in games for learning. *E-Learning and Digital Media, 7*, 3–20.

Dirksen, K. (2012, June 25). *Internet of food: Arduino-based, urban aquaponics in Oakland* [Video file]. Retrieved March 7, 2015, from https://www.youtube.com/watch?v=3IryIOyPfTE

DiSalvo, C., Fries, L., Lodato, T., Schechter, B., & Barnwell, T. (2010). *GrowBot garden* [Web log post]. Retrieved March 7, 2015, from http://carldisalvo.com/posts/growbot-garden/

Edelson, D. C., & Joseph, D. M. (2004, June). The interest-driven learning design framework: Motivating learning through usefulness. In *Proceedings of the 6th International Conference on Learning Sciences* (pp. 166–173). New Brunswick, NJ: International Society of the Learning Sciences.

edX. (2015). *The chemistry of life*. Retrieved March 11, 2015, from https://www.edx.org/course/chemistry-life-kyotoux-001x-0#.VQDY1EJFow4

Entertainment Software Rating Board. (n.d.). *How much do you know about video games?* Retrieved March 11, 2015, from http://www.esrb.org/about/video-game-industry-statistics.jsp

Farley, P. C. (2013). Using the computer game "FoldIt" to entice students to explore external representations of protein structure in a biochemistry course for nonmajors. *Biochemistry and Molecular Biology Education, 41*, 56–57.

Fok, E. (2014, December 13). Maker movement making its presence felt. *The Economic Times.* Retrieved March 7, 2015, from http://articles.economictimes.indiatimes.com/2014-12-13/news/57012212_1_maker-faire-maker-movement-workshops

Fortson, L. (2011). *The birth of the Zooniverse: How citizen scientists are taking on research from galaxies to climate change*. Public lecture at Wisconsin Institute for Discovery on April 13, 2011. Retrieved from http://www.physics.wisc.edu/twap/view.php?id=2166

Frueh, A. (n.d.). *What is GardenBot?* Retrieved March 7, 2015, from http://gardenbot.org/about/

Gasevic, D., Kovanovic, V., Joksimovic, S., & Siemens, G. (2014). Where is research on massive open online courses headed? A data analysis of the MOOC research Initiative. *The International Review of Research in Open and Distributed Learning, 15*, 134–176.

Gee, J. P. (2004). *What video games have to teach us about learning and literacy*. New York, NY: Macmillan.

Gee, J. P. (2007). *Good video games + good learning: Collected essays on video games, learning, and literacy*. New York, NY: Peter Lang.

Gibson, W. (1986). *Neuromancer*. New York, NY: The Berkley Publishing Group.

Granot, Y., Ivorra, A., & Rubinsky, B. (2008). A new concept for medical imaging centered on cellular phone technology. *PLoS One, 3*, e2075.

Gross, D. (2012). Gaming reality: Turning gamers into citizen scientists. *CNN*. Retrieved April 25, 2015, from http://edition.cnn.com/interactive/2012/08/tech/gaming.series/research.html

Gütl, C., Rizzardini, R. H., Chang, V., & Morales, M. (2014). Attrition in MOOC: Lessons learned from drop-out students. In L. Uden, J. Sinclair, Y.-H. Tao, & D. Liberona (Eds.), *Learning technology for education in cloud. MOOC and big data* (pp. 37–48). Cham, Switzerland: Springer International.

Hackerspaces.org. (2015). *List of hacker spaces*. Retrieved March 7, 2015, from http://hackerspaces.org/wiki/List_of_Hacker_Spaces

Hammer, D., Sherin, B., & Kolpakowski, T. (1991). Inventing graphing: Meta-representational expertise in children. *Journal of Mathematical Behavior, 10*, 117–160.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*, 111–127.

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education, 94*, 506–524.

Jansen, P. (2013, October 22). *Toward an inexpensive open-source desktop CT scanner* [Web log post]. Retrieved March 14, 2015, from http://www.tricorderproject.org/blog/towards-an-inexpensive-open-source-desktop-ct-scanner/

Jansen, P. (2014). *Open source computed tomography (CT) scanner*. Retrieved March 14, 2015, from https://github.com/tricorderproject/openct

Jordan, K. (2014). Initial trends in enrolment and completion of massive open online courses. *The International Review of Research in Open and Distributed Learning, 15*, 133–160.

Kamar, E., Hacker, S., & Horvitz, E. (2012, June). Combining human and machine intelligence in large-scale crowdsourcing. In *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems* (Vol. 1, pp. 467–474). Saint Paul, MN: International Foundation for Autonomous Agents and Multiagent Systems.

Kapur, M. (2006). Productive failure: A hidden efficacy of seemingly unproductive production. In *Cognitive Science Conference.* Vancouver, Canada.

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences, 21*, 45–83.

Khatib, F., DiMaio, F., Cooper, S., Kazmierczyk, M., Gilski, M., Krzywda, S., & Foldit Void Crushers Group. (2011). Crystal structure of a monomeric retroviral protease solved by protein folding game players. *Nature Structural & Molecular Biology*, *18*, 1175–1177.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*, 75–86.

Koedinger, K. R., Pavlik, P., McLaren, B. M., & Aleven, V. (2008). Is it better to give than to receive? The assistance dilemma as a fundamental unsolved problem in the cognitive science of learning and instruction. In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (pp. 2155–2160). Austin, TX: Cognitive Science Society.

Kolowich, S. (2013, August 8). The MOOC 'revolution' may not be as disruptive as some had imagined. *The Chronicle of Higher Education*. Retrieved from http://chronicle.com/article/MOOCs-May-Not-Be-So-Disruptive/140965/

Krapp, A. (1999). Interest, motivation and learning: An educational-psychological perspective. *European Journal of Psychology of Education, 14*(1), 23–40.

Krasnow, B. (2013, January 8). *DIY X-ray CT scanner controlled by an Arduino* [Web log post]. Retrieved March 14, 2015, from http://benkrasnow.blogspot.com/2013/01/diy-x-ray-ct-scanner-controlled-by.html

Larson, C. (2014, June 26). The maker movement gains ground in China. *Bloomberg Business*. Retrieved March 7, 2015, from http://www.bloomberg.com/bw/articles/2014-06-26/chinas-maker-movement-gets-government-support-for-diy-workshops

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Leckart, S. (2012). The Stanford education experiment could change higher learning forever. *Wired Magazine*, 20.

Lenhart, A., Kahne, J., Middaugh, E., Macgill, A. R., Evans, C., & Vitak, J. (2008). *Teens, video games, and civics: Teens' gaming experiences are diverse and include significant social interaction and civic engagement*. Washington, DC: Pew Internet & American Life Project.

Litts, B., & Ramirez, D. (2014). Making people fail: Failing to learn through games and making. In A. Ochsner, J. Dietmeier, C. C. Williams, & C. Steinkuehler (Eds.), *Proceedings GLS 10, Games Learning Society Conference* (pp. 160–166). Madison, WI: ETC Press.

Maru, D. S., Schwarz, R., Jason, A., Basu, S., Sharma, A., & Moore, C. (2010). Turning a blind eye: The mobilization of radiology services in resource-poor regions. *Global Health, 6*, 18.

McCombs, B., & Vakili, D. (2005). A learner-centered framework for e-learning. *The Teachers College Record, 107*, 1582–1600.

Mitchell, M. (2013). Home/Grown (Made with love far away). Retrieved March 7, 2015, from http://www.megmitchell.com/index.php?/project/homegrown-made-with-love-far-away/

Moll, L. C., & Whitmore, K. F. (1999). Vygotsky in classroom practice. In D. Faulkner, K. Littleton, & M. Woodhead (Eds.), *Learning relationships in the classroom* (pp. 131–155). London, UK: Routledge.

Mora, N., Caballé, S., Daradoumis, T., Barolli, L., Kulla, E., & Spaho, E. (2014). Characterizing social network e-assessment in collaborative complex learning resources. In *2014 Eighth International Conference on Complex, Intelligent and Software Intensive Systems* (pp. 257–264).

Nathan, M. (2011). *Google's secret perk? A private hackerspace*. Retrieved March 7, 2015, from http://hackaday.com/2011/04/27/googles-secret-perk-a-private-hackerspace/

Obama, B. H. (2014, June 18). *Remarks by the President at the White House Maker Faire*. Retrieved March 7, 2015, from http://www.whitehouse.gov/the-press-office/2014/06/18/remarks-president-white-house-maker-faire

Parker, E. (2014, May 14). The Chinese government is investing heavily in the maker movement [Web log post]. *Future Tense*. Retrieved March 7, 2015, from http://www.slate.com/blogs/future_tense/2014/05/14/the_chinese_government_is_investing_heavily_in_the_maker_movement.html

Parry, R. (2014) Episteme and techne. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy,* fall 2014 ed. Retrieved April 25, 2015, from http://plato.stanford.edu/archives/fall2014/entries/episteme-techne

Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan, 95*, 22–27.

Pilz, D., & Gewald, H. (2013). Does money matter? Motivational factors for participation in paid- and non-profit-crowdsourcing communities. In *Wirtschaftsinformatik* (p. 37).

Quinn, A. J., & Bederson, B. B. (2011, May). Human computation: A survey and taxonomy of a growing field. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1403–1412). New York, NY: ACM.

Romano, Z. (2013, October 10). *A baby monitor goes open source: Interview to the team* [Web log post]. Retrieved March 7, 2015, from http://blog.arduino.cc/2013/10/10/a-baby-monitor-goes-open-source/

Rosé, C. P., Carlson, R., Yang, D., Wen, M., Resnick, L., Goldman, P., & Sherer, J. (2014, March). Social factors that contribute to attrition in MOOCs. In *Proceedings of the First ACM Conference on Learning@ Scale* (pp. 197–198). New York, NY: ACM.

Rothkrantz, L. (2014). New didactical models in open and online learning based on social media. In *International Conference on e-Learning* (Vol. 14, p. 10).

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*, 265–283.

Seaton, D. T., Reich, J., Nesterko, S. O., Mullaney, T., Waldo, J., Ho, A. D., & Chuang, I. (2014). *7.00 x Introduction to biology: The secret of life MITx on edX course report-2013 Spring*. Retrieved from http://ssrn.com/abstract=2382325

Shapiro, R. B., Squire, K., & The Educational Research Integration Area. (2011). Games for participatory science. *Educational Technology, 51*, 34–43.

Sheridan, K. M., Halverson, E. R., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*, 505–531.

Short, B. (2014). *Radiology in Haiti*. Retrieved March 14, 2015, from http://radiologyinhaiti.blogspot.com

Squire, K. (2011). *Video games and learning: Teaching and participatory culture in the digital age.* Technology, Education—Connections (the TEC Series*).* New York, NY: Teachers College Press.

Steinkuehler, C., & Duncan, S. (2009). Scientific habits of mind in virtual worlds. *Journal of Science Education and Technology, 17*, 530–543.

Tabarnak. (2014). Tradition: Three cities approaches. In *Civilization Fanatics Center.* Retrieved March 7, 2015, from http://forums.civfanatics.com/showthread.php?s=7f2f424b781607962b68d75883093c8c&t=523371

Takahashi, D. (2013, November 25). More than 1.2 billion people are playing games. *VentureBeat*. Retrieved March 11, 2015, from http://venturebeat.com/2013/11/25/more-than-1-2-billion-people-are-playing-games/

Team Liquid. (2014). Protoss unit statistics. In *Liquipedia*. Retrieved March 7, 2015, from http://wiki.teamliquid.net/starcraft2/Protoss_Unit_Statistics

Toppo, G. (2012). *White House office studies educational benefits of video games*. Retrieved from http://usatoday30.usatoday.com/news/washington/story/2012-01-26/edcuational-video-games-white-house/52908052/1

Trautmann, N. M., Shirk, J. L., Fee, J., & Krasny, M. E. (2012). Who poses the question. In J. L. Dickinson & R. Bonney (Eds.), *Citizen science: Public participation in environmental research* (pp. 179–190). Ithaca, NY: Comstock.

Trumbull, D. J., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education, 84*, 265–275.

Tufts Maker Network (n.d.). Retrieved March 7, 2015, from http://maker.tufts.edu/

Van Der Meulen, R., & Rivera, J. (2013, December 16). Gartner says worldwide video game market to total $93 billion in 2013. *Gartner*. Haettu.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Yang, D., Sinha, T., Adamson, D., & Rose, C. P. (2013, December). Turn on, tune in, drop out: Anticipating student dropouts in massive open online courses. In *Proceedings of the 2013 NIPS Data-Driven Education Workshop* (Vol. 10, p. 13).

Zusho, A., Pintrich, P. R., & Coppola, B. (2003). Skill and will: The role of motivation and cognition in the learning of college chemistry. *International Journal of Science Education, 25*, 1081–1094.

Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community

Deborah A. Fields, Yasmin B. Kafai, and Michael T. Giang

Understanding Social Practices That Support Learning in Online Communities

A growing body of research in massive online communities, often defined by having millions of voluntary users, has sought to understand patterns of participation in online sites, games, social networking sites, and virtual worlds (e.g., Boyd, 2013; Gee, 2003). Research on participation patterns and profiles in these massive communities has provided insights into how people participate and can develop collaborations within and beyond the designed structures, for instance, by developing fluid social networks for information gathering and gameplay (Williams, Contractor, Poolec, Srivastad, & Cale, 2011), by building trust in long-term relationships that promote more effective teamwork (Chen, 2012), and by engaging in knowledge sharing and problem solving in game forums (Steinkuehler & Duncan, 2009). Yet collaboration in massive sites is often more diffuse and less obvious than the clear teamwork or knowledge building described above. For instance, some studies (see Boyd, 2013; Ito et al., 2009) have illustrated how younger users (children and youth) engage in social practices that are less directly "collaborative" but en masse result in distributed peer support for learning through knowledge diffusion (Fields & Kafai, 2009, 2010), praise and constructive criticism (e.g., Black, 2008), or simply engagement with an interested audience (e.g., Magnifico, 2010).

D.A. Fields (✉)
Utah State University, Logan, UT, USA
e-mail: deborah.fields@usu.edu

Y.B. Kafai
University of Pennsylvania, Philadelphia, PA, USA
e-mail: kafai@gse.upenn.edu

M.T. Giang
Mount Saint Mary's University, Los Angeles, CA, USA
e-mail: gtravis@msmu.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_11

These social practices also hold great potential in an emerging genre of online communities where socializing centers around things that people create: do-it-yourself (DIY) social networking forums. These DIY social networking forums differ from the more typically thought of social network sites (SNS, see Boyd & Ellison, 2007) like MySpace and Facebook where user participation focuses on reports of daily life (Grimes & Fields, 2012). Instead, DIY social networking forums are communities where participants share their own self-created DIY media and where communication, profile pages, and networking residues all focus in some way on user-created projects that range from film to fan fiction to programming (Grimes & Fields, 2015). Commonly designed social networking features such as comments, "likes," favorites, or even the simple ability to share projects form a baseline of social support and encourage young writers, programmers, and artists to pursue their personal interests (e.g., Black, 2008; Resnick et al., 2009). Yet despite these potentials, studies are rare for *youth* amateur design communities. Most of the current research has focused on adults' online activities (e.g., Benkler, 2006; Luther, Caine, Ziegler, & Bruckman, 2010), possibly because such communities are easier to access and study due to participants' age and overlapping interests with that of researchers (Kafai & Fields, 2013).

Further, with millions of participants and projects, it is not always clear who is participating and what they are contributing; thus, patterns and trends that might reveal issues of equity in participation are not easily discerned by the naked eye. Participating in these sites can be a rich but also challenging experience, in particular for youth as we have observed (Kafai, Fields, & Burke, 2010). Creative participation that involves highly technical expertise such as programming has only recently received more attention due to the increased interest in promoting computational thinking and access to computing (Kafai & Burke, 2014). Some ethnographic studies illustrate that many youth do not engage in activities that hold the most potential for learning through creating, perhaps socializing and "messing around" rather than creating and posting content or "geeking out" as Ito et al. (2009) express. Larger-scale studies reveal differential patterns of participation (and, by extension, possible collaborations) in massive online communities with often a relatively small group of established users driving the majority of the interactions and contributions, raising concerns about equity and diversity in participation (e.g., Giang, Kafai, Fields, & Searle, 2012; Yee, 2014). At the same time, issues of broadening access and deepening participation are particularly critical because of technology's long-standing history of underrepresentation of women and minorities (Margolis, Estrella, Goode, Holme, & Nao, 2008; Margolis & Fisher, 2001). At the same time, understanding site-wide patterns of youth amateur design communities can allow us to make more informed decisions on how to design for collaborative supports and learning at a massive level, as well as identify which users (e.g., gender or newbies) may need scaffolds in participating in such large DIY communities.

In this chapter, we tackle two challenges related to understanding social practices that support learning in social networking forums where users engage in design. First, we study a *youth* programmer community called Scratch.mit.edu that garners the voluntary participation of millions of young people worldwide. Second, we report on *site-wide* distributions and patterns of participation that illuminate the relevance of different online social practices to ongoing involvement in the Scratch online community. Drawing on a random sample of more than 5000 active users of Scratch.mit.edu over a 3-month time period in early 2012, we examine log files that captured the frequency of four types of social practices that contribute to enduring participation: DIY participatory activities, socially supportive actions, socially engaging interactions, and identity-building activities. We apply latent transition analysis (LTA) to investigate the following questions: (1) What types of users shape the Scratch online community and what combinations (or patterns) of social practices differentiate their participation? (2) Do gender and length of membership play a role in these patterns of participation? (3) Finally, what changes in participation can we see over time? In the discussion, we consider what this says about who is getting the most out of their participation and what designed-for practices may contribute to long-standing engagement in these massive online communities. We review our approach to analysis and outline implications for the design and study of online communities and tools for youth.

Background

Understanding Collaborative Learning in Massive Online Communities

We situate our study in the larger context of research conducted on *collaborative* learning, which for the most part has focused on youths' abilities to interact in and contribute to small groups inside and outside of schools. Hundreds, if not thousands, of studies have investigated various aspects of collaborative learning, including the nature of various group arrangements such as reciprocal teaching or jigsaw techniques; interactions with members of different gender, race, ability, and experience; and causes for success and failures of group work (for general overviews, see O'Donnell, 2006; Webb & Palincsar, 1996). Studies that examine collaboration in larger groups, especially with the support of computers, are only now beginning to develop such a knowledge base. Most notable is here the work on the Computer-Supported Intentional Learning Environments (CSILE; now, Knowledge Forum) (Scardamalia & Bereiter, 1991) and other studies following the knowledge forum tradition, as they have examined how students' knowledge sharing, knowledge construction, knowledge creation, and knowledge assessment come into play through student-driven inquiry that builds knowledge at a community level (e.g., Ares, 2008; Eddy, Chan, & van Aalst, 2006; van Aalst, 2009). Most CSILE implementations have operated within a classroom environment, sometimes connecting students from other classes or previous years through an emphasis on collective cognitive responsibility (Scardamalia, 2002; Zhang, Scardamalia, Reeve, & Messina, 2009). What becomes apparent from these studies is that productive collaborative interactions can take place at larger scales beyond small groups, through a mixture of unstructured and structured groups, concurrent asynchronous and synchronous interactions, and persistent shared virtual environments that can hold community-level knowledge. Yet even these relatively larger-scale studies are quite far away in scale from the size of social media communities today, particularly communities that rely on voluntary participation outside of any classroom requirements (e.g., Rick & Guzdial, 2006).

A number of studies have identified key social practices that can support users' learning and deepening participation in massive online DIY social networking forums. Black's (2008) work on youth' fan fiction sites documents the importance of peer feedback in the form of comments on multiple iterations of written fiction projects. Users share sections of stories, solicit readers' feedback, and revise their writing based on the comments of others. Enthusiastic comments, often expressed in desires to see new or extended work, can encourage youth to stick with their writing or even their programming (see also, Brennan, Valverde, Prempeh, Roque, & Chung, 2011). Relatedly, Magnifico (2010) theorizes about this important role of audience that online communities can provide for users' work. Learning to write, program, or draw in order to gain the attention and interest of an online audience can focus youths' creative work in ways rarely available in classrooms (e.g., Lammers, Curwood, & Magnifico, 2012). While comments may be the most obvious evidence of an authentic audience, other traces of users' viewing of one's work, called networking residues (Grimes & Fields, 2012), also provide feedback. These networking residues may include traces such as "love-its," friend requests, "favorites," "likes," comments, replies, downloads, and even gifts depending on what websites record and display on users' artifacts and profiles. They may even become a type of commodity as they elevate the virtual presence of a person or project through signs of popularity. Many DIY social networking websites organize their front pages by featuring "most liked" or "most viewed" designs.

We have established that these participatory practices from social networking forums focused on story and digital media productions also apply to youth software production communities such as Scratch. Our recent study of a random selection of comments about projects on the Scratch website points to the overall positive ethos of the site where 72 % of these comments were positive and 14 % were neutral in emotional tone (Fields, Pantic, & Kafai, 2015). We also found that about half of the comments were generally constructive: 58 % contained at least some minor level of detail in the feedback beyond more generic "awesome" or "cool!" statements. Our analysis of the purpose of these comments supports the idea that motivationally encouraging feedback is key in shaping participation on the Scratch site (58 % of the comments) and that drawing an audience to one's work is also a significant felt need among users (23 % of the comments). These outcomes support the findings of other studies of the Scratch community that have documented how members solicit and leverage networking residues to support user-created design contests, offering projects, illustrations, love-its, and friending as prizes (Nickerson & Monroy-Hernández, 2011).

Beyond the more obvious social practices of commenting or otherwise leaving markers of audience in DIY social networking forums, Grimes and Fields (2015) point to the importance of simply sharing one's creations. Sharing projects online makes them visible to others for feedback, viewing, and remixing; this is a key feature that is often missing in website design for children. Transparency of projects is necessary in order to leave and receive feedback, even in the milder forms of a thumbs-up or a "like" button. In the Scratch community, transparency of projects goes a step further than most DIY social networking forums (Grimes & Fields, 2015) in that it enables users to download, see inside, and even remix others' projects. Remixing projects involves taking someone's existing work, changing something about it (whether a minor or major change), and re-sharing it online. Remixing can provide an opportunity to learn by seeing how someone's project works and exploring what various changes do. It can also solicit a form of fandom when users post projects intended for remixing (e.g., adding a character to a dance party project) or even use remixing as a way to exchange projects in collaborative work (Monroy-Hernández, 2012).

While there may be a range of collaborative practices available to users on DIY social networking forums, thus far, it has been difficult to evaluate how widespread or distributed these practices are across a full range of users as well as whether and how these patterns shift over time. Our work aims at filling some of these gaps, in particular identifying patterns of social practices found in the Scratch youth amateur design (or do-it-yourself, DIY) community that is the focus of this paper. Here we consider less the smaller enterprises of small collaborative groups who work together on shared projects online in favor of studying broader dynamics of participation in amateur design communities. Although there are growing numbers of such communities where youth share designed artifacts such as art (e.g., Deviant Art, Bitstrips), mods of games (e.g., Little Big Planet, the Sims), or stories (e.g., Fanfiction.net, Storybird), we know little about who is participating in what practices and for how long. To contribute to a framework for understanding "mass collaboration," we analytically bring together different designed-for social practices that support participation on a massive scale, from creating to remixing to commenting to favoriting, and investigate who engages in these practices, in what combinations of activity, and for what duration. Our larger goal is to understand what the large numbers reveal about participation and collaboration that is not visible at smaller scales.

Researching Collaborative Learning in Massive Online Communities

As described above, in youth amateur design communities, many different types of activities contribute to the community and provide supports for learning to design. To study these activities at a massive scale, we need to identify key types of practices that can be tracked through backend (or log file) website data. While case study and ethnographic research can illuminate the roles these practices play in learning (see above section), quantitative or analytical research must be used to understand patterns of use at a large scale. Based on the research concerning feedback, audience, networking residues, sharing, and remixing, we identified three types of social practices that may contribute to learning that are recorded and identifiable in log file data:

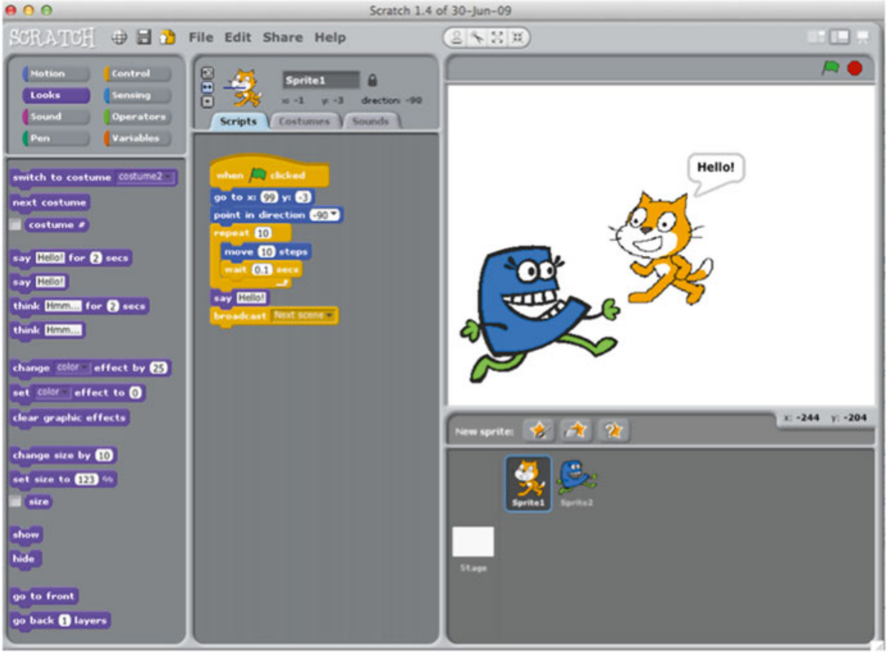
- *DIY participatory activities*: These activities involve *sharing* projects users have created, *remixing* projects (editing and posting changes to another's project), and *downloading* projects. They primarily involve users creating, sharing, and editing content which are innately but not obviously social. In other words, they do not involve direct social interaction with another user.
- *Socially supportive actions*: These actions include socially oriented actions that are supportive but do not directly engage a response from a user. They include simple networking residues that can be left with a simple click, such as *loving* projects (clicking "love-it" on projects one likes) and *favoriting* projects (clicking "favorite" on a project).
- *Socially engaging interactions*: Certain actions on the social networking forums are more directly interactive, namely, writing comments on a user's project or submitting a friend request. We consider these more socially engaging as they invite and are more likely to generate a response. *Comments* provide an opportunity for conversation (many users actually respond to others' comments). *Friending* another user results in a notification to that user (implicitly inviting a responsive friending action) and allows the requester to get notifications of that user's new projects.

Equally important to understanding social practices that form participation is understanding *who* engages in the various forms of participation designed for on DIY social networking forums. The sheer number of projects and members, often reaching millions in these massive online communities, can mask differential levels of participation amidst the seemingly endless activity on sites. The few studies that have been able to assess participants often find that a relatively small number of members, between 5 and 10 %, are highly active and generate most of the social interactions and content, while other, larger groups range from more distant involvement to simply being onlookers (see Kafai & Fields, 2013 research of a virtual world and Yee's, 2014 research of gaming communities). The issue of access and participation becomes even more salient when we look at motivations, or the lack thereof, of new members joining such massive communities: not everyone is interested in becoming a central member of online communities (Kafai et al., 2010). While newcomer membership is an important factor in judging participation in online communities, there are unanswered questions about how diverse and open such communities are in inviting in others. In particular, digital communities pertaining to gaming and computing are predominantly male, with few exceptions (e.g., Kafai, Heeter, Denner, & Sun, 2008), thus replicating discrepancies found in the technology culture at large, whether the participants are adults or youth.

Whether and how users participate are of relevance when examining youth amateur communities that focus on making and sharing programming designs, as will be the case in this paper. While the Scratch community consists of one-third female users, thus far, we have not been able to judge the extent to which they engage in contributing and collaborating in the online site. Further, almost no attention has been paid to whether length of membership on a site influences the types of social practices users engage in. To understand the practices that form the underlying social fabric that encourages and supports continuing participation in a youth design community, we examine whether and how users engage in different activities through an analyses of log files from a random sample of users in the Scratch online community. We look systematically at the massive scale of participation in Scratch, asking what patterns of participation users exhibit, how this changes over time, and how these patterns relate to gender or length of user membership in the Scratch site.

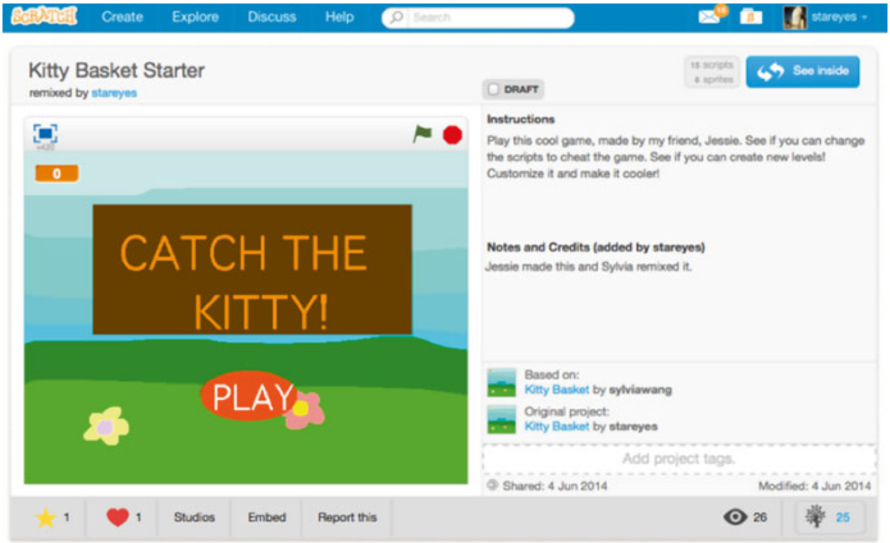
Scratch Online Community

Scratch.mit.edu is an online massive community where participants, mostly youth ages 11–18 years, share their computer programs (Resnick et al., 2009; see also Roque & Resnick, this volume). Kids who share an interest in programming post animations, games, stories, science simulations, and the interactive art they have made in the visual programming environment of Scratch (see Figs. 1 and 2). Scratch is a visual programming environment, allowing designers to create various media



```
when [flag] clicked
go to x: 99 y: -3
point in direction -90
repeat 10
    move 10 steps
    wait 0.1 secs
say Hello!
broadcast Next scene
```

Fig. 1 Scratch programming interface (version 1.4)



Kitty Basket Starter
remixed by stareyes

Instructions

Play this cool game, made by my friend, Jessie. See if you can change the scripts to cheat the game. See if you can create new levels! Customize it and make it cooler!

Notes and Credits (added by stareyes)

Jessie made this and Sylvia remixed it.

Based on: Kitty Basket by sylviawang

Original project: Kitty Basket by stareyes

Add project tags.

Shared: 4 Jun 2014 Modified: 4 Jun 2014

Fig. 2 User profile on Scratch.mit.edu (of the first author)

through a process of dragging-and-dropping command blocks of code then stacking these blocks together to form coding scripts that can become increasingly complex and nuanced depending upon a user's facility with coordinating a range of command blocks through programming concepts such as loops, synchronization, variables, conditionals, and more (Maloney, Peppler, Kafai, Resnick, & Rusk, 2008).

Launched in May 2007, as of May 2015, the Scratch site has grown to more than six million registered members with nearly 1500 Scratch projects shared everyday (a total of nine million projects since 2007). Notably, the data from this investigation come from the version of the Scratch site that existed from May 2007 to May 2013, familiarly known as Scratch 1.0 (to 1.4). In May 2013, the Scratch Team released a new version of the site that had several new design features. Most notably, the site now allows users to program projects directly on the site and to edit (remix) others' projects without having to download them. In other words, users do not need to program offline (though they can) and subsequently share their projects online. Instead, they can simply program online without having to upload. They can also "see inside" the code of others' projects without having to download them. With these changes, user participation on the site has nearly quintupled (from 75,000–160,000 active users each month: see http://scratch.mit.edu/statistics for details). While our study examines the data from Scratch 1.0, the social networking features and project uploads we studied continue to be key participation practices in the Scratch 2.0 online community.

We chose several types of social networking features to study, namely, designed-for activities that shape user interaction on the Scratch site and that were also available through backend log file data. In our study, these include DIY participatory activities (*sharing*, *downloading*, and *remixing* projects), socially supportive actions (*loving* and *favoriting* projects), and socially engaging interactions (*commenting* and

Get the latest version of Scratch for Windows or Mac.

What are your hopes, goals, and dreams for 2009? Make a project that shares your plans for the upcoming year.

Fig. 3 The front page of Scratch.mit.edu (version 1.0 2007–2012)

friending). Although these activities are done by individual users, as a whole, they leave traces of users' views and opinions on projects, demonstrating the presence of an audience. Accumulations of high numbers can result in a user's project being posted on the prized front page of the Scratch site (see Fig. 3) through categories like "Featured Projects," "What the Community is Loving," and "What the Community is Viewing." Thus, we chose these activities as a lens of social practices that shape mass participation, for both convenience of data collection, the breadth of user practices they demonstrate, and their prominence in shaping the Scratch site.

One goal of our analysis in this paper is to reveal how these networking activities are related to programming activities. In a related study, we examined computational participation on the Scratch site by analyzing trends in users' posted projects, using the same sample of users as this study (Fields, Giang, & Kafai, 2014). In this case, we used latent class analysis on sets of programming practices rather than social practices to understand classes of Scratch programmers. Using categories of programming blocks such as loops, variables, operators, broadcasts, and Booleans, we found four stable and cohesive classes of programmers in the Scratch community that reflect a range of experience based on their use of programming concepts. Beginners tended to create smaller, simpler projects with a small number of loops and none of the other more advanced programming concepts. Intermediate users created slightly larger (middle-sized) projects and also included variables, operators, and broadcasts. Advanced users utilized all of those concepts as well as Booleans in middle-sized projects. Experienced users were similar to the advanced users except that their projects were much larger in terms of using increased numbers of commands in all of the concepts studied. Looking at gender and length of membership, we found that girls were disproportionately represented in the beginner class and likewise underrepresented in the advanced and experienced class. We found little relationship in terms of length of membership except for a slight underrepresentation of the newest users (newbies) and an overrepresentation of the longest users (oldies) in the experienced class. We return to these findings in the discussion, considering the relationship between programming and participation on the Scratch site and reporting how findings reported in this paper relate to analyses about programming.

Methods and Analyses

Data Sample: Participants

Our analysis initially drew from a random sample of 5004 users drawn from among more than 20,000 users who logged into Scratch during the month of January 2012. While Scratch usage fluctuates month to month over the course of a year, with summer months usually showing a higher usage than other months, in consultation with Scratch community managers, we chose these winter months as times of typical steady participation. Our random sample reflected the broader population on Scratch in regard to self-reported gender and age. Members on the Scratch site as of April 2015 are self-reported 38 % female, 58 % male, and 4 % other/NA. Age on Scratch is also only known through self-report (i.e., whatever birth year the user chooses). Of course, because age and gender are by self-report, users can choose to state otherwise. Other studies of youth online have shown that youth may lie about their age online, sometimes showing a difference between age and grade reporting. This may be because kids gain some social status from being older (see Kafai & Fields, 2013) and because of national laws governing what data websites can collect from youth under 13 years of age (e.g., COPPA in the United States). Many youth may increase their reported age so that they are allowed to participate in social networking sites like Facebook that refuse access to youth under 13 because of these regulations (Grimes & Fields, 2012, 2015). In our sample, the mean age was 20 years old, the median 14, and the mode 12. Since there were a surprising number of individuals (more than 70) who were over 100 years old or under 4 years old (more than 50), we view the averages with great skepticism. (Similarly, there are a surprising number of individuals reporting their home country as Antarctica or Aruba.) In this paper, we focus more on the length of membership of Scratch users rather than their reported age, though the generally accepted age range of the majority of participants on Scratch is 11–18 years of age.

We collected data on this sample of users for 3 months. During these 3 months, 1379 users shared an original project in 1 of the 3 months (January–March 2012), 533 created a project in each of 2 months, and 313 created a project in all 3 months. These 2225 users (67 % boys and 33 % girls, reflective of the broader Scratch population in January 2012) who created at least one project across a 3-month period formed *the new subsample from which all further analyses reported in this paper are drawn*. This subsample represents about 44.5 % of the initial random sample of users (Fields, Giang, & Kafai, 2013). At this moment, we do not have access to participation information from other related youth programming sites that can serve as a benchmark for whether this participation rate is standard or unusual. Data collected from the backend of massive online youth communities is notoriously difficult to come by because most companies consider this information proprietary and do not share it with outside members.

The reason we focus on this 2225 subsample is that the remaining 2779 users did not engage key activities used for the study. In addition, though these remaining users logged on to Scratch and likely browsed the site during the time of the study, we do not have information about what they did on Scratch. Most likely, they viewed webpages without leaving any networking residues: they did not click “like” or favorite projects, and they did not leave comments. This data was unavailable because the Scratch Team at MIT did not record this data in log files. This division of users who created and shared projects (and of those some who left comments or “love-its” or favorites) and those who did not create and share projects was a surprise to us. Based on our analyses, sharing a project on the Scratch site defines the baseline of all other active participation beyond viewing. Thus, our next step in understanding broad trends of programming and participation on the Scratch website focused on participation profiles of these project creators, identifying how users engaged in downloading, commenting, remixing, “loving,” or friending in the online Scratch community, treating it as a type of DIY social networking forum (Grimes & Fields, 2015).

Data Analysis: Latent Class and Transition Analysis

At any given period on Scratch, players engage in multiple modes of participation. As described earlier, we categorize these forms of participation into *DIY participatory activities* (i.e., downloading and remixing projects), *socially supportive actions* (i.e., loving and favoriting project), and *socially engaging interactions* (i.e., commenting and friending). We apply latent class analysis (LCA) to identify whether they are distinct types of players who share common modes of participation. LCA’s advantages relative to other statistic techniques (e.g., mean splits or cluster analyses) are its conservative ability to identify similar groups of individuals that are uniquely different from other groups (i.e., classes), provide probabilities for classifying individuals into each class, and examine the influence of covariates (e.g., gender) on membership. For instance, LCA can identify whether there are groups (or classes) of players who only focus on DIY participatory activities and do not engage in more complex social activities and others who do the exact opposite; it then estimates the likelihood that each player is placed into these classes. After these classes have been identified, latent transition analysis (LTA) examines whether individual players transition to different classes of participation across time or stay where they are comfortable (Collins & Lanza, 2010).

This process of analysis begins with LCA. The goal of which is to identify the optimal number of latent classes through an iterative post hoc process (Hagenaars & McCutcheon, 2002; Muthen, 2002). For example, given six indicators of participation, LCA would first examine whether a model with two classes (e.g., social vs. nonsocial players) would provide a better fit than a one-class model (e.g., nonsocial). If so, LCA continues to test models with additional latent classes until model fit indices and substantive interpretation are satisfactory. The interpretation process examines the participation patterns (based on the extent of use for each indicator in a given class) and the number of individuals in each class to determine whether the specific number of latent classes and membership are meaningful. This LCA process of identifying the optimal number of latent classes is repeated across all time points (e.g., January, February, and March) to determine the number and consistency of classes. Latent transition analysis examines whether and how individuals within these classes change membership across time; in other words, it examines the likelihood that novice users remain novices or move onto different forms of participation. Through the same process of analyses, LTA also examines the influence of other variables (e.g., gender, membership time) in the classification process. This would examine whether gender plays a role in participation patterns and whether newbies and oldies (veteran players) utilize Scratch in the same fashion.

In terms of statistical criteria, multiple indicators of model fit are often used as there is no definitive model fit index for these analyses. For this study, the Akaike information criterion (AIC), the Bayesian information criterion (BIC), the sample size-adjusted BIC (aBIC), the Lo-Mendell-Rubin likelihood ratio test (LMR-LRT), and entropy values are provided. Model selection is often based on the lowest values on the AIC, BIC, and aBIC, or a scree-like test, in which selection was based on where the indices begin to level off. The LMR-LRT compares models with different numbers of classes, wherein a nonsignificant value indicates whether a simpler model with one fewer classes provides a better fit for the data. The entropy value is a standardized measure of classification accuracy based on the model's posterior probabilities; this value ranges from 0 to 1, with higher values reflecting better classification. The (average) posterior probabilities reflect the most likely (or probable) class membership across all users. When the average probabilities for the most likely class are high (above 80 %), coupled with low probabilities (below 20 %) for the other classes (i.e., misclassification), these numbers suggest good fit. Given the potential ambiguity in model fit indices, the substantive aspect of LCA allows the researcher flexibility in identifying the optimal number of latent classes to balance statistical and theoretical interpretation of each model. This avoids the potential of identifying classes with only a few users or a class that is generally similar to another except for minor statistical differences in specific observed activity.

Analysis: Gender and Scratch Membership

To further test whether length of membership or gender was proportionately represented in each of the latent classes, multiple chi-square tests for independence analyses were performed for each of the 3 months. These analyses utilize results from LCA, where each player is classified into a specific latent class (based on how they participate). These tests of independence will then examine whether classes of participation play are linked to gender and length of Scratch membership (the total lifetime of the user's account as of January 2012). Length of membership was distributed across four categories of members: users with brand new accounts created in January 2012 (newbies), users with accounts up to 3 months old (young), accounts up to 12 months old (1 year), and accounts over 1 year old (oldies) (see Table 1). Notably, age distribution was roughly equal between the overall sample and the subsample of 2225 project-sharing participants. There was a slightly larger percentage of newbies and slightly smaller percentages of 1 year and oldie participants, but these differences are small. A significant chi-square test would show that there is a relationship between gender (or membership) and latent classes profiles. Follow-up standardized residual scores test whether the actual count of individuals in a given cell is greater than ($z < |2 \text{ or } 3|$) or less than expected ($z < |2 \text{ or } 3|$) at $p = .05$ or $p = .01$. For example, a significant standardized residual would indicate that the number of

Table 1 Distribution of Scratch membership in entire sample ($n = 5004$) and among project-sharing participants ($n = 2225$)

Scratch membership	Frequency	Percent of sample
Entire sample (n = 5004)		
Newbie (new account)	1436	28.7
Young (0–3 months)	1364	27.3
One year (4–12 months)	973	19.4
Oldie (12+ months)	1165	23.3
Missing data	66	1.3
Among project-sharing participants (n = 2225)		
Newbie (new account)	756	33.9
Young (0–3 months)	628	28.2
One year (4–12 months)	411	18.5
Oldie (12+ months)	404	18.2
Missing data	26	1.2

females in a given membership class is significantly greater ($z > 2$) or less ($z < 2$) than expected.

Findings

Profiles: Project Creators vs. Browsers

Our examination of a random sample of 5000 users revealed that participation on the Scratch website begins with project creation. To our surprise, creating and sharing projects were a baseline for all other kinds of online participation, demonstrating the centrality of programming and project creation on the Scratch website and providing a potentially new model for social networking forums from the bottom up. Prior statistics on Scratch participation highlighted only the frequency trends of all users over the entire age of the Scratch site (see scratch.mit.edu/statistics). From these statistics and from case study research, others have reported that Scratchers tend to prefer either project creation or commenting, usually divided by gender (with male users engaging in more project creation and female users posting more comments; see Brennan, 2011). However, our analyses of Scratchers suggest a different pathway, namely, that project creation is the basic form of participation on the Scratch website (beyond simply browsing which we could not study). Further, nearly all commenters on the Scratch site are also project sharers. For instance, in the month of January, there were no users who posted comments who did not create at least one project, whereas there were many users who created projects but did not post comments. The simple finding that users who did not create projects largely did not participate in any other traceable way on the Scratch site suggests a new model of social networking forum that focuses on user-created content sharing rather than the more commonly thought of activities conducted on social network sites (Boyd & Ellison, 2007) that feature reports of personal daily activity (e.g., Facebook, Vine, Twitter).

Patterns: Transitions in Participation Over Time

We conducted latent class analyses to identify the types of participation patterns for each time point (January, February, and March). Each month suggested a different number of classes. Table 2 presents the multiple goodness-of-fit indices for each of the three waves of analyses. For January, a five-class model provides the most optimal fit based on decreasing model fit indices (BIC, aBIC) and a nonsignificant LMR-LRT at the six-class model; in the five-class models, players had high average probabilities of being classified into a specific class (with the most likely class membership probability between 75.6 and 94.2 %) compared to being classified into

Table 2 Model-fit indices for participation profiles in January, February, and March 2012

	Likelihood	Free par	BIC	aBIC	LMR-LRT *p*-value	Entropy	AIC
DICH, January (N = 2225)							
1	−7550.943	6	15,148.132	15,129.069	N/A	N/A	15,113.887
2	−6150.005	13	12,400.208	12,358.905	0.0000	**0.852**	12,326.011
3	−6043.122	20	12,240.395	12,176.852	0.0009	0.699	12,126.245
4	−6006.607	27	12,221.316	12,135.533	0.0072	0.688	12,067.213
5	−5976.236	34	**12,214.528**	**12,106.504**	**0.0000**	0.839	12,020.472
6	−5967.036	41	12,250.081	12,119.817	0.1129	0.790	**12,016.073**
7	**−5960.683**	48	12,291.327	12,138.824	0.0066	0.821	12,017.367
DICH, February (N = 2225)							
1	−6260.815	6	12,567.875	12,548.812	N/A	N/A	12,533.630
2	−4158.034	13	8416.265	8374.962	0.0000	**0.943**	8342.067
3	−4040.316	20	**8234.781**	8171.238	0.0000	0.868	8120.631
4	−4017.073	27	8242.249	**8156.466**	**0.0183**	0.859	8088.147
5	−4007.576	34	8277.207	8169.184	0.0799	0.894	**8083.152**
6	−4002.081	41	8086.161	8320.169	0.1361	0.910	8086.161
7	**−3997.482**	48	8364.925	8212.421	0.3965	0.856	8090.964
DICH, March (N = 2225)							
1	−5400.273	6	10,846.791	10,827.728	N/A	N/A	10,812.546
2	−3354.877	13	6809.952	6768.649	0.0000	**0.963**	6735.754
3	−3250.281	20	**6654.712**	**6591.168**	0.0000	0.904	6540.561
4	−3238.291	27	6684.684	6598.901	0.0011	0.937	6530.581
5	−3228.587	34	6719.229	6611.206	**0.0312**	0.947	6525.174
6	−3219.988	41	6755.984	6625.720	0.1582	0.939	**6521.976**
7	**−3213.203**	48	6796.367	6643.864	0.3879	0.938	6522.407

Note: **Bold** type indicates the best fitting model based on the given fit index

another class (with a misclassification probability between 0.1 and 24.4 %). Moving on to February, the LMR-LRT, aBIC, and substantive interpretation of three different models suggest a four-class model would provide the most meaningful model. In addition, the average posterior probabilities range from 75.0 to 96.8 % for the highest probability class and between 0.1 and 20.7 % for misclassification. For the analyses of March data, the BIC and aBIC hit their lowest point at the three-class model, and the class sizes and substantive interpretation of the other models also point to a three-class model. Similar to the other models, the average posterior probabilities for the most likely class membership ranged from 85.5 to 98.0 %, and misclassification numbers were between 0.1 and 5.7 %.

Based on the latent class analysis results, we next conducted latent transition analyses to examine whether and how users changed membership from 1 month to the next. In the analyses, the model and thresholds for each month were constrained to consist of the same number and pattern of classes discussed above. In addition,

Table 3 Description of participation profiles in the Scratch online community from January to March 2012

Name			Abbreviation	Description	Months present
Browsers	55.5 % ($n=2779$)	Browsers	B	Browses the website leaving no discernable trace to others (or in the available data)	January, February, March
Latent classes—project sharers	44.5 % ($n=2225$)	Low networkers	LN	Creates and shares projects but does nothing else visible on the site	January, February, March
		Downloaders	D	All of the above + downloads projects	January
		Commenters	C	All of the above + comments on projects	January, February, March
		Networkers	N	All of the above + some likelihood of “love-its” or “favorites” and some friending	January, February
		High networkers	HN	All of the above + usage of “love-its,” favorites, and friending as well as a higher likelihood of remixing	January, February, March

the influence of gender and length of membership as covariates in the classification process were also assessed. The transition process and the influence of gender and length of membership on the classification of players into each class will be discussed in the interpretation sections.

Interpretation of Latent Classes

Our latent class analyses revealed five classes of project sharers on the Scratch site, which we describe in Table 3 as low networkers, downloaders, commenters, networkers, and high networkers. As described earlier in the model results section, one class disappeared every month, a phenomenon we explain later in interpreting our latent transition analysis. Below we describe each class as well as the changes we saw in each month based on the number and types of profiles in that month.

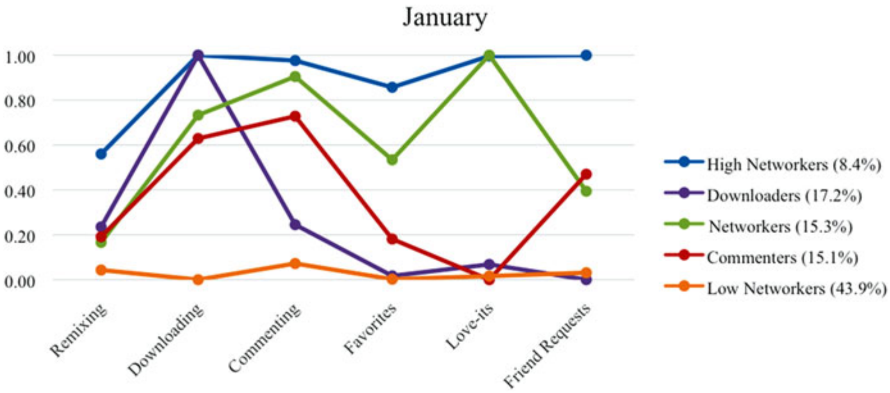


Fig. 4 Latent class patterns for January

January. Among the five distinct latent classes identified in January (see Fig. 4), the majority (43.9 %) of users were classified as low networkers, who are unlikely to do anything except post a project during the month. Moving to a more engaged class, downloaders (17.2 % of the sample) have a 100 % chance of downloading projects from the Scratch site in addition to posting a project, but exhibit almost none of the other activities. Commenters (16.1 %) exhibit a strong likelihood of downloading projects, commenting on projects, and friending, with low likelihoods of favoriting or loving projects. Networkers (17.2 %) are very likely to participate in downloading, commenting, favoriting, loving, and less likely friending. Finally, the high networkers (8.4 %) stand out as the Scratchers most likely to be involved in nearly every social activity on the Scratch site: they have a 55 % chance of posting a remix, a 100 % chance of downloading a project, very high (above 85 %) chances of commenting on or favoriting a project, and a 100 % chance of loving a project and making a friend request. They stand out beyond the networkers particularly in the areas of favoriting, remixing, and friending, being twice as likely as networkers to engage in remixing and friending.

Thus, from this month, each profile appears to provide both quantitative and qualitative higher levels of participation. Low networkers and downloaders engage in DIY participatory activities, namely, sharing projects and (for downloaders) additionally downloading projects, and commenters take part in socially engaging actions as well through commenting. Networkers further include socially supportive actions, namely, favoriting and loving projects, two activities we originally thought would be much more common across users. High networkers stand out as more likely than networkers to engage in all of the social and identity-building activities available on the Scratch site. They are much more likely to engage in favoriting (which has an identity-building role in addition to the socially supportive role it plays) and also have the strongest likelihood of participating in all of the above activities as well as friending and remixing.

February. Among the five classes discovered in January, four of them emerged in February (see Fig. 5). The low networker (70.1 %), commenter (12.5 %),

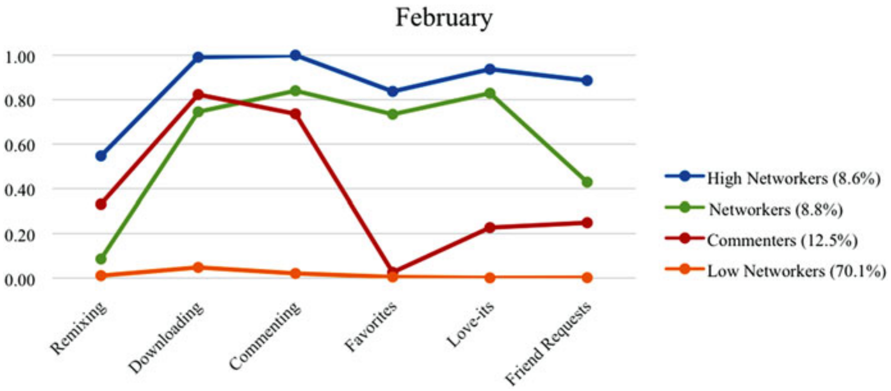


Fig. 5 Latent class patterns for February

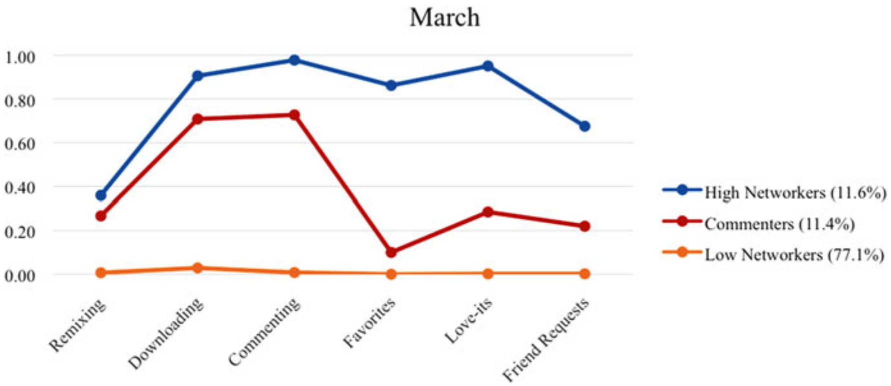


Fig. 6 Latent class patterns for March

networker (8.8 %), and high networker (8.6 %) classes showed similar latent class profiles as those found in the prior month.

March. Among the classes discussed in the previous months, latent classes of low networkers (77.1 %), commenters (11.4 %), and high networkers (11.6 %) also appeared in March. Although the patterns of participation (or latent class profiles) were very similar to the previous months, the likelihood of friend requests was much lower compared to the previous months for all three latent classes. Figure 6 shows the profile patterns in March.

Against our expectations, there was no class of individuals who were likely to participate in socially engaging or socially supportive actions (e.g., commenting, favoriting, loving, or friending others) without also having a strong likelihood of downloading projects, an activity which suggests that Scratchers are not just sharing self-created projects but investigating and looking into them. In other words, besides posting a project, downloading a project is a second gatekeeper to social activity on the Scratch site, then commenting, and finally other types of social networking (i.e., favorites, loves, friending, and remixing). Although leaving socially supportive networking residues such as favorites, love-its, and friend requests originally seemed to us to involve the lowest bar of participation (i.e., simply clicking a button), this actually appears to be a practice in which only those who are most involved in a full range of practices on the site participate, namely, the networkers and high networkers.

Further, we can already see changes in participation through the ways each class grows, shrinks, or disappears. The low networker class grew substantially from January to February (from 43.7 to 70.1 %) and grew slightly larger in March (to 77.1 %). In contrast, the high networker class stayed constant in numbers between January (8.4 %) and February (8.6 %) and increased a little in March (11.6 %). All of the other classes (i.e., downloaders, commenters, and networkers) slowly shrink or disappear entirely. On one level, this may suggest that those users who do not start engaging in socially engaging or socially supportive practices (i.e., loving, favoriting, and friending) may not stay as engaged on Scratch, highlighting the importance of social activities for website activity, even on a site focused on project creation. To further understand these phenomena, we look toward gender and Scratch membership to see if those hold hints about changing patterns of participation.

Interpretation of the Latent Transitions

We found that participation online shifted dramatically over the 3-month time period of the study. Tables 4 and 5 show the probabilities of players classified in one class transitioning to another class the following month; Fig. 7 illustrates these same

Table 4 Likelihoods of members of one profile transitioning to another profile

	February			
January	High networkers (8.67 %)	Commenters (12.6 %)	Networkers (8.79 %)	Low networkers (69.9 %)
High networkers (8.34 %)	65.4 %	2.5 %	11.7 %	20.4 %
Networkers (15.6 %)	8.0 %	11.5 %	16.1 %	64.4 %
Commenters (15.3 %)	6.9 %	16.5 %	4.5 %	72.1 %
Downloaders (16.9 %)	0.0 %	9.2 %	1.4 %	89.3 %
Low networkers (43.7 %)	1.9 %	14.8 %	10.3 %	73.0 %

Table 5 Likelihoods of members of one profile transitioning to another profile

	March		
February	High networkers (11.9 %)	Networkers (12.1 %)	Low networkers (75.9 %)
High networkers (8.67 %)	74.7 %	10.5 %	14.8 %
Networkers (8.79 %)	21.6 %	10.4 %	68.0 %
Commenters (12.6 %)	5.4 %	29.0 %	65.6 %
Low networkers (69.9 %)	4.1 %	9.4 %	86.5 %

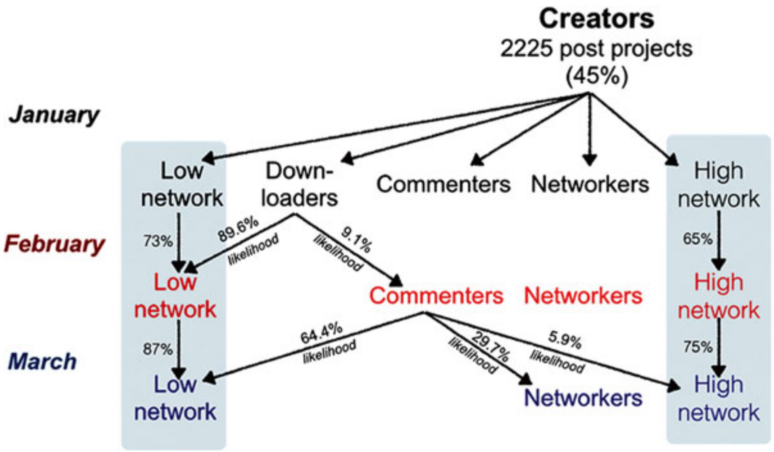


Fig. 7 Visualizing some of the transitions to "low network" participation and the tendency of high networkers to stay as high networkers

patterns of change. In general, Scratchers who were not engaged in any activity (low networkers) were likely to stay in that class across the months. This transition was less dramatic from January to February as a quarter (27 %) of low networkers transitioned into commenters, networkers, and even involved high networkers. From February to March, only 13.5 % of low networkers evolved to more advance players (as either networkers or high networkers). A similar shift in participation also appeared for high networkers. That is, there was a strong likelihood that high networkers stayed as high networkers from month to month.

The majority of commenters and networkers followed traditional website trends shifting to lower and lower engagement (as low networkers) or continuing similar participation practices across time with very fewer players moving upward in their participation. It is also interesting to note that downloaders, a pattern of participation that ceased to exist after January, became less active as low networkers (89.3 %) with a few members shifting to the practices of commenters. Moving to the last month, although commenters disappeared as a class, a large number of these users (34.4 %) showed the most promise in their play and turned toward participation as

Table 6 Multinomial logistic regression [coefficient (odds ratio)] results predicting latent class membership based on gender and length of membership

	High networkers	Commenters	Networkers	Downloaders
January				
Length of membership	0.37*** (1.44)	–0.16* (.85)	0.02 (1.02)	–0.34*** (.71)
Gender (female)	0.51** (1.66)	0.15 (1.16)	0.22 (1.25)	–0.01 (.99)
February				
Length of membership	0.09 (1.09)	0.27*** (1.31)	0.51*** (1.67)	
Gender (female)	0.01 (1.01)	–0.39* (.67)	–0.10 (.90)	
March				
Length of membership	0.59*** (1.81)	0.60*** (1.82)		
Gender (female)	0.19 (1.21)	–0.38* (.69)		

Note: $^*p<.05$, $^{**}p<.01$, $^{***}p<.001$. For each comparison, low networkers serve as the reference group

networkers (downloading, commenting, and otherwise networking) or high networkers (engaging in all aspects of Scratch).

Gender and Membership in Scratch Community

We now turn to two additional features of members in Scratch online community, gender and length of membership. Two sets of further analyses were conducted to examine the influence of these variables on latent class membership. Under the umbrella of LTA, we first utilized multinomial logistic regression to test whether gender and length of membership influenced membership at each time point. Second, we examined the distribution of gender and membership groups across the latent classes (based on the highest probability classification) through the use of chi-square tests of independence.

Multinomial Logistic Regression

Using results from our latent transition analyses, multinomial logistic regression analyses were performed to predict latent class membership at each time point using gender and length of membership as predictors. Prior to these analyses, the low networker class, the largest class for most months, was selected as a reference group; thus, the outcome variable is a dichotomous variable with the higher value indicating membership into a specific class (e.g., high networker class) relative to the lower networker class. Table 6 presents the influence of gender and length of membership as regression coefficients (and odds ratio) predicting class membership. For January classes, results show that increased length of membership on Scratch was a significant predictor of membership into the high networker class (relative to the low networker class). However, this length of membership significantly decreased the likelihood of membership into the commenter and downloader class in favor of the low networker class. Thus, at the initial month, there is a duality in terms of membership length: for some, the longer they stayed on Scratch, the more likely they will be highly involved (as high networkers); for others, lengthier membership status encouraged inactivity in relation to being commenters or downloaders. For February, the length of membership functioned as a significant predictor of increased classification as commenters and networkers (relative to the low networkers), suggesting social involvement becoming key to retention. Similarly, in March, length of membership played a significant role in predicting increases in membership in both the active classes of commenters and high networkers. No other significant results were found for length of membership.

The story of gender as a predictor of latent classes suggests equity in membership. In general, gender played a marginal role in terms of how users participated in Scratch. In January, results showed that girls were significantly more likely than boys to be in the high networker class (rather than the low networker class). In February and March, girls were significantly less likely than boys to be in the commenter class. Gender was not found to significantly predict membership for the other classes. This lack of significant differences suggests that patterns of participations are less dependent on gender and more dependent on enduring membership.

Tests for Gender and Membership

To examine the distribution of gender and length of membership across the latent classes for each month in greater detail, chi-square tests of independence were conducted. Prior to these analyses, all users were categorized into their highest probability class for each month.

Gender. In general, gender played a marginal role in class membership. Although the chi-square test of independence for January revealed a significant relationship between gender and latent class memberships [$\chi^2(4)=9.635$, $p=.047$], an examination of the standardized residuals revealed only one marginally significant finding: a higher proportion of girls who were categorized as high networkers in January than expected ($z=2.030$). The results for February did not yield a significant relationship, χ $(2)=5.613$, $p=.132$. For March, there was a lower proportion of girls in the commenters than expected ($z=-2.132$), $\chi^2(2)=10.040$, $p=.007$.

These analyses suggest that while males dominate the population of Scratch at large, within participation profiles gender differences are minimal, a remarkable finding for a youth amateur design site focused on programming. Notably, our own prior ideas about the Scratch online community suggested that girls dominated comments by sheer numbers while boys dominated projects, a pattern easily visible in simple frequency data on comments, projects, and gender (see scratch.mit.edu/research). However, by looking at participation patterns, our analysis opens up an alternative look at these trends. From this perspective, all active users of the site are project creators, and among those are three groups of individuals who engage in

Table 7 Distribution of January latent class members by the age of their Scratch accounts[a], $\chi^2(12)=118.82$, $p<.001$

	January				
	High networkers (8.40 %)	Downloaders (16.9 %)	Commenters (15.4 %)	Networkers (15.6 %)	Low networkers (43.7 %)
Newbie (new account), $N=740$	**3.4 %**$^{--}$	**26.6 %**$^{++}$	**13.4 %**$^{+}$	14.9 %	41.8 %
Young (0–3 months), $N=625$	7.0 %	20.2 %	9.9 %	14.4 %	48.5 %
One year (4–12 months), $N=409$	**15.4 %**$^{++}$	**11.7 %**$^{--}$	9.3 %	18.3 %	45.2 %
Oldie (12+ months), $N=403$	**14.1 %**$^{++}$	**12.4 %**$^{--}$	9.2 %	14.4 %	49.9 %

[a] *Notation*: $^{+}z>2.0$, $^{++}z>3.0$. $^{-}z<-2.0$), $^{--}z<-3.0$; these notations indicate whether the actual count of individuals in a given group is significantly greater than ($z>2$ or 3) or less than ($z<-2$ or -3) expected (at p < .05 or p = < .01.)

Table 8 Distribution of February latent class members by the age of their Scratch accounts, $\chi^2(9)=108.94$, $p<.001$

	February			
	High networkers (8.67 %)	Commenters (12.6 %)	Networkers (8.79 %)	Low networkers (69.9 %)
Newbie (new account), $N=740$	**4.5 %**$^{--}$	**8.1 %**$^{-}$	**5.5 %**$^{--}$	**81.9 %**$^{++}$
Young (0–3 months), $N=625$	8.0 %	11.2 %	7.5 %	73.3 %
One year (4–12 months), $N=409$	**17.6 %**$^{++}$	13.0 %	**11.2 %**$^{+}$	**58.2 %**$^{--}$
Oldie (12+ months), $N=403$	11.7 %	**15.4 %**$^{+}$	**11.2 %**$^{+}$	**61.8 %**$^{-}$

Notation: $^{+}z>2.0$, $^{++}z>3.0$. $^{-}z<-2.0$), $^{--}z<-3.0$; these notations indicate whether the actual count of individuals in a given group is significantly greater than ($z>2$ or 3) or less than ($z<-2$ or -3) expected (at p < .05 or p = < .01.)

commenting and other social networking activities (e.g., commenters, networkers, and high networkers). There are almost no gender differences among these classes of users and certainly no gender differences that hold over time.

Length of membership. The length of time users had accounts on Scratch.mit.edu (i.e., their Scratch membership) was most certainly related to which participation classes they were in, especially for users who created new accounts in January 2012 (i.e., "newbies" who joined the month our data collection began) and for more senior Scratch users. Tables 7, 8, and 9 show the chi-square results and the proportional distribution of users by membership over each month. Overall, we see several interesting trends. First, while the percentages of Scratchers that were low networkers increased each month from January to March, this trend was much stronger for

Table 9 Distribution of March latent class memberships by the age of their Scratch accounts, $\chi^2(6) = 178.22$, $p < .001$

	March		
	High networkers (11.9 %)	Networkers (12.1 %)	Low networkers (75.9 %)
Newbie (new account), $N = 740$	**5.3 %**$^{--}$	**6.1 %**$^{--}$	**88.6 %**$^{++}$
Young (0–3 months), $N = 625$	10.4 %	**8.6 %**	81.0 %
One year (4–12 months), $N = 409$	**19.6 %**$^{++}$	**18.3 %**$^{++}$	**62.1 %**$^{--}$
Oldie (12+ months), $N = 403$	**17.6 %**$^{++}$	**22.3 %**$^{--}$	**60.0 %**$^{--}$

Notation: $^{+}z > 2.0$, $^{++}z > 3.0$. $^{-}z < -2.0$), $^{--}z < -3.0$; these notations indicate whether the actual count of individuals in a given group is significantly greater than ($z > 2$ or 3) or less than ($z < -2$ or -3) expected (at p < .05 or p = < .01.)

those whose accounts were new in January (newbies) or less than three months old. More senior Scratch users were far more likely to be in a more involved class of participation than the younger users. Second, in January, there were far more newbies in the downloader class than expected. This may be an explanation for why this class disappeared between January and February. Overall, each month, the newest users, those who joined Scratch at the start of the study, are less likely to be represented in the more involved participation classes (i.e., commenters, networkers, and high networkers). This shows a fairly typical form of online engagement seen in many other sites where new users join, engage in the website, then shift to lower participation, or disappear altogether from the site (see Kafai & Fields, 2013).

Parallel to these trends among junior Scratchers, more senior users (all those whose Scratch accounts are >3 months old) were more likely to be involved in all aspects of the Scratch site overall. For instance, the top two categories of senior users were more likely to be in the high networker class each month (except senior users in the month of February, see Table 8) as well as the networker class in February and March. Similarly, they were markedly less likely to be in the downloader class in January. After January, they were also considerably less likely to be in the low networker class. Thus, we would expect that users who continue to post projects on Scratch after at least a few months would be more likely to participate in more aspects of the Scratch community over time.

Discussion

This chapter examined broad qualitative and quantitative trends of social practices that shape participation in a youth do-it-yourself (DIY) social networking forum focused on the production of programming projects. While revealing visible distinct types of users that define participation on a massive scale, our findings also call into question some earlier views about participation on the website. In the following sections, we discuss our new insights on enduring participation in the Scratch community, consider implications for equity, discuss the relationship of programming and participation, outline considerations for designing for collaborative learning on a massive scale, and propose directions for future research.

Project-Focused Participation: DIY Social Networking Forums

Perhaps most surprisingly, our findings suggest that the key forms of participation on the Scratch site are sharing and downloading content, activities that reflect that Scratch is most predominantly a DIY community. Remarkably, nearly 45 % of Scratch users posted projects, a tremendously high level of user contribution in a massive online community. We suggest that this denotes a very different form of basic participation than more well-known patterns in traditionally thought of social network sites visited by far larger numbers of users (e.g., Facebook, Vine, MySpace) where users commonly post happenings and events in their daily lives. Instead, we suggest that DIY social networking forums may have their own unique patterns of participation where sharing one's own content is the baseline of participation rather than more socially engaging or socially supportive actions. One reason for this may be that in DIY social networking forums, sharing self-created content involves not just adding content to a site, but is the most core form of identity display in those online communities. It is all too easy to differentiate users as "project creators" or "socializers." Rather, in Scratch at least, all active users who left any traces of their participation were project sharers and that this project sharing is both a participatory activity (sharing a creation with other users) and an identity-building activity (where projects reflect who one is on the site). Among those project sharers, users engaged in different types of social activity that differentiated their types of participation with high networkers being the most stable class of users.

Interestingly, the seemingly easy socially supportive actions (simple networking residues like loving and favoriting) were only evident among the most involved users: networkers and high networkers. Of course, these users engaged in the entire spectrum of social practices we identified: from sharing projects to commenting, loving, favoriting, friending, and remixing, truly forming the "core" group of Scratch users. Further, several of the above actions may play another role beyond social interaction through direct display on users' profile pages. For instance, on the Scratch site, *sharing* and *favoriting* projects hold far more prominence on users' personal pages than the thumbnail picture and city/country information on a user's profile (see Fig. 2). These activities have the added layer of identity building on the site in that they represent a user's abilities, interests, and preferences. This puts a different lens on sharing projects as a basic form of participation in DIY social networking forums. Not only is it a type of content creation, but it is also the primary way of establishing a presence in the online community. Favoriting projects, an activity engaged in the most by the high networkers, also holds identity-building meaning on the site. Seeing these DIY social networking activities in light of establishing an identity may provide another layer of interpretation as to their importance.

While large numbers of participants in sites with millions of registered users result in overall high activity, it is in fact often the smallest group of users that drives the most activities and attains the most visibility (i.e., Kafai & Fields, 2013). In other words, while everyone has access to the site, not everyone is as highly engaged or contributes in the same manner in informal online communities. What does this mean? For one, it means that those users most likely to draw the attention of designers and researchers are a relatively small group. Researchers who focus on case studies or ethnographies as well as designers who respond to users' posts and concerns are dependent on users who engage in commenting or other forms of written communication. If other massive DIY social networking forums follow the trends of Scratch.mit.edu, then those who leave comments may actually be a small minority of the overall population. Those who stay socially engaged month by month are an even smaller minority. The celebration of rich opportunities for learning in studies of affinity spaces, gaming communities, and social networking sites may thus only apply to a small proportion of users on a site. This observation indicates that actual collaborations in massive online communities are limited to a far smaller number of users than the overall size of the community seems to suggest.

Participation vs. Programming

Overall, we found an encouraging lack of gender differences among classes of users in Scratch.mit.edu based on engagement in social practices online. Given that programming communities are heavily male dominated (even Scratch is 58 % male), the fact that girls are proportionately part of all participation classes is remarkable. However, interesting questions about gender and participation arise when we compare classes of participants to classes of programmers. In our related study on the same sample of users, we analyzed classes of programmers, finding four stable classes based on the relative sophistication of programming commands used in Scratch projects (see Fields, Giang & Kafai, 2014). In this case, gender differences appeared in the highest and lowest classes of programmers: girls were much more likely to be in the largest, most novice programming class (e.g., not moving beyond loops in their programming) and much less likely to be in the "advanced" and "experienced" classes of programmers that used many different types of more challenging commands at relatively high levels of frequency (e.g., Booleans, variables, conditionals).[1] This finding raises interesting questions about the differential appearance of gender differences: while there is a gender difference

---

[1] Just because a user only uses loops and does not use seemingly more complex commands does not necessarily mean that their programs are less sophisticated. However, our analysis, detailed in Fields, Giang and Kafai (2014), supports a view of increasing eliteness in programming based on the latent classes of programmers we identified. See Fields, Giang and Kafai (2014) for a fuller discussion of this topic.

in programming at a high programming profile, there is essentially no difference with regard to gender in any of the participation profiles.

Further, when we compared participation classes to programming classes from the same sample, we found no relationships *except* between the “high networker” class of participation and the highest, “experienced” class of programmers which strongly overlapped (Fields, Giang & Kafai, 2014). In the tech community, there has been a strong push to involve women in the socialization of computer science, assuming that such socialization will result in more involved and higher levels of coding. Yet these results indicate that we need better understandings of how social engagement may or may not relate to depth of programming engagement. Beyond programming, this raises questions about the relationship between deep participation and deep expertise in any given domain of design in online communities (e.g., writing, drawing, video making, etc.). While Ito et al. (2010) suggest a trajectory of participation from hanging out to messing around to geeking out, we found that these social networking activities, even at high levels, may not directly result in moving into “geeking out,” at least at the higher levels of more sophisticated programming. Although case studies of successful Scratch users (Brennan, 2013) share the stories of members who managed to transition into more extensive programming, more research is needed to understand to what extent these transitions happen on a larger scale, for which classes of users, and over what kinds of time frames.

Designing for Online Participation

The larger goal of this research is to illuminate participation practices in massive communities that support learning and design, to see who is participating and collaborating in those activities, and to evaluate how to sustain those types of activities. One area that our findings contribute to is the affordances of different social networking features in online communities. Our findings suggest that sharing self-created projects may be a strong entry point for participating in online amateur design sites. Designers of DIY social networking forums, an up and coming genre of website for children and youth (Grimes & Fields, 2015), should note the key role of sharing one’s creations in participation. Many, many websites that promote or provide tools for making things do not actually support sharing, yet this designed-for ability may be a key feature of promoting social engagement in interest-driven communities that support user design.

At the same time, users may need assistance in developing “participatory competencies” (Kafai & Burke, 2014) with more conversational types of networking residues such as comments, “likes,” favorites, and friending/following. In our analysis, it was highly unlikely for new users to engage in these features (i.e., to be in the commenter, networking, or high networking classes). Interestingly, those users who engaged in the full range of networking features were highly likely to stay engaged in the long term. However, this does not necessarily mean that engaging in “loving” and “favoriting” will result in more enduring participation (i.e., a causal interpretation)—it is simply a part of the activities of the most engaged users. Our current analysis does not allow for a clear-cut interpretation of this finding but will require more research. Case study and ethnographic analyses of the Scratch community provide similar insights into the more social features of the site and how important developing relationships or a sense of community is to participation. Users who engage in commenting and who receive constructive and positive comments tend to credit their engagement to those socially engaging activities (see Brennan et al., 2011). Our research of another online community, the virtual world Whyville.net, also highlighted the importance of reciprocal social engagement (i.e., conversing and hanging out) in the most involved (top 7 %) users (Giang et al., 2012). Yet users often may not know how to begin to comment appropriately on projects or even how to reply to others' comments, how to find collaborators, how to get feedback on their projects, and how to become a part of the community. Our research in local Scratch workshops confirms that many youth may feel disconnected from or even intimidated by larger online communities (Fields, Vasudevan, & Kafai, 2015; Kafai et al., 2010). Further, another challenge in online communities is users who engage in discouraging behaviors, leaving insulting comments, copying projects without giving credit, and pressuring others to be similar rather than creative (Brennan, 2011).

One effort we have made to support users' participatory and programming competencies has been to hold special "Collab Camps" where users are invited to program a special themed project in a small group (2+ users) (see chapter "Supporting Diverse and Creative Collaboration in the Scratch Online Community" by Roque, Rusk, & Resnick, 2016). From 2012 to 2013, we ran a series of three Collab Camps that utilized a specific time line where groups (or collabs) had to post a draft of their project by a specific time, receive constructive criticism from the Scratch Team and trained Scratchers (Collab Counselors), and then post a final version 2–3 weeks later. This successfully supported project revisions and deepening of programming and media skills (Fields, Kafai, Strommer, Wolf, & Seiner, 2014) and an increase in constructive criticism left by participants on each others' projects (Roque, Kafai, & Fields, 2012). We also implemented Collab Camps locally with novice Scratch students. In our third Collab Camp, we integrated design features from the online challenge in a local workshop, training high school students to provide each other with positive, constructive feedback and providing transparency into each others' projects. Students cited these efforts as enabling them to improve their projects and identify more strongly with computing (Fields et al., 2015). Interestingly, the local users we engaged found the local audience of their peers the most meaningful; they were generally not interested in participating further on the website, though they valued the feedback and audience of the broader community. These provide but a few examples of the potential for helping local and online users build participatory competencies in DIY social networking forums and for utilizing design strategies implemented online in face-to-face and hybrid settings.

Directions for Future Research

We are only at the initial phase of understanding learners in amateur online design communities (or DIY social networking forums), especially youth programming communities. The type of broad scale research we conducted is useful for noting widespread trends not easily visible from more qualitative analyses, enabling us to put findings from case studies and ethnographies into a larger perspective. At the same time, by itself, it has clear limitations in the depth of what it can say about users within the community and within each identified class. Other studies of online communities, namely, gaming and social network communities (Boellstorff, Nardi, Pearce, & Taylor, 2013; Hine, 2000; Williams, Yee, & Caplan, 2008), reveal an unhealthy split in either quantitative or qualitative research approaches. For instance, survey methods and statistical data mining seem to drive many efforts in coming to grips what engages members in these massive online communities. On the other end, we have ethnographies of single massive communities (see Boellstorff, 2008; Taylor, 2006) that inform us with a fine-grained detail of cultural practices and activities. Of course, others have rejected this dichotomy and argued for a mixed methods approach (Williams, 2005), but it is difficult to bring together the diverse expertise and resources (much less permission for backend data from websites) needed to accomplish both thick and broad analyses. In our view, it is not just about juxtaposing data sources and analytical methods but also about developing perspectives that integrate both approaches in a productive manner. As a case in point, we have suggested and employed connected ethnographies that make use of the data mining and reduction in large data sets to identify particular participants based on their contribution profiles and to cross reference and develop these through in-depth ethnographies (Kafai & Fields, 2013; see also, Reimann, 2009). Such analyses leverage the explanatory potential of each method and allow us to contextualize cases within larger community trends.

Finally, the participation and patterns from the Scratch website do not generalize easily to other communities. Rarely, the Scratch website was created and developed in a university environment, one with a particular ethos of openness expressed through an open source computing tool (Scratch) as well as broad openness on the website (all comments and shared projects are fully public). Indeed, the breadth of networking features on Scratch is relatively rare when compared to other DIY social networking forums for kids (Grimes & Fields, 2015). Thus, in addition to rich, mixed method research into individual sites, we also need research that systematically compares the designs and participation of multiple types of sites. Studying and supporting collaborative forms of learning in massive online communities are not simply a matter of involving larger numbers of participants but also of considering the nature of activities; the various roles of participants, educators, and designers; and the creation, sharing, and socializing around artifacts.

Acknowledgments This material is based upon work supported by a collaborative grant from the National Science Foundation (NSF#1027736) to Yasmin Kafai with Mitchel Resnick and Yochai Benkler. The views expressed are those of the authors and do not necessarily represent the views of the National Science Foundation, Utah State University, St. Mary's College, or the University of

Pennsylvania. Particular thanks to Anant Seethalakshmi for help with gathering data and to the Scratch Team for providing repeated feedback on analysis. An earlier version of the latent class analysis appeared in the proceedings of the Annual Conference of Computer-Supported Collaborative Learning (Fields et al., 2013).

References

Ares, N. (2008). Cultural practices in networked classroom learning environments. *International Journal of Computer Supported Collaborative Learning, 3*, 301–326.

Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. London, UK: Yale University Press.

Black, R. W. (2008). Adolescents and Online Fanfiction. New York, NY: Peter Lang. Retrieved from http://www.amazon.com/Adolescents-Fiction-Literacies-Digital-Epistemologies/dp/082049738X

Boellstorff, T. (2008). *Coming of age in second life: An anthropologist explores the virtually human*. Princeton, NJ: Princeton University Press.

Boellstorff, T., Nardi, B., Pearce, C., & Taylor, T. L. (2013). *A handbook of ethnographic methods for virtual worlds*. Princeton, NJ: Princeton University Press.

Boyd, D. (2013). *It's complicated*. New Haven, CT: Yale University Press.

Boyd, D., & Ellison, N. B. (2007). Social network sites: Definition, history and scholarship. *Journal of Computer-Mediated Communication, 13*, 210–230.

Brennan, K. (2011). Mind the gap: Differences between the aspirational and the actual in an online community of learners. In *Proceedings of the International Conference of Computer Supported Collaborative Learning*.

Brennan, K. A. (2013). *Best of both worlds: Issues of structure and agency in computational creation, in and out of school* (Doctoral dissertation). Massachusetts Institute of Technology.

Brennan, K., Valverde, A., Prempeh, J., Roque, R., & Chung, M. (2011). More than code: The significance of social interactions in young people's development as interactive media creators. In *World Conference on Educational Multimedia, Hypermedia and Telecommunications* (Vol. 1, pp. 2147–2156).

Chen, M. (2012). New York, NY: Peter Lang. Retrieved from http://www.amazon.com/Leet-Noobs-Warcraft-Literacies-Epistemologies/dp/1433116103.

Collins, L. M., & Lanza, S. T. (2010). *Latent class and latent transition analysis with applications in the social, behavioral, and health sciences*. Hoboken, NJ: Wiley.

Eddy, Y. C. L., Chan, C., & van Aalst, J. (2006). Students assessing their own collaborative knowledge building. *International Journal of Computer Supported Collaborative Learning, 1*, 57–87.

Fields, D. A., Giang, M., & Kafai, Y. B. (2013). Understanding collaborative practices in the Scratch online community: Patterns of participation among youth designers. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.), *To See the World and a Grain of Sand: Learning Across Levels of Space, Time, and Scale: CSCL 2013 Conference Proceedings, Full Papers & Symposia* (Vol. 1, pp. 200–207). Madison, WI: International Society of the Learning Sciences.

Fields, D. A., & Kafai, Y. B. (2009). A connective ethnography of peer knowledge sharing and diffusion in a tween virtual world. *International Journal of Computer Supported Collaborative Learning, 4*, 47–68.

Fields, D. A., & Kafai, Y. B. (2010). Knowing and throwing mudballs, hearts, pies, and flowers: A connective ethnography of gaming practices. *Games and Culture, 5*, 88–115.

Fields, D. A., Giang, M. T., & Kafai, Y. B. (2014). Programming in the wild: Patterns of computational participation in the Scratch online social networking forum. In *Proceedings of the 9th Workshop in Primary and Secondary Computing Education* (pp. 2–11). New York, NY: ACM.

Fields, D. A., Kafai, Y. B., Strommer, A., Wolf, E., & Seiner, B. (2014). Interactive storytelling for promoting creative expression in media and coding in youth online collaboratives in Scratch. In *Proceedings of Constructionism*, Vienna, Austria. Retrieved from http://constructionism2014.ifs.tuwien.ac.at/papers/3.2_2-8540.pdf

Fields, D. A., Pantic, K., & Kafai, Y. B. (2015). "I have a tutorial for this": The language of online peer support in the Scratch programming community. In *Proceedings of Interaction Design and Children*, *(IDC'15)*. New York, NY: ACM.

Fields, D. A., Vasudevan, V., & Kafai, Y. B. (2015). The programmers' collective: Fostering participatory culture by making music videos in a high school Scratch coding workshop. *Interactive Learning Environments, 23*(5), 1–21.

Gee, J. (2003). *What videogames have to teach us about learning and literacy*. New York, NY: Palgrave.

Giang, M. T., Kafai, Y. B., Fields, D. A., & Searle, K. A. (2012). Social interactions in virtual worlds: Patterns and participation of tween relationship play. In J. Fromme & A. Unger (Eds.), *Computer games and new media cultures: A handbook on the state and perspectives of digital games studies* (pp. 543–556). New York, NY: Springer.

Grimes, S. M., & Fields, D. A. (2015). Children's media making, but not sharing: The potential and limitations of child-specific DIY media websites for a more inclusive media landscape. *Media International Australia, 154*, 112–122.

Grimes, S. M., & Fields, D. (2012). *Kids online: A new research agenda for understanding social networking forums.* New York. The Joan Ganz Cooney Center at Sesame Workshop. Retrieved from http://www.joanganzcooneycenter.org/reports-38.html

Hagenaars, J., & McCutcheon, A. (2002). *Applied latent class analysis*. Cambridge, UK: Cambridge University Press.

Hine, C. (2000). *Virtual ethnography*. London, UK: Sage.

Ito, M., Baumer, S., Bittanti, M., Boyd, D., Cody, R., Herr, B., … Tripp, L. (2009). Hanging out, messing around, geeking out: Living and learning with new media. Cambridge, MA: MIT Press.

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Cambridge, MA: MIT Press.

Kafai, Y. B., & Fields, D. A. (2013). *Connected play: Tweens in a virtual world*. Cambridge, MA: MIT Press.

Kafai, Y. B., Fields, D. A., & Burke, W. Q. (2010). Entering the clubhouse: Case studies of young programmers joining Scratch community. *Journal of Organizational and End User Computing, 22*, 21–35.

Kafai, Y. B., Heeter, C., Denner, J., & Sun, J. Y. (2008). *Beyond Barbie [R] and Mortal Kombat: new perspectives on gender and gaming*. Cambridge, MA: MIT Press.

Lammers, J. C., Curwood, J. S., & Magnifico, A. M. (2012). Toward an affinity space methodology: Considerations for literacy research. *English Teaching: Practice and Critique, 11*, 44–58.

Luther, K., Caine, K., Ziegler, K., & Bruckman, A. (2010) Why it works (when it works): Success factors in online creative collaboration. In *GROUP '10: Proceedings of the ACM Conference on Supporting Group Work* (pp. 1–10). New York, NY: ACM.

Magnifico, A. M. (2010). Writing for whom? Cognition, motivation, and a writer's audience. *Educational Psychologist, 45*, 167–184.

Maloney, J., Peppler, K., Kafai,Y., Resnick, M., & Rusk, N. (2008, March). *Programming by choice: Urban youth learning programming with Scratch*. Paper presented at the SIGCSE 2008 Conference, Portland, OR.

Margolis, J., Estrella, R., Goode, J., Holme, J. J., & Nao, K. (2008). *Stuck in the shallow end: Education, race, and computing*. Cambridge, MA: MIT Press.

Margolis, J., & Fisher, A. (2001). *Unlocking the clubhouse*. Cambridge, MA: MIT Press.

Monroy-Hernández, A. (2012). Designing for remixing: Supporting an online community of amateur creators (Doctoral dissertation, Massachusetts Institute of Technology).

Muthen, B. (2002). *Statistical and substantive checking in growth mixture modeling.* Retrieved from http://www.gseis.ucla.edu/faculty/muthen/full_paper_list.htm

Nickerson, J. V., & Monroy-Hernández, A. (2011). Appropriation and creativity: User-initiated contests in Scratch. In *Proceedings of the Hawaii International Conference on System Sciences (HICSS '11).*

O'Donnell, A. M. (2006). The role of peers and group learning. In P. Alexander & P. Winne (Eds.), *Handbook of educational psychology* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum.

Reimann, P. (2009). Time is precious: Variable- and event-centered approaches to process analysis in CSCL research. *International Journal of Computer Supported Collaborative Learning, 4*, 239–257.

Resnick, M., Maloney, J., Hernández, A. M., Rusk, N., Eastmond, E., Brennan, K., … Kafai, Y. B. (2009). Scratch: Programming for everyone. *Communications of the ACM, 52,* 60–67.

Rick, J., & Guzdial, M. (2006). Situating CoWeb: A scholarship of application. *International Journal of Computer-Supported Collaborative Learning, 1*, 89–115.

Roque, R., Kafai, Y. B., & Fields, D. A. (2012). From tools to communities: Designs to support online creative collaboration in Scratch. In *Proceedings of the 11th International Conference on Interaction Design and Children* (pp. 220–223). New York, NY: ACM.

Roque, R., Rusk, N., & Resnick, M. (2016). Supporting diverse and creative collaboration in the Scratch online community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass Collaboration and Education*. Cham, Switzerland: Springer International.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago, IL: Open Court.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1*, 37–68.

Steinkuehler, S., & Duncan, S. (2009). Scientific habits of mind in virtual worlds. *Journal of Science Education and Technology, 17*, 530–543.

Taylor, T. L. (2006). *Play between worlds*. Cambridge, MA: MIT Press.

van Aalst, J. (2009). Distinguishing knowledge-sharing, knowledge-construction, and knowledge-creation discourses. *International Journal of Computer Supported Collaborative Learning, 4*, 259–287.

Webb, N., & Palincsar, A. (1996). Collaborative learning. In D. Berliner (Ed.), *Handbook of educational psychology* (pp. 345–413). New York, NY: Macmillan.

Williams, D. (2005). Bridging the methodological divide in game research. *Simulation & Gaming, 36*, 1–17.

Williams, D., Contractor, N., Poolec, M. S., Srivastad, J., & Cale, D. (2011). The virtual worlds exploratorium: Using large-scale data and computational techniques for communication research. *Communication Methods and Measures, 5*, 163–180.

Williams, D., Yee, N., & Caplan, S. (2008). Who plays, how much, and why? Debunking the stereotypical gamer profile. *Journal of Computer-Mediated Communication, 13*, 993–1028.

Yee, N. (2014). *The Proteus paradox: How online games and virtual worlds change us-and how they don't.* New Haven, CT: Yale University Press.

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge building communities. *Journal of the Learning Sciences, 18*, 7–44.

Supporting Diverse and Creative Collaboration in the Scratch Online Community

Ricarose Roque, Natalie Rusk, and Mitchel Resnick

Design Environments for Creative Collaboration

A young boy plays with a choose-your-adventure project and decides to leave a comment with suggestions for the creator. A young girl sees a simple maze game and decides to remix it to add new levels in the game. A young boy watches an animated music video and asks the creator if she wants to collaborate on a project. Two friends who met online decide to make a birthday card together for a mutual friend, then ask their network of friends to add a message to the project by remixing it; by the end of the day, hundreds of other young people have remixed the original project.

These stories highlight the experiences of young people in a mass collaboration environment—namely, the Scratch online community (http://scratch.mit.edu). With the Scratch programming language, young people can create their own interactive media, such as animations, games, and stories, and share these projects in a dynamic online community with young people from all over the world. Since Scratch launched in 2007, more than eleven million projects have been shared and more than nine user accounts created. Scratch was designed with collaboration in mind. In particular, it enables creative collaboration—that is, coming together to design, build, and invent shared artifacts. Whether they involve just two people or hundreds of people, creative collaborations in Scratch are embedded and supported within an active and large online community.

These stories also represent the diversity of ways that young people are collaborating: providing feedback, sharing ideas, building on existing projects, and coordinating the creation of a single project. How they organize themselves can vary across time, membership, and level of coordination. In the process, they learn new

---

R. Roque (✉) • N. Rusk • M. Resnick
MIT Media Lab, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: ria@media.mit.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_12

things from one another. As they build on one another's projects, they can learn how the previous projects were made. As they work with others who have varying levels of ability, they can learn new skills and techniques. They may experience obstacles, such as conflict, misunderstandings, and mutual disappointment (for example, when a collaborative project does not turn out as planned). However, despite—and sometimes through the process of working through—these challenges, young people can learn valuable things about themselves as creators and collaborators.

Scratch provides a lens onto different styles of collaboration than have been traditionally studied by the educational research community. Whereas previous research has often focused on small-group structured collaborations in classroom settings, Scratch and other online environments have opened opportunities for collaborations that involve larger number of participants, working on projects driven by participants' interests, and where participants' roles and goals evolve fluidly over time.

In this chapter, we explore two questions:

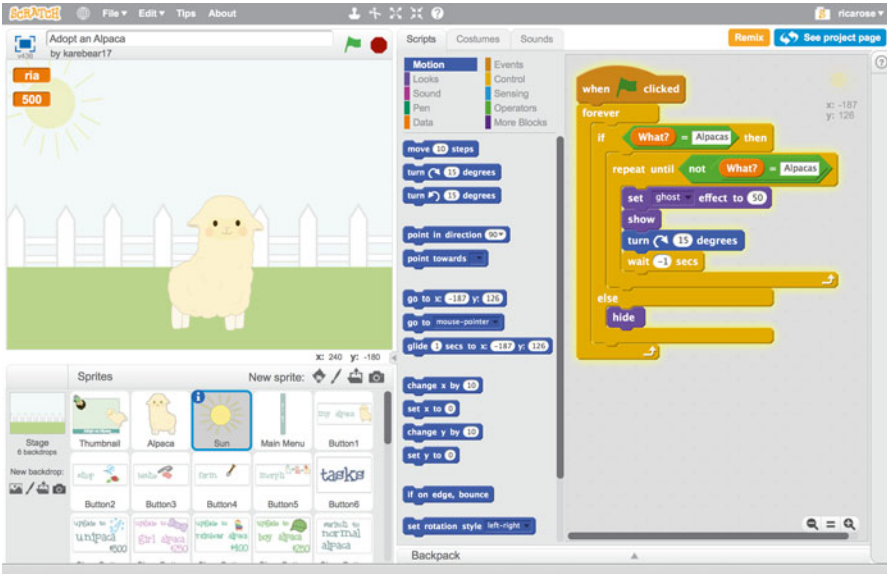
- What are the different ways that young people engage in creative collaboration?
- How can we design environments to encourage and support diverse and creative collaboration?

First, we will explore these questions in the context of the Scratch programming language and online community. We describe varied and emergent collaborative activities, driven by members of the Scratch community members, and we describe the ways in which they are learning as they engage in these activities. We then discuss our design strategies for encouraging and supporting diverse and creative collaboration and how we implemented these strategies across technical and social structures in the community.

Scratch Online Community

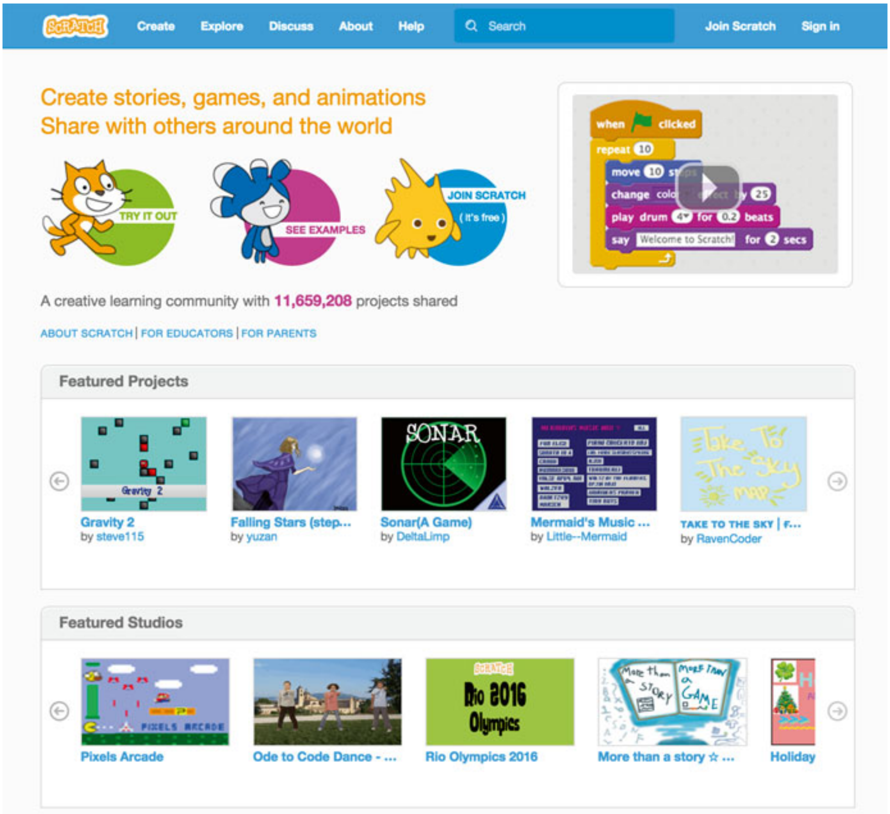
Scratch is a programming language (Fig. 1) and online community (Fig. 2) where young people can create and share interactive media such as games, animations, and stories (Resnick et al., 2009). Scratch is designed and maintained by the MIT Scratch Team, which we are members of. Since Scratch launched in 2007, it has grown into a vibrant community with more than 15,000 projects shared every day, by young people all around the world, primarily between the ages of 8 and 16.

In designing Scratch, we wanted everyone to be able to express and share their ideas. To support broad participation from many interests and backgrounds, we made it easy for young people to create and personalize their projects. They can upload images and music, create their own graphics, and record their own sounds. Scratch members have created a wide variety of projects that include animated music videos of popular music, holiday cards for their friends, quirky musical instruments, biology simulations, interactive newspapers, tutorials about Scratch, and adaptations of popular games.



```
when [flag] clicked
forever
  if <(What?) = Alpacas> then
    repeat until <not <(What?) = Alpacas>>
      set ghost effect to 50
      show
      turn ↻ 15 degrees
      wait -1 secs
    end
  else
    hide
  end
```

Fig. 1 Scratch programming interface. Young people can snap together graphical blocks that have different programming commands. They can stack these blocks and execute sequences of commands that control the attributes and actions of sprites, or objects, in their project



Create stories, games, and animations
Share with others around the world

A creative learning community with **11,659,208** projects shared

```
when [flag] clicked
repeat 10
  move 10 steps
  change color effect by 25
  play drum 4 for 0.2 beats
  say Welcome to Scratch! for 2 secs
end
```

Fig. 2 Home page of the Scratch website. On the home page, members can browse projects and see the latest activity in the community

The Scratch website provides opportunities for members to create and connect with other creators from around the world. Members can easily share their projects by clicking on a "Share" button and showcase their project on a dedicated project page, where other members can interact with their project and leave comments. Members can also immediately view and interact with a project's code by clicking on the "See Inside" button in the project page. To explore projects in the Scratch community, members can start from the home page, which includes projects curated by the MIT Scratch Team, recent projects from people they follow, and projects that the rest of community is "loving."

The Scratch website is also rich in collaborations. Members frequently build on top of each other's ideas, images, sounds, and projects through remixing. Members can also gather and work together in a number of ways. The Scratch website includes a discussion forum, where members can ask questions, converse about Scratch-related topics, and find collaborators. Members can collect and curate projects into shared pages called *studios*. Studios have an area where anyone can write comments. Members can organize the studio by inviting others to become curators.

Creative Collaboration in Scratch

As membership has grown in the Scratch community, young people have collaborated in ways beyond what we had originally anticipated. More and more young people have taken the initiative to connect, coordinate, and collaborate on projects and activities—from forming collaborative groups that developed sophisticated projects to crowd-sourcing project ideas to the entire community (Aragon, Poon, Monroy-Hernández, & Aragon, 2009). In this section, we describe five stories of creative collaboration across the Scratch community to demonstrate the diverse ways Scratch members connect, coordinate, and work together. These stories are based on online activity in the Scratch website (using pseudonyms of Scratch usernames for anonymity).

Remixing Projects and Ideas: Jumping Monkey[1]

Remixing is a common collaborative activity on the Scratch website—about a third of the projects shared in Scratch are remixes (Monroy-Hernandez, 2012). Remixing refers to taking an existing project and making changes to make your own version. All projects on the website are covered by Creative Commons ShareAlike license: When a member shares a project in Scratch, anyone can remix the original project and share it again on the website. Remixing allows members to build on top of other projects and change it in to add new features.

In the Scratch project "Jumping Monkey," Jessy9, an elementary school student, created a simple game where the goal was to help a monkey eat bananas by using

---

[1] This story of creative collaboration on Scratch was adapted from Andrés Monroy-Hernandez's dissertation, *Designing for Remixing* (2012).

the arrow keys to move around the screen (Fig. 3a). Choaz, age 34, played the game and had a number of ideas for improving it. There were several simple black platforms in the game, and Choaz thought the game would be more interesting if the monkey could land on the platforms. So Choaz decided to remix the project and added a color detection technique he called "pink slippers." Choaz painted pink shoes on the monkey and programmed the monkey to react whenever the pink shoes touched any of the black platforms. He also decided to create another remix that was a more developed game, which featured moving platforms and a different character (Fig. 3b). He made sure to credit Jessy9 in the project description for the inspiration: "I'd never have started this if it wasn't for her jumping monkey."

As other community members interacted with Choaz's remixes, some of them shared their own remixes of his projects. A remix by MagicX, a middle school student, added obstacles to the game (Fig. 3c), and she created another project that was more sophisticated. Scratch member GummyBear, a college student, saw MagicX's remix and asked if she could remix the project. MagicX responded by asking GummyBear to collaborate on a project, and together they developed a sophisticated game with music and professional-looking graphics (Fig. 3d). The project soon gained community-wide attention and had more than 10,000 views, far more than any of the "ancestor" projects in the remix tree.

Organizing Contests in the Community: The Creativity Challenge

Scratch members often create contests and challenges for their friends and other community members (Nickerson & Monroy-Hernández, 2011). Each contest can instigate the creation of many projects. For example, "coloring contests" challenge members to color in a line drawing in interesting ways, and the original creator chooses a winner. Other examples include projects that challenge members to add a character to a project, such as a dancer to a dance party or a character running away from a rolling boulder.

MrBreakfast, a middle school student, liked the spirit of these contests and challenges, but he wanted to do something different. Rather than having people work on the same project such as coloring the same character, he wanted people to come up with different ideas. He built a simple project to explain his challenge, which he called The Creativity Challenge, and he asked Scratch members to create something using a simple line drawing of what looked like a caterpillar, but they were not allowed to draw a caterpillar. He gave other rules, such as no copying and making sure to follow the Scratch community guidelines[2]. To help people get started, he created an example: a giraffe wearing a colorful scarf on a sunny day. He shared the project and gave the community 2 weeks to share their projects.

---

[2] Scratch community guidelines: http://scratch.mit.edu/community_guidelines.

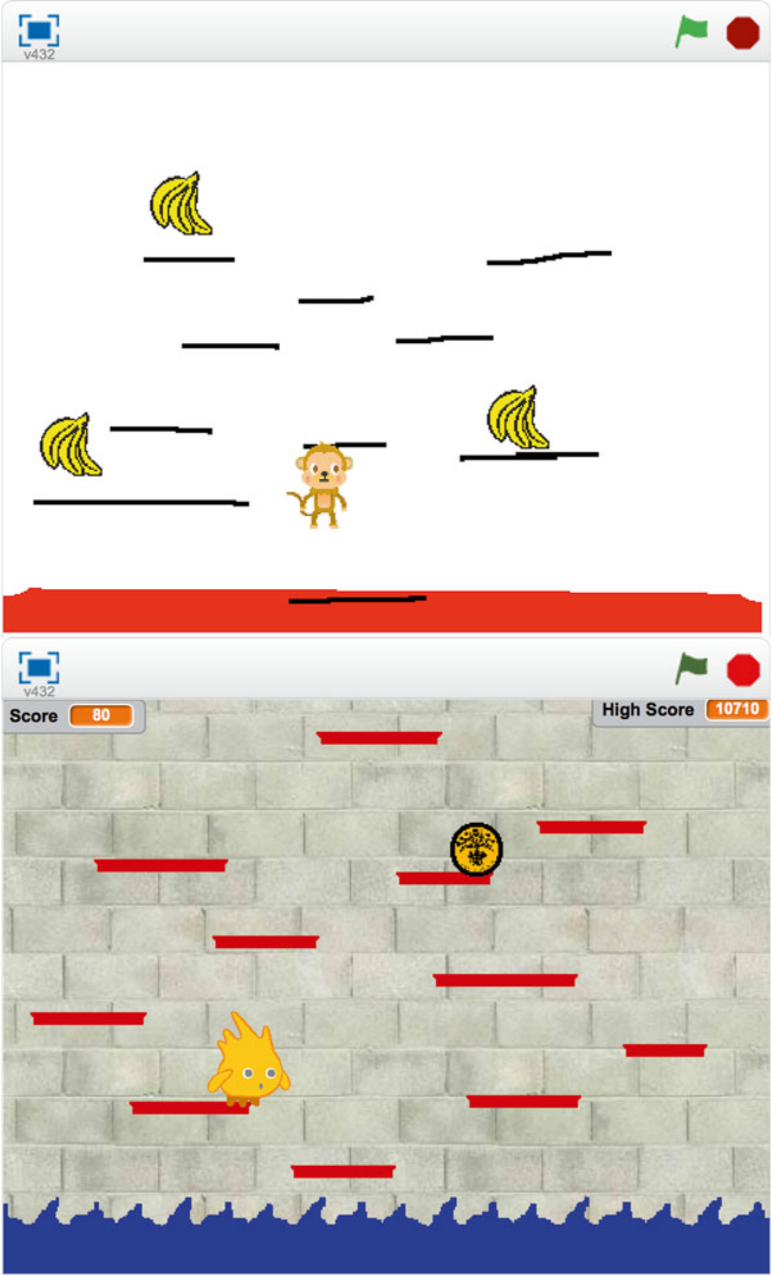


Fig. 3 “Jumping Monkey” project and remixes. Original game by Jessy9 (**a**) and remixes by Choaz (**b**), MagicX (**c**), and GummyBear (**d**)

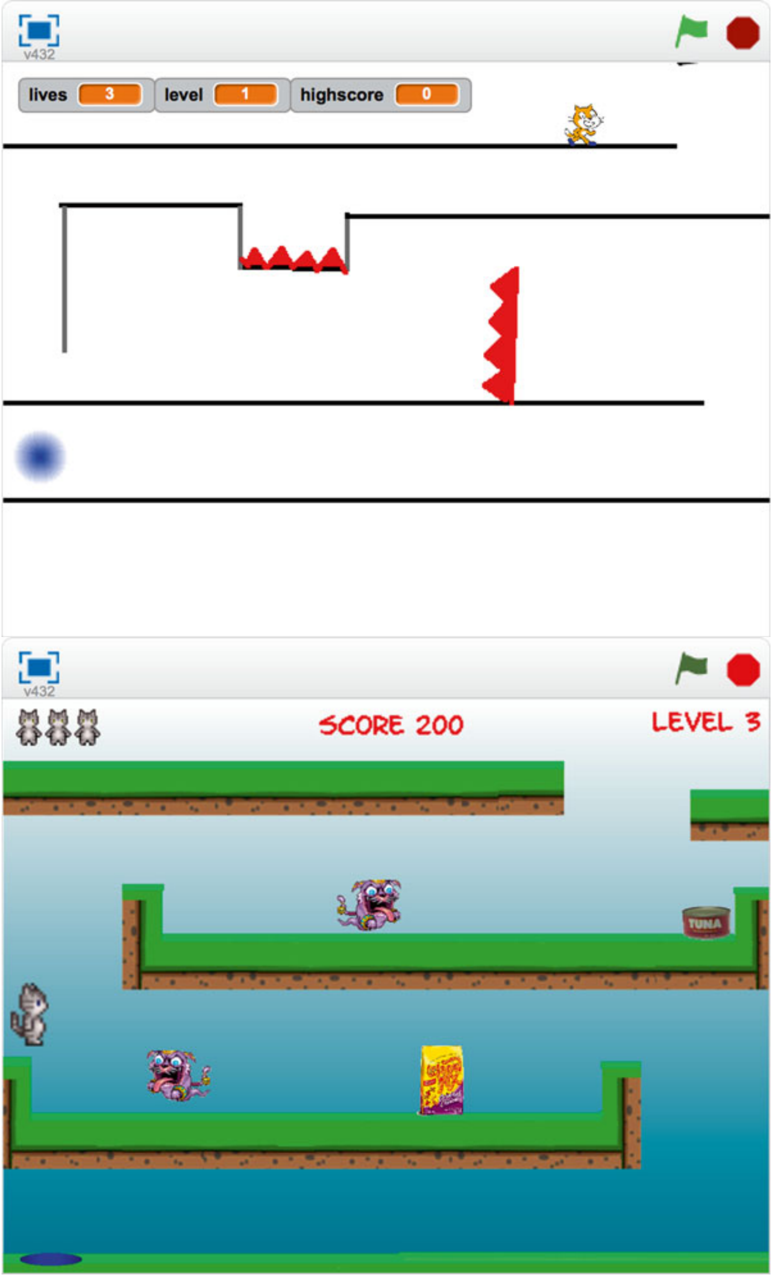


Fig. 3 (continued)

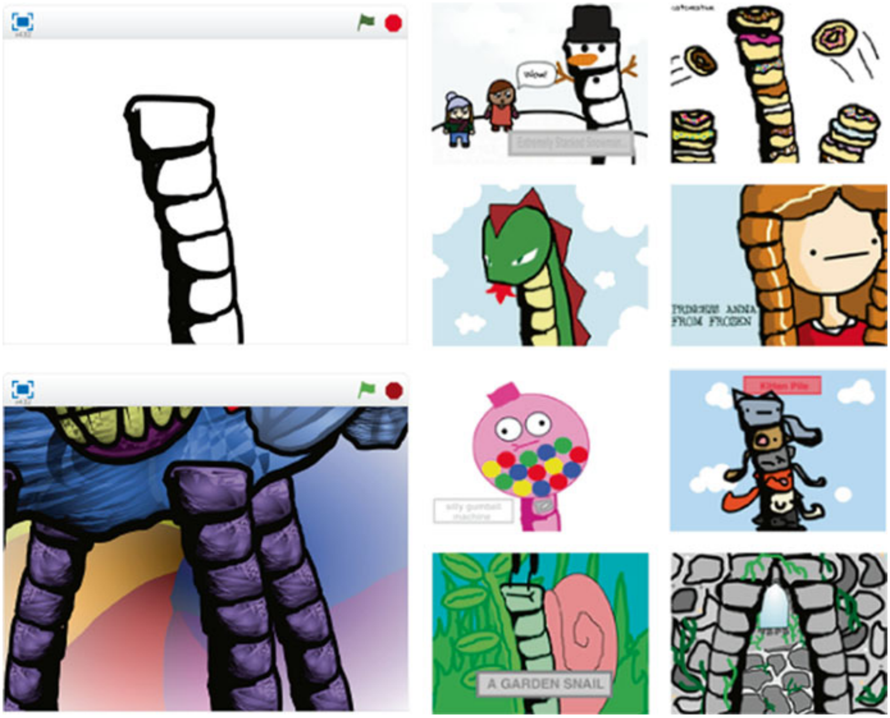


Fig. 4 Original project by MrBreakfast (*top left*), winning project (*bottom left*), and other remixes by Scratch members

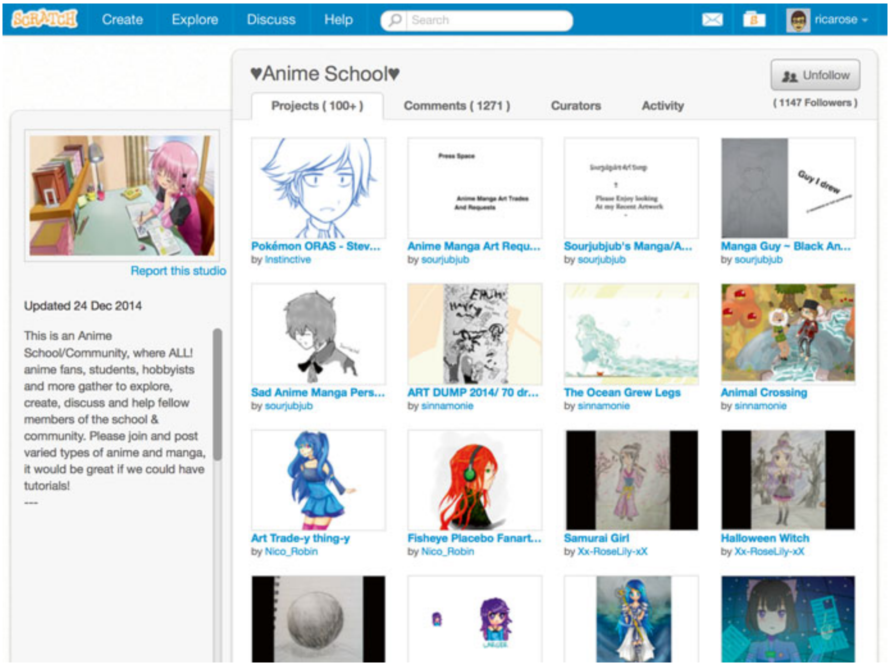
By the time the contest ended, MrBreakfast's project inspired more than 200 remixes (Fig. 4). Members created projects beyond his expectations. Many were whimsical, inspiring, and funny. Some interpreted the line drawing as piles of different things, such as piles of cute puppies, a tower of sugary donuts, and scoops of ice cream. Others incorporated the line drawing into different elements of things and people, such the braids of a young princess, a stone archway into a secret garden, and the stand of a silly gumball machine. Others made fantastical and fictional characters such as fire-breathing dragons, a marshmallow creature wearing a hat, and the lost ruins of the city made of eggplant.

He announced the winner as well as the other "honorable mentions" in a new project. With each announced winner, he gave positive feedback, highlighting the features that excited him about each of their projects. The winning project amazed him. The project creator made a beautiful and fanciful image of an elephant, with the line drawing incorporated into its legs (Fig. 4). The project was also interactive and allowed people to move around the project to see the other parts of the elephant. It was beyond anything he had expected. "The vector art blew my mind, and a tremendous amount of effort was obviously put into it," he wrote in his project announcement. Even after the challenge was over, many Scratch members continued to build on top of his original drawing to create more projects. In the meantime, Scratch members asked MrBreakfast to develop another creativity challenge.

Creating Supportive Spaces for Communities of Interest: Anime School

"This is like an anime school, where ALL anime fans, students and more gather to explore, create, discuss and help fellow members of the Anime World! Please join!" Nancy2020, a middle school student, said in a Scratch studio she called "Anime School" (Fig. 5). She wanted to create a space where people could share ideas, learn from one another, and interact with others interested in talking about all things anime. Additionally, she wanted to find Scratch members who could help create and collect helpful tutorial projects about anime. She recruited people throughout the Scratch website, posting in the discussion forums and asking people to "apply" and explain why they wanted to help.

Within a few days, she got enthusiastic responses from dozens of Scratch members. Many expressed how much they also loved anime and wanted to share their love of anime with others. Some members described how tutorials created by other members had helped them in the past and now they wanted to return the favor to the community. As one Scratch member wrote: "I want this role to help both myself and my friends to learn to draw and improve on my/their anime skills. The tutorials help me find new ideas and methods of guidelines, shading, and textures, and they all help me find my own style."



Updated 24 Dec 2014

This is an Anime School/Community, where ALL! anime fans, students, hobbyists and more gather to explore, create, discuss and help fellow members of the school & community. Please join and post varied types of anime and manga, it would be great if we could have tutorials!

Fig. 5 Anime School studio page

Another Scratch member commented, "There are a whole bunch of people on Scratch with AMAZING anime potential, and they just need a little guidance or tips!" For people who were ready with tutorials to share, she added their projects to the studio and gave them role of "teacher."

Together they created a few tutorials, but their biggest task was searching the Scratch website to find anime-related tutorials created by other members. They found tutorials that included projects such as how to draw eyes, bodies, and hair in an anime style, how to use Scratch programming to animate their anime characters, and how to use other illustration tools like CorelDRAW. Many Scratch members who came to the studio found this wide and large collection of more than 100 projects. Within the tutorial projects themselves, Scratch members were enthusiastically thanking the creators in the project comments.

After several months, their studio was featured on the home page of Scratch by the MIT Scratch Team, which gave the studio more visibility across the community. And as the studio gained visibility, so did the tutorial projects that were a part of the Anime School, as Scratch members made suggestions of other projects to add. The comments and questions in the studio also increased as more people also wanted to join and help with the Anime School. To help manage the increasing activity within the studio, Nancy2020 promoted some of the most helpful members as "Managers." As Nancy2020 became busy outside of Scratch, these managers took the lead in running the school. The Anime School continues to grow with more than 300 projects, which include tutorials, art, animations, and other anime-related projects, and more than two dozen managers and curators who maintain the school.

Imagining New Worlds Together: Jellies RPG

Role-playing games (RPGs) are a popular activity in the Scratch community. In RPGs, Scratch members create projects about their characters and collect these projects in studios. Within the studios, they use the comments to role-play the actions and dialogue of their characters. Scratch members transformed studios, which the MIT Scratch Team had designed as pages for members to curate projects, into social spaces to role-play characters in worlds they create. ComfyCabin, a middle school student, decided to start his own RPG using creatures he called "jellies." Two things inspired jellies: the wiggling movement of Jello and the epic stories of comic book superheroes. Jellies moved and bounced liked Jello. They were also an alien species from a planet that got destroyed by The Dark Jellie. The few who managed to escape crash landed in different parts of the Earth. The "Jellie RPG" began after they arrived on Earth.

ComfyCabin announced this RPG and backstory in a project, and he opened the RPG to anyone interested in playing along in the story. Like many RPGs in Scratch, some members role-played in the studio comments. Comment-by-comment, Scratchers would describe what their character did and said in response to their interactions with other members' characters. Some Scratchers, including

ComfyCabin, also created short animations to make their adventures come alive. They took turns and built on top of each other's story line. For example, two Scratchers, MooshyJello and Gree, took turns making simple animations about their two jellies and their adventures together as they encountered other jellies in different parts of the Earth. These short animations and their stories converged in a final series with their characters combining their powers to defeat The Dark Jellie.

Meanwhile, the idea of jellies spread throughout the Scratch community, beyond the original studio and their short animations. Some Scratch members put together a magazine called "Jellies' Weekly," creating journalistic stories about different jellie characters. Others created animated music videos featuring different jellie characters. Others started spin-off stories of the jellies on Earth. And even as ComfyCabin moved on to other interests, many continued the role-playing game studio while others started their own. After a group of Scratch members completed a storyline about the The Dark Jellie's defeat, another Scratch member started a sequel RPG and rallied other members interested in continuing the saga.

Coordinating a Multi-animator Project (MAP): Dr. Who

OhHai, a middle school student, is a big Dr. Who fan. On Scratch, she met other "Whovians," a name that Dr. Who fans call themselves. During one summer, OhHai decided to "let her inner Whovian out" in the community through an animated music video featuring a Dr. Who song. However, instead of doing it on her own, she decided to invite her Scratch friends and anyone else in the community. Together, they would create a "multi-animator project" (MAP). In a MAP, creators animate different segments of a story or a song. OhHai offered to put all the projects together. She created a base project with the song split up into 17 segments, each covering 10 s of the song. She shared this project and invited anyone to sign up.

About a dozen animators signed up with some offering to animate more than one segment. Some reinterpreted different Dr. Who scenes with cats as characters, since many of them, including OhHai were also cat lovers. While many of the animators submitted their segments in a few days, OhHai took a few more months to share the completed MAP. In the project description, OhHai proudly wrote in the number of sprites and coding scripts that the project contained: 78 sprites and more than 350 scripts. She also wrote that even though she put it together, the animators deserved much of the credit for their animated segments. Soon after she posted it, her project appeared on What the Community is Loving row in the home page, which gave it even more visibility in the community.

The project also became a place for other Scratch members to ask OhHai questions about learning how to put a MAP together. Initially, she helped these members by individually replying to their questions. However, after getting the same questions, she created a tutorial project in Scratch, where she shared techniques, such as ways to organize scripts and sprites from different animators, ways to import different assets, and how to split up audio into different segments. People incorporated her advice and shared links to MAPs that they created. Others also shared more suggestions to add to her tutorial, which she then incorporated in her tutorial project. OhHai was excited to see the different kinds of MAPs emerging around the community and was glad to help others create their own. In the meantime, she also began her next MAP, featuring another Dr. Who song, and coordinated another group of animators to contribute to the larger animation.

Learning Through Creative Collaboration

In these stories, we see the rich and diverse ways that Scratch members are engaging in creative collaboration. The forms that they took varied across many dimensions, such as scale, level of coordination, time, and membership. Some collaborative activities included a small group of individuals remixing projects, while others involved hundreds of young people remixing and adapting a project. Some activities had a consistent set of members contributing, while membership in other activities continually shifted. For some of these activities, a central leader was involved, like Nancy2020 in the Anime School recruiting members and assigning roles and tasks to participants. Other activities were more distributed, with Scratch members like MrBreakfast and ComfyCabin developing the initial concept, then giving creative freedom to participants. Some collaborations occurred over a period of time, such as the MAP, while some are ongoing and continue to develop and evolve over time, like the Anime School.

These stories also highlight the different ways that Scratch members are learning across these collaborative activities. In each case, Scratch members are engaging in *design*—making artifacts such as remixing a game to add more obstacles or creating a musical animation. Scratch is inspired by constructionist learning philosophy, which argues that people learn most effectively when they are designing and building personally meaningful artifacts (Kafai & Resnick, 1996; Papert, 1980). The construction of physical and digital artifacts play an important role in constructing knowledge. Papert wrote about the importance of “objects to think with”—as young people build artifacts, they are also building new ideas and thinking about their own thinking.

They are also learning through their shared *interests*, such as an interest in a popular TV show, anime art, or role-playing adventures. When young people design and build projects inspired by their own interests, they are willing to work longer and harder on the projects, and they persist through challenges and difficulties. Within online and networked settings, interests can also be a catalyst for learners to connect and develop “affinity spaces” around their shared interests (Gee, 2004), such as the way the Anime School on Scratch developed to support interests in anime. These interest-driven spaces can also support young people from “hanging out” to “geeking out” or engaging more deeply in their learning (Ito et al., 2009).

And finally, these shared activities are being supported by a *community* of other creators (Brennan & Resnick, 2012). Within the Scratch online community, members learn through peripheral as well as proactive participation (Lave & Wenger, 1991). For example, some members learned from observing OhHai's collaborative process in arranging the MAP project, while others participated directly by contributing animated segments for the overall project. In the community, members have access to many projects that they can remix, that they can learn from, and that can inspire new ideas. They can also leverage the community and crowdsource for ideas, projects, or elements in a new project. And finally, Scratch members serve many important roles in helping each other learn, acting as guides, critical friends, and collaborators.

These collaborative experiences demonstrate the ways that Scratch members learn by designing, motivated by their interests and supported by a community of other creators. However, not all members engage in collaborative activities (see chapter "Coding by Choice: A Transitional Analysis of Social Participation Patterns and Programming Contributions in the Online Scratch Community" by Fields, Kafai, & Giang, 2016) and not all these activities are productive or promote learning in Scratch (Brennan, 2011). Some members leave negative comments or unconstructive feedback in projects, which can be especially discouraging to newcomers. Additionally, while studios are helpful in curating projects and gathering people, some members create "Add Everything" studios with the intention of collecting as many projects as possible regardless of how they are related. Finally, while the remixing platform has made it easy for members to build on one another's projects, the remixing features have also made it easy for members to copy projects, without changing the original work.

Designing for Diverse and Creative Collaboration

These experiences of different forms of creative collaboration make use of the technical and social structures we designed in the Scratch website—structures that we continually and iteratively revise, based on emergent activity in the community. In reflecting on these stories, the following lessons emerged.

Design Tools and Environments That Are Simple and Easy to Appropriate

Scratch members continually surprise our team in the ways they use the website and its tools beyond what we had imagined. For example, studios are often appropriated beyond the original intention as spaces for collecting and curating projects. Scratch members have used the studio features to engage in role-playing, to coordinate collaboration teams (which they often call "collabs"), and to create meeting places for subcommunities of interest. When designing studios, we aimed to keep them easy and simple, with only a few features beyond curating projects (for example, an area for exchanging comments). We also provided ways for members to personalize their studios by editing the name, description, and icon of the studio. The simplicity of studios led to generativity, enabling community members to adapt studios for their own purposes.

Highlight Diversity and Amplify Examples

We use different spaces and features on the website to showcase interesting and diverse examples of collaboration in the community. Highlighting different kinds of projects and activities through the highly visible home page or community-wide events can also be a source of inspiration for Scratch members. When we featured the Anime School among the featured studios, members appreciated the access to tutorials about anime, and soon many asked if they could also help. In the last few years, we have also explicitly created a variety of "Collab Camps," or collaborative challenges where we ask members to work together and create projects based on a creative constraint (Roque, Kafai, & Fields, 2012). These events have raised awareness of collaborative activities, which may not have been obvious to some Scratchers as an activity they could engage in.

Create a Social Environment That Supports Diverse Projects and Activities

Our commitment to supporting a variety of interests, backgrounds, and ways of creating and connecting in Scratch is embedded into our technical and social design, but it is also articulated in our policies. We created a set of community guidelines[3] that include being respectful of others and promoting constructive critique. The guidelines are presented in clear and friendly language. We use the guidelines to maintain a welcoming and respectful environment for members. For example, while we are open to the diverse and varied expressions of Scratch projects, we block projects that seem inappropriate for a community that includes children as young as 8 years. In addition to our efforts, members on the site actively promote the guidelines with others and report comments or projects that go against the guidelines.

Next Steps

The diversity of collaboration in the Scratch community enables multiple entry points into and trajectories through creative collaboration experiences for young people. In Scratch, participation can be as simple as sharing a project—which can then be viewed and remixed by other members of the community. Working with

---

[3] Scratch community guidelines: http://scratch.mit.edu/community_guidelines.

others can be as brief and easy as remixing a simple drawing or as prolonged and complex as merging two dozen animations into one large project. These multiple ways of collaborating provide avenues for both newcomers and old-timers to learn from one another and deepen their engagement.

Collaborating online, especially engaging in more sophisticated activities like collaboratively building projects, requires both technical and social savvy. The emergent activities show us both the learning opportunities and the challenges that Scratch members face when trying to engage in these activities. For example, newcomers are juggling both learning how to use Scratch and how to collaborate. Some members have trouble finding collaborators to work with or coordinating one another's efforts. The text-based medium of the comment areas can make explaining a sequence of Scratch blocks hard to describe.

These challenges as well as these collaborative activities from the community continue to inspire us as we revise and design new features in Scratch. For example, in 2013 we redesigned the website to make the Scratch programming editor available online. This change enabled members to see inside others' projects to see how they are created and more easily remix and learn from others' projects. We also redesigned the studio structure to better support collaboration, allowing members to add and manage multiple curators. In addition, we added a "backpack" feature in the editor for members to reuse scripts and media across Scratch projects. We are exploring designs to allow Scratch members more to readily provide help for each other, inspired by the ways that Scratch members already support one another (Fernando, 2014). As we plan and design support structures in Scratch, we aim to provide new entry points for young people to design together, to pursue and connect over their interests, and to support one another through community.

References

Aragon, C. R., Poon, S. S., Monroy-Hernández, A., & Aragon, D. (2009). A tale of two online communities: Fostering collaboration and creativity in scientists and children. In *Proceedings of the Seventh ACM Conference on Creativity and Cognition, C&C '09*. New York, NY: ACM.

Brennan, K. (2011). Mind the gap: Differences between the aspirational and the actual in an online community of learners. In *Proceedings of the 2011 Computer Supported Collaborative Learning Conference* (pp. 342–394).

Brennan, K., & Resnick, M. (2012). Imagining, creating, playing, sharing, reflecting: How online community supports young people as designers of interactive media. In N. Lavigne & C. Mouza (Eds.), *Emerging technologies for the classroom: A learning sciences perspective* (pp. 253–268). New York, NY: Springer.

Fernando, C. (2014). *Online learning webs: Designing support structures for online communities* (Masters thesis). Retrieved from DSpace@MIT

Fields, D. A., Kafai, Y. B., & Giang, M. T. (2016). Coding by choice: A transitional analysis of social participation patterns and programming contributions in the online Scratch community. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International.

Gee, J. P. (2004). *Situated language and learning: A critique of traditional schooling* (1st ed.). London, UK: Routledge.

Ito, M., Baumer, S., Bittanti, M., Boyd, D., Cody, R., Herr-Stephenson, B., … Tripp, L. (2009). *Hanging out, messing around, and geeking out: Kids living and learning with new media*. Cambridge, MA: MIT Press.

Kafai, Y. B., & Resnick, M. (1996). *Constructionism in practice: Designing, thinking, and learning in a digital world*. Hillsdale, NJ: Erlbaum.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Monroy-Hernandez, A. (2012). *Designing for remixing: Supporting an online community of amateur creators* (Doctoral dissertation). Retrieved from DSpace@MIT

Nickerson, J. V., & Monroy-Hernández, A. (2011). *Appropriation and creativity: User-initiated contests in Scratch*. System Sciences (HICSS) 44th Hawaii International Conference, 1–10.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., … Kafai, Y. (2009). Scratch: Programming for all. *Communications of the ACM*, *52*, 60–67.

Roque, R., Kafai, Y., & Fields, D. (2012). From tools to communities: Designs to support online creative collaboration in scratch. In *Proceedings of the 11th International Conference on Interaction Design and Children, IDC '12*. New York, NY: ACM.

Citizen Science: Connecting to Nature Through Networks

Brigid Barron, Caitlin K. Martin, Véronique Mertl, and Mohamed Yassine

Evolving Forms of Coordinated Interaction

The human capacity to invent increasingly diverse forms of cooperative and collaborative activity is one of our most precious resources for learning. As the authors of the framing chapters of this volume note (see chapter "A Brief History of Mass Collaboration: How Innovations over Time have Enabled People to Work Together More Effectively" by Collins, 2016; chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" by Fischer, 2016; chapter "Stigmergic Collaboration: A framework for Understanding and Designing Mass Collaboration" by Elliott, 2016), there is an increasingly diverse range of networked efforts that reflect this capacity, and their rapid evolution is fueling innovation at an unbelievable pace. Our theoretical frameworks for understanding the nature of these forms of coordinated interaction are also in transition, and we need a range of research methodologies to advance our understanding of the sources and consequences of variability among them. In this chapter, we consider citizen science efforts, particularly those that have education as a primary goal, as one genre within this broader spectrum of what is being called mass collaboration. Citizen science initiatives capitalize on the interest and efforts of nonscientist collaborators who join forces with professional scientists to contribute data or analysis that helps address scientific and environmental investigations. Recent work views citizen science as part of the broader effort of public participation in science research (PPSR), defined as intentional collaborations in which members of the public engage in the process of research to generate new science-based knowledge (Shirk et al., 2012). Both of these descriptions highlight the practice of citizen science as a form of mass collaboration,

---

B. Barron (✉) • C.K. Martin • V. Mertl • M. Yassine
Stanford School of Education, Stanford, CA, USA
e-mail: barronbj@stanford.edu; ckmartin@stanford.edu;
vm.mertl@stanford.edu; myassine@stanford.edu

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_13

broadly defined as efforts that bring large numbers of people together to work on shared problems or projects.

Our chapter is organized into three main sections. We begin by situating citizen science within the broader category of mass collaboration and describe its relevance and importance to reform in science education. We next provide a qualitative case of a classroom teacher and the evolution of his participation in a citizen science effort to begin to illuminate the varied ways that large-scale scientific efforts can connect to the learning trajectories of teachers and students. Our intention with this analysis is to contribute a framework that can help us understand the ways that individual goals emerge within the collective goals that organize these collaborative efforts (see chapter "A Brief History of Mass Collaboration: How Innovations over Time have Enabled People to Work Together More Effectively" by Collins, 2016). We close with several ideas for research that can advance theory and practice.

Citizen Science as Mass Collaboration

Mass collaboration has long been recognized as a way to increase commercial productivity, from the industrialization of American factories to Amazon's Mechanical Turk crowdsourcing. Recently, greater attention has been paid to the potential for mass collaboration to impact other areas of global interest, such as the rapid generation of shared knowledge during disasters, civic and political engagement, and the monitoring and understanding of environmental change. The practice of citizen science has always used a model of mass collaboration, as ordinary citizens around the world are invited to gather and classify data and contribute to scientist-initiated collection and analysis efforts. For example, the first citizen science projects such as the Christmas Bird Count, founded in the early 1900s by the National Audubon Society, were focused on species identification and documentation and relied on volunteers who were geographically distributed to provide data.

As with other examples of mass collaboration, networked technologies have dramatically increased the number and types of citizen science projects and the number of people involved, expanding the potential for this form of mass collaboration to contribute to knowledge and innovation. There are currently hundreds of online citizen science projects available to the general public, easily found through searches and listed in popular magazines such as *Scientific American*. Some have very low barriers to participation, where a user does not need to create an account before beginning to contribute. For example, millions of people around the world have participated in the SETI@home project alone, a citizen science project asking for public contributions of local radio signals in the search for intelligent extraterrestrial life.

Mobile technologies and networked databases are particularly important for expanding the opportunities in citizen science platforms. Mobile GPS-enabled data collection devices allow data contributions to easily be shared: applications like Google Maps make it easy to identify geographic coordinates, and online databases make data contributions available to professional scientists and community members.

Developmental psychologists from the University of London's Birkbeck Babylab have launched the Baby Laughter Project to better understand how humor relates to cognitive and emotional development. They invite parents to contribute data by submitting videos and field reports of the particular incidents that make their babies laugh. Participants can share artifacts across geographical locations and time and build knowledge (Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2014). Other platforms have championed the use of social network features, such as Project Noah, where members have online profiles where their GIS-linked photographs of plants, fungi, and animals are posted, shared, liked, and commented on. Similarly, Snowtweets asks citizens to their personal Twitter accounts and a common hashtag to share the snow depths in their area, which are then extracted and mapped using a data visualization tool. Forums and message boards allow for updates and discussions around data and allow modular groups to form that dig into specific questions or topics.

In addition to inviting data contributions from participants, many citizen science projects now engage participants in analysis of massive datasets. For example, Galaxy Zoo invites participants to contribute to astronomy by classifying galaxies according to their shapes using images from telescopes. Everyday citizens can contribute to meteorology through Cyclone Center where volunteers are asked to classify tropical cyclone satellite images.

Simulations and games are also being used to engage volunteers. For example, neuroscientists have recently launched EyeWire, a game inviting participants to map connections between retinal neurons. The variety of projects comes as the result of the array of institutions developing and promoting these citizen science initiatives. Universities are common sponsors of these projects, such as the Cornell Lab of Ornithology, but also government agencies such as NASA, nonprofits such as the National Geographic Society, and start-up for-profit companies such as uBiome.

As a form of mass collaboration, the product or ideas that come out of the work around the focal question or scientific knowledge is a key component. Communities of nonscientists have the ability to contribute genuine scientific insights. Scientists benefit by crowdsourcing data collection and analysis, having high-quality data collected by more and more varied sources and locations than would be possible by the scientists alone (Gallo & Waitt, 2011; Lepczyk, 2005) and also more minds and human resources to process the large amount of data available through various channels (Raddick et al., 2009). As an example, players in the protein-folding game Foldit have successfully determined the structure of the Mason-Pfizer monkey virus (M-PMV) retroviral protease, a task which scientists were not able to solve using existing algorithms (Khatib et al., 2011).

As with any form of collaboration, there can and hopefully should be benefits for the individual contributor from their participation in the collaborative effort (see chapter "Mass Collaboration as Co-Evolution of Cognitive and Social Systems" by Cress, Feinkohl, Jirschitzka, & Kimmerle, 2016). Research on individual outcomes from participation in citizen science has included findings of improved scientific literacy and increased civic awareness and engagement (e.g., Rippel, Schaefer, Mistree, & Panchal, 2009). For example, a study from the Cornell Laboratory of Ornithology analyzed letters written by more than 700 primarily adult participants of a national bird-monitoring effort and found that nearly 80 % revealed engagement in thinking processes similar to those that are part of science investigations (Trumbull, Bonney, Bascom, & Cabral, 2000). Another Cornell analysis of The Birdhouse Network, which leads participants to construct nest boxes in their local environment and report data about bird usage, used pre-post survey data from approximately 50 primarily adult users and found that participation had an impact on people's knowledge of bird biology (Brossard, Lewenstein, & Bonney, 2005). Other research is beginning to look at community-relevant outcomes. For example, researchers (Gallo & Waitt, 2011) studying participant engagement in a Texas-based invasive species-monitoring program looked at online submission activity of over 870 adult volunteers over 5 years and determined that the program was successful in mobilizing a community around their local environmental problems. Projects that include more personally consequential outcomes are also emerging. For example, consumers can also discover the balance of bacteria in their bodies while adding their information to mass data collected by uBiome to advance understanding of the human microbiome. While these efforts' results are promising, much more research and development in this area is needed (Brossard et al., 2005; Raddick et al., 2009; Trautmann, Shirk, Fee, & Krasny, 2012). The research is especially scarce on impact of participation on younger citizen scientists.

The rapid expansion of projects has led to the development of a number of typologies of citizen science efforts that classify them by their participatory roles (Bonney et al., 2009, 2014) or broader program goals (Wiggins & Crowston, 2011). Taking an empirical approach, Wiggins and Crowston (2011) classified 80 citizen science projects into five genres including action, conservation, investigation, virtual, and education. In this classification scheme, organizational and structural properties are taken into account with project goals, the use of virtual space and related technologies, and the importance of the physical environment for participation considered in classifying projects. The emergence of these differing typologies reflects the diversity of projects that fit into this broader category of citizen science. Below, we focus on projects they call educational, defined as efforts that make outreach and education primary goals facilitated by the provision of curricular materials and associated activities.

Citizen Science Goes to School

Some citizen science programs have entered classrooms, providing curriculum, resources, and educational goals for teachers to guide the work of their students, sometimes linked to an online website allowing users to submit and share findings. For example, citizen science sites, such as Galaxy Zoo, Project Noah, and Rocks Around The World, have educator outreach programs where students conduct investigations and teachers share lessons and resources. In formal classroom settings, students learn to navigate websites, upload investigations, and use additional technologies such as GPS devices and Google Maps. For some projects, students venture outside and collect data in the field (around school, in backyards, at a local beach, etc.). By submitting investigations online, students enter a networked community where information is shared and participants communicate virtually across locations. Students are not just using technology, they are learning how to use these technologies within a structured context facilitated by their teacher, the site administration, and a curriculum in a larger educative endeavor (Patrichi, 2011).

Citizen science programs have the potential to combine many, if not all, of the practices that are presented in the Next Generation Science Standards (NGSS Lead States, 2013) as well as Common Core State Standards for Math and English Language Arts, including authentic inquiry-based science work, using synergistic opportunities across subject areas, making strong claims through the use of evidence, and finding patterns in data. Such inquiry-based opportunities have been identified as crucial to student learning and are a primary component of the National Research Council's 2011 report, "Framework for K-12 Science." The Next Generation Science Standards, released in April 2013 (NGSS Lead States), are based on this framework. They explicitly call out the important real-world application and practices of science that span elementary and high school science education, including asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information. The focus on authentic, cross-disciplinary longer-term, inquiry-based science and math opportunities represents a significant change in how formal education has approached learning in these subject areas, and resources and models will be critical in helping teachers and schools understand and adopt these new practices and approaches set out to prepare students for college, career, and citizenship.

With citizen science projects, students are also part of a mass collaboration, as they enact modular work within their classroom or district and share it with others working on the same problem, allowing comparisons of practice and outcomes across different types of participants and enhancing discussions and further questions, all connecting students to authentic science practices. This may happen in formal classrooms within a school, within a school district, within a state, or nationally. This may also happen between classrooms and out-of-school setting, such as universities (in communication with scientific researchers) and citizen science organizations. These exciting opportunities, however, can be mitigated by the regulations imposed on the use of socially-mediated technologies in the classroom. Many citizen science sites use social networking features, including profile pages and means of communication, to share data, publish findings, and coordinate next steps. The use of such features is limited for classrooms unless the sites comply with COPPA privacy standards (Children's Online Privacy Protection Act).

Despite issues of access, the potential for use of citizen science projects in the classroom is significant, but there has been little research on how citizen science is taken up by teachers. The work that has been done suggests that there are some major challenges to overcome. For example, one review of seven citizen science programs designed for classroom implementation found that few truly supported participants to move beyond the phase of data collection (Trautmann et al., 2012). Other studies of inquiry-based learning implementations have had similar findings pointing to the need to support teachers in their preparation to implement science in the real world, using data collection procedures designed by and expected by scientists, which is not typically part of classroom practice for science teachers (Penuel & Means, 2004; Polman, 2000).

To more broadly and deeply capitalize on the potential for citizen science to invigorate inquiry-based science at school, we need to better understand how it is taken up in particular classrooms. We need to understand what motivates teacher engagement, the forms of support that are needed, and how participation changes over time. This understanding is especially important, as studies have found that the demands of implementing open-ended inquiry-based science instruction in the classroom necessitate more than just resources for implementation, such as activity guides or an interactive platform.

Advancing Our Understanding of Pathways to Citizen Science

Our research framework builds on ecological theories of development to conceptualize learning ecologies as dynamic systems connected to the relationships, activities, and networks that provide opportunities for learning across setting (Barron, 2006; Brown, 2000). Sustained engaged participation is rarely the result of a single experience or resource. Most often, it results from a confluence of learning opportunities, access to social networks associated with varying communities of practice, and the alignment of activities with goals (Azevedo, 2013; Barron, Gomez, Pinkard, & Martin, 2014). The importance of understanding motivation for participation in mass collaborative efforts at different levels is highlighted by Fischer (chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" by Fischer, 2016), who stresses the need for not only sustained participation but movement, as participants take on more active and demanding roles over time. This perspective suggests the utility of multidimensional analyses that can take into account the varied resources, preferences, and settings that support ongoing participation (Azevedo, 2013; Barron, 2006).

In this chapter, we share an analysis of the confluence of the biographical, geographical, technical, and social resources that led to the adoption and development of Vital Signs, a citizen science opportunity. Vital Signs is a public networked citizen science program connected to public school classrooms in the state of Maine but open to anyone who wants to learn and contribute. Created and run by the Gulf of Maine Research Institute[1] in 2009, the program is specifically designed to engage teachers and students in seventh- and eighth-grade science classrooms in inquiry-based science education around activities designed to study habitat invasion by non-native species. The Vital Signs program is an example of citizen science as mass collaboration (as defined in chapter “Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration” by Fischer, 2016), using Internet-based tools to allow people to work together to solve a problem, share information, and engage in the joint construction of artifacts and knowledge. According to the Shirk et al. (2012) citizen science typology, Vital Signs uses a blended model of participation as participants assist scientists in developing a study and collecting and analyzing data for shared environmental monitoring and research, but participants can also define their own missions and request assistance from other colleagues and community members. Table 1 describes the specific features of mass collaboration found in the Vital Signs program and the socio-technical environment.

To better understand the development of engagement in Vital Signs program participation, and the deepening of contribution both online and in the classroom, we draw from a study that retrospectively and concurrently documented the work of one science teacher, Mr. Paulson. We followed him most closely as he taught 100 seventh-grade students at Barberry Middle School over the course of 1 year. Barberry is located in an inland rural area where some students are bussed over one-and-a-half hours to and from school within the district boundaries, which span approximately 260 mile^2. At the time of our study, students were 94 % Caucasian, reflecting state demographics. Socioeconomic status varied, indicated by almost half of students (45 %) qualifying for subsidized lunch. Approximately two thirds of eighth graders scored at or above proficiency on state standardized tests. We use a case-based approach to help advance our understanding of the evolution of engagement in this environment. Our analysis is organized to address our focal research question: What social, technical, spatial, and personal resources contribute to a teacher pathway of sustained and deepening participation in citizen science?

In foregrounding the teacher’s role in their own professional development, it also provides a new lens for conceptualizing how structured opportunities for learning can launch more personalized learning pathways. This framing builds on conceptualizations of engagement that foreground the dynamic nature of topical interests (e.g., Hidi & Renninger, 2006) to deepen our understanding of how sustained participation in any voluntary activity is related to conditions of practice and preferences for diverse dimensions of activities (Azevedo, 2013). These include access to social, ideational, and information-based resources that can sustain an interest-driven activity. To advance our capacity to support educators developing new forms of practice, it is useful to document and theorize the specific types of resources that contribute to the emergence and evolution of stable inquiry-based teaching practices.

---

[1] The Gulf of Maine Research Institute (GMRI) is a nonprofit marine science center located in Portland, Maine. GMRI was incorporated in 1968, with the mission of laying the foundation for a new genre of marine science, education, and community institution, including translating rigorous science into engaging formal and informal educational materials.

Table 1 Mass collaboration features in the Vital Signs program and the socio-technical environment

Nature of the collaboration	The socio-technical environment of Vital Signs supports participants to solve problems related to the spread of invasive species in the state of Maine. This issue is approached through a series of “field missions,” questions posed by practicing scientists as well as educators and other community members. Participants select a mission, collect data in their area, and then share observations through a guided online submission process. Through this modular activity, individual students or classroom groups around the state contribute local data to the larger dataset on their own time schedule to answer ecological questions in the state of Maine. Participants (students, teachers, and community members) can also create their own missions related to invasive species and invite the community to join them in the work
Roles, contributions, and access of participants	In Vital Signs, as with other mass collaborations, the roles and expectations of participants are decentralized. This includes teachers and students working alongside each other to collect field data as citizen scientists, and scientists and community citizen scientists of all ages working together on shared field missions representing local ecological problems of concern. The modular nature of the work allows novices to get started on questions of scientific importance while also enabling a problem space that is jointly created as users come up with their own missions. Vital Signs also provides real-time access to full field report datasets, allowing schools, homes, and other informal communities to monitor and analyze scientific datasets on their own and in real time
Socially distributed features	The Vital Signs environment employs social network features to share information directly between individual users and to support a community of practice made up of these individuals, including user profile pages and the ability for teachers, students, community members, scientists, and Vital Signs administrations to comment on submitted data artifacts
Objects of production	Individual submissions of species observations include field notes, written evidence, photographs and sketches, GPS coordinates, and other log data. This fluid data can be automated and organized in different ways and shared for different audiences and purposes by the technical system. Individual submissions can be presented as searchable multimedia web pages and printable PDFs. Aggregated data can be constructed into artifacts and knowledge that can be used to make progress on the field missions, including geographic information system (GIS) data maps, searchable and sortable by date, location, species, and other fields, as well as exports of datasets created by the community

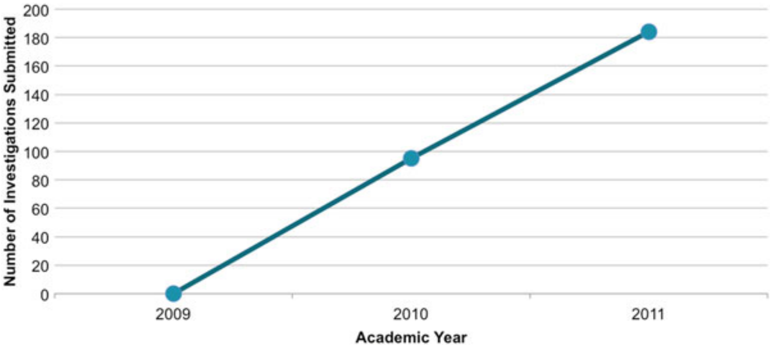


Fig. 1 Submissions across 3 years of participation

A Pathway to Sustained and Deepening Participation

In this analysis, we trace the multiyear journey from Mr. Paulson's first participation in a professional learning opportunity related to a local citizen science effort, to personal exploration as a participant in the citizen science community, to the challenging first experimental year doing this work in the classroom, to a refined and deepening classroom practice that moved from basic data collection to the defining of a place-based investigation with questions generated on the ground that evolved over two subsequent years. It was clear that the students benefited, as did the Vital Signs community. The number of submissions grew from zero in the first year to 184 in the third year (see Fig. 1). In the focal year of our research, the majority of Paulson's students reported taking Vital Signs knowledge and practice out of the classroom, with over two thirds of students (69.9 %) reporting that they looked at plants differently after in-depth investigations throughout the course of the year. We documented evidence of individual student learning opportunities originating from the Vital Signs work. Because our theoretical perspective foregrounds the situated and historically grounded nature of learning and because of our interest in how these environments can be better designed to support inquiry learning for both teachers and students, we developed a multidimensional methodological approach that included observations, interviews, student surveys, and the analysis of digital traces of communication.

We argue that four dimensions of Paulson's personal learning ecology contributed to his sustained and evolving participation: (1) alignment between the citizen science opportunity with his personal interests and teaching goals, (2) access to a networked community with curricular resources and a technical infrastructure, (3) an integrated indoor and outdoor classroom space that promoted place-based inquiry opportunities, and (4) a set of collaborative practices that created conditions for an expanding set of partnerships.

Alignment with Personal Interests and Teaching Goals

As Fischer (chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" 2016) notes, participation in mass collaboration efforts is voluntary and as such depends on the intrinsic value to volunteer through the experience of joint creativity, a sense of common purpose, and a sense of mutual support. For Mr. Paulson, a veteran science teacher of 31 years, we identified several sources of motivation including the alignment of the opportunities with deeply rooted personal preferences for the topics and forms of investigation as well as the perception that this project would help him achieve his teaching goals. Paulson was raised in the rural area of northern Maine near the Canadian border. Growing up, he spent a lot of time in nature on his own, frequently fishing and hunting, in addition to enthusiastically participating in school sports. He was interested in natural sciences from an early age and attributes some of this interest to opportunities to learn outside of the classroom. He remembers one science teacher in particular, Sister Madeline, who bravely went beyond the walls of the classroom to engage her learners in fieldwork. Paulson states,

> *The reason why I liked science is because I had a nun, Sister Madeline Marcet, and we had several nuns at our public schools way up in northern Maine. …Yeah. I'll never forget. She took us on a field trip to a bog, and when we got to see pitcher plants with bugs in them and the sundew—the carnivorous plants—like, "Holy cow," and we were walking on these bugs. I grew up there and spent a lot of time fishing and hunting and that sort of stuff, and I never ran—it is like, "Wow, this is cool."*

In high school in the mid-1970s, citing his interest in science and sports, Paulson wanted to be a teacher and a coach, but his school guidance counselor "talked [him] out of it" due to the low salary expectations. Paulson chose to focus on the ecological and biological sciences, majoring in natural resource management at the University of Maine, but only "because I liked science" as opposed to having a clear science career trajectory in mind. After graduation, finding himself without a job, he took summer classes to get his science teaching certificate. He started teaching high school science and math and then moved to Barberry, where he has been teaching middle school science for 18 years.

Paulson has had a long-standing interest in inquiry-based projects and noted the difficulties doing and sustaining this type of work in public K-12 school environments.

> *[Mostly around here] it is Betty Crocker science. There is step A, B, C, and it has to come out this way, and there is your science, which is not really science. Science is all about not knowing what is going to happen. …Unfortunately, at our school here, we've got standards, and they are on the board—these learning types, these really specific little snippets and in there, there is nothing about inquiry. There is nothing about it. It bothers me to no end, because we used to have some of that stuff, and it's been taken out because it is so hard to assess.*

Paulson's interest in local invasive species was sparked shortly before he heard about the Vital Signs program. In the fall of 2008, he attended a conference of the National Science Teachers Association (NSTA) held in New England, where the topic of invasive species came to the forefront as a locally relevant environmental challenge.

> *This area is very invasive species. It is like ground zero—milfoil, hydrillas, and other plants in our district towns—yeah, real bad stuff. When I started teaching here, there were no invasive lake plants. …I've been teaching for 18 years or whatever, so halfway through—not that long ago—there weren't any. I remember going to a [science teachers] conference and hearing about it. That was the big buzz, invasive aquatic plants. …I'll never forget, he says, "You can't really stop it. You just detect early and you try to control it." Those words—[I was] like, Holy cow, really?*

That spring, Paulson heard about Vital Signs, a new inquiry-based citizen science opportunity through an e-mail from a regional science teacher listserv, and he immediately followed up. His interest peaked; he attended the free 2-week training session during the summer of 2009, enthusiastic about the opportunity to connect his interests in inquiry-based teaching and fieldwork with a compelling problem relevant to the local community.

Access to a Networked Community with Curricular Resources and a Technical Infrastructure

Current perspectives on teaching frame teacher learning as an ongoing intellectual pursuit that benefits from professional development that is aligned with curriculum (Darling-Hammond, 1998; Putnam & Borko, 2000). Fischer (chapter "Exploring, Understanding, and Designing Innovative Socio-Technical Environments for Fostering and Supporting Mass Collaboration" 2016) identifies the benefits of access to systems that provide modular activities that are temporally and geographically distributed, and these elements are especially relevant to connecting classrooms.

In addition to being aligned with Paulson's prior interests, the technical infrastructure, associated curricular support, and professional development opportunities were critical to his engagement. The Vital Signs program was designed to reach students around the state by leveraging Maine's unique one-to-one laptop program[2] and to share collected data directly with the science community. Curriculum and related resources for educators, such as how-to guides, printable species identification cards, field note templates, and assessment rubrics, are freely distributed through the educator tools section of the Vital Signs site. Educators are encouraged to submit their own contributions to this database through a forum. The program offers free professional development sessions for participating teachers, both through webinar sessions and in-person institutes. At the time of our research, 177 educators had been trained in the Vital Signs program, and the website reported over 23,000 visitors each year and over 2500 active accounts.

---

[2] Since 2002, the state of Maine, as a result of the Maine Learning Technology Initiative, has had a program that equips every middle school student with his or her own laptop computer for use at school and home, and all schools are equipped with high-speed wireless networks, technical assistance, and access to Department of Education-sponsored professional development.

During the Vital Signs classroom unit, students go into the field as a class or on their own and use digital cameras and GPS receivers to monitor freshwater, upland, and coastal ecosystems for native and invasive species. The freely accessible website and online tools, including geospatial mapping, discussion forums, and databases of submitted work (http://vitalsignsme.org), are designed to help students organize and analyze the data collected in the field and to help teachers share curriculum materials and best practices. Website visitors can access information about particular species and field methods, visualize data on interactive maps, query and export data for graphical or numerical analysis, or incorporate it into GIS layers for spatial analysis. Participants can communicate with experts and share their growing expertise publicly through comments and discussion. Scientists in Maine, who have agreed to be "species experts," are responsible for confirming or questioning student submissions. The Vital Signs experience has been designed to give novices a chance to learn science through active participation in practice—asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, and engaging in argument from evidence. There are no time constraints, allowing participants to contribute on their own schedules as individuals and classrooms conduct local work.

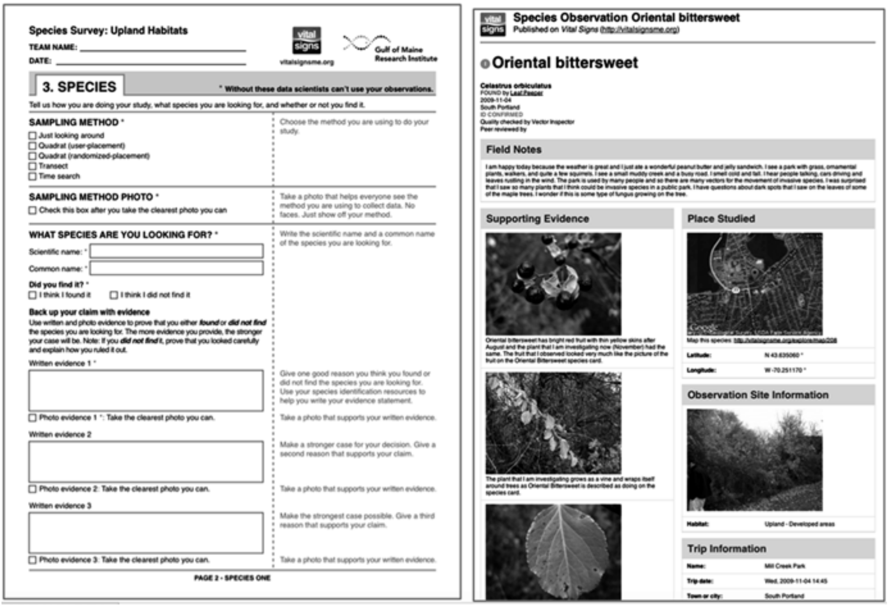
The fall following his initial summer training, Paulson carried out the Vital Signs program in his classrooms. The three basic steps to participation, as per the Vital Signs website, are to choose a mission, go look for species, and publish your data online (see Fig. 2). Paulson chose an existing Vital Signs mission with the research question: "How is purple loosestrife [*Lythrum salicaria*] affecting biodiversity in Maine?" Over a span of a few weeks, Paulson and his students went out on the school grounds to find a possible culprit and gather evidence and then worked in the classroom to figure out if their documented species were or were not purple loosestrife and submitted their observations to Vital Signs (Fig. 3). Many challenges that have been documented in the literature shared earlier were faced during this first year of implementation, including managing an entire class of students outside the walls of the classroom, ensuring completed and accurate evidence, and finding time for inquiry-driven practice—especially given weather uncertainties and the requirements of a standards-based curriculum.

1. Choose a Mission
2. Go look for species
3. Publish your data online

- Where have species been found?
- How are they changing over time?
- Is your lake at risk?

- Make a video, blog, more!
- Best projects
- Connect with the community

Fig. 2 The primary components of the Vital Signs site, accessible from the home page



Species Survey: Upland Habitats

TEAM NAME: ______________________

DATE: ______________________

vitalsignsme.org

Gulf of Maine Research Institute

3. SPECIES * Without these data scientists can't use your observations.

Tell us how you are doing your study, what species you are looking for, and whether or not you find it.

SAMPLING METHOD *

☐ Just looking around
☐ Quadrat (user-placement)
☐ Quadrat (randomized-placement)
☐ Transect
☐ Time search

Choose the method you are using to do your study.

SAMPLING METHOD PHOTO *

☐ Check this box after you take the clearest photo you can

Take a photo that helps everyone see the method you are using to collect data. No faces. Just show off your method.

WHAT SPECIES ARE YOU LOOKING FOR? *

Scientific name: *

Common name: *

Write the scientific name and a common name of the species you are looking for.

Did you find it? *

☐ I think I found it ☐ I think I did not find it

Back up your claim with evidence

Use written and photo evidence to prove that you either ***found*** or ***did not find*** the species you are looking for. The more evidence you provide, the stronger your case will be. Note: If you ***did not find*** it, prove that you looked carefully and explain how you ruled it out.

Written evidence 1 *

Give one good reason you think you found or did not find the species you are looking for. Use your species identification resources to help you write your evidence statement.

☐ Photo evidence 1 *: Take the clearest photo you can.

Take a photo that supports your written evidence.

Written evidence 2

Make a stronger case for your decision. Give a second reason that supports your claim.

☐ Photo evidence 2: Take the clearest photo you can.

Take a photo that supports your written evidence.

Written evidence 3

Make the strongest case possible. Give a third reason that supports your claim.

☐ Photo evidence 3: Take the clearest photo you can.

Take a photo that supports your written evidence.

PAGE 2 - SPECIES ONE

Species Observation Oriental bittersweet

Published on *Vital Signs* (http://vitalsignsme.org)

Oriental bittersweet

Celastrus orbiculatus
FOUND by Leaf Peeper
2009-11-04
South Portland
ID CONFIRMED
Quality checked by Vector Inspector
Peer reviewed by

Field Notes

I am happy today because the weather is great and I just ate a wonderful peanut butter and jelly sandwich. I see a park with grass, ornamental plants, walkers, and quite a few squirrels. I see a small muddy creek and a busy road. I smell cold and fall. I hear people talking, cars driving and leaves rustling in the wind. The park is used by many people and so there are many vectors for the movement of invasive species. I was surprised that I saw so many plants that I think could be invasive species in a public park. I have questions about dark spots that I saw on the leaves of some of the maple trees. I wonder if this is some type of fungus growing on the tree.

Supporting Evidence

Oriental bittersweet has bright red fruit with thin yellow skins after August and the plant that I am investigating now (November) had the same. The fruit that I observed looked very much like the picture of the fruit on the Oriental Bittersweet species card.

The plant that I am investigating grows as a vine and wraps itself around trees as Oriental Bittersweet is described as doing on the species card.

Place Studied

Map this species: http://vitalsignsme.org/explore/map/208

Latitude:	N 43.635060 °
Longitude:	W -70.251170 °

Observation Site Information

Habitat:	Upland - Developed areas

Trip Information

Name:	Mill Creek Park
Trip date:	Wed, 2009-11-04 14:45
Town or city:	South Portland

Fig. 3 An example of the investigation submission worksheet on the left and a final published investigation that has been confirmed on the right

> *The first investigation that I did here—I really wasn't prepared. I had gone to the institute. I may not have paid attention as much as I should have. I thought, "Well, I will just try it and see what happens."*

Paulson remembers that first year of investigations (2009–2010) being "like a freaking nightmare." When students submitted their investigations to Vital Signs, all had errors in their global positioning coordinates, and as Paulson was unsure how to fix them, none accurately appear in the online species database. However, he had the feeling that he was onto something and focused on improving his own literacy and understanding of the process. That spring, he participated in a Vital Signs refresher professional development institute. Then, as they did every summer, Paulson and his family traveled 5 hours north to their "camp" near the Canadian border. During that summer—on his own vacation time—he conducted six of his own investigations and submitted them to the Vital Signs site. This was a critical opportunity for him to better understand the process for collecting data and reporting evidence as well as for refining his observational skills.

> *I decided, at the end of that year, that it was going to be worth the while to get out again, and so I spent a summer making mistakes in northern Maine doing my own investigations. I found a few of the loosestrifes that ended up not being loosestrife, but submitted it as such [and it was questioned on the site] but I show my kids that. I say, "Look, I made mistakes." I found giant hogweed also up there, which wasn't true, but it sure looked like something. I made mistakes, but I learned a lot about looking closely and all that sort of stuff and using the equipment and the cameras and all of that stuff.*

His summertime participation as a solo citizen scientist had an effect on both his own learning and his teaching. He developed more confidence as a guide, and he was able to share his own stories of making mistakes with his students, positioning them to think of themselves as developing participants who would become better citizen scientists over time and with experience. The following academic year (2010–2011), he implemented three cycles of Vital Signs in his classes.

An Integrated Indoor and Outdoor Classroom Space That Promoted Place-Based Inquiry Opportunities

The role of access to a physical space that allows for participation in monitoring and stewardship of a specific region has been acknowledged in recent discussions of potential synergies between citizen science and environmental education (Wals, Brody, Dillon, & Stevenson, 2014). It was a critical condition for Paulson. The Barberry middle school building was located in a flat marshy area near a pond. A mile-long driveway looped around the school building and connected the vast parking lot to the public roads, a quarter-mile away. One side of the school grounds was made into sports fields, while the other areas were left relatively wild. Paulson's second floor classroom windows looked out over the parking lot into this wetland. Paulson recognized the potential of the location, and he applied for and received a grant from Project Learning Tree, a nonprofit environmental literacy organization, to create trails around the pond near the school and purchase a picnic table and benches. He began to use this outdoor classroom space to monitor invasive species, and it was a perfect fit with the resources and structure provided by the Vital Signs project. Paulson and his students were able to do multiple-day observations, go back into the field if they needed additional data, and reschedule their outings if weather was not cooperating (Fig. 4). The immediate proximity of their investigative space provided pressing questions that were relevant to their school population, narratives

Fig. 4 Paulson on the school grounds with his students doing field observations and using the purchased picnic tables to organize and document what they saw

Fig. 5 Images of Paulson's classroom

for inquiry that unfolded over multiple years. In the regular classroom, an extension of the investigation space, the students accessed their computers to organize, analyze, and submit their data.

Paulson's indoor classroom was cluttered with the immediate work of science and teaching. His desk held piles of papers, folders, and books. The lab counters that extended from two walls of his corner classroom were similarly occupied, with field guides, plant and bug specimens, potted plants, microscopes, and various student works. Individual student desks were organized in five clusters of four or five desks facing inward toward each other. Mobiles of birds and branches hung from the ceiling, and the floor along the edges of the classroom was strewn with equipment from recent outdoor field trips, including quadrats, fishing waders, and student boots of every size and color (Fig. 5).

The second year (2010–2011), Paulson led his students through two back-to-back fall investigations on the school grounds and another in the spring around their homes. He again used the Vital Signs mission about the spread of purple loosestrife, and 95 student investigations were successfully submitted to the Vital Signs site. One of these submissions reported finding the invasive plant on campus, which was confirmed by Vital Signs scientists. Students also found *Galerucella* beetles on the plant, an insect introduced in North America as a biological control agent for purple loosestrife. Paulson and his students had to decide what to do next, given this local knowledge. They decided not to pull up the plant, thinking the beetles could more naturally contain the spread. This dilemma led Paulson to develop a compelling local mission, and he published it to the Vital Signs site: "Is purple loosestrife spreading on the Barberry Middle School campus? Are *Galerucella* beetles or Japanese beetles keeping it in check?"

> *We've got to see if [loosestrife] is spreading, and so we go out. [The students] already have their mission. They already know why it is important. They've got kids at the high school wondering about their work and that sort of a thing, and so there is a real purpose. There is a real mission, and so they take it fairly seriously—one would hope.*

During the third year (2011–2012), Paulson's students participated in this new localized mission. Paulson planned to monitor the field near the school for the next

10 years by investigating permanent quadrants to count loosestrife and measure their height and other dimensions of growth. That year, Paulson created another mission on Vital Signs. Not only did he want to monitor the spread of the invasive species found on campus, but also wanted to formally document every species, invasive and native, found on school grounds and the surrounding areas of students' homes (covering six townships and over 260 mile^2), broadening the scope of the work to the larger district. The students that year did three separate cycles of Vital Signs investigations, two in the fall and one in the spring, and also carried out investigations in the winter months submitting to Project Noah, another online citizen science networked project.

In his fourth year of implementation (2012–2013), Paulson revised his loosestrife mission, devising an experimental approach, "Student scientists at Barberry Middle School have observed an apparent balance of invasive *Lythrum salicaria* [purple loosestrife] and non-native *Galerucella* beetles on their school grounds. Can they replicate this balance on a larger scale by introducing *Galerucella* to a larger site where loosestrife is spreading?" They planned to document the growth of the existing loosestrife plants found on campus to date and any new species of plant or beetle. They then planned to raise beetles on campus to release into the local environment and to monitor change over time of the beetles and plants. The project was envisioned as unfolding inquiry-based work that would be passed from one seventh-grade cohort to the next.

A Set of Collaborative Practices That Created Conditions for an Expanding Set of Partnerships

Collegial communities can motivate engagement and participation. This is evident in online mass collaborative environments (Chapter "Mass Collaboration as Co-Evolution of Cognitive and Social Systems" by Cress et al., 2016), citizen science programs (Shirk et al., 2012), and face-to-face learning environments such as professional development opportunities. Cress et al. (Chapter "Mass Collaboration as Co-Evolution of Cognitive and Social Systems" 2016) identify how different participant roles in a mass collaboration system influence ways of aggregating and vetting information. Specifically, while some spaces lead to building new knowledge as a shared collective, others are driven by more dominating administrators or moderators with a preconceived outcome of the shared user space.

Opportunities for collaboration with others with shared scientific and educational interests were important in sustaining and deepening Paulson's engagement. These partnerships supported him through a set of challenges that remained a part of implementation of Vital Signs even after that initial year. Although school began at the end of August, logistical issues resulted in students often receiving their school-issued laptops late in the fall, after they had done the outdoor investigations. Without laptops in the classroom, students could not look at and organize photographs, type up field notes, or submit their evidence, often leading to investigations submitted weeks after they were conducted, when the class had moved on to another topic or investigation, causing students to backtrack. Weather was another barrier, as many trees and plants begin to lose their leaves and other identifying features such as flowers, soon after school begins in the fall. Mapping classwork directly to required science standards, ensuring that all standards were covered, and finding ways to assess a project that was repeated throughout the year were yet other issues.

We were interested to know more about how Paulson persisted in this difficult but rewarding work. We found that in a rural school with only three science teachers, Paulson expanded his own professional science education network. He was incredibly active in securing resources for his teaching practice and developing strong science-oriented relationships with the larger scientific community around Vital Signs, including a local university science mentoring program and Vital Signs program staff.

To understand how he engaged in and sustained collaborative practices that supported his own work in the classroom and his individual professional identity as a science teacher, we observed students in the classroom, collected artifact and log data from the Vital Signs platform (student work, commenting, forum use, downloads, and submissions), and had ongoing dialogue with the site designers and Vital Signs staff. We also looked closely at e-mail correspondence between Paulson and the Vital Signs staff.[3] Although this is not a complete dataset of either their history (we know staff and teacher were in communication for over one year prior to our research) or even the extent of communications during that year, it contributes a uniquely detailed look at the nature of the interactions between the teacher and the program staff.

A coding scheme was developed to reveal patterns in e-mail exchanges related to science-related learning and teaching interactions. We identified four practices that Paulson engaged in to further his own learning and teaching practice and to expand the learning experiences of his students: recruiting collaborators, sharing networked learning resources, showcasing student work, and reporting from the field. Definitions and examples are presented in Table 2.

Recruiting collaborators. After that first difficult year, Paulson found a National Science Foundation-supported program, SPARTACUS (Systemic PARTnership Aimed at Connecting University and School), through the local science teaching listserv where he found out about Vital Signs.

> *They were looking for teachers in the Sallum River watershed who work on place based work. It seemed to fit in well with my newly discovered Vital Signs citizen science opportunity so with Vital Signs on my application, I was accepted. It was the perfect storm of place-based opportunities.*

Paulson secured 4 years of weekly classroom support from a graduate student in biological sciences. In addition to providing another adult for outdoor trips, the fellows shared knowledge and resources with Paulson and his students including tools such as GPS devices and water quality monitors, current scientific knowledge and practices from their particular area of study, resources and ideas from the field, and

---

[3] Our dataset included 22 e-mails, eight from the Vital Signs staff (primarily the project coordinator, who also ran the professional development and developed most of the curriculum) to Paulson and 14 from Paulson to the Vital Signs staff. We coded 41 unique segments of these e-mails that represented collaborative practices, 29 from Paulson and 12 from the Vital Signs staff.

Table 2 Categories of collaborative practices

Practice	Description	Examples
Recruiting collaborators	Offering or suggesting a new opportunity for learning and participation in science-related activities. This included the cocreation of new or revised teaching materials	[Tch → VS] My principal has been bugging me for years to present at NELMS (New England League of Middle Schools…I think). … Anyway, I may well do something this year. I have no details. Would VS be willing to work with me on this?
Sharing networked learning resources	Providing information about science learning and teaching resources. These exchanges brokered new information relevant to specific Vital Signs project work and science learning more generally, often including direct links	[Tch → VS] There was a brief CBS News clip on a major rediscovery. It just falls into place with all the tree of life work and all the classification/identification work we have done here. http://www.cbsnews.com/8301-18563_162-57361530/charles-darwin-collection-found-165-years-later/
Showcasing student work	Recruiting and broadening audience and opportunities for youth work related to the project efforts, including linking directly to student work and suggesting opportunities for students to share work	[Tch → VS] Just had my first few kids submit to Project Noah. Our mission is called Barberry Biodiversity Mission. They are submitting fungi (yes they are) and so far so good. Check some out if you have a minute. There will be several more tomorrow. [link]
Reporting from the field	Telling stories from field-related project work, including challenges, successes, and the descriptive unfolding of stories over time as the project is implemented in an actual classroom environment. This type of exchange also included affirmations of contributions	[Tch → VS] An update on woolly adelgid on campus. We sent a sample in and Akanoti confirmed that it was not. It was great to get the feedback from the expert. I have to comment on the submissions from the two students to let them know … I'll keep you posted

their own experiences choosing science as a career. The fellow in Paulson's classroom during the focal year of our research was a young woman getting her master's degree in the department of marine sciences whose area of focus was the distribution of mussels in the region.

Beyond his collaboration with the graduate students, in e-mails with Vital Signs staff recruiting collaborators meant Paulson frequently sought informal feedback on his ideas in the classroom, often laying out an extensive plan, followed by, "What do you think?" Other times he directly requested social and material resources, including asking Vital Signs staff to confirm/question some of his student's work from the previous year that had gone unchecked. Paulson also invited the staff to copresent at a local science teacher related conference. Simultaneously, the Vital Signs staff invited Paulson to participate in a number of learning opportunities, including being part of our research initiative, copresenting the Vital Signs program at another local conference geared toward science teaching and professional development, and publishing his projects and teaching materials to the educator database on Vital Signs. The e-mail exchanges showed one instance of a cocreation interaction, revolving around the development of rubrics to evaluate youth learning and collaboration during the Vital Signs work (see Field Story 1).

Field Story 1: Collaborative Development of Vital Signs Learning Rubrics
In mid-October, Paulson reached out to the Vital Signs staff, sending them two rubrics for assessment of student work and asking for their contributions, "Any ideas, feedback would be much appreciated. This is the first draft, so feel free to tear it apart." Within one day, Paulson received an e-mail back including general encouragement, links to resources on the Vital Signs site, and specific suggestions for revision. The Vital Signs project coordinator also asked for his advice on their idea to create a rubric to assess Vital Signs collaboration in the classroom. Paulson responded immediately, clarifying his thinking about his own tools and sharing enthusiasm for the potential collaboration rubric.

The story continued a few months later when Vital Signs asked their teacher community to share any rubric ideas on the online teacher forum in order to develop a master rubric for Vital Signs "incorporating elements of [Maine Learning Standards], Next Gen Science Standards, deep learning, and more!" The Vital Signs staff initiated the forum with the work Paulson had submitted that fall. The next day, Paulson wrote to say that he was looking forward to seeing and using their final product and added his own perspective from the field.

> *There is always the tendency to try to measure too much. There are so many good things in a VS submission so we will try to measure everything. As a result, the rubric becomes wordy, complex and unmanageable. This happens over and over with rubrics I've created and others I've used over the years, including the VS rubrics I made.*

These exchanges reveal the reciprocal nature of the collaboration, where the Vital Signs staff gained a user perspective from a participating classroom, and Paulson received opportunities, information and connections to expert networks that he engaged for his own professional growth as well as connecting these things directly to the classroom.

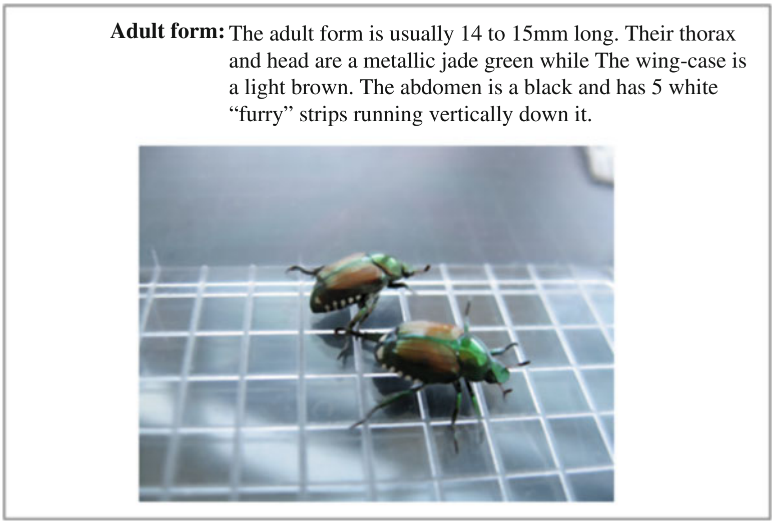
Sharing networked learning resources. E-mail exchanges between Paulson and Vital Signs staff sometimes brokered new information relevant to the Vital Signs project and science learning more generally. In one instance, Paulson shares a 60-min video clip about mushrooms, with the idea of investigating and identifying fungus species during the winter months. Fungus was not supported by expert scientists or by resource materials on the Vital Signs site. Vital Signs staff responded to Paulson suggesting that he use Project Noah, a web-based international citizen science community with less regulated submission requirements and a larger community presence for questioning, commenting, and identification. On the site, people from all over the world upload species photos to explore and document wildlife. The site allowed Paulson and his students to broaden their species investigations throughout the school year, implementing the Vital Signs practices in the Project Noah environment.

> *What I was thinking was, wouldn't it be cool to have a national and or international invasive species mission of some kind on Project Noah? Vital Signs has so much to share with all the data collected in our region. It would be great to have a site that would be a place to submit and compile data from other regions on global invasive species. This would also provide a more scientific model for Project Noah as well.*

Showcasing student work. Both the teacher and the Vital Signs staff used their e-mail exchanges to broker opportunities for youth. Paulson created opportunities for his students' work to be seen more broadly by sending project documents or links to their creations, even when that work was outside the scope of Vital Signs (e.g., sending links to student work on Project Noah). The Vital Signs staff did this by sending the teacher links to the work of other classrooms and also offering new publishing opportunities for the students. In Field Stories 2 and 3, we illustrate the new experiences gained by two of Paulson's students from their participation in Vital Signs coupled with the opportunities set up for sharing their work with a broader audience arranged by Paulson and the Vital Signs staff.

Field Story 2: Positioning Student Authorship of Field Guide Resources

Naomi, an eighth grader, had been observing and collecting bugs since she was a little girl making a snail zoo in her backyard. By eighth grade, she was systematically mounting different bug specimens for her collection and raised live bugs, sometimes putting a dot of nail polish on their backs and letting them free to track their movements around her house. During Vital Signs in seventh grade, her observation for the invasive purple loosestrife plant included information about and drawings of Japanese beetles, which her team found on their plant. She expressed frustration with the fact that the Vital Signs website did not include a species card for the bug. Mr. Paulson, recognizing her love of the entomological world, e-mailed the Vital Signs program coordinator to tell her about Naomi. Together the adults arranged for Naomi to create the Vital Signs species ID card for the Japanese beetle. With support from Paulson and the Vital Signs staff recommending revisions, Naomi completed the formal Vital Signs species ID card. The online artifact credits Naomi and includes her research, writing, and macrophotographs (see Fig. 6).



Adult form: The adult form is usually 14 to 15mm long. Their thorax and head are a metallic jade green while The wing-case is a light brown. The abdomen is a black and has 5 white “furry” strips running vertically down it.

Fig. 6 Field guide resource

Field Story 3: Showcasing Civically Engaged Citizen Science Efforts

At the beginning of December, Paulson had an idea to connect the invasive species content activities in the classroom with broader community awareness. He hatched a plan to invite his students to participate. In a note to Vital Signs, he wrote:

> *We have a good friend who has been giving us Christmas wreaths as gifts for years. The unfortunate thing is that some of the “berries” she has attached over the years must have included multiflora rose hips, as I have a hardy plant growing near my front door. …My guess is the public is really unaware of how many invasive plants may be spread by the “berries” this time of year. No offense to VS, but I am not sure how many Martha Stewarts regularly monitor Vital Signs submissions. The word about this seasonal spread of invasive species needs to get out (again). I was wondering if a few of my smarty pants Language Artsy kids would do a write up or presentation of some sort on the perils of invasive species spreading through the holidays, do you think there would be a media source of some sort that could pick it up (newspaper? TV)?*

Before the winter break, one of his students, Enid, took up Paulson’s challenge and drafted a letter to the local paper. In her letter, Enid mentioned the Vital Signs project, encouraging readers to go there to learn more. Paulson helped Enid edit and send the letter and he shared her efforts with Vital Signs staff. Her activities went above and beyond the required work, including doing research to identify her species at home and using free time in her literacy classes to dive into local field guides. When the letter was published, Paulson shared the link with Vital Signs staff, who posted it to their site where it was featured throughout the winter. That letter led to further civic learning opportunities for Enid–an invitation to be a “page for a day” at the state capitol building for a state legislator who was impressed with her call to action.

Reporting from the field. Paulson often used e-mail to illustrate in great detail how Vital Signs was unfolding in his classroom, his plans for classroom implementations in the future, perceptions of students, and his own personal learning and opportunities. These e-mail excerpts, which were the longest of the different segments we collected, sometimes spanning paragraphs, kept Vital Signs aware of the work that Paulson was doing, offering a unique window into classroom user experiences with their curriculum and online environment, and allowed them to jump in when there was a synergistic connection or opportunity that they knew about.

In conjunction with these stories were often compliments about the work being done from both sides. Paulson thanked the staff members at Vital Signs for creating and maintaining a program that offered learning opportunities to students in his classes that they did not have elsewhere. One example was letting them know that the program provided an outlet to showcase student artistic talents through field sketches and evidence photography, in a school where the art program had recently been cut. Another shared how Vital Signs influenced individual students to develop a scientific eye, "I had a great year doing tons of field work and getting kids to look closer at the stuff most people don't even notice. I had fun and so did the kids. Thanks VS."

The Vital Signs staff acknowledged Paulson's contributions as well, both in terms of the Vital Signs work in particular ("Your rubrics make me really happy. *REALLY*. I especially love that you have sections on evidence and use of scientific vocabulary") and his work in the classroom ("Thanks for putting so much time and energy and care into how and what your students are learning"). The Vital Signs staff also marked instances when they followed Paulson's links and checked out the work done by him and his students, often in response to his initial prompts for audience. This acknowledgment is important in the case of online audiences, for although publishing on the Internet means that work is presented widely, the author is often not aware of who is looking at it.

In summary, Paulson's personal interests and teaching goals, access to networks and resources, an integrated indoor/outdoor place-based inquiry space, and collaborative partnerships supported his deepened engagement in a citizen science program like Vital Signs over multiple years. It is through this expanded analysis of Paulson's actions and interests that we gain a more nuanced understanding of what it takes to realize and develop an ongoing inquiry-based learning opportunity in the classroom.

Discussion

Citizen science is a powerful and growing form of mass collaboration. Additionally, there is significant potential for citizen science projects to advance inquiry-oriented science education. At the same time, a recent essay that describes the state of the field calls for a redesigned future of citizen science (Mueller & Tippins, 2012).

There is a call to design programs that enable participants to collect rigorous and reliable data, using contemporary tools such as digital photographs and GPS devices while supporting participants to be more involved with the larger project at hand, asking their own questions, connecting the work and data to their own environments and community, and using that data to make a difference. Related to that call is the need for scientists and designers of platforms to recognize and incorporate the local knowledge, expertise, and practice of the participants (Calabrese-Barton, 2012; Haywood, 2014), which aligns with the recognition of funds of knowledge (Bang & Medin, 2010; Moll, Amanti, Neff, & González, 1992) identified in The Next Generation Science Standards (NGSS Lead States, 2013). Making more rigorous citizen science platforms for both ordinary citizens and students in schools has the potential to nurture effective spaces for mass collaboration where participants can share their scientific knowledge and background and contribute to scientific advancements. Engaging young people in these opportunities positions future generations as contributors to local and global issues, understanding their individual role in mass collaborative efforts using evolving technological supports. From efforts in schools and districts across the state of Maine working to understand and monitor the spread of invasive species to people all over the world watching their patch of the night sky to continue the search for intelligent life in our galaxy and beyond, citizen science as a form of mass collaboration is poised for increasing areas of impact.

At the same time, there are issues of quality and reliability of the resulting data and artifacts without serious data quality monitoring, especially recruiting novices and students who are required to do this work and whose training on collecting quality data will differ from classroom to classroom. Also, true mass collaboration is a shared problem space, where participants return to data and results and come up with ways to understand and act accordingly. In classrooms, there are cycles of participation tied to the academic year, and then users move on to their next classroom. How can we retain participation in these online environments after the classroom requirements are complete? How can we encourage classrooms to become engaged not only in the contribution of data points but also in the development of questions and the process of analysis?

The research reported in this chapter confirms the importance of connecting to local knowledge and place, expecting engagement to deepen with time and expertise. It also highlights the importance of access to professional development opportunities, curricular resources, and a stable technical infrastructure. Taking a learning ecologies perspective, we foregrounded both teacher practices that sustained learning and the technical and social citizen science infrastructure that led to collaborative partnerships and provided opportunities for student contributions. Our case portrait shows the utility of a multidimensional analytic framework that can help conceptualize the forms and functions of diverse learning resources that contribute to continued engagement within a community-based citizen science project. This kind of research is important now as citizen science projects become more prevalent and organizers become increasingly interested in recruiting teachers and learners as participants. It also contributes to broader conceptualizations of teacher learning that have begun to differentiate formal professional development opportunities from workplace learning opportunities and to articulate the interrelationships between them and changing teacher practice over time (Parise & Spillane, 2010). We close with several ideas for future work that can advance theory, design, and practice.

First, more attention is needed specifically on how teachers construct their own learning outside of school and how citizen science opportunities specifically might support the intellectual work within broader patterns of personalized learning. Strong links between life history and professional thought and action are documented (Butt & Raymond, 1989; Butt, Raymond, McCue, & Yamagishi, 1992; Powell, 1992, 1996; Goodson, 1992; Pajak & Blase, 1989). In studies where researchers co-constructed biographical narratives with teachers, formal teacher education was rarely mentioned; influences were more often related to significant experiences in their life outside of school, including family relationships (Butt, 1984; Fickel, 1999). Teachers' own personal and professional histories are increasingly thought to play an important role in determining what they learn from professional development opportunities (Ball, 1996). However, little is known about how informal teacher learning relates to organized professional development or how they impact teacher practice and student learning and engagement or how to study this. The little research there is about teacher content interest and engagement suggests a positive correlation between teacher and student interest in core topics (Long, 2003). To advance the design of networked communities, there is a need to know more about how teachers learn from the resources and social networks that are available to them, how their own interest and engagement are sparked and fostered, and how they mediate through the opportunities that are offered to them in formal and informal settings, as they move through their life pathway as learners.

Second, to better understand a broader range of teachers and how they engage in citizen science programs, we need to develop new research design and tools that can collect both quantitative and qualitative data. While distributed teachers, scientists, volunteers, and students provide an opportunity to study learning and engagement across large numbers of diverse participants, the quality and type of data that might be collected are somewhat limited. Survey studies have been developed to try and collect systematic data from larger samples (Bonney et al., 2009), but there are many indications that we need more refined measures, tools, and research designs to capture outcomes and theorize practices. Learning analytics and data mining offer opportunities for analysis of log data, but in order to look at results, we must understand what forms of data to collect and have the permission to do so and transparency about what we are asking participants to share. For example, given our assumption that it is typically not one experience that is transformative for a learner's expertise or interest, we need longitudinal studies of engagement in citizen science that include varied experiences, peer and mentor partnerships, and resources that combine to sustain participation. Pathway stories from large numbers of participants both in particular citizen science programs and over time and across experiences would be useful in advancing our theoretical understanding of teacher learning and the role of resources that can be provided through online socio-technical systems.

Third, we need to understand more about local spaces and how inquiry in educational settings function and why. A significant resource for Mr. Paulson was the capacity to have integrated outdoor classroom space that could be revisited easily and over years. In the field of environmental education, researchers have sought to articulate peoples' relationships to their local environments and how these relationships are consequential for actions that protect or harm them at local, regional, or global scales. This is a critical issue given the increasing vulnerability of natural resources to human behavior and the need to find ways to cultivate a sense of stewardship and agency within communities. One construct that has drawn interest in this field is "sense of place," defined in terms of a connection to local geography with emotional, cognitive, and behavioral components (Ardoin, Schuh, & Gould, 2012; Haywood, 2014). What are the implications for urban schools? Although some schools are starting to build garden plots on campus, what other types of outdoor laboratories can we imagine that could be aligned with citizen science projects? And what kind of citizen science projects can we design for a broader range of environments, linking to global ecological systems?

Fourth, we need to know more about the practices and opportunities for teacher collaboration. A willingness and facility to collaborate may be a large part of the learning process for teachers to develop expertise in their field, as they work closely with other teachers, administrators, and students each and every day (Parise & Spillane, 2010). Some teachers see their role as being part of a larger, collaborative, professional community where colleagues help each other become more successful and make efforts to improve educational practice in other places (Glazer, 1999). According to Glazer, teachers who espouse a more collaborative stance toward the profession are more likely to build a professional identity than those who engage in more private practice. Building on the work of Gutierrez and Rogoff (2003), Barron et al. (2009) describe how people develop repertoires of collaborative practice, ways of engaging in collaborative activities that they draw upon when they encounter a new collaborative situation. These repertoires are developed through prior experiences collaborating and feedback in those situations about what is effective or problematic. Implementation of specific practices is strongly influenced by the context, the different collaborators, and the cultural affordances of the community in which the episode occurs. More research needs to be done on whether teachers see the classroom and professional development opportunities as collaborative spaces where they have agency to develop and use repertoires of collaborative practices with colleagues to improve their practice.

In closing, the authors of the 2011 report "Successful K-12 STEM Education: Identifying effective approaches in science, technology, engineering, and mathematics" suggest that excellent inquiry-based science teaching, the kind that sparks important outcomes such as student interest, is not the norm. Instead, they venture that this type of teaching happens with singular teachers in rogue classrooms—"It is typically facilitated by extraordinary teachers who overcome a variety of challenges that stand between vision and reality" (NRC, 2011, p. 19). In this chapter, we chose to focus on one such highly engaged teacher and the evolution of his citizen science practice over years to inform a conceptual framework that can be used in future research to guide new forms of professional development, resources for learning, and studies with bigger sample sizes. We see much potential in citizen science as a form of mass collaboration that can help bridge the gap between vision and reality for many more teachers. There is much work to do and great possibilities for doing it if we can recruit the collective efforts of interdisciplinary groups of researchers, educators, scientists, and designers. Let's do it!

Acknowledgment This work is supported by the National Science Foundation Cyberlearning program (Grant REC-1124568) and Learning in Informal and Formal Environments Science of Learning Center, a National Science Foundation-funded (Grant REC-354453) effort seeking to understand and advance human learning through a simultaneous focus on implicit, informal, and formal learning, thus cultivating generalizable interdisciplinary theories that can guide the design of effective new technologies and learning environments. We also acknowledge and thank "Mr. Paulson," the Vital Signs staff members, and the other teachers, students, and parents who contributed their time and invaluable expertise and ideas to this work.

References

Ardoin, N. M., Schuh, J. S., & Gould, R. (2012). Exploring the dimensions of place: A confirmatory factor analysis of data from three ecoregional sites. *Environmental Education Research, 18*, 583–607.

Azevedo, F. S. (2013). The tailored practice of hobbies and its implication for the design of interest-driven learning environments. *Journal of the Learning Sciences, 22*, 462–510.

Ball, D. L. (1996). Teacher learning and the mathematics reforms: What do we think we know and what do we need to learn? *Phi Delta Kappan, 77*, 500–508.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*, 1008–1026.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development, 49*, 193.

Barron, B., Gomez, K., Pinkard, N., & Martin, C. K. (2014). *The digital youth network: Cultivating digital media citizenship in urban communities*. Cambridge, MA: MIT Press.

Barron, B., Martin, C. K., Mercier, E., Pea, R., Steinbock, D., Walter, S., … Tyson, K. (2009, June). Repertoires of collaborative practice: Theoretical introduction and background. In C. O'Malley, D. D. Suthers, P. Reimann & A. Dimitracopoulou (Eds.), *CSCL'09 Proceedings of the 9th International Conference on Computer Supported Collaborative Learning* (Vol. 2, pp. 25–27). New Brunswick, NJ: International Society of the Learning Sciences.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). *Public participation in scientific research: Defining the field and assessing its potential for informal science education. A CAISE Inquiry Group report.* Washington, DC: Center for Advancement of Informal Science Education (CAISE).

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science, 343*, 1436–1437.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education, 27*, 1099–1121.

Brown, J. S. (2000). Growing up digital: How the web changes work, education, and the way people learn. *Change, 32*, 10–20.

Butt, R. (1984). Arguments for using biography in understanding teacher thinking. In R. Halkes & J. K. Olson (Eds.), *Teacher thinking* (pp. 98–123). Lisse, Netherlands: Swets & Zeitlinger.

Butt, R. L., & Raymond, D. (1989). Studying the nature and development of teachers' knowledge using collaborative autobiography. *International Journal of Educational Research, 13*, 403–419.

Butt, R. L., Raymond, D., McCue, G., & Yamagishi, L. (1992). Collaborative autobiography and the teacher's voice. In I. F. Goodson (Ed.), *Studying teachers' lives* (pp. 51–98). New York, NY: Teachers College Press.

Calabrese-Barton, A. M. (2012). Citizen(s') science. A response to "The future of citizen science." *Democracy and Education*, *20*. Retrieved from http://democracyeducationjournal.org/home/vol20/iss2/12/

Children's Online Privacy Protection Act (COPPA). Retrieved from http://www.coppa.org

Collins, A. (2016). A brief history of mass collaboration: How innovations over time have enabled people to work together more effectively. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International.

Cress, U., Feinkohl, I., Jirschitzka, J., & Kimmerle, J. (2016). Mass collaboration as co-evolution of cognitive and social systems. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International.

Darling-Hammond, L. (1998). Teacher learning that supports student learning. *Educational Leadership, 55*, 6–11.

Elliott, M. (2016). Stigmergic collaboration: A framework for understanding and designing mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International.

Fickel, L. (1999, April). *Democracy is messy: Exploring the beliefs and personal theories of a high school social studies teacher*. Paper presented at the American Educational Research Association, Montreal, Canada.

Fischer, G. (2016). Exploring, understanding, and designing innovative socio-technical environments for fostering and supporting mass collaboration. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer International.

Gallo, T., & Waitt, D. (2011). Creating a successful citizen science model to detect and report invasive species. *BioScience, 61*, 459–465.

Glazer, J. (1999, April). *Considering the professional community: An analysis of key ideas, intellectual roots, and future challenges*. Paper presented at the American Education Research Association, Montreal, Canada.

Goodson, I. F. (1992). Sponsoring the teacher's voice: Teachers' lives and teacher development. In A. Hargreaves & M. G. Fullan (Eds.), *Understanding teacher development* (pp. 110–121). New York, NY: Teachers College Press.

Gutierrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher, 32*, 19–25.

Halatchliyski, I., Moskaliuk, J., Kimmerle, J., & Cress, U. (2014). Explaining authors' contribution to pivotal artifacts during mass collaboration in the Wikipedia's knowledge base. *Computer-Supported Collaborative Learning, 9*, 97–115.

Haywood, B. K. (2014). A "sense of place" in public participation in scientific research. *Science Education, 98*, 64–83.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*, 111–127.

Khatib, F., DiMaio, F., Cooper, S., Kazmierczyk, M., Gilski, M., Krzywda, S., & Foldit Void Crushers Group (2011). Crystal structure of a monomeric retroviral protease solved by protein folding game players. *Nature Structural & Molecular Biology, 18*, 1175–1177.

Lepczyk, C. A. (2005). Integrating published data and citizen science to describe bird diversity across a landscape. *Journal of Applied Ecology, 42*, 672–677.

Long, J. (2003). *Connecting with the content: How teacher interest affects student interest in a core course* (Electronic thesis or dissertation). Retrieved from https://etd.ohiolink.edu

Moll, L. C., Amanti, C., Neff, D., & González, N. (1992). Funds of knowledge for teaching: A qualitative approach to connect households and classrooms. *Theory Into Practice, 31*, 132–141.

Mueller, M. P., & Tippins, D. (2012). The future of citizen science. *Democracy and Education, 20*, 2.

National Research Council. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics. Committee on Highly Successful Science Programs for K-12 Science Education. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Pajak, E., & Blase, J. (1989). The impact of teachers' personal lives on professional role enactment: A qualitative analysis. *American Educational Research Journal, 26*, 283–310.

Parise, L., & Spillane, J. (2010). Teacher learning and instructional change: How formal and on-the-job learning opportunities predict change in elementary school teachers' practice. *The Elementary School Journal, 110*, 321–346.

Patrichi, M. (2011, April). *Threats to using mass collaboration in education*. Paper presented at the 7th International Scientific Conference eLearning and Software for Education, Bucharest, Romania.

Penuel, B., & Means, B. (2004). Implementation variation and fidelity in an inquiry science program: Analysis of GLOBE data reporting patterns. *Journal of Research in Science Teaching, 41*, 294–315.

Polman, J. L. (2000). *Designing project-based science: Connecting learners through guided inquiry*. New York, NY: Teachers College Press.

Powell, R. R. (1992). The influence of prior experiences on pedagogical constructs of traditional and nontraditional preservice teachers. *Teaching and Teacher Education, 8*, 225–238.

Powell, R. R. (1996). Epistemological antecedents to culturally relevant and constructivist classroom curricula: A longitudinal study of teachers' contrasting world views. *Teaching and Teacher Education, 12*, 365–384.

Putnam, R. T., & Borko, H. (2000). What do new views on knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*, 4–15.

Raddick, M. J., Bracey, G., Carney, K., Gyuk, G., Borne, K., Wallin, J., … Planetarium, A. (2009). *Citizen science: Status and research directions for the coming decade. AGB Stars and Related Phenomenastro 2010*. Position Paper at the Astronomy and Astrophysics Decadal Survey, 46.

Rippel, M., Schaefer, D., Mistree, F., & Panchal, J. H. (2009). Fostering collaborative learning and mass-customization of education in a graduate engineering design course. *International Journal of Engineering Education, 25*, 729.

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., … Bonney, R. (2012). Public participation in scientific research: A framework for deliberate design. *Ecology and Society, 17*, 2.

Trautmann, N. M., Shirk, J. L., Fee, J., & Krasny, M. E. (2012). Who poses the question?: Using citizen science to help K-12 teachers meet the mandate for inquiry. In J. L. Dickinson & R. Bonney (Eds.), *Citizen science: Public participation in environmental research* (pp. 179–190). Ithaka, NY: Comstock.

Trumbull, D. J., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education, 84*, 265–275.

Wals, A. E., Brody, M., Dillon, J., & Stevenson, R. B. (2014). Convergence between science and environmental education. *Science, 344*, 583–584.

Wiggins, A., & Crowston, K. (2011). From conservation to crowdsourcing: A typology of citizen science. In *Proceedings of the 44th Annual Hawaii International Conference on Systems Sciences, Koloa, Hawaii*. Retrieved from http://dx.doi.org/10.1109/HICSS.2011.207

Altogether Now! Mass and Small Group Collaboration in (Open) Online Courses: A Case Study

Sabrina C. Eimler, German Neubaum, Marc Mannsfeld, and Nicole C. Krämer

Online Learning with Mass Collaboration: The MOOC Idea

The spread of the Internet in the last decades has caused a variety of changes in what resources people can access, how people manage information, how and with whom they can communicate (anytime, anywhere), and how they learn, create, spread, and share (their) knowledge. It has also made multimedia learning content easily accessible; networking and sharing of information in and outside formalized learning contexts has become an everyday activity for users of social networking sites like Facebook and Twitter or learning management platforms like Moodle.

In recent decades, collaborative learning supported by technology has especially gained attention in the computer-supported collaborative learning (CSCL) community, who explored how technological support of (collaborative) learning settings can foster and influence peer interaction and group work, the sharing and distribution of knowledge (Lipponen, 2002; Stahl, Koschmann, & Suthers, 2006). CSCL authors emphasize the importance of social interaction in the learning process (e.g., Stahl et al., 2006). Collaborative learning assigns an active role to the learner and is suggested to have positive effects on learning motivation and learning outcomes. In a wider sense, it involves the collective meaning-making and negotiation in a process of joint activity directed at a specific goal (e.g., Koschmann, 2002). It might appear in dyads, small groups, and larger social groups (mass collaboration) (Engeström, 2004).

In education-related settings, mass collaboration (in the sense of a large number of people collectively pursuing the same goal while each of them works independently on his/her part of the problem solution) is not only present when people

---

S.C. Eimler (✉) • G. Neubaum • M. Mannsfeld • N.C. Krämer
Social Psychology—Media and Communication, University of Duisburg-Essen, Duisburg, Germany
e-mail: sabrina.eimler@uni-due.de; german.neubaum@uni-due.de; marc.mannsfeld@uni-due.de; nicole.kraemer@uni-due.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_14

jointly create publicly available knowledge repositories like Wikipedia (see chapter “What is Knowledge? Who Creates it? Who Possesses it? The Need for Novel Answers to Old Questions” by Oeberst, Kimmerle, & Cress, 2016) but also plays a role in environments specifically designed for learning such as online courses and, more recently emerging, massive open online courses (MOOCs). MOOCs might have mass collaborative features, such as forums and wikis. Also peer feedback loops—in the sense of evaluating the assignment of other students—might be conceived of as mass collaboration in a course which includes a large group of participants. All these tools and assignments have in common that a large number of students are called to solve a problem (e.g., write a definition entry in a wiki), have to find common understandings, and provide suggestions to each other in order to finally provide a solution.

MOOC formats appeared around 2008 for the first time. While massive open online courses (MOOCs) have become popular especially in the USA (e.g., EdX, Coursera, Udacity; see https://www.mooc-list.com/ for a comprehensive list), they have not been very prominent in Germany (see exceptions such as iversity or openHPI offered by the Hasso Plattner Institute). During the last 2 years, however, more and more courses are launched in Germany as well (Bremer & Weiß, 2013). The term MOOC is typically used to describe online courses that are open to all kinds of interested people and have high subscription numbers. According to Bremer and Weiß (2013), a course can be described as massive when the number of participants exceeds 150. This number is deduced from Dunbar’s number and the social brain hypothesis (Dunbar, 1993), which assumes that based on a comparison on primate brain sizes and group size, it can be concluded that the human brain can process an average of 150 social contacts.

Generally, two different kinds of MOOCs are differentiated in the literature (e.g., Rodriguez, 2013): cMOOCs and xMOOCs. While xMOOCs, also known as Stanford MOOCs, typically follow a clear agenda with weekly structured learning material that is chronologically worked on, the c in cMOOCs stands for connectivist indicating that the course is based on the concept of connectivism (Siemens, 2005) making it more open, flexible, and self-regulated for the interconnected learners (Schulmeister, 2013). In this course format, the learners decide on their own when and how intensely they want to engage in the course and also define their personal learning goals on their own. More importantly, cMOOCs put a higher priority on the interaction and interconnection of the learners. Therefore, mass collaboration can rather be expected in cMOOCs than in xMOOCs.

MOOCs as course concepts in higher education may be specifically useful for German universities, witnessing a growing number of applying students on the one hand, as well as a trend toward and a necessity of establishing interdisciplinary education (because of a rising complexity of society’s future challenges). Not only because of economic advantages resulting from a larger number of students that can subscribe to a course offered by a single lecturer or a small group of lecturers but also because of the flexibilization these course formats bring along, they may be regarded as promising. Because of their independence from location and time (Kay, Reimann, Diebold, & Kummerfeld, 2013), they are attractive for heterogeneous groups, for example, people with special needs due to vision impairment, a specific level of language proficiency that makes it hard to follow simultaneous course formats, or physical handicaps, and might offer a better compatibility of family and studies and/or work, which is beneficial for students and lecturers alike. Also, it might promote general computer skills and especially foster the acquisition knowledge regarding web-based applications (also see Chukwunonso, Ibrahim, Selamat, Idama, & Gadzama, 2013 for a review).

While open educational concepts such as MOOCs provide an immense potential allowing people a more independent way of learning, instructors and designers of these environments are confronted with a number of challenges regarding the diverse background of students. Little by little scholars try to understand people's motivation to learn in MOOCs, the (pre)conditions of constant, active engagement in individual and group assignments, and the way these programs have to be designed to cater for individual needs and produce maximum satisfaction and learning outcome/gain. Learning materials have to be thoroughly conceptualized in order to meet individual needs of a large group of students with different backgrounds and to orchestrate the mass collaboration in a way that the interaction people show in small and large groups is beneficial for both individual motivation and learning outcomes (see Table 1 for potentials and barriers). Since learning can be understood as an inherently social process (e.g., Stahl, 2000), it is a challenge of these comparably anonymous formats to find tasks allowing and motivating collaboration with other participants and thereby to encourage participants to log in week after week.

In order to encourage interaction within a massive online course, we conceptualized a course, which incorporated both small group and large group collaboration tasks. Within this course, common goals among students were set not only in weekly assignments but also in terms of passing the final exam of the course. Given this setting, the course promised to stimulate collaborative processes in diverse group sizes and different constellations. In the following, we first describe (social) psychological foundations of learning in (larger) groups and derive potentials and barriers of collaboration. Then, we describe the course we conceptualized for students of the University Alliance Ruhr including details about specific (mass) collaborative opportunities and how they were used and evaluated by the learners.

(Social) Psychological Foundations of Learning in (Larger) Groups

The role of groups or social interaction in learning has been emphasized by different scholars long before computer technologies played a role in learning. Some of the most influential scholars in this area were Albert Bandura (1965, 1971) and Lev Vygotsky (1962, 1978).

From a social psychological view, the social context of learning processes has been raised by the social learning theory (Bandura, 1971). This theory is driven by the idea that learning processes can be stimulated by observing one's surrounding,

Table 1 Potentials and barriers of working in small and large groups from a social psychological perspective

MOOCs	Potentials	Barriers
Large groups	Depending on the task group may be more productive and achieve better performance than individuals alone → synergy effects	Social loafing: Students experience a lack of involvement and are less willing to contribute to the group's work due to diffusion of responsibilities (Latané, Williams, & Harkins, 1979; Piezon & Donaldson, 2005)
	Multiple perspectives, innovation, creativity	Conformity: Creativity and quality of the work are influenced by the tendency to conform to the group's opinion or attitude; limited to the homogenous nature of learners' exchange of perspectives (Beran, Drefs, Kaba, Al Baz, & Al Harbi, 2015)
	Social disinhibition: Affordances of online environments such as asynchronicity or anonymity help individuals to expose ideas and thoughts more openly (benign disinhibition; Suler (2004))	Social disinhibition: Due to characteristics of computer-mediated communication such as visual anonymity, individuals are more prone to employ rude language or uncivil comments (toxic disinhibition; Suler (2004))
	Audience effect, social facilitation: Presence of others might boost individual's performance	Social isolation, physical distance
Small groups	People get to know each other, their strength and weaknesses; effective peer tutoring	Peer pressure
	Social comparison processes with beneficial outcomes (motivation via upward comparison; Festinger (1954), Michinow and Primois (2005))	Social comparison processes with negative outcomes (upward comparison without assimilation effect; Festinger (1954))
	Accountability, responsibility	
	Groups building, group identity	Roles need to be negotiated which takes time
	Communication skills and team management skills can be trained, social competence development	Flexibility is reduced, collaboration/cooperation is necessary, asynchronous working on the task not always possible
No groups, individual learning in isolation		Lack of social interaction and its beneficial effects
	Highly flexible (Gordon, 2014)	High dropout rates (Halawa, Greene, & Mitchell, 2014)

i.e., other people. Individuals acquire knowledge (procedural and factual, as well as attitudes) by attention that is focused on a specific object, e.g., a person, observation and retention (memorizing) and (conscious or unconscious) imitation of this object, as well as a (self-)motivational process reinforcing the successful imitation and acquired learning content.

The implications for mass collaborative spaces are that collaborators do not only benefit from the knowledge others provide here but also by observing their conduct and their lines of thoughts (e.g., when resolving tasks). Also, vicarious rewards can be influential, for example, when other participants are rewarded for specific behavior and learning outcomes, e.g., by badges.

Vygotsky (1962, 1978) argued interactive processes are essential in learning. Therefore, his ideas have become influential in the context of collaborative learning. Two terms are of importance in his theory—scaffolding and the zone of proximal development. Scaffolding refers to the idea that different levels of support and guidance are necessary for the learner to succeed and that the intensity of support may be successively reduced. Guidance by teachers or organizers in online courses is important, especially when teachers and students never meet in person. In the beginning, there should be information available that helps understanding the rules and organization of the course. In the course of the time, guiding information may be reduced. The concept of "zone of proximal development" suggests that learning takes place when a situation or task is challenging to the individual. There are different levels of expertise in individuals comprising a group and advanced peers or teachers that may facilitate the progress in the learning process. This social conceptualization of learning has gained renewed interest when computer-supported learning processes were more and more enabled (Salomon, Globerson, & Guterman, 1989; Scardamalia & Bereiter, 1991). This line of research argued that computer-supported cooperation might address the zone of proximal development in the sense that text-based communication enables learners to reflect upon each other's contributions, advise each other, and, in doing so, advance knowledge considering each other's learning stage.

In computer-supported mass collaborative settings with large numbers of individuals having diverse backgrounds and experiences, people can involve in reciprocal teaching or peer tutoring. Everyone can be a teacher for someone sometimes. Given that due to the large number of participants teachers will not be able to support and cater for the individual needs of every student, MOOC teachers have to rely especially on the possibilities of peer teaching and peer support. Indeed, studies investigating dropout rates in higher education (distance learning) show high dropout rates when learners are left on their own. Dropout rates are approximately 10–20 % higher in online courses compared to traditional course formats with face-to-face meetings (Holder, 2007).

Based on these considerations, it might be advisable to conceptualize a course in a way that participants interact with each other in various settings (i.e., various group sizes) and combinations. As people in a large group will probably not reorganize to various small groups to support each other, it might be necessary to distribute people to smaller groups for single tasks.

Additionally, it will be advantageous when participants are aware of the fact that (a large number of) others participate in the course. In a review article, Rovai (2000) emphasizes the role of a sense of community for a reduction of the dropout rate and successful learning atmosphere that includes cooperation among members of a group, mutual support, and satisfaction. Due to the physical separation and other aspects that come with the specific characteristics of computer-mediated settings, learners in online courses might have a reduced community feeling. However, it is not impossible to establish a sense of community. Depending on the specific conceptualization, community does not necessary need co-location but can be a virtual classroom setting as well (cf. Hill, 1996; Rheingold, 1991; Wellman, 1999). We argue that in a virtual classroom like in an MOOC, a combination of large group and small group assignments can compensate feelings of isolation and lack of belonging but rather enable a more intense interaction between the group members and allow integration, trust, and establishment of a common "group" identity by working toward a common goal (which is completing a group task).

From a social psychological point of view, collaborating in small as well as in large groups has diverse potentials and barriers. Classic negative effects such as social loafing and diffusion of responsibility can first and foremost be expected in large groups, while positive as well as negative effects of social comparisons (Festinger, 1954) will be more likely in small groups as the members get to know more about each other. Table 1 briefly summarizes the potentials and barriers for the different group sizes.

On the grounds of these theory-based considerations, we conceptualized a course which included tasks for mass collaboration but also for small group interaction. By this, we hoped to include the potential benefits of both forms while minimizing potential negative effects.

Course Example

Background

Between October 2013 and January 2014, the online course was accessible for 11 weeks and especially advertised for students at two large German universities who could gain credits for participating actively in the course and passing the final exam. Altogether 162 students enrolled in the course.

The course dealt with psychological foundations of computer-mediated communication with a special focus on learning and teaching, covering classical theories of computer-mediated communication in order to understand the changes that (might) occur by this mediation as compared to face-to-face settings. In focusing on this topic, the students were provided with hands-on experiences, for instance, in terms of virtual collaborations in small groups of students working on one specific assignment.

This course was not conceptualized as an MOOC in its traditional sense, targeting a huge, heterogeneous mass of learners with different academic and nonacademic backgrounds and age levels. It rather addressed only students, however, from very diverse fields such as business administration, education, or media studies. Apart from the target group, the course integrated several components typical for MOOCs such as instructional videos, discussion forums, wiki, weekly assignments, quizzes, peer interaction, and feedback. Also, the course integrates a variety of collaborative tasks and peer feedback mechanisms. The underlying idea of mass collaboration involves a microlevel (small group) and a macrolevel (large group, public interaction). On the microlevel, people collaborate in smaller workshop groups, and on the macrolevel, they are engaging in a larger community of learners via the public parts of the course, e.g., the wiki and discussion boards (see Table 2 for details on tasks). A peer feedback mechanism promotes the exchange of solutions and makes available other's solutions for the same problem.

Concept and Structure

Upon registration to the Moodle-based course environment, people were informed about organizational conditions and requirements to succeed. Moodle (www.moodle.org) is a commonly used learning management system in higher education. People were told to access the course environment regularly and not to be absent for more than two subsequent weeks (otherwise, they would be automatically excluded from the course). Moreover, they were informed that they would regularly get the chance to voluntarily complete questionnaires to comment on their course experience in order to improve the course. The weekly learning material provided consisted of a video (1.5–11.5 min in length), in which one of the course organizers (male and female) contextualized the content and introduced the new material and tasks that could be accessed and downloaded. Besides the videos, one or two texts a week, preferably in German language, were provided as core material, as well as some additional material (e.g., video links and text documents) that could optionally be used as "outside the box" material.

Also, the completion of quizzes and individual assignments were part of the required activities. Individual assignments were, e.g., summarizing or comparing texts; others involved engaging in discussion boards or the general forum. Some were organized in a way that individual solutions were made available for all learners after completion of the task. Collaboration tasks are a special format we wanted to test that differs from most conventional MOOCs. People had to complete two out of three of these tasks in which they worked in a group of three to four students for 1 week. Weeks in which these tasks had to be completed were announced beforehand, and students had to register for the collaboration task to make sure that they would work on it during the week. Therefore, different kinds of interactions took place: teacher to student (videos, texts), students to teachers (help forum), students with platform (quizzes, self-assessment), student to student (small group workshops),

Table 2 Overview about course weeks and task types

Week	Task	Format/accessibility
1	Forum: People were invited to post short messages explaining their expectations for the course, what they would like to learn, and special wishes and requirements they had	Forum, accessible for all course participants
2	Forum: Each student was asked to apply to the online course what he or she had learned about theories of computer-mediated communication (cmc) and learning and teaching in this environment. Guiding questions were provided, e.g., what are the chances and dangers of collaborative learning in cmc?	Individual task, solution accessible for all course participants via the forum
3	Social presence workshop: Students learned about the concept of social presence and its relevance for computer-mediated learning settings. In small group workshops, they worked on the implications for user behavior	Small group workshop; selected solutions could be accessed in week 6
4	Students were asked to submit three potential exam questions based on what they had learned the weeks before	Individual task, made public in the forum in week 6
5	Students should write and submit an essay on actions to take for the development of trust in virtual teams	
6	Students had to evaluate at least three of the potential exam questions submitted by other course participants with regard to content (how interesting) and overall relevance	Individual task, solution accessible for all course participants via the forum (given that they had provided questions before)
	Optional task (outside the box section): Answering three of more of the potential questions for the exam. Trigger discussions about solutions in the forum before the exam	
7	Optional task (outside the box task): Forum about net-based knowledge communication	Individual task (optional), solution accessible for all course participants via the forum
8	Brainstorming workshop: Students learned about conditions under which successful brainstorming can be facilitated or hindered. In the workshop, they should develop ideas to improve the brainwriting method	Small group workshop; solution of another group had to be evaluated in week 9
9	Peer feedback task: Students got to know different facets of giving feedback and how these can be used in cmc settings	
10	Scripting workshop: Students gained an overview about scripts and their functions in collaboration and developed a cooperation script themselves	Small group workshop; solution of another group had to be evaluated in week 11
11	Wiki: Students learned theoretical and practical aspects of (mass) collaborative knowledge construction in a wiki they were asked to edit and prepared for the exam at the same time	Wiki, accessible for all course participants
12	Exam	

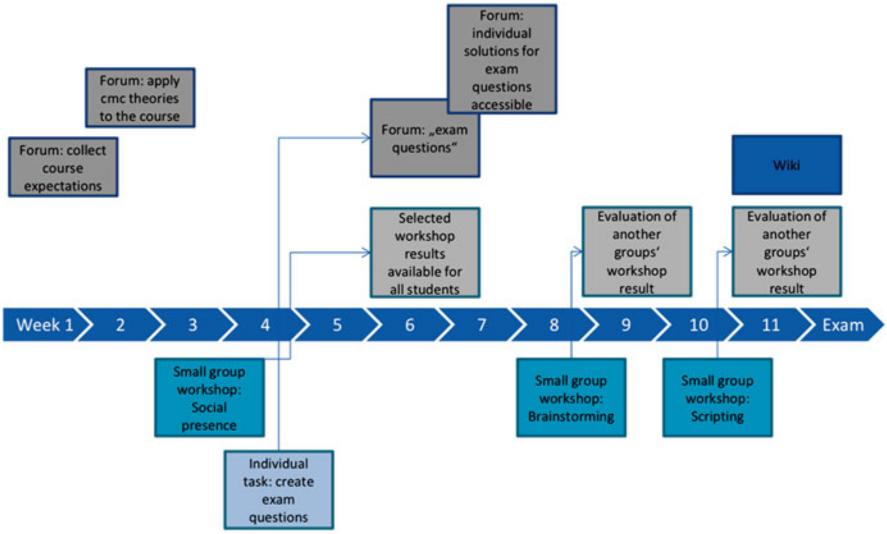


Fig. 1 Course overview

and student to crowd in the sense of all participants (wiki, discussion boards). Our aim was to observe how dynamics in collaboration processes develop depending on the size and constellation of different group tasks (see Fig. 1 for an overview of the course material and assignments).

A main characteristic of this course was the concept of self-paced learning (Kumar, Packer, & Koller, 2010), enabling students to individually determine their tempo. By providing "outside the box" material, we intended to also cater for the needs of those students who are fast learners or interested in further details regarding a specific topic. Another important similarity to a MOOC is that students voluntarily decided to attend this course, which they selected from a wide range of further course options. Given these similarities to the traditional concept of MOOCs, this course and the corresponding research data might give further insights into what characterizes people who voluntarily register for an online learning course and which course elements might contribute to students' satisfaction with this specific learning format. In the following, we will elaborate on attributes of participants and preliminary evaluations of this course.

Participant's Characteristics

In order to tailor such a course to the learners' needs, it is important to know the characteristics of voluntary participants of such a course in terms of demography (e.g., gender, age, background) but also with regard to affinity toward technology (cf. Terras & Ramsay, 2015). In order to characterize participants of the online course, we assessed several demographic variables in questionnaires that could be voluntarily completed during the course. These included variables such as gender and age, as well as potential immigrant background, if people have children, their self-reported proficiency of English, and if their vision is impaired. Some of these variables, for example, knowledge of English and vision impairment, have immediate impact on material selection, while others such as gender or parent status are pivotal to identify the target group of future supplementary online learning courses. Altogether 162 students enrolled in the course. One hundred students (i.e., 61.72 % of students who registered in the first week) took part in the initial survey, 51 of which were female, 48 male, and one person refused to indicate his/her gender. The mean age of those people completing the first questionnaire was $M = 23.34$ ($SD = 2.30$). Eighty percent indicated to take the course as part of the supplementary course program (studium liberale in German bachelor's program), while 3 % did not provide their background. Four percent of the participants indicated to have children, about 21 % had an immigrant background, and 9 % reported to have impaired vision.

Since proficiency in using the computer, especially Internet-related applications, might lead to problems in using the material, influence satisfaction and dropout decisions, we assessed online self-efficacy. Online self-efficacy was measured by six self-constructed items (Cronbach's $\alpha = .70$) asking for how confident people felt in using different Internet applications and pursing specific tasks with computers (e.g., "I feel confident using the Internet," "I'd say I have an affinity toward technology"). Answers were assessed on 5-point Likert scales (1 = does not apply at all, 5 = fully applies). The mean was very high, $M = 4.42$ ($SD = .54$), indicating a high confidence in using the Internet. ANOVAs showed a significant difference between men and women, $F(1,89) = 19.55, p < .001, \eta_p^2 = .18$, revealing that men have a higher efficacy with regard to technology ($M_m = 4.64$, $SD_m = .44 > M_f = 4.19$, $SD_f = .53$).

Evaluation

In the following section, results are presented regarding the evaluation of data illustrating the usage and judgment of the mass collaborative elements, i.e., wiki and forum. Additionally, the small group collaboration task and a peer feedback evaluation task are described. Data were gathered from voluntary questionnaires provided online at different points of measurement and actual data from log files. In addition to questionnaire data, participants of the course were invited to take part in in-depth, semi-structured qualitative interviews focusing on different aspects of their course experience (e.g., expectations and evaluations, learning support and motivation for participation, design and features of course content and platform, potentials for improvement).

Usage of Mass Collaboration Resources: Wiki and Forum

As mass collaboration opportunities, we provided a forum in which everyone was able to post questions and answers to the whole group in which we triggered activity by mandatory tasks given throughout the course. Additionally, we provided a wiki structure during the last 2 weeks of the course in which students could post their knowledge on the different topics.

Unsurprisingly, forum usage was highest, when activity was triggered by a task, especially the "potential exam question task" in which people were asked to provide, rate, and answer questions that might come up in the final exam. However, questions and answers were posted regularly throughout the whole course starting from the week in which the task was given to the students.

With regard to the wiki, we were surprised by the high level of activity. Although nothing but the technical structure and a heading for the respective topic were given, content was filled in quickly and by various authors. Not only did various authors provide large parts of content but also various additional persons provided support by implementing small changes and additions. This was accompanied by various discussions on difficult aspects of the respective topic. An analysis by Ziebarth et al. (2015) of a subgroup of participants, those 69 people who took part in the final exam and engaged in the discussion, demonstrated that this behavior was probably motivated by exam preparations: 85.5 % of the students taking the exam actively engaged by editing 1, 2, and 4 of the 11 articles and 79.7 % by writing comments to one to three articles.

Even more impressively, analyses revealed that students also relied heavily on this sort of learner-generated content when learning for the exam (for further details, see Ziebarth et al., 2015): Every student read at least one article and the average of articles that were read at least once was 9.7 and the median 11 (all); on average, each student accessed 47 times one of the wiki articles. Qualitative interviews also confirmed that students valued the wiki as very useful for learning and preparation for the exam.

Additionally, the forum was used for exam preparation as reading activity in the forum increased during the exam week. This was also commented on in the interview. One interviewee explained: "If you had questions, these were already listed in the forum, you could access them which I have done often when I did not know something while learning. The task that involved the preparation of exam questions was also nice because one had a collection of potential exam questions afterwards."

Small Group Collaboration Tasks

Besides the mass collaboration elements, it seems relevant to evaluate the effectiveness of those elements and features involving small group interaction and collaboration. For this purpose, we exemplarily elaborate on self-report data that was gathered in relation to an assignment of virtual collaboration in small groups. Students were asked to come up with a “Social Presence Book” and create guidelines how one can signalize to be socially present. As communication channels for the group work, they could, for example, use a specific forum set up for the group. The solution could be presented in a variety of forms such as videos, Powerpoint slides, or text documents. Data from the questionnaire showed that people indeed most often used the forum to communicate with their group members, while other channels (e.g., Google groups, e-mail, Skype) were only used rarely. In line with this, the qualitative interviews revealed that interviewees considered it to be positive that when using the forum, the complete conversation between all group members could be accessed at one glance. Three people mentioned that it was good that the internal forum was available and that participants did not have to search for an own communication platform.

Small groups enable participants to intensively discuss about individual questions and support each other when dealing with the learning material (Cohen, 1994). However, working in small virtual teams can be a challenge due to unawareness of situational and contextual factors that might determine the communication of the collaboration partners (Cramton, 2001). In this regard, Walther and Bunz (2005) have shown that sticking to specific collaboration rules (see below) can increase trust within a virtual team. These rules are as follows: (1) get started right away, (2) communicate frequently, (3) multitask getting organized and doing substantive work simultaneously, (4) overtly acknowledge that you have read one another’s messages, (5) be explicit about what you are thinking and doing, and (6) set deadlines and stick to them.

Thus, the more students stick to such rules, the more trust might have been in their virtual collaboration group. In order to explore how communication has operated within the virtual cooperation groups of the present online learning course, we asked students ($N=91$) to report how much they had complied with the specific rules provided (1 = not at all, 5 = completely). The mean calculated over all rule items was $M=3.23$ ($SD=.88$) (see Table 3 for means and standard deviations of the individual rules). Rules 4 and 5 had the highest means, indicating that people were explicit about their assignment-related activity and gave feedback about having read each other’s messages.

Moreover, *satisfaction* with the cooperation task (4 items, $\alpha=.93$), intensity of *knowledge sharing* (4 items, $\alpha=.86$), perceived intensity of *other participant’s involvement* (3 items, $\alpha=.92$), and *intention to participate in future collaboration tasks* (3 items, $\alpha=.87$) were assessed. All items were measured on 5-point Likert scales (1 = doesn’t apply at all, 5 = fully applies) and partly adapted from Ho and Huang (2009) who used them to define success factors for online video games

Table 3 Rule adherence ($N=91$)

	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6
M	2.80	3.24	3.07	3.49	3.45	3.32
SD	1.15	1.06	1.21	1.15	1.14	1.42

Table 4 Cooperation task evaluation

Measures	*M*	*SD*	*T* (df = 91)	*p*
Satisfaction	3.44	1.78	7.66	<.001
Knowledge sharing	3.54	.93	10.81	<.001
Other's involvement	3.33	1.10	7.23	<.001
Future participation	3.06	1.04	5.17	<.001

communities. All means deviated significantly from the scale mean in the positive directions (see Table 4).

To see if and how these four aspects of cooperation experience relate to each other, correlation analyses were conducted revealing positive correlations between all the aspects, with the exception of a nonsignificant correlation between knowledge sharing and intention to future participation. The strongest correlations could be found for satisfaction with the cooperative experience and the involvement of the other participants as well as for satisfaction and rule compliance. Though one has to be careful in claiming a causal relationship, based on Walther and Bunz's results (2005), it can be said that the more groups adhered to the rules, the more they were satisfied with the cooperation. In line with this, it may be especially useful to provide students with such rules in order to enhance their course experience. Moreover, rule compliance may be linked to the perception of high involvement of group members that also seems to be connected to satisfaction.

Results of the interviews show that people developed a feeling of responsibility toward their small group on the one hand and tried to avoid negative evaluation by the other small group members by actively engaging in the group on the other hand. This also shows that norms that exist outside this specific learning context influence behavior in this context. Moreover, people report a high self-perceived learning gain based on the small group tasks.

That this learning gain was probably also perceived as resulting from the large group of people became apparent during the interviews. When participants of the interview were asked for the benefits and disadvantages of the small group workshops, six interviewees mentioned as an advantage that they got to know different and new perspectives while working with their group members. One participant more pronouncedly stated that he/she evaluated the fact that he/she did not know the other group members positively since this would raise less prejudices and enrich the collaboration by different perspectives and working styles. Especially the latter is not given in common seminars or lectures in which students stem from one or merely a few different subject areas.

Exemplary Evaluation of a Small Group Peer Feedback Task

In large-scale courses, providing feedback that is tailored to open-ended solutions from students such as written essays is a challenge for instructors. Therefore, we integrated a peer feedback feature in small group works in which students were asked to anonymously give feedback to the work of students from other small groups. The basic challenge here was to motivate students to give elaborated feedback that goes beyond a simple assessment such as “very good” or “could have been better.” Therefore, by means of an experimental manipulation, we tested how different incentives can stimulate how much and what kind of feedback students give to other students (cf. Neubaum, Wichmann, Eimler, & Krämer, 2014). Results showed that the prospect of receiving a peer rating for one’s feedback (in the sense of how helpful one’s feedback was) motivates students to give a longer and more elaborated feedback than having the prospect of getting access to additional course material or receiving no incentive. It seems that receiving feedback on one’s feedback addresses people’s need to estimate their own abilities and opinions (Festinger, 1954). These findings might help to organize constructive feedback loops in courses with a large number of students. At the same time, this shows that anonymous interactions among dyads of students are an important motivational factor.

Overall Course Evaluation: Perceived Enjoyment, Difficulty, Knowledge Gain, and Demonstration

For the overall evaluation of the online course ($N = 73$), subdimensions (reported enjoyment, perceived difficulty, knowledge, demonstration) of the Training Evaluations Instrument (TEI, Ritzmann, Hagemann, & Kluge, 2014) that assesses subjective evaluation of a course as well as aspects of the course design (1 = does not apply at all, 5 = fully applies) were used. The *reported enjoyment* dimension consisted of three items and asks for how much fun people felt with regard to taking part in the course and how much they enjoyed the course atmosphere. The *perceived difficulty* dimension was measured by five adapted items, asking for how well people could follow the course and understand the course material and how suitable they found the time given for the completion of the individual tasks and workshops. The *knowledge* dimension, consisting of three items, assessed to what degree people think they will memorize the course content and how their knowledge has expanded. Finally, the *demonstration* dimension (seven items) asked if the learning goals had been clarified and been reached and if the (available) media used were helpful and suitable. All means significantly deviate from the scale mean in the positive direction (see Table 5).

Table 5 TEI evaluation dimensions

	M	SD	T (df = 72)	p	α
Enjoyment	3.22	1.03	5.98	<.001	.91
Difficulty	3.26	.86	7.56	<.001	.80
Knowledge	3.21	.97	6.31	<.001	.93
Demonstration	3.23	.89	7.09	<.001	.90

Conclusion

While open educational concepts such as MOOCs are widely discussed, both in the scientific community and in the mass media, empirical research on these formats and their participants is scarce. Based on psychological theories, this chapter addressed potentials and barriers for collective learning experiences in large online courses. Lessons learned from a large online course that involves individual tasks, small group workshops, and large group collaboration opportunities into a successful and long-term engaging concept for the learner have been illustrated, and results from log file analyses, questionnaire data, and in-depth interviews have been presented. These data revealed that the juxtaposition of different task formats with different group sizes and constellations appear to contribute to learners' general satisfaction with the course. Specifically, we have argued that the strength of different interaction formats can be realized by this specific collection of different opportunities that allow people to access videos and text, test their knowledge via quizzes, engage in group activities in small groups, use the wiki and discussion boards, and allow an individual learning path in the context of a larger community of learners who collaboratively negotiate a socially shared idea of the learning content and work toward the goal of passing the exam.

Combining social psychological concepts and evidence from our preliminary evaluation of the course, we would like to outline potential benefits of implementing (large) group tasks in open educational settings:

(a) A large group allows for joint commenting and discussing of topics. Similar to what is described as being provided by "the crowd" in Web 2.0, the ideological and educational heterogeneity of a large group leads to the production of many ideas which can then be commented on and refined by all resulting in more reliable results (see, e.g., the collection of potential exam questions and the joint work on the wiki and the data on the number of people actually using this information as well as the positive evaluation in the self-report assessments).

(b) Large groups enable teachers to profit from the diversity of the group. A large number of participants allow repeated small group building while guaranteeing high variance within the group (when people are assigned to groups randomly, chances are high that participants will meet new peers every time and that they will work with others from different backgrounds). While we relied on randomization, future developments will enable a more controlled orchestration of group building (Ounnas, Davis, & Millard, 2009). In future courses, it might be especially interesting to use diversity data (e.g., background, language skills, parent status, etc.) for group formation purposes and for the development of learner models. It might be a specifically enlightening experience to find problem solutions in different heterogeneous constellations. The diverse social contexts might provide new sources for upward social comparisons (i.e., comparison with people who are better in performing specific tasks) and for mutual guidance in the zone of proximal development. Moreover, interacting with heterogeneous others might contribute to the reduction of stereotypes. Studies in the context of the so-called contact hypothesis (Allport, 1954) have shown that intergroup cooperation with common goals can help reducing prejudices (Forsyth, 2009). Another approach to group formation might be to group students according to their achievement potential and, for example, either intentionally assort high potentials among each other or students with high and low potential. Technically, it would be possible to continuously assess these parameters. For our course, survey and interview data clearly showed that students enjoyed working with others from different backgrounds, whether this is actually beneficial for the learning outcome has yet to be tested.

(c) Future work will have to show to what extent the mere awareness that numerous other people complete the same tasks, read the same texts, and learn the same contents at the same time can be beneficial or disadvantageous. From a social psychological point of view, benefits such as enhanced creativity or social facilitation can result in a "wisdom of the crowd" from which individual learners can significantly benefit. At the same time, less desirable social dynamics such as toxic disinhibitions or social loafing can lead to less constructive and homogenous solutions and learning results. To explore when and how these mechanisms arise, experimental tests employing more subtle or even implicit measures on the participants' mindset can be helpful. Also, experimental settings manipulating the perceived number of participants will advance our state of knowledge regarding these newly emerging open educational settings.

Especially aspect (b) is in line with our general argumentation that a mixture of mass collaboration and small group activities will be most beneficial with regard to optimizing student motivation, engagement, and learning outcome.

With respect to the specific course concept presented here, some additional aspects should be discussed in the following. While typical elements of MOOCs such as videos and quizzes and a self-paced learning strategy were implemented, our online course was not openly accessible to everyone but for students of two universities only. In this line, it could be argued that this concept and the actual number of participants of the present case study might not represent a mass collaboration in its traditional sense. However, in our view, the present data provides knowledge about how tasks involving a group larger than a typical class size can be implemented. We believe that this course addresses typical characteristics of mass collaboration processes (in the sense of a large group pursuing a common goal—in this case, e.g., the final exam) as well as specifics of massive open online courses in the sense of a certain heterogeneity of participants. Heterogeneity is realized here in terms of different age levels, study program backgrounds, different levels of academic progress, as well as a certain degree of involvement of students with other than German roots. Also, besides requiring regular completion of quizzes and individual assignments, we asked students to work in the small group workshops in which we set deadlines for the completion of the tasks. Not only because of the deadlines but also because people had to coordinate their inputs, our concept deviated from the time independence of typical MOOCs. However, the concept can be easily adapted for larger groups of people and also expanded for international use. Independent from the specific content used in this course, the course elements (e.g., video and text material) and sorts of tasks (e.g., handing in, answering and discussing potential exam questions) can be used in diverse fields and can be set up in platforms other than Moodle as long as they offer similar functionality. The concept is therefore widely applicable to other contexts and platforms.

Certainly, a number of open questions need to be addressed with regard to the evaluation of the course and future developments and system design. First of all, it should be asked if the results obtained for this group also hold true for other than student groups. In a more general sense, it needs to be asked how these courses can be used in lifelong learning scenarios with very heterogeneous groups and if potentially different motivational patterns (e.g., receive credits vs. just taking the course for fun) are compatible. Furthermore, it remains open, if such courses are interesting because of their novelty or are attractive beyond their novelty effect because people perceive a high need fulfillment. Future systems should assess individual preferences so that the environment is able to offer varying degrees of interaction tailored to the learners' current needs. As already mentioned above, also technical solutions for grouping participants for small group tasks should be developed. Subsequently, it should be tested how diverse a group can be and how much diversity and similarity a group needs or can take to be successful. Moreover, future projects should address how much guidance is necessary, at what times and by whom—can course members take this role, can self-organization in the sense of cMOOCs be successful, and how can this be triggered? May technical implementations be helpful for the organizer to follow up on the "mood" of the course participants? Can critical phases in individuals or groups be automatically identified, so that organizers have a chance to intervene in early stages of loss of motivation? And similarly, can dropout be predicted from specific behavior in the online course (Yang, Sinha, Adamson, & Rose, 2013)?

In sum, lessons learned from this course open up a variety of aspects that should be considered in future course concepts and can be addressed from and by different disciplines. From an analytical point of view, an MOOC-like environment offers a number of different data types and research perspectives that can be taken. Besides focusing on self-report data in questionnaires and in-depth interviews, it proved to be valuable to have a look at the actual behavioral data (learning analytics, log file analysis, or social network analyses). Different methods from various disciplines, e.g., psychology and computer science, may thus be fruitfully integrated as shown by Ziebarth et al. (2015).

All in all, this study gives an overview on a semi-open online course adapting MOOC-like involving mass and small group collaboration elements. It shows that the environment does not only provide a valuable new instructional format but can also be used as an interesting platform for research as well.

References

Allport, G. W. (1954). *The nature of prejudice*. Cambridge, MA: Perseus Books.

Bandura, A. (1965). Influence of models' reinforcement contingencies on the acquisition of imitative responses. *Journal of Personality and Social Psychology, 1*, 589–595.

Bandura, A. (1971). *Social learning theory*. New York, NY: General Learning Press.

Beran, T., Drefs, M., Kaba, A., Al Baz, N., & Al Harbi, N. (2015). Conformity of responses among graduate students in an online environment. *The Internet and Higher Education, 25*, 63–69.

Bremer, C., & Weiß, D. (2013). Massive open online courses: Kategorisierung und Analyse des Teilnehmerverhaltens am Beispiel der OPCOs 2011 und 2012. In T. Köhler & N. Kahnwald (Eds.), *Online communities, enterprise networks, open education and global communication. 16. Workshop GeNeMe'13* (pp. 305–316). Dresden, Germany: TUD Press.

Chukwunonso, F., Ibrahim, R. B., Selamat, A. B., Idama, A., & Gadzama, W. A. (2013). The impact of the internet and the world wide web on distance and collaborative learning. In J. Terzakis, C. Paleologu, & T. Gyires (Eds.), *ICCGI 2013, The Eighth International Multi-Conference on Computing in the Global Information Technology* (pp. 7–15). Wilmington, DE: International Academy, Research, and Industry Association.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research, 64*, 1–35.

Cramton, C. D. (2001). The mutual knowledge problem and its consequences for dispersed collaboration. *Organization Science, 12*, 346–371.

Dunbar, R. I. M. (1993). Coevolution of neocortical size, group size and language in humans. *Behavioral and Brain Sciences, 16*, 681–694.

Engeström, Y. (2004). New forms of learning in co-configuration work. *Journal of Workplace Learning, 16*, 11–21.

Festinger, L. (1954). A theory of social comparison processes. *Human Relations, 7*, 117–140.

Forsyth, D. R. (2009). *Group dynamics*. Pacific Grove, CA: Brooks/Cole.

Gordon, N. (2014). *Flexible pedagogies: Technology-enhanced learning*. York, England: The Higher Education Academy.

Halawa, S., Greene, D., & Mitchell, J. (2014). Dropout prediction in MOOCs using learner activity features. *ELearning Papers, 37*, 1–10.

Hill, J. L. (1996). Psychological sense of community: Suggestions for future research. *Journal of Community Psychology, 24*, 431–438.

Ho, S. H., & Huang, C. H. (2009). Exploring success factors of video game communities in hierarchical linear modeling: The perspectives of members and leaders. *Computers in Human Behavior, 25*, 761–769.

Holder, B. (2007). An investigation of hope, academics, environment, and motivation as predictors of persistence in higher education online programs. *Internet & Higher Education, 10*, 245–260.

Kay, J., Reimann, P., Diebold, E., & Kummerfeld, B. (2013). MOOCs: So many learners, so much potential …. *IEEE Intelligent Systems, 28*, 70–77.

Koschmann, T. (2002). Dewey's contribution to the foundations of CSCL research. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community: Proceedings of CSCL 2002* (pp. 17–22). Boulder, CO: Lawrence Erlbaum.

Kumar, M. P., Packer, B., & Koller, D. (2010). Self-paced learning for latent variable models. *Advances in Neural Information Processing Systems, 23*, 1189–1197.

Latané, B., Williams, K., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37*, 822–832.

Lipponen, L. (2002). Exploring foundations for computer-supported collaborative learning. In G. Stahl (Ed.), *Proceedings of the conference on computer support for collaborative learning: Foundations for a CSCL community* (pp. 72–81). Boulder, CO: International Society of the Learning Sciences.

Michinow, N., & Primois, C. (2005). Improving productivity and creativity in online groups through social comparison process: New evidence for asynchronous electronic brainstorming. *Computers in Human Behavior, 21*, 11–28.

Neubaum, G., Wichmann, A., Eimler, S. C., & Krämer, N. C. (2014). Investigating incentives for students to provide peer feedback in a semi-open online course: An experimental study. *Proceedings of The International Symposium on Open Collaboration, OpenSym'14*. New York, NY: ACM. doi:10.1145/2641580.2641604.

Oeberst, A., Kimmerle, J., & Cress, U. (2016). What is knowledge? Who creates it? Who possesses it? The need for novel answers to old questions. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass Collaboration and Education*. Cham, Switzerland: Springer

Ounnas, A., Davis, H. C., & Millard, D. E. (2009). A framework for semantic group formation in education. *Educational Technology & Society, 12*, 43–55.

Piezon, S. L., & Donaldson, R. L. (2005). Online groups and social loafing: Understanding student-group interactions. *Online Journal of Distance Learning Administration, 8*. Retrieved from http://www.westga.edu/~distance/ojdla/winter84/piezon84.htm.

Rheingold, H. R. (1991). *Virtual reality*. New York, NY: Summit Books.

Ritzmann, S., Hagemann, V., & Kluge, A. (2014). The training evaluation inventory (TEI)—Evaluation of training design and measurement of training outcomes for predicting training success. *Vocations and Learning: Studies in Vocational and Professional Education, 7*, 41–73.

Rodriguez, O. (2013). The concept of openness behind c- and x-MOOCs (Massive Open Online Courses). *Open Praxis, 5*, 67–73.

Rovai, A. P. (2000). Building and sustaining community in asynchronous learning networks. *Internet and Higher Education, 3*, 285–297. doi:10.1016/S1096-7516(01)00037-9.

Salomon, G., Globerson, T., & Guterman, E. (1989). The computer as a zone of proximal development: Internalizing reading-related metacognitions from a reading partner. *Journal of Educational Psychology, 81*, 620–627.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1*, 37–68.

Schulmeister, R. (Ed.). (2013). *MOOCs—Massive open online courses*. Münster, Germany: Waxmann.

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2*, 3–10.

Stahl, G. (2000). A model of collaborative knowledge-building. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences* (pp. 70–77). Mahwah, NJ: Lawrence Erlbaum Associates.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409–426). Cambridge, England: Cambridge University Press.

Suler, J. (2004). The online disinhibition effect. *Cyber Psychology & Behavior, 7*, 321–326.

Terras, M. M., & Ramsay, J. (2015). Massive open online courses (MOOCs): Insights and challenges from a psychological perspective. *British Journal of Educational Technology, 46*, 472–487.

Vygotsky, L. S. (1962). *Thought and language*. Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Walther, J. B., & Bunz, U. (2005). The rules of virtual groups: Trust, liking, and performance in computer-mediated communication. *Journal of Communication, 55*, 828–846.

Wellman, B. (1999). The network community: An introduction to networks in the global village. In B. Wellman (Ed.), *Networks in the global village* (pp. 1–48). Boulder, CO: Westview Press.

Yang, D., Sinha, T., Adamson, D., & Rose, C. P. (2013). Turn on, tune in, drop out: Anticipating student dropouts in Massive Open Online Courses. Paper presented at *NIPS Data-Driven Education Workshop*, Lake Tahoe, NV. Retrieved from http://lytics.stanford.edu/datadriveneducation/papers/yangetal.pdf.

Ziebarth, S., Neubaum, G., Kyewski, E., Krämer, N.C., Hoppe, H.-U., Hecking, T., & Eimler, S. C. (2015). Resource usage in online courses: Analyzing learner's active and passive participation patterns. *11th International Conference on Computer Supported Collaborative Learning*, Gothenburg, Sweden.

Socio-Technical Procedures of Facilitated Mass Collaboration for Creative E-Participation

Thomas Herrmann

Democratic Dialogues as Mass Collaboration

Mass collaboration has been described according to the different contexts of various tasks to which it can contribute. Most prominently, it has been analyzed in the context of collaborative knowledge construction (Cress & Kimmerle, 2008) within Wikipedia. This analysis is referred to in various chapters of this book. Other areas where mass collaboration is applied include, for example, citizen science (Chapter "Citizen Science: Connecting to Nature Through Networks" by Barron, Martin, Mertl, & Yassine, 2016; Dickinson et al., 2012), open innovation (Lakhani & Panetta, 2007), and others. This chapter describes mass collaboration in the context of citizen dialogues, e-participation, or democratic dialogues (see section "*Theoretical Background*," Pruitt & Thomas, 2007) which pursue the development of innovative solutions for societal challenges.

The underlying questions in this chapter are:

1. How can a large number of people be supported in contributing their opinions and experiences to the solving of problems in the societal context?
2. How can the creativity of the contributors be encouraged so that they can develop innovative ideas which go beyond the concepts, goals, and measures that have already emerged from the professional, political arena?
3. How can democratic principles be fostered such that equal weight is given to the participants' contributions even if they are contradictory or diverge in direction?
4. How can a large number of people be involved in such a way that their ideas and beliefs are compared with each other and an opportunity for synergetic convergence is provided?

T. Herrmann (✉)
Department of Information and Technology Management, Institute for Applied Work Science, University of Bochum, Bochum, Germany
e-mail: thomas.herrmann@rub.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_15

The last question addresses the problem as to whether mass collaboration in the context of democratic dialogues mainly focuses on collecting information and opinions from a lot of people, or whether democratic dialogues can enable real interaction and exchange where collaboration takes place, as CSCL is understood by Dillenbourg (1999).

All four questions were derived from the case presented here of a German citizen dialogue on demographic change, where six meetings were conducted in six German towns with about 80 participants in each place. The citizens were invited to exchange their experiences and to contribute to solutions for urgent societal problems being caused by demographical change. The analysis of this case does not definitively answer the four questions by directly observing the participants' or the organizers' behavior but provides the reasons to raise them. The answers provided here are derived by interpreting the background of the occurring problems in the context of theoretical findings. This citizen dialogue was not conducted by means of Web 2.0 but was organized and facilitated through a series of face-to-face meetings. The constellations of this case give us the opportunity to analyze the effects of conventionally organized political participation, mainly to understand its potentials and deficits. The analysis is run in an explorative way, and the interpretation of the observations could serve as a basis for answering the four questions above by drafting possible solutions.

The case is also an example of a kind of mass collaboration which is different from Wikipedia as one of the most intensively discussed phenomena of mass collaboration: The case presented here was initiated from outside and not from within the community of the collaborators. Most of the participating citizens were not experts within any certain knowledge domain. Instead, they were political laypersons and had no background as researchers or academics. The tasks did not involve collaborative writing, but involved mainly the exchange of oral statements within a discourse. The statements were only partially noted down by a person playing the specific role of a note-taker.

However, there are also similarities between this case and Wikipedia, since knowledge construction and learning did take place in this setting. We could observe that a variety of personal experiences were exchanged and merged. With "knowledge construction," we refer to cyclic procedures of knowledge building where personal beliefs are articulated and succeedingly challenged by others' perspectives to achieve a new level of shared understanding about the topic under discussion (Herrmann, 2003; Stahl, 2000). Because of the effects of technically enhanced mass collaboration within the area of knowledge construction, we view Web 2.0 applications as an opportunity to include more people more efficiently in citizen dialogues, as is e-participation (Macintosh, 2004). We suggest that the combination of e-participation and mass collaboration requires designing a socio-technical process: On the one hand, appropriate technical features have to be included. On the other hand, organizational measures have to be taken—mainly with respect to coordination and facilitation—to make sure that the numerous contributions relate to each other and are effectively tied together. The purpose of citizen dialogues and e-participation usually goes beyond deciding among prescribed options in that the attempt is to develop and propose new choices. Therefore, the socio-technical process must also encourage the participants' creativity. With respect to answering the four questions listed above, our approach is to identify the relevant elements in a socio-technical process of mass collaboration which support the emergence, collection, merging, and convergence of the potentially manifold contributions.

From a methodological point of view, the complexity of supporting mass collaboration for citizen dialogues demands that four theoretical viewpoints be taken into account:

- The concept of collaboration which goes beyond that kind of cooperation which merely focuses on the collecting of a large number of contributions
- The approach of e-participation
- The need for facilitation and coordination in the context of mass collaboration
- The concept of collaborative creativity

The empirical methods were determined by the explorative approach. The author took part in the citizen dialogue as an invited expert in two towns and in the final summit. The documents which accompanied the dialogue were analyzed, and the process and the outcome of the dialogue were described. It was possible to listen in on the organizers' planning of the dialogue and to observe how far this plan was brought into reality. These observations and their interpretation were checked and completed by a second expert who took part in one town meeting and in the summit.

In the following sections, we first describe the concrete case of mass collaboration—the German citizen dialogue on demographic challenges. Afterward, we outline the theoretical background of the intersection of mass collaboration, democratic dialogues, coordination and facilitation, as well as collaborative creativity support. The observations made are discussed in the light of these theories to understand what the advantages and challenges would be if such a citizen dialogue were transferred to online-mediated mass collaboration. Finally, the requirements for a socio-technical procedure of facilitated creative e-participation are outlined, and relevant research questions are assigned to the proposed socio-technical design.

The Case of a Citizen Dialogue

In 2012, the Federal Ministry of Education and Research initiated a citizen dialogue on demographic change which took place in six midsize cities for one day. The goals were that the citizens would be offered the opportunity to inform themselves, to build a substantiated opinion by communicating with experts, to discuss topics of shaping the future, and to develop a range of opinion and proposals for actions (based on the support of experts). The citizen dialogue on demographic change was focused on three topics: living together, working life, as well as lifelong learning and education (Bürgerreport, 2013). Each topic includes subthemes.

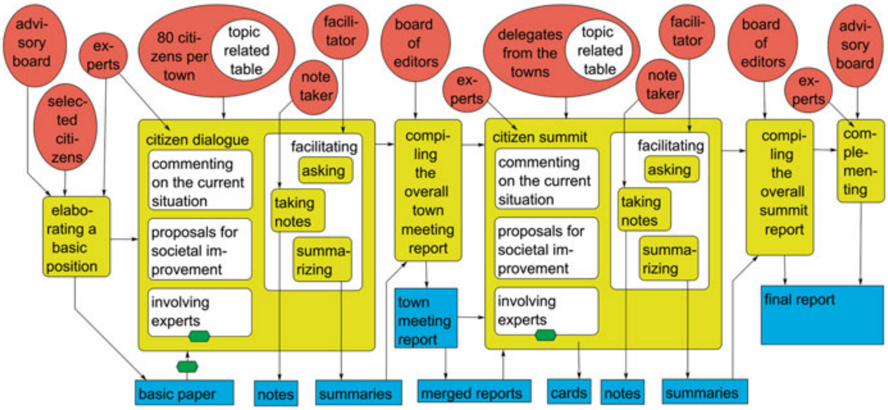


Fig. 1 The process of the citizen dialogue

The process of the citizen dialogue is displayed in Fig. 1. Every citizen dialogue lasted a whole day. At the beginning, the goals of the citizen dialogue were presented. The citizens were asked to start with their own experience with the regional problems of their town and subsequently focus on recommendations to meet nationwide political challenges. The underlying expectation was that the dialogue would support the emergence of innovation and employ creativity to potentially go beyond those solutions which were already under discussion in Germany. To support innovation and richness of ideas was one of the clear goals of the citizen dialogue, which was organized by a company of professional facilitators. At each meeting, a group of up to eight experts was introduced. About half of them came from a context of local politics and administration and were familiar with regional problems. The other half were researchers in the area of demographic development who were familiar with nationwide trends and knowledgeable about relevant projects which deal with demographic challenges. The experts were expected to contribute to innovativeness by helping the citizens understand what knowledge and solutions were already under discussion in Germany and which ideas had been already tried out in other contexts. For further support, a paper with basic information was developed in advance and made available for the participants before the dialogue started.

The citizen dialogue was focused on ten subthemes. Each of these was assigned to one round table where the discussion was coordinated by a facilitator and supported by an assistant who took notes to document the conversation. The discussants were encouraged to reflect upon their own experience with regional problems and to make proposals for societal improvement. The facilitators tried periodically to summarize orally the discussion in accordance with the notes taken, and they encouraged the participants to express their opinions and to engage in critical discourse. The proposals for summaries were partially modified by the discussants. The summaries from the different tables were noted and electronically transferred to a central board of editors who worked in the background to produce an overall summary of the whole day, covering the results of all ten subthemes. Before the end of the meeting, the compiled summaries were printed and handed out as a town meeting report to the citizens at the end of the day, to give them the feeling that their participation had contributed to a concrete product. The mix of participants at every table remained stable for the whole day. There was only marginal exchange among the tables: Two to three times the day, a representative of every table was chosen and asked to stand up and give brief (about 4 min) insight into the main statements which had so far been developed. Furthermore, the experts walked from table to table and offered their help. This gave them the opportunity to report about the findings of other tables. The organizers had planned for the experts to be actively integrated into the participants' discussions. However, this plan was not realistic. Instead, the experts were only rarely involved. Therefore, some of the experts occasionally offered help on their own.

After the six dialogues, all six town meeting reports were merged into one version by the organizers. The experts with a research background were then asked to review the outcome and to add those aspects to the report which they found missing. To be able to do this, the experts had been asked to take part in more than one citizen dialogue. The citizens themselves were not asked to participate in the editing of the merged reports. However, the result was again discussed at a so-called citizen summit in Berlin where about 90 representatives of the citizen dialogues came together to have another discussion on the basis of the merged town reports. They were asked to produce final proposals, which were once again summarized by the facilitators. This was carried out on the basis of notes at the various tables in the same way as it had been done at the town meetings. Finally, 350 concrete ideas for solutions which had been documented in the town meeting reports were converged into 31 proposals and documented in the *final report*. Additionally, in a final procedure, the proposals were ranked (Bürgerreport, 2013, p. 10). However, it remained unclear during the summit how exactly this list of ranked proposals would be used for further official political decision-making.

The whole procedure was also accompanied by an online forum where about 300 contributions were produced. However, it remained unclear from the perspective of the dialogue participants whether and how the online contributions had influenced the final report.

All in all, the following groups actively participated:

- Coordinators:
  - Overall facilitator
  - Table facilitator
  - Note-taker
- Experts:
  - From research
  - From city administrations, politics, or NGOs
- Citizens who volunteered to take part

It has to be noted that all meetings were initiated and coordinated by people who were not part of the group of citizens or experts. Consequently, the meetings were not self-organized from the inside by the participating discussants, but from outside by the organizers. Although it is usually expected that organizers and especially the facilitators stay neutral with respect to the topic under discussion, this requirement was hard to fulfill with such a topic of general interest. In this case, organizers and facilitators became gradually involved in the topic and developed their own beliefs with respect to the discussions. However, the facilitators were intent not to act on the basis of their opinions.

Theoretical Background: Mass Collaboration, E-Participation, Coordination, and Collaborative Creativity

Collaboration vs. Cooperation or Collection

Not every procedure in which a lot of people contribute in the context of a certain task necessarily represents a case of collaboration. Several types of interaction among many people based on Web 2.0 applications can be differentiated. Malone, Laubacher, and Dellarocas (2009) analyze the phenomenon of *collective intelligence* and propose the following differences between hierarchies and crowds. In hierarchies, people can assign certain tasks to others. By contrast, in crowds "… activities can be undertaken by *anyone in a large group who chooses to do so,* without being assigned by someone in a position of authority" (Malone et al., 2009, p. 4). Similarly, Dillenbourg (1999) states that collaboration is nonhierarchically structured and therefore can be characterized by symmetry of action, of status, and of knowledge among the participants. The way crowds carry out certain tasks differs when work is done independently or dependently and when something is created or decisions are made. Assigning independent subtasks to the main people who have contributed their individually achieved outcomes of these tasks to a compiled result is considered to be *cooperation* (Dillenbourg, 1999). Similarly, Malone et al. (2009) describe *collection* as contribution of items which are created independently, whereas they consider working together to create something to be *collaboration*. The question arises what "working together" exactly means. Dillenbourg, in the context of CSCL, points out that collaboration avoids division of labor, where work is split into subtasks to be carried out individually. According to him, collaboration is highly interactive, and the interactions are synchronous rather than asynchronous. The collaborators pursue shared goals and are mutually aware of them mainly because they have negotiated them. Closely working together also implies that criteria have been negotiated as to how the participants' contributions should be merged and fit together.

Thus, for Malone et al., dependent decision-making is "group decision" but is not collaboration. It includes activities like voting, finding consensus by final agreement of all participants, averaging of ranking, etc. Others describe "decentralized decision-making" as a part of mass collaboration (Fathianathan, Panchal, & Nee, 2009). With Dillenbourg (1999), voting and polling are not highly interactive and more on the side of cooperation—however, decision-making can be accompanied by discussions and negotiation (cf. McGrath, 1984, differentiation of task performing in groups). Therefore, we suggest that decision-making can at least imply phases of collaboration.

Dillenbourg (1999) emphasizes that interactions can be more or less collaborative. Consequently, the participation of a mass of people in contributing to tasks via Web 2.0 can include various ways of being related to each other—being part of a crowd can be mixed with hierarchies—collective contribution of independent items can be combined with collaboration. For example, the whole range of articles in Wikipedia represents a collection and a result of cooperation, while many of the single entries are the result of collaboration (Malone et al., 2009). Similarly, those activities which try to build links and to describe the relationships between Wikipedia articles (Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2014) can happen as the activity of collecting independent contributions or, by contrast, as collaborative activity. We suggest that the more direct the communication between people is, the more appropriate it is to describe their interaction as collaboration. This applies specifically to mass collaboration for the purpose of knowledge construction (Cress & Kimmerle, 2008), which is usually not understood as the automatic evaluation of a collection of information items—as in surveys, for instance. Instead, collaboration for knowledge construction is understood as an endeavor where diverging experience and opinions are compared, negotiated, and partially merged. As hidden-profile experiments reveal (Stasser & Stewart, 1992), the quality of collaboratively achieved decisions depends on the degree to which information being provided by others is consistently taken into account and how far the various perspectives of the participants are shared. Such a sharing goes beyond the mere exchange of information and requires close communicative interaction—as collaboration is characterized (Dillenbourg, 1999), since it supports the understanding, valuing, and integration of exchanged information.

With respect to the meetings of the citizen dialogue investigated here, collaboration took place at the table itself, while the merging of the table's outcomes into a final report was a result of collection and cooperation. The organizers identified subtopics and assigned them as independent subtasks to the tables, although the content of the subtopics was interwoven. By contrast, a more socio-technically enhanced procedure could aim to transform the collection of the tables' contributions into a collaborative endeavor, where participants would mutually report the various results to each other and reflect upon them. Furthermore, the hierarchy with organizers and the board of editors at the top and the participants at the bottom could be transformed into a more symmetrical relationship, so that the town meeting report could become a more jointly discussed subject.

E-Participation

Participative processes in political arenas are not mainly focused on knowledge construction, but they involve developing new knowledge and learning processes. The more political participation includes many people's experience, expertise, and perspectives, the higher the chance is that new solutions for societal problems will be found. Therefore, this type of participation is a considerable example of mass collaboration. However, we suggest that increased inclusion of many people requires certain socio-technical enhancement of the procedure.

Many participatory processes are organized to contribute to regional problems, as it is the case with urban planning (Arias, Eden, Fischer, Gorman, & Scharff, 1999). It is not only a matter of developing a variety of ideas but also of supporting the making of concrete decisions. The local context makes it easier to influence political decisions and to comprehend whether the participatively proposed solutions are turned into reality. Since the case of citizen dialogues described here deals with nationwide concepts and solutions, it offers little possibility of knowing whether the developed proposals will have any influence. It thus becomes apparent that the socio-technical challenge is to find means of following up on the effect of participative engagement.

The challenge of integrating a mass of people into political participation has a long tradition. Attempts have been made to develop organizational procedures to increase the scale of participating people—e.g., world cafés (Brown, 2005) or open space technology (Owen, 2008). These procedures are mainly supported by facilitators and coordinators who try to run large meetings in a way which complies with certain rules. Hartz-Karp (2005, p. 2) proposes the following building blocks as key elements of deliberative democracy:

- Participants who are representative of the population, seated in ways to maximize diversity;
- A focus on thoroughly understanding the issues and their implications;
- Serious consideration of differing viewpoints and values;
- A search for consensus or common ground; and
- The capacity to influence policy and decision-making …
- Deliberation: open dialogue, access to information, space to understand and reframe issues, respect, movement toward consensus.

Technology support had already become an important enabler for public participation before the advance of Web 2.0 applications. This is exemplarily described for the Twenty-first Century Town Hall Meeting (Lukensmeyer & Brigham, 2002). It "…enables thousands of citizens to simultaneously participate in intimate, face-to-face deliberation and contribute to the collective wisdom of a very large group." (p. 352). At the core of these meetings are multiple small group dialogues where "demographically diverse groups of ten to twelve participants come together with the support of a trained facilitator for in-depth discussion of values and key aspects of the issue under consideration." (p. 353). The interaction within and among the groups is supported with networked computers which are used to create records of the ideas exchanged, wireless transmission to a central editorial board which distills proposals for a voting process, electronic exchange of comments between small groups, keypads for continuous voting, and large screens to present data and collected ideas in real time for all groups. Most of those possibilities were not employed for the citizen dialogue presented here, with the exception of wireless transmission of text to a central board.

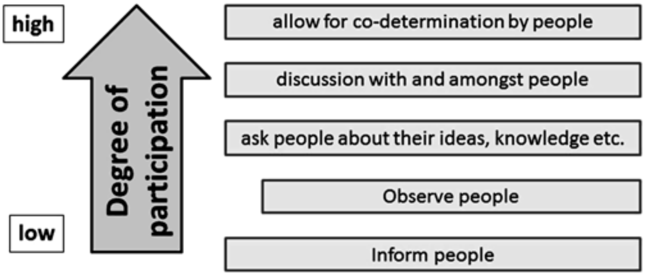


Fig. 2 Levels of participation

With the emergence of Web 2.0, the kinds of meetings above can be substituted by various types of mediated communication, forums, and platforms to support communities. However, it seems that the wealth of experience in how these kinds of meetings are initiated, coordinated, facilitated, framed by rules, supported by note-taking and visualization of results, etc. is not systematically transferred to Internet-based mass collaboration and e-participation. The type of organization and the chosen features for technical support depend on the degree to which participants are allowed to participate and have influence.

Figure 2 represents various levels of participation. The highest degree, the possibility of real codetermination, applies only to a few cases. For instance, the German law on industrial relations allows the employees to elect a work council as representatives of the personnel. For certain issues the work council has the right of codetermination, for example, whether and how workers' behavior will be automatically monitored (Betriebsverfassungsgesetz, §87(1)6). In many other cases, the work council has only the right to be involved as a consultant whose contributions do not necessarily have to be taken into account. This type of consultation represents the level in the figure of involving people in discussions. On the next lower level, there is no consultative discussion but only the opportunity to add an idea or some knowledge-based information to an ongoing decision process. In the realm of workers' participation, it is also argued that a more objective picture of people's needs evolves if a lot of them are systematically observed or surveyed instead of asking their representatives. We suggest that it is possible with the advance of technically enhanced mass collaboration to overcome the limitations of representative participation, by directly engaging a lot of voices and supporting them in taking a more active part in elaborated, consultative discussions. The weakest level is that people are only informed about plans and ongoing decision processes but cannot influence them. This is less a version of real participation and more an entry point which allows the participants to decide whether they want to become involved or not.

In the field of public participation, the goal is to complement the decision-making of political representatives through additional citizen influence. Also in this context, a differentiation of degree of involvement similar to that in Fig. 2 is proposed by Macintosh (2004, p. 2), to prepare a framework for e-participation:

- Information: a one-way relationship in which government produces and delivers information for use by citizens.
- Consultation: a two-way relationship in which citizens provide feedback to government. It is based on the prior definition of information. Governments define the issues for consultation, set the questions, and manage the process, while citizens are invited to contribute their views and opinions.
- Active participation: a relationship based on partnership with government in which citizens actively engage in defining the process and content of policy-making. It acknowledges equal standing for citizens in setting the agenda, although the responsibility for the final decision rests with government.

The case here of the citizen dialogue mainly supported information exchange, from governmental representatives to the citizens, among the citizens and back. The input of the citizens can be viewed as a starting point for considering their advice. But the citizen dialogue did not yield any real discourse as is meant by the category of "consultation." Apparently, Macintosh addresses a type of participation which needs a longer time period and can hardly be carried out in meetings of 1 or 2 days.

Most approaches of electronically enhanced inclusion of citizens focus on how to improve information gathering. For example, Phang's and Kankanhalli's (2008) framework for ICT-supported public participation mainly address what is involved in increasing citizens' ability to provide information and to properly evaluate it for the purpose of decision-making. By contrast, Macintosh (2004, p. 3) pursues an approach of ICT support which includes empowerment of the participants. She differentiates between:

- E-enabling is about supporting those who would not typically access the internet and take advantage of the large amount of information available. …
- E-engaging with citizens is concerned with consulting a wider audience to enable deeper contributions and support deliberative debate on policy issues. …
- E-empowering citizens is concerned with supporting active participation and facilitating bottom-up ideas to influence the political agenda.

The combination of e-engaging and e-empowering represents an approach where citizens not only serve as information providers but also as collaborative knowledge constructors who are directly involved in solving problems that affect them. For supporting e-engagement, she proposes tools for collaborative argumentation and argumentation visualization, along with "issue based information systems" (Kirschner, Buckingham-Shum, & Carr, 2003). There is a close connection between these systems and using dialogue mapping to make discussion processes and disputed items visible as proposed by Conklin (2005). To fulfill the expectations of e-empowerment, tools such as e-petitions or e-referenda are needed as well as discussion forums which help to establish communities of interest (cf. Macintosh, 2004, p. 4). Such tools give communities a platform to develop and declare mutual will. The level of participation of the citizens observed in this investigation could probably have been elevated by employing those technical means. However, it remains an open question whether and how the coordinative function of facilitation could have been integrated into this type of technically enhanced e-participation.

Facilitation and Coordination of Mass Collaboration

Organizing e-participation is usually coupled with coordinative tasks and rules of communication and therefore also with the task of professionally trained people who take on the role of facilitators. There is a wealth of literature describing how to facilitate meetings, especially for practitioners. The need for professional facilitation is commonly substantiated by referring to examples of ineffective and inefficient meetings or to their insufficient outcome (Briggs, Kolfschoten, De Vreede, Albrecht, & Lukosch, 2010). To overcome these deficits, the following responsibilities are assigned to the role of facilitators (cf. Schuman, 2012):

- Overseeing the setting of the meeting room, how people are seated and related to each other, which information sources they share, etc.
- Observing and influencing the social dynamics: resolving conflicts and disagreements, supporting the building of trust, and the valuing of participants' contributions
- Fostering creativity, e.g., with group brainstorming and other creativity techniques
- Promoting mutual understanding; visualization of information and dialogue structures
- Designing and facilitating the dialogue and the team process
- Supporting decision-making

On a more abstract level, facilitators' activities are listed as: manage agenda, observe group process, diagnose problems, design solutions, make intervention (Macaulay & Alabdulkarim, 2005). With respect to communication support, Herrmann and Kienle (2008) propose that facilitators are in charge of initiating discussions, focusing and directing attention, stimulating contributions, summarizing contributions, building bridges between diverging perspectives, revealing and avoiding misunderstandings, and coordinating the underlying procedure of a meeting. Also, in the context of organizing democratic dialogues (Pruitt & Thomas, 2007), it is required that people are needed who make sure that certain principles are acknowledged, such as the priority of asking questions, transparency, and self-reflection. Facilitators have the choice among several procedures which can be applied, depending on the goals of a democratic dialogue. A typical example is the following list of stages of a dialogue journey:

1. Starting out
2. Eliciting perspectives
3. Enriching perspectives and achieving understanding
4. Framing choices and deliberating
5. Deciding
6. Implementing and taking action (Pruitt & Thomas, 2007, p. 117)

Facilitators are in charge of designing such procedures, making sure that the course of a meeting complies with the chosen procedure if reasonable, and, if not, being flexible enough to adapt the procedure to the situation. Furthermore, the process of a deliberately participative dialogue consists not only of one but of a series of meetings, and the facilitators also have to take care of any activity which should take place between the meetings (Pruitt & Thomas, 2007, p. 136).

Apparently, facilitators are concerned with formal organizational tasks such as setting and pursuing an agenda on the one hand and—on the other hand—informal tasks requiring a lot of sensitivity for group dynamics and understanding of people's idiosyncrasies. Subsequently, facilitators should be able to reflect upon their role and their self-concepts (Schuman, 2012). This wide variety of tasks becomes relevant to the question of how far a facilitator's work can be integrated into a socio-technical mass collaboration which includes various types of technical support. Also important is whether or how the facilitators' tasks can be formalized and be delegated to software functionality.

The main concern of the facilitation which took place in the citizen dialogue case was the interaction of the small groups at the tables. Merging the table's contributions was more of an editorial task and less focused on facilitation. Also in the literature, the description of the facilitator's tasks is mainly grounded in the context of small group face-to-face meetings. However, there is an increasing attention toward the facilitation of (very large) groups and/or virtual teams. Typical examples for meeting support of large groups are world café (Brown, 2005) or Town Hall Meetings (Lukensmeyer & Brigham, 2002). For virtual teams (Duarte & Snyder, 2011), it is also proposed to use facilitation techniques. The task description is similar to what is expected in face-to-face meetings: taking care for the agenda of the meeting, keeping the group focused, being aware of the team dynamics, and summarizing decisions and actions.

All in all, the body of experience gained from running meetings suggests the need for somebody who guides the process of a meeting but is also not the "owner of the problem." Facilitators usually try to remain in a neutral position, remaining primarily interested in and concerned with the goals and the outcome of the meeting.

The need for somebody to take care of the coordination of collaboration seems to be quite obvious and of increasing relevance in the context of mass collaboration, since the number of people collaborating increases. However, in several cases, such as Wikipedia, the coordinative role is reduced to the task of supervising whether the rules are followed or have to be enforced or to be adjusted. The constellation of Wikipedia leads to the question as to whether human-based facilitation could be substituted by providing a structure for the content to be built by means of self-regulation or whether a real facilitator could still add some potential improvement to the coordination of mass collaboration. The literature on the role coordination within the realm of knowledge construction and collaborative learning sheds some light on this question.

Kittur and Kraut (2008) found that with respect to the article quality in Wikipedia, the relevance of coordination increases with the number of editors. They differentiate between implicit and explicit coordination. Both contribute to the quality of articles. Implicit coordination describes a task division where only a few editors do the main work of writing and others contribute subtasks such as revising, adding selected aspects, etc. Explicit coordination refers to the communication-based planning of how the article will be written. This kind of coordination by communication is also considered to be an opportunity where contributors adjust their perspectives and intentions to those of the others. In the case of an increasing number of editors, only implicit coordination leads to an improvement. Both types of coordination increase article quality when compared to constellations in which the editors work independently without any coordination, especially without discussion. Kittur's and Kraut's study reveal the strength of a coordinated collaboration mode compared to a mode of independent collection of contributions.

Kittur and Kraut do not focus on how coordination is initiated or instantiated, whether coordination is supported by someone's taking the role of a facilitator or by someone's proposing a procedure of how to proceed. The question of the relevance of proposing procedures of how to proceed with coordination is investigated by Wichmann and Rummel (2013) in the context of computer-supported collaborative learning. They found that proposing scripts which trigger students to do revisions in the course of collaborative writing had a positive effect on coherence (i.e., the integration of perspectives) in written articles. The script proposes that on the first day, texts should begin to be drafted, followed by a review phase on the second day, and revisions by rewriting on the third day. For the revision phase, the script proposes: "One person selects a sentence that needs to be revised and pastes that sentence into the discussion board. Another person then edits the sentence, and the third person in the group integrates it into the wiki-page." (Wichmann & Rummel, 2013, p. 265). This kind of task subdivision allows students to rotate among various tasks and is therefore still in accordance with Dillenbourg's (1999) understanding of collaboration. The script was not instantiated by a facilitator but was added as a textual recommendation to the discussion board. The students were also asked to plan their collaboration, and they complied with this request. It would be interesting to see whether the same effects (increased revision and coherence) could also be achieved or even be improved by the role of a facilitator who continuously provides prompts and flexibly adapts the proposed procedure.

Apparently, explicit coordination supports the shift from the mere collection of contributions to collaboration and helps to improve the results of collaborating, especially with respect to sharing perspectives. Coordination can be implicit or explicit and can be provided from outside via scripts or it can be based on procedures and interventions being provided by a facilitator. According to Wichmann and Rummel (2013), the literature findings suggest that scripting is only feasible if a division into subtasks is possible. Subsequently, it can be assumed that facilitators are helpful if they are needed to find reasonable subtasks and to assign them to the collaborators. This would seem to be the case if various opinions about a societal problem have to be merged into a summarizing report on feasible proposals for solutions.

However, in the context of mass collaboration, it may turn out to be difficult to employ human facilitation. It might be unrealistic to find a sufficient number of professional facilitators. Continuous interacting with facilitators and waiting for their interventions might also slow collaboration down and decrease willingness to participate. Therefore, it is relevant to consider possibilities for delegating aspects of facilitation to technical components—not primarily to replace the facilitator but to support him or her. Macaulay and Alabdulkarim (2005) describe various levels of facilitation support for e-meetings. The simpler versions are where facilitators record the content which is provided by the contributors or provide a dictionary of the key concepts and terms which are used. Another level is to support the facilitator in establishing the workflow for the procedure which is planned to coordinate the activities during the meeting. This is formal support which is only feasible if the social dynamics or the complexity of the problem do not require further interventions. Therefore, problem diagnosis is another option as a kind of support. On yet a higher level, Briggs, De Vreede, and Nunamaker (2003) propose groupware solutions as a means of replacing facilitators' activities, by integrating patterns (so-called ThinkLets) which mirror facilitation routines into the technical support. Their goal (Briggs et al., 2010) is not to replace the facilitator. They argue that "… computers are not yet sufficiently advanced that they can play the full role of a facilitator (p. 2)." Consequently, they seek to support groups of collaborators to helping them to facilitate themselves without the help of a professional facilitator. For example, they propose ThinkLets as a kind of groupware components which include scripts for guiding collaboration, but which can be modified or exchanged by the participants. The technical support is intended to help teams understand how professional facilitation works so they can behave like collaboration engineers. The basic idea is to provide "… a collection of simple, decoupled, highly configurable, elementary collaborative software components. Examples could be multi-user text trees, multicriteria polling tools, audio and video channels, voting tools, presence indicators, and shared document editors, to name but a few. The configurability of the components is important …" (Briggs et al., 2010, p. 3). This approach recognizes the relevance of facilitated coordination within collaboration and considers coordination as a task which has to be flexibly supported on a meta-level. Flexibility has special relevance if facilitation has to deal with group dynamics, building trust and valuing the participants' contributions. Those aspects also mirror the differences between a deliberate process of building political opinion and making decisions vs. collaborative writing and knowledge construction when domain expertise is called for. ThinkLets also support the phase of convergence in a way which helps to compare contributions in order to be able to combine, to merge, to modify, and to build synergy among several collectively added contributions before voting and prioritizing take place.

The described approaches—from facilitation of small face-to-face meetings to the coordination of mass collaboration and/or virtual teams—can also lead to further approaches where virtual collaboration of many participants is systematically and deliberately combined with series of face-to-face meetings such as those conducted in the citizen dialogues presented here. All in all, it turns out that coordination is especially necessary if an outcome of collaboration has to be documented and that this need increases with the number of participants. The more collaborators are included, the more an explicit coordination procedure is required. The more flexible this procedure needs to be, the higher the relevance of facilitation seems to be. Facilitation cannot be completely delegated to software applications but can be supported in a way which helps participants to take over the role of a facilitator.

Collaborative Creativity

Mass collaboration is also an area where creativity can emerge and be promoted. This is indicated in studies by terms such as "collective creativity" (Sanders & Stappers, 2008), "social creativity" (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005), and "collaborative creativity" (Mamykina, Candy, & Edmonds, 2002). The term "collaborative creativity" emphasizes that individuals actively interact to share their experiences with the goal of being creative.

In the context of mass collaboration, we propose to apply Guilford's (1959) differentiation between divergent and convergent thinking to phases of collective interaction. To produce divergent thinking requires the crowd-based collection of many varied relevant ideas which might help to solve a problem. Such a collection of ideas can be the result of widely independent brainstorming of many individuals. By contrast, convergence requires more than just a prioritizing of ideas, e.g., by voting, as it also requires collaboration, in the sense of Malone et al. (2009), differentiation between collecting and collaboration. The effort to produce a collaborative convergence of ideas includes perspective sharing, negotiation, merging of ideas, etc. and flexible switching between individual work in solitude and different modes of collaboration (cf. Herrmann, 2009).

The Internet provides a multitude of tools which support initiating and conducting brainstorming sessions where many people can take part. However, this presents two principle problems:

(a) The early literature on creativity emphasizes that idea generation needs a phase of preparation which provides a deliberate understanding of the problem to be solved (Wallas, 1926). This is also taken into consideration in practical guides for creativity support. For example, Osborn and Parnes (cf. Kaufman & Sternberg, 2006, p. 17) propose phases of mess finding, fact finding, and problem finding before idea generation can be started. Conducting such a phase-oriented procedure usually requires a facilitator.

(b) While typical problems of groupthink or "production blocking" (Diehl & Stroebe, 1987) might be avoided if individuals independently produce ideas via Internet, the problem of cognitive inertia remains relevant (Santanen, 2005). Cognitive inertia describes the tendency to stick with well-established concepts and trusted ways of thinking. This tendency hinders the emergence of new ways of unconventional thinking and combining ideas. To overcome cognitive inertia, creativity techniques are applied. A typical example is prompting (Santanen, Briggs, & Vreede, 2004), which stimulates individuals to overcome their established ways of thinking. For instance, facilitators prompt participants by asking them to consider a problem from another, unusual viewpoint or to try to transfer solutions from another field to the challenge under discussion.

There is a wealth of creativity support techniques which are designed to increase the creativity of small groups (e.g., De Bono, 1995). Those techniques have to be specific with respect to the difference between divergence and convergence. For example, a core brainstorming rule requires that contributions must not be criticized. By contrast, during convergence, a critical review of the ideas is a necessity. The ThinkLets approach both fosters ITC-based creativity and supports facilitation. The research challenge which remains is to investigate potentials and designs of transferring the small group support techniques to the conditions of mass collaboration.

We can summarize this section by pointing out that the intersection of e-participation, coordinated and facilitated mass collaboration, and collaborative creativity is a promising research area which has so far been neglected. The challenge is to prepare and support e-participation in such a way that the participants have a chance to develop innovative ideas which go beyond concepts which have already been under discussion in the arena of established representative politics. Meeting societal challenges requires not only collaborative knowledge construction and learning but also a deliberate exchange of diverging perspectives and negotiation under conditions of conflicting interests and subtle power relations. The more that diverging viewpoints and interests nurture the discussion, the higher the potential impact on knowledge construction might be.

Discussion of the Citizen Dialogue Case

The citizen dialogue case presented here is an instance of the differentiation described by Malone et al. (2009), where a large group's *collaboration* at the tables is mixed with *collecting* the results of the tables. The meetings seemed to be crowd based. However, at least informal hierarchies can be observed in the interactions, with the organizers and facilitators at the top of the pyramid, followed by the experts and partially by the well-informed opinion leaders at the tables, with the citizens at the bottom. With respect to *collaboration*, the main deficits were:

(a) Lack of exchange and networking among the topic tables and among the six town meetings. At each town meeting, there were one or two opportunities during the day to present the highlights of the discussion at a table to the other subgroups. This task was usually taken over by opinion leaders. There was no utilization of computer-based information exchange among the tables. The continuously growing body of notes which evolved at each table was not made available to the other tables. This was considered to be reasonable since every table was focused on its own topic. However, the decision whether to take into account what others had discussed or not was not left up to the participating citizens themselves.

(b) The citizens were not included in a real group decision process dealing with the final result, where the summaries of the tables were merged into a report in the evening. The report was compiled by a separate editorial board whose work was not influenced by the participating citizens. Since nationwide demographical challenges were the overall theme, it was not possible to focus the collaboration on concrete upcoming regional measures where discussants could have been

> involved in the decisions for action and their implementation. Subsequently, there was no real interaction with any political representatives who were in charge of making decisions related to the topics discussed.

We can assume from the evolving notes and the final report that collaborative *knowledge construction* and *learning* took place. Yet these processes were hidden and not publicly reflected upon. There was no real evaluation or reassurance about whether perspectives had been shared or how much the background and contributions of the participants were reciprocally valued.

The dialogue case does not address the higher levels of *participation* in Fig. 2: There was no participatory decision-making, either on the results described in the report or on the implementation of proposed concepts. Furthermore, the level of real consulting was not really reached, although vivid discussions took place: The final decision-makers—e.g., members of the governments or the parliament—were not involved in any phase of the discussion. Concludingly, the participation mainly involved elaborating mutually reflected upon statements about current problems and possible solutions. But these statements might or might not be taken into account by the political representatives. There was no built-in obligation to act upon the results of the dialogue. This seems to be a general problem of a democratic dialogue which addresses nationwide societal problems. With respect to Macintosh's (2004) differentiation, transformation of this dialogue case to Internet-based mass collaboration would only have resulted in a type of weak e-engagement but certainly not e-empowerment.

During the discussions at the tables, the participation was based on the equal right to contribute. We made the following observations: Especially in the phase of analyzing the situation, all participants tried to make some kind of contribution. During the phase of making proposals, those who had a more substantial information basis or a preconceived opinion dominated the communication and tried to push their ideas through. For a more intensive participative collaboration, it would have been helpful to provide more *transparency*: Participants should have been able to see the notes which were taken instead of only being provided with reading out a summary to them from time to time. Neither the process of filtering those ideas which were included in the report was transparent nor the process of compiling the report. It would have been advantageous if tools for visualizing and structuring the argumentation etc. had been applied. In the days after the meeting, experts were allowed to complete the report. However, this completion was not influenced at all by the citizens who had participated.

The kind of *facilitation* in the dialogues was coherent with the lower level of participation. The facilitators were focused on assuring that the preplanned phases were timely conducted in a timely way. Since the work at the ten tables had to be synchronized in time, flexibility in adapting the procedure to the needs of the participants was reduced. The discussion was dominated by the goals that the planned topics had to be dealt with and that contributions for the final report had to be extracted. From time to time, a concluding summary of phases of the discussion was read out to the citizens to ask them for their agreement to convey the summary to the board of editors. However, this was a weak way of trying to involve the citizens in the decisions. Since the notes were not visible to them and the summaries were only read out to them, they could not follow in detail which parts of the discussion were reflected in the summaries. Therefore, they had no influence on the final outcome which was submitted to the editors. Furthermore, there was no opportunity to control whether a summary was eventually represented in the final report.

From time to time, the facilitators tried to activate the more passive people and to reduce the influence of opinion leaders. However, these interventions took place only if the group discussion was proceeding according to the timetable. The discussion obviously suffered from production blocking (Diehl & Stroebe, 1987). The facilitators did not apply any creativity techniques to foster idea generation. The one exception was at the final summit when cards were collected to give the participants time to develop their ideas and make them visible to others.

There was no subtle *coordination of the collaboration*. The participants could discuss the statements which were proposed to the editorial board to be included in the report. However, the criteria of the decisions—whether a participant's contribution was noted down, became included in a summary, or was finally represented in the report—were neither reflected upon nor discussed. The discussions were more about opinions and less about results. No splitting into more detailed subphases or subtasks took place, which could have helped the participants to work more intensively and in more detail with the emerging proposals—e.g., to do research via the Internet about the discussed proposals and ideas. No script or procedure was offered, which would have helped merge, synergize, or modify contributions in a negotiation process.

Use of technology was mainly dedicated to the support of the facilitators, note-takers, and editors, but not the citizens. The rationale behind this decision seems to be that the organizers did not intend to make the participants feel as if they need to know how to use a computer and to do so. Such an expectation as well as the usage of ICT could have been distracting for some people or might have put them into a disadvantageous position. However, the use of displays to distribute information would have been a less disturbing technology.

Apparently, transferring the meeting of these groups to an Internet-based type of mass collaboration could have offered some advantages: Subtasks could have been delegated to the participants, such as note-taking, summarizing, reviewing text, or rewriting it. Even the task of facilitating could have been partially delegated, and the discussion could have been partially conducted in breakout groups. Tools could have been applied to support the comparison, clustering, and merging of contributions, as well as to offer possibilities of voting, ranking, and negotiation for group decision-making.

However, it has to be taken into account that current versions of mass collaboration rely on people's ability to provide written contributions. This can be awkward and establish barriers in the realm of democratic dialogues, since expressing political opinions about complicated issues can require a high capacity for articulation. In oral discussion, there seems to be less willingness to participate in situations where written contributions are required which might possibly be displayed to the public.

The content of the discussion and the documented results justify the assumption that most of the participants did not have the opportunity to be *prepared* at a level which could have enabled them to contribute ideas new to the nationwide societal discourse. The paper providing the basics was available but was not discussed in any way that deepened the understanding of its theses or that encouraged systematic exchange of the discussants' various perspectives on the main statements. The organizers tried to intensify the preparation by asking the experts to give presentations and to answer questions during an interview in front of the whole audience of a town meeting. However, after the first town meetings, the expert presentations were withdrawn, because the citizens felt that the longer expert statements were a distraction and a kind of paternalism. It was then agreed upon that experts would stay passive until the participants asked them questions to fill a perceived knowledge gap. However, it was hard for the participants themselves to realize whether they lacked knowledge—e.g., whether an idea they were elaborating on had already been tried out or implemented somewhere else. Consequently, it was difficult for the participants to reach a level where they could contribute proposals with a certain degree of novelty. All in all, the citizens were highly interested and willing to be engaged, but were not necessarily prepared enough to contribute new ideas. At least the level of preparation was heterogeneous. It was obvious that the participants also had different levels of affinity with the Internet as a source for becoming well informed. Valuable information in the context of the citizen dialogue is documented in the Internet. An option for improvement might have been to nudge the participants to use the Internet before the meetings took place to improve their knowledge.

With respect to *creativity*, facilitators did not make a clear distinction between divergent and convergent production. Brainstorming phases for producing a huge number of ideas without being disturbed by critical remarks were rare, and prompting the discussants to overcome cognitive inertia was rare as well. Participants made proposals which they thought were new but which were not. They were not aware of the fact that most of their proposals had already undergone a practical test and the results of these tests were not available to them. The participants were very strongly focused on practical knowledge concerning the problems of the more local region, and they therefore collected very concrete examples. However, they were not systematically supported in deriving options for societal innovation with nationwide relevance beyond the singular experiences and interests they articulated. Consequently, there were hardly any contributions which had not already been discussed in the context of political activities. Only at the summit was the effort made to produce results with innovative relevance for political decisions. However, for the participants themselves, the citizen dialogue did provide the opportunity to improve their ability to make political statements which revealed reflection about their personal experience and the situation in their region.

All in all, the most challenging issue appears to be to establish a procedure of making a huge number of contributions converge and to exploit the potential for synergy and novelty. The higher the number of participants and the more creativity and innovation are expected, the more crucial coordinative facilitation is to enable true collaboration which relates as many contributions as possible to each other. Specifically in this dialogue case, the interaction among the tables should have been increased by additional coordinative support.

Perspectives of Socio-Technical Support of Mass Collaboration for Creative E-Participation

Designing and understanding Internet-based mass collaboration for creative democratic dialogues is an interdisciplinary challenge which requires the integration of technical and organizational measures. Transferring large, facilitated, face-to-face meetings to technically mediated mass collaborations can reap benefits but also implies risks. To achieve improvement with respect to the case described here, the socio-technical design would have had to integrate findings from web-design, cognitive psychology, and political science concerning enabling participatory democratic dialogues of large groups. Practical and empirical knowledge about the facilitation of groups should have been applied. Typical psychological barriers to be overcome are production blocking, cognitive inertia, and hidden-profile problems.

The strengths of Internet-based phases of *divergent production* are that a lot of different people can independently contribute a large number of ideas. As an answer to the first and second questions in the introduction, the collecting of manifold contributions can be socio-technically promoted and improved by:

- Encouraging and supporting the formation of subgroups which include an appropriate mix of divergent perspectives.
- Providing prompts—by a facilitator or other contributors, or automatically—which inspire new ideas and help to overcome habitual ways of thinking.
- Providing the possibility to see what others have contributed at an appropriate point in time; being aware of others' contributions can be a source of inspiration (Herrmann, Nolte, & Prilla, 2013); if it happens too early, it can distract from the flow of production.
- Lowering the threshold of entering date, e.g., by offering speech recognition and people who help to edit textual contributions.

Although it was awkward for the participants that the note-taking was not visible for them in the dialogue case, it was an advantage that they could express their contributions orally without having to worry about well-formulated text passages. In the case of a computer-mediated mass collaboration, it would be advisable to collect contributions in small groups before they are made public to a larger group. The advantage of small groups is that roles can informally emerge which take care of proper formulations in collaboration with the contributors.

Supporting the *phase of convergence* (cf. questions 3 and 4 of the introduction) is more challenging, since it requires—at least from an idealistic viewpoint—that contributions are reciprocally valued and that perspectives are compared and partially shared to build coherence (Wichmann & Rummel, 2013). An appropriate socio-technical procedure can assure that contributions are valued and exploited in deciding how much they can be included in the overall result. Such a procedure requires:

- Prompting and facilitation which initiates the phases of collaboration where contributions are compared, additional group members are invited, passive people are activated, relations are built between the collected items, etc.

- Proportional representation of opinions and interests within those small groups or boards which take on the task of scanning through the contributions, to cluster and to merge them and eventually integrate them into a preliminary or final documentation.
- Support of explicit coordination of and reflection upon criteria and modes of coordination. Compared with Kittur's and Kraut's (2008) findings, leaving the coordination in democratic dialogues to a small group of editors may lead to dominance of opinion leaders and minimize the opportunity for equal participation.
- Deliberate splitting into subtasks can promote collaborative elaboration of the collected contributions and help to increase the degree of novelty. Those subtasks can cover additional research, reviews, rewriting, facilitation, etc.
- Complementing pure voting or ranking in the context of group decision-making with collaborative negotiation. Hidden-profile problems (Stasser & Stewart, 1992) may lead to the effect that people prioritize those contributions which are most familiar to them, while new insights beyond their habitual ways of thinking are neglected. To avoid this problem, the phases of discussion and negotiation can help to draw more attention to unusual contributions and their background. Carell and Herrmann (2009) propose a script about how voting and negotiation can be combined.

Flexibly switching among the different phases of preparation, divergence and convergence must be made possible, since it can turn out that during one phase of a dialogue, another phase has to be repeated. Similarly, the participants should be supported in switching between modes (Herrmann, 2009) of independent collection of contributions and closely coupled collaboration; breakout groups should be flexibly initiated if needed, work in solitude should possibly alternate with interacting in large groups, and taking on various roles or subtasks should be encouraged as well as the informal emergence of certain roles (Jahnke, Ritterskamp, & Herrmann, 2005). Flexible switching and smooth transitions among various tasks and modes of interaction are prerequisites for supporting collaborative creativity. Creativeness requires phases of incubation (Wallas, 1926). Therefore, it is an advantage that Internet-based mass collaboration works asynchronously and allows the participants more time for their contributions. However, the atmosphere at the face-to-face meetings promoted intensive discussions where people seem to be highly engaged comparable with phases of flow (Csikszentmihalyi, 1999). From this point of view, the socio-technical procedure for mass collaboration could benefit from combining online collaboration with face-to-face meetings in a series of collaborative events.

With respect to an achievable *level of participation*, it became apparent that the people collaborating could become more influential if a concrete problem were addressed by which they were personally affected. More importantly, if participants knew they would be informed about and connected to any real implementation of the solution they were involved in, they could be more motivated to participate and contribute. In Wikipedia, the resulting outcome of collaboration in knowledge construction is immediately realized in the Wikipedia article itself. In political participation, the outcome is much more indirectly related to the textual descriptions of potential solutions. In a political context, citizens collaborate to make decisions with the goal of having them eventually mirrored in political programs. Therefore, a concept of socio-technical mass collaboration for democratic dialogues has to include those political representatives who are decision-makers with respect to the topics under discussion. They have to be included in the Internet-based communication channels. The technological means of the Internet may help to make the effects of participatory influence on political decisions more visible.

A socio-technical design which takes the above-outlined requirements into account has to be investigated with research into the following questions:

- To what extent are people encouraged to relate their ideas to each other and have special awareness for contributions which go beyond their established opinions and way of thinking?
- To what extent can participants be motivated and be supported in preparing themselves to become aware of existing knowledge or expertise and to apply them to their own contributions, in order to have a chance to go beyond existing concepts?
- How far can the opinion-leader vs. follower relations, which are especially observable in the political arena, be transformed into more symmetrical relations?
- How can a smooth transition among various modes of interacting be supported—especially from mass contribution to mass collaboration?
- Which facilitation strategies are efficient (such as visualization, prompting, etc.) to support the shift from just adding masses of contributions to making them converge into a synergetic result?

References

Arias, E. G., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (1999). Beyond access: Informed participation and empowerment. In *Proceedings of International Conference on Computer-Supported Collaborative Learning* (pp. 20–32). Palo Alto, CA: International Society of the Learning Sciences.

Barron, B., Martin, C. K., Mertl, V., & Yassine, M. (2016). Citizen science: Connecting to nature through networks. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Briggs, R. O., De Vreede, G. J., & Nunamaker, J., Jr. (2003). Collaboration engineering with ThinkLets to pursue sustained success with group support systems. *Journal of Management Information Systems, 19*, 31–64.

Briggs, R. O., Kolfschoten, G. L., De Vreede, G. J., Albrecht, C. C., & Lukosch, S. G. (2010). Facilitator in a box: Computer assisted collaboration engineering and process support systems for rapid development of collaborative applications for high-value tasks. In *Proceedings of the 43rd Annual Hawaii International Conference on System Sciences (HICSS'10)*. Los Alamitos, CA: IEEE.

Brown, J. (2005). *World café. Shaping our futures through conversations that matter*. San Francisco, CA: Berrett-Koehler.

Bürgerreport (2013) Bürgerdialog Demografischer Wandel—Wie bleibt unser Land ideenreich und innovativ? Retrieved from www.bmbf.de/pubRD/BDZ_D_Buergerreport_final_barrierefrei.pdf.

Carell, A., & Herrmann, T. (2009). Negotiation-tools in CSCL-scenarios—Do they have a valid use? In C. O'Malley, D. Suthers, P. Reimann, & A. Dimitracopoulou (Eds.), *Computer supported collaborative learning practices: CSCL2009 Conference Proceedings* (pp. 557–567). Rhodes, Greece: International Society of the Learning Sciences.

Conklin, J. (2005). *Dialogue mapping: Building shared understanding of wicked problems*. Hoboken, NJ: Wiley.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with Wikis. *International Journal of Computer-Supported Collaborative Learning, 3*, 105–122.

Csikszentmihalyi, M. (1999). *Creativity: Flow and the psychology of discovery and invention*. New York, NY: HarperCollins.

De Bono, E. (1995). Serious creativity. *Journal for Quality and Participation, 18*, 12–18.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment, 10,* 291–297.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology, 53*, 497–509.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford, England: Elsevier.

Duarte, D. L., & Snyder, N. T. (2011). *Mastering virtual teams: Strategies, tools, and techniques that succeed*. Hoboken, NJ: Wiley.

Fathianathan, M., Panchal, J. H., & Nee, A. Y. C. (2009). A platform for facilitating mass collaborative product realization. *CIRP Annals-Manufacturing Technology, 58*, 127–130.

Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M., & Ye, Y. (2005). Beyond binary choices: Integrating individual and social creativity. *International Journal of Human-Computer Studies, 63*, 482–512.

Guilford, J. P. (1959). Three faces of intellect. *American psychologist, 14*(8), 469–479.

Halatchliyski, I., Moskaliuk, J., Kimmerle, J., & Cress, U. (2014). Explaining authors' contribution to pivotal artifacts during mass collaboration in the Wikipedia's knowledge base. *International Journal of Computer-Supported Collaborative Learning, 9*, 97–115.

Hartz-Karp, J. (2005). A case study in deliberative democracy: Dialogue with the city. *Journal of Public Deliberation*, *1*.

Herrmann, T. (2003). Learning and teaching in socio-technical environments. In T. J. Van Weert & R. K. Munro (Eds.), *Informatics and the digital society: Social, ethical and cognitive issues* (pp. 59–72). Boston, MA: Kluwer.

Herrmann, T. (2009). Design heuristics for computer supported collaborative creativity. In. *42nd Hawaii International Conference on System Sciences (HICSS'09)* (pp. 1–10). Los Alamitos, CA: IEEE.

Herrmann, T., & Kienle, A. (2008). Context-oriented communication and the design of computer-supported discursive learning. *International Journal of Computer-Supported Collaborative Learning, 3*, 273–299.

Herrmann, T., Nolte, A., & Prilla, M. (2013). Awareness support for combining individual and collaborative process design in co-located meetings. *Computer Supported Cooperative Work, 22*, 241–270.

Jahnke, I., Ritterskamp, C., & Herrmann, T. (2005, November). Sociotechnical roles for sociotechnical systems: A perspective from social and computer sciences. In *Roles, an interdisciplinary perspective: Papers from the AAAI Fall Symposium* (Technical Report FS-05-08, pp. 81–86). Menlo Park, CA: AAAI Press.

Kaufman, J. C., & Sternberg, R. J. (Eds.). (2006). *The international handbook of creativity*. New York, NY: Cambridge University Press.

Kirschner, P. A., Buckingham-Shum, S. J., & Carr, C. S. (Eds.). (2003). *Visualizing argumentation: Software tools for collaborative and educational sense-making*. Berlin, Germany: Springer.

Kittur, A., & Kraut, R. E. (2008). Harnessing the wisdom of crowds in Wikipedia: Quality through coordination. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (pp. 37–46). New York, NY: ACM.

Lakhani, K. R., & Panetta, J. A. (2007). The principles of distributed innovation. *Innovations, 2*, 97–112.

Lukensmeyer, C. J., & Brigham, S. (2002). Taking democracy to scale: Creating a town hall meeting for the twenty first century. *National Civic Review, 91*, 351–366.

Macaulay, L. A., & Alabdulkarim, A. (2005, March). Facilitation of e-meetings: State-of-the-art review. In *e-Technology, e-Commerce and e-Service, 2005. EEE'05. Proceedings. The 2005 IEEE International Conference* (pp. 728–735). Los Alamitos, CA: IEEE.

Macintosh, A. (2004). Characterizing e-participation in policy-making. In *Proceedings of the 37th Annual Hawaii International Conference on System Sciences (HICSS'04).* Los Alamitos, CA: IEEE.

Malone, T., Laubacher, R., & Dellarocas, C. (2009). *Harnessing crowds: Mapping the genome of collective intelligence*. Cambridge, MA: MIT Sloan School of Management.

Mamykina, L., Candy, L., & Edmonds, E. (2002). Collaborative creativity. *Communications of the ACM, 45*, 96–99.

McGrath, J. E. (1984). *Groups: Interaction and performance*. Englewood Cliffs, NJ: Prentice Hall.

Owen, H. (2008). *Open space technology: A user's guide*. New York, NY: Berrett-Koehler.

Phang, C. W., & Kankanhalli, A. (2008). A framework of ICT exploitation for e-participation initiatives. *Communications of the ACM, 51*, 128–132.

Pruitt, B., & Thomas, P. (2007). *Democratic dialogue: A handbook for practitioners*. Washington, DC: International IDEA.

Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *CoDesign, 4*, 5–18.

Santanen, E. (2005). Resolving ideation paradoxes: Seeing apples as oranges through the clarity of ThinkLets. In *Proceedings of the 38th annual Hawaii International Conference on System Sciences (HICSS'05).* Los Alamitos, CA: IEEE.

Santanen, E. L., Briggs, R. O., & Vreede, G. J. D. (2004). Causal relationships in creative problem solving: Comparing facilitation interventions for ideation. *Journal of Management Information Systems, 20*, 167–198.

Schuman, S. (Ed.). (2012). *The IAF handbook of group facilitation: Best practices from the leading organization in facilitation* (Vol. 1). Hoboken, NJ: Wiley.

Stahl, G. (2000). A model of collaborative knowledge-building. In *Fourth International Conference of the Learning Sciences* (Vol. 10, pp. 70–77). Mahwah, NJ: Erlbaum.

Stasser, G., & Stewart, D. (1992). Discovery of hidden profiles by decision-making groups: Solving a problem versus making a judgment. *Journal of Personality and Social Psychology, 63*, 426–434.

Wallas, G. (1926). *Art of thought*. London, England: C.A. Watts.

Wichmann, A., & Rummel, N. (2013). Improving revision in Wiki-based writing: Coordination pays off. *Computers & Education, 62*, 262–270.

Part IV
Methods to Empirically Analyze Processes of Mass Collaboration

Theoretical and Empirical Analysis of Networked Knowledge

Iassen Halatchliyski

Mass Collaboration, Social Media, and *Networked Knowledge*

Social media attracts great numbers of people with different backgrounds and goals (Wasko & Faraj, 2005) to interact with each other about mutual interests, sharing own feelings, thoughts, and knowledge (Jenkins, Clinton, Purushotma, Robinson, & Weigel, 2006). Although these interactions often seem to be transient and ad hoc, they lead to the emergence of aggregate phenomena that may span over prolonged periods of time such as mass collaboration (Cress, 2013; Tapscott & Williams, 2006), social movements (Gerbaudo, 2012), folksonomies (Mathes, 2004), and others. *Networked knowledge*, that is, interconnected information collectively created online, can be of almost scientific quality even under conditions of uncertain and inconsistent information (Giles, 2005; Oeberst, Halatchliyski, Kimmerle, & Cress, 2014). The private contributions and interactions among the users are intertwined in a dense web of hyperlink references.

This chapter refers to a type of mass collaboration that directly relates to the development of networked knowledge. It introduces a structural approach to the meaningful and chronological knowledge interrelations emerging within an online community as a complex system. With the help of network analysis methods, structurally significant artifacts representing pivotal knowledge can be identified, and their relevance for the continuous development of new networked knowledge can be demonstrated.

I. Halatchliyski (✉)
Knowledge Construction Lab, Leibniz-Institut für Wissensmedien, Tubingen, Germany
e-mail: i.halatchliyski@iwm-tuebingen.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_16

Theoretical Foundation of Networked Knowledge

The interdisciplinary learning sciences renounce the extreme mentalist focus on information processing *within* individuals in its view on the nature of knowledge and learning. Intersubjectivity is highlighted instead as a phenomenon emerging in the interaction *between* individuals (Bonk & Cunningham, 1998; Suthers, 2006). Cognition is seen as situated in a sociocultural context (cf. Brown, Collins, & Duguid, 1989). Learning and knowledge are thus not regarded as private properties of individuals but as contextualized and continuous social interaction, a joint meaning-making discourse (Stahl, Koschmann, & Suthers, 2006). Research in computer-supported collaborative learning (CSCL) tackles the question how technology can enhance this process in which individual learning is coupled with collaborative knowledge building (cf. Scardamalia & Bereiter, 1994).

Shared material and conceptual artifacts enable an iterative process of networked knowledge development over sustained periods of time. They mediate the interaction of participants, and their creation and transformation may also be the deliberate goal of collaboration. Besides studying how individuals learn by acquiring concepts and information and how situational learning takes place through the long-term socialization of people in communities of practice (Lave & Wenger, 1991; Wenger, 1998), the collaborative creation of knowledge should also be taken into account (Paavola, Lipponen, & Hakkarainen, 2004). As postulated by the trialogical interaction model (Paavola & Hakkarainen, 2005), artifacts extend the dialogical collaboration between individuals. Cognition can thus be seen as distributed among individuals as well as physical and symbolic artifacts (Hutchins, 1995). The actor-network theory (Latour, 1987) even ascribes equal importance to humans and nonhuman entities for the emergence of knowledge in a dynamic complex network.

Large-scale knowledge practices on the Internet have opened a whole new field of questions for research in CSCL (Stahl et al., 2006). Consequently, a systemic view has been adapted to the mass collaboration mediated by shared digital artifacts in Web 2.0. Online environments such as wikis and folksonomies can be seen as social systems that are independent from the cognitive systems of their users (Kimmerle, Cress, & Held, 2010). Both systems cross-fertilize each other in such a way that both the individual and the networked knowledge coevolve (Cress & Kimmerle, 2008). The knowledge-building theory (Scardamalia & Bereiter, 1994, 2006) is another related approach, which is based on Popper's (1968) philosophical view on the gradual improvement of scientific knowledge. It illustrates how communities advance their collective knowledge by developing written conceptual artifacts (Bereiter, 2002) in a digital environment over a sustained period of time. All active participants take over collective responsibility (Scardamalia, 2002) for reaching deeper insight into the domain of interest of the community by sharing, discussing, and building on each other's ideas.

Epiphenomena of Mass Collaboration around Digital Artifacts

The social web affords large-scale interaction dynamics among very heterogeneous masses of individuals. Direct interaction between all the participants is not feasible and is not a prerequisite for mass collaboration. Intersubjective understanding and coordinated activities are enabled through the use of shared digital workspaces. By creating artifacts in these workspaces, people externalize their heterogeneous knowledge and make it available to each other. Depending on the specific technological affordances for manipulation, the ideas expressed in artifacts can be revised, remixed, referred to, and developed further in a collaborative process. Cocreated artifacts can coordinate a long-term collaborative process (Paavola & Hakkarainen, 2009) with many different people who may anonymously work in parallel. This mechanism of mediated interaction is also referred to as *stigmergy*, where the artifacts created or modified by some individuals stimulate the subsequent activity of other individuals (Susi & Ziemke, 2001). It greatly amplifies the amount of interactions and leads to the emergence of epiphenomena.

The created artifacts organized together as a digital knowledge base of interlinked contributions represent the networked knowledge of a community (cf. Bruckman, 2006). This is an emergent (Theiner, Allen, & Goldstone, 2010) product of the wisdom of the crowds (Surowiecki, 2005) or the collective intelligence (Levy, 1999) of the community as a whole. Although it develops on the basis of the activity of individuals, it is more than a collection of their individual ideas. Each single contribution needs to be adequately integrated into the existing networked knowledge. New knowledge for the community arises, as new concepts, connections, and ideas are introduced to the knowledge base. In a continuous development process of convergent and divergent contributions (Halatchliyski, Kimmerle, & Cress, 2011) over time, some ideas codified in the artifacts of a knowledge base may stand the test of time and become more prominent than others that fade away. Thus, mass collaboration goes along with development and improvement of ideas and artifacts according to goals and rules that emerge through self-organization in a community.

A Complex System Perspective on Mass Collaboration

Given the difficulty to grasp the dynamic patterns of interplay of all relevant aspects of mass collaboration, a complex system perspective (Luhmann, 1984; Oeberst et al., 2014; von Foerster, 2003) provides a suitable framework. A knowledge-related system autopoietically maintains a code of operation (Maturana & Varela, 1987) that consists of criteria for evaluating participative activities and for integrating or rejecting contributions. Thus, it directs the individual behavior and defines the acceptable knowledge. Existing knowledge controls the subsequent integration of new knowledge. Communities develop in this way their own socially constructed and interpretative view on reality (cf. Berger & Luckmann, 1966; Kimmerle et al., 2013; von Glasersfeld, 1995).

Knowledge-related systems such as the scientific community demonstrate dialectics between structural patterns and dynamic processes (Lucio-Arias & Leydesdorff, 2009). *Static structures* arise from the tension between variation and selection of the elements such as scientists, publications, and institutions. *Temporal dynamics* is created by forces of change and stabilization that operate over the course of history. Structure and dynamics can be identified at different levels of a system. In science, for example, researchers collaborate with each other, publish their work in a written form, and build on each other's work by citing existing papers. Lucio-Arias and Leydesdorff (2009) also identified a second-order dynamics referring to scientific ideas that have a life on their own as part of a scientific discourse once they are published (cf. Bereiter, 2002; Popper, 1972). As scientists select their specific research questions, methods, and the previous works to build on, global structural patterns of knowledge development emerge and stabilize over time. Thus, ideas may form a paradigm (Kuhn, 1962) that then again exerts top-down selection on the behavior of scientists. A paradigm represents a structure that is reified through the publication of consistent scientific work over time. Eventually, spontaneous breakthroughs, contradicting evidence, and stabilization of alternative views may introduce a bottom-up change in the structure of science.

Network Analysis Approach to Mass Collaboration Systems

The generative processes, conditions, and patterns of development of networked knowledge and learning at the level of a community (Nonaka & Nishiguchi, 2000) can be appropriately investigated using a network approach. Mass collaboration thus implies the emergence of knowledge networks (Saviotti, 2009) in the context of online social networks (Lipponen, 2002; Ryberg & Larsen, 2008). A network is an abstract structure with certain patterns which consist of different sets of nodes such as individuals, artifacts, and of their links. The concept has already been used to describe knowledge organization at different levels such as the semantic memory of individuals (e.g., Collins & Loftus, 1975), the interrelated ideas in a scientific community represented in papers citing each other (Garfield, 1972), or the Wikipedia knowledge base of interlinked artifacts (Voss, 2005). Networked knowledge essentially emerges from the specific semantic interconnections between knowledge artifacts such as topical relations, problem-solution chains, discourses, etc. This structural approach (cf. Wellman, 1997) also allows dynamic analysis, as both the nodes and connections in a network are constantly changing.

A "new science of networks" (Barabási, 2002) unites research on networks from physical, biological, social, and computer science, offering a variety of tools and methods to measure, describe, and visualize global network properties as well as relative positions of single nodes. Social network analysis (SNA; Wassermann & Faust, 1994) is increasingly adopted in CSCL research (e.g., Aviv, Erlich, Ravid, & Geva, 2003; Cho, Stefanone, & Gay, 2002; de Laat, Lally, Lipponen, & Simons, 2007; Reffay & Chanier, 2002) for analyzing log data on interactions among collaborating students. Bibliometric research (Glänzel, 2003) often applies network analysis techniques to networks of scientific papers that cite each other. Webometrics (Almind & Ingwersen, 1997; Björneborn & Ingwersen, 2004) adapts appropriate methods following a direct analogy between the analysis of scientific citations and of hyperlinks between Web pages. Thus, network analysis methods can be used to meet the complexity introduced by the interaction of many network nodes in a knowledge-creating system.

The network science has only lately started to expand the limited focus on measuring static structures in order to acknowledge the dynamics of complex networks. Temporal analyses are usually only descriptive and consider differences between network snapshots at particular moments in time (Mali, Kronegger, Doreian, & Ferligoj, 2012). During online mass collaboration, new networked knowledge is sequentially built upon the existing knowledge in an essentially temporal process. Aggregation across time based on coding and counting of events easily leads to a biased analysis of individual and community-level variables. Correspondingly, there is a strong need for temporal analysis methods in the learning sciences (Mercer, 2008; Reimann, 2009). Due to the analogy between scientific and online knowledge-building communities, established analytical approaches can be borrowed from bibliometrics and scientometrics. These research fields offer a variety of methods tailored for the quantitative analysis of knowledge artifacts, scientific work, and their authors. They can greatly enrich the newly emerging research in learning analytics (Siemens, 2012; Suthers & Verbert, 2013). One such method is the main path analysis (Hummon & Doreian, 1989) that examines temporally developing knowledge flows and uptakes (Suthers, 2006) in knowledge networks. It takes into account the structure of connections between artifacts together with the temporal order of development and has been applied to scientific citation networks and to knowledge-building discourse in schools (Halatchliyski, Oeberst, Bientzle, Bokhorst, & van Aalst, 2012).

Examples of Mass Collaboration in Web 2.0

Among the Web 2.0 technologies, wikis are especially suitable for knowledge building by enabling myriads of users to work in parallel, forming a community, and cocreating a knowledge base of shared digital artifacts (Forte & Bruckman, 2006) as in the case of Wikipedia and Wikiversity, two mass collaboration projects of the Wikimedia Foundation. The mass collaboration process is open ended, and the networked knowledge is constantly changing, as new articles are created and content is added or deleted. The participants also benefit in this process (Moskaliuk, Kimmerle, & Cress, 2009, 2012), so wikis can be used to support individual learning even in formal educational contexts (Konieczny, 2007). Open wikis like Wikipedia and Wikiversity are also suitable for research, as they provide the entire development history of the collective artifacts in which different opinions are integrated and conflicts are argued out. These wikis are tools for generating, connecting, and revising networked knowledge rather than disseminating information (Purdy, 2009). Indeed, Wikipedia is not aimed at developing new knowledge, and the information added to it must not be novel according to its own "no original research" rule. Nevertheless, the externally sourced information is integrated in an original way (cf. Swarts, 2009) and presents a new product of emerging networked knowledge. Thus, Wikipedia's knowledge base is a novel product of the community and involves development processes that are typical of genuine knowledge-building communities (Cress & Kimmerle, 2008; Forte & Bruckman, 2006). Wikiversity is understood by its active members as an "open learning community" in which users can actively produce learning resources for a broad range of topics and thus learn while they participate.

Networked knowledge develops on many levels in wikis: article content is edited by adding, modifying, or deleting parts of it and thus changing its textual structure, hyperlinks are extensively used to establish connections between articles, and new articles are constantly created building up entire knowledge domains as well as connecting different domains. System rules and community practices are the backbone for such developments guiding individual activities and regulating the collaborative process (Niederer & Van Dijck, 2010). They ensure the achievement of coherence and consensus from the diversity of views offered by the participants. High-quality articles in Wikipedia (Wöhner & Peters, 2009) can thus be created by experienced participants in the community who lack a domain-specific expertise (Oeberst et al., 2014). Contributions that are not accordant with the rules are reverted and thus refused by the system. Vandalism in Wikipedia, for example, is fixed very fast (Viégas, Wattenberg, & Dave, 2004). These rules, their interpretation, and application are subject to change over time through social negotiation too (Forte & Bruckman, 2008).

In sum, Wikipedia and Wikiversity are multifaceted wiki environments for mass collaboration around networked digital artifacts. They offer a unique field for studying the statics and dynamics of networks of emerging knowledge from the activity of contributors in a community that represents a complex system.

Empirical Studies

In the light of the foregoing, social media has a high practical relevance for the development of networked knowledge in contemporary society. Based on the theoretical grounding from the interdisciplinary learning sciences, the present chapter advances an approach for studying and understanding the principles that underlie the development of networked knowledge during online mass collaboration.

Networked knowledge is an epiphenomenon emerging in a complex system. Therefore, it can be appropriately studied by a network approach that acknowledges both its macrolevel structure and the microlevel of single artifact relations and contributions by participants. Networked knowledge is measured by focusing on artifacts cocreated in a community of learners. As they are both means and ends of collaboration (Dohn, 2009; Lipponen, Hakkarainen, & Paavola, 2004), they are fundamental in the large-scale and long-term, stigmergic process.

The approach is briefly exemplified in the following three empirical studies that are reported in detail in the respective journal publications. They focus on different questions related to mass collaboration wikis. Employing network analysis techniques, real-life data from Wikipedia and Wikiversity, is quantitatively modeled and evaluated in order to make statistical inferences. The studies present tests of hypotheses on causal relationships between static structures of pivotal knowledge, contribution activities of different groups of participants, and dynamic processes of networked knowledge development over time. The multifaceted character of networked knowledge emerging is also investigated exploratively.

Study 1 (Halatchliyski, Moskaliuk, Kimmerle, & Cress, 2014) modeled cross-sectionally the structural representation of networked knowledge in a mass collaboration system using the German Wikipedia on January 16, 2012, as a data source. Given the large-scale dimensions of online interaction, a suitable starting point for grasping the internal logic of networked knowledge was not the detailed written content but the structural aspects of the artifacts. The hyperlink structure of the knowledge base in wikis suggests viewing their content as a network of interconnected articles categorized in different knowledge domains. According to this perspective, the meaning of a single article in such networks is structurally defined by the presence and absence of relations to other articles and by its specific position in the network as a whole. Well-connected and central articles in a network tend to represent the pivotal knowledge of the knowledge base.

The study included all interconnected articles from the knowledge domains psychology and education. Altogether these were over 10,000 articles, which were grouped into two separate single-domain networks and one combined network including both domains. This manifest structure of networked knowledge was analyzed using two standard network analysis measures for each article. Thus, pivotal articles, which occupied outstanding topological position in the three networks, were identified. For one thing, central articles within each of the two single-domain networks had high measures of eigenvector centrality (Bonacich, 1972). For another, pivotal articles were also the boundary-spanning articles across the two knowledge domains, which had high measured of betweenness (Freeman, 1979) within the combined network of the domains.

A second level of analysis considered all of the over 8000 authors who contributed this networked knowledge and their different levels of contribution experience. Thus, networked knowledge was regarded both as substance (i.e., collaborative artifacts) and as participatory activity (i.e., collaborative contributions). The study aimed at establishing the relation between these both conceptions of networked knowledge through statistical modeling that integrates both levels of analysis.

The focus of the investigation was the relation between the authors' experience and their contribution to the two types of pivotal articles that either have a high eigenvector centrality or betweenness. Authors' experience in the community was measured by counting their contributions to different articles.

The most remarkable result was the significant positive relationship between authors' experience and their contribution to both types of pivotal articles. There was also evidence of a division of labor, as authors with experience in only one of the studied domains predominantly contributed to central articles within this domain and authors with experience in both domains predominantly contributed to boundary-crossing articles across the domains.

Overall, the contribution experience of the participants can be seen as an indicator of how well they have mastered the rules and goals of the mass collaboration community, so that they can make substantial contributions to its knowledge base by working on pivotal articles within, as well as across different domains. Designing sophisticated mechanisms to stimulate repeated contributions to different artifacts is of vital importance for a sustained mass collaboration.

Study 2 (Halatchliyski & Cress, 2014) investigated the structural development of the knowledge base of Wikipedia following a longitudinal network analysis approach in order to explain the appearance of new networked knowledge. Focusing on the generative mechanism of preferential attachment (Barabási & Albert, 1999), it aimed at more decisive conclusions on causality in the complex process of networked knowledge development in Wikipedia. The rationale was that new contributions need to be adequately integrated into the existing structure of the knowledge base. The statistical models in the study established a relation between the network position of existing interconnected articles, the change in their position over time, and the appearance of new knowledge.

Building on the Study 1, the data consisted of the articles and authors in the same two adjacent knowledge domains psychology and education. The development of the networks of hyperlinked articles in each of the single domains and in both combined domains was analyzed at seven snapshots from 2006 to 2012 with an interval of 1 year between them. Longitudinal data on the topological position of each article in the networks was used to model the appearance of new knowledge over time. Using multilevel statistical analysis of periodic snapshots of the studied networks, the study showed that the structure of networked knowledge is causally related to its evolution over time. The established network analysis metrics betweenness and eigenvector centrality identified the pivotal articles in each periodic snapshot of the studied networks. The pivotal articles in a knowledge base can be interpreted as a structural backbone of the networked knowledge in a complex system. As in Study 1, they can be central within one of the knowledge domains or boundary-crossing across both domains at a given point in time.

The results demonstrated that both types of pivotal articles represent an important factor of the long-term development of networked knowledge. In correspondence with the preferential attachment hypothesis, it was shown that the new knowledge that appeared in the networks is significantly more likely to link to the pivotal than to the other articles among all previously created articles. New networked knowledge in Wikipedia was modeled in three ways: as the number of new articles that have become neighbors of an existing article, as the change in the total sum of edits of the neighbors of an existing article, and as the number of new contributions to an existing article. Thus, articles that are pivotal in the static organization of networked knowledge are also pivotal for its dynamic development. This result complements the findings in Study 1 that pivotal articles are written by experienced Wikipedia contributors.

Using additional covariates in the statistical models, it was further demonstrated that the age of an article was a negative factor for attracting new networked knowledge, so aging in the network has a negative impact on the development process. Articles that received many contributions had the potential to drive further development of networked knowledge, independent of whether they are pivotal in the network or not.

The examination of the development of networked knowledge that took place in the German Wikipedia as a complex system yielded the distinction of two stages. The period until 2006 was marked by an exponential growth in the number of articles, authors, and other relevant variables. The mass collaboration system then entered a saturation stage with a stagnating number of new articles and stable overall growth rates. This stage bears the critical points that new encyclopedic topics that could still be added to the networked knowledge are scarce. Thus, inexperienced authors face rising thresholds for participation, and the bulk of work is complex and can be completed by only a tiny percentage of the authors.

Study 3 (Halatchliyski, Hecking, Göhnert, & Hoppe, 2014; see also chapter “Applying Network Models and Network Analysis Techniques to the Study of Online Communities” by Hoppe, Harrer, Göhnert, & Hecking, 2016) was an explorative investigation of the detailed paths of development of topics in the networked knowledge and the different roles of contributors in the knowledge-building community Wikiversity. It followed a dynamic network perspective on mass collaboration and illustrated an adaptation of the scientometric method of main path analysis (Hummon & Doreian, 1989) to the networked knowledge developed in a wiki environment. In scientometrics, the method is applied to networks of scientific publications that are chronologically connected through citations. The update versions of a set of Wikiversity articles can also be identified chronologically and interconnected based on hyperlinks between articles.

Networked knowledge has the quality of a process, as it essentially develops over longer periods of time and goes along with a continuous change of the shared knowledge base. The relations and the temporal sequence between these changes can be analyzed avoiding biases of aggregation over time. Beyond the cross-sectional and longitudinal analyses of static article networks presented in the previous studies 1 and 2, the current approach took the temporal sequence of each contribution to the articles and the article hyperlinks into account. The evaluation considered each contribution as a single element in the networks of different knowledge domains. With the help of main path analysis, pivotal contributions were identified not in the static structure of networked knowledge but directly in the dynamic trajectories of its evolution. Contributions that relate to many other preceding as well as subsequent contributions are deemed more relevant for the collaborative development of networked knowledge and receive higher ratings by the algorithm.

The analysis was based on an algorithm that calculates a certain weight for each contribution in the dynamic network in correspondence with its importance in the chronological development of the networked knowledge. Data on the Wikiversity articles from two scientific domains, biology and electrical engineering, was used. Based on the calculated weights of the contributions, pivotal contributions were identified as those that build on many preceding contributions and influence many subsequent contributions and thus constitute the main paths of the evolving networked knowledge in a specific domain. These can be the core topics and ideas or other important moments of collaboration for the studied time interval.

The main path analysis results allowed structural comparisons of the studied domains regarding topical coherence and intensity of collaboration over time. The biology domain contained articles on a wide range of topics; the pivotal contributions, which were identified on the main paths of development, were grouped in several unrelated clusters suggesting heterogeneous knowledge development organized in separate topics and little collaboration between contributors.

Electrical engineering was a smaller and neatly arranged domain with a main path of distinctive but interrelated topics developing over time. With small exceptions, the pivotal contributions were on tightly interwoven topics, building a coherent cluster of core knowledge. The networked knowledge in this domain was the product of a large number of intensively collaborating contributors.

The main path analysis further facilitated the characterization of different outstanding roles of contributors in Wikiversity by taking the authors of the pivotal contributions into account. As in Study 1, the network analysis results were combined with further data on the participants' activity in order to enhance the interpretation.

The following three contributor roles were identified: specialists did a lot of edits on a small number of articles, maintainers made small formal changes such as spelling corrections to a large number of different articles, and leaders were the main prolific contributors within a domain with a high number of edits on many different articles. Considering which of the contributions were pivotal, the important authors within each role could be identified. These authors made contributions that formed the historical main paths of networked knowledge development within a domain. The results showed that pivotal authors were not necessarily the authors with the highest numbers of contributions.

The employed method of main path analysis bears high potential for a real-time evaluation of collaborative processes that can be used for supportive interventions by moderators or teachers or for self-regulative purposes by the community as a whole or by single contributors. Possible aspects that can be explored and evaluated include topical coherence of the contributions, structure, intensity and pivotal moments of collaboration, topical gaps that present contribution opportunities, and important roles of contributors. This is definitely a fertile field for future research in learning analytics concerning the overall learning process as well as the individual contributions of the participants.

Conclusion

The three empirical studies demonstrated different network analysis approaches to the interplay of structure and dynamics of networked knowledge emerging in mass collaboration contexts. Using data on complete knowledge domains in Wikipedia and Wikiversity, this research provides quantitative models of the complex and mutually determining influence of knowledge structures and of contribution activity of participants on the process of networked knowledge development. Cross-sectional models allowed hypothesis-based statistical tests of the relation between pivotal artifacts and contributions of experienced authors. Longitudinal analysis enabled causal interpretation of the impact of pivotal contributions on the subsequent development of networked knowledge. Finally, a network analysis of the main paths of networked knowledge development was shown to provide fine-grained and immediate evaluation of the pivotal contributions from a temporal perspective on the collaborative process.

Taken together, the current chapter advanced an approach for studying and understanding the principles that underlie the development of networked knowledge during mass collaboration. The work provides a starting point in the quantitative research field of learning analytics. With its theoretical view on networked knowledge as substance and as participatory activity based on a complex systems perspective, the work also contributes to the theoretical development of the learning sciences and CSCL in particular.

References

Almind, T. C., & Ingwersen, P. (1997). Informetric analyses on the world wide web: Methodological approaches to ‘webometrics’. *Journal of Documentation, 53*, 404–426.

Aviv, R., Erlich, Z., Ravid, G., & Geva, A. (2003). Network analysis of knowledge construction in asynchronous learning networks. *Journal of Asynchronous Learning Networks, 7*, 1–23.

Barabási, A. L. (2002). *Linked: The new science of networks*. Cambridge, MA: Perseus.

Barabási, A. L., & Albert, R. (1999). Emergence of scaling in random networks. *Science, 286*, 509–512.

Bereiter, C. (2002). *Education and mind in the knowledge age*. Hillsdale, NJ: Erlbaum.

Berger, B. L., & Luckmann, T. (1966). *The social construction of reality: A treatise in the sociology of knowledge*. New York, NY: Anchor.

Björneborn, L., & Ingwersen, P. (2004). Toward a basic framework for webometrics. *Journal of the American Society for Information Science and Technology, 55*, 1216–1227.

Bonacich, P. (1972). Factoring and weighting approaches to status scores and clique identification. *Journal of Mathematical Sociology, 2*, 113–120.

Bonk, C., & Cunningham, D. (1998). Searching for learner-centred, constructivist, and sociocultural components of collaborative educational learning tools. In C. J. Bonk & K. S. King (Eds.), *Electronic collaborators: Learner-centred technologies for literacy, apprenticeship, and discourse* (pp. 25–50). Mahwah, NJ: Erlbaum.

Brown, M. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*, 32–42.

Bruckman, A. (2006). Learning in online communities. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 461–472). New York, NY: Cambridge University Press.

Cho, H., Stefanone, M., & Gay, G. (2002). Social network analysis of information sharing networks in a CSCL community. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community. Proceedings of the computer-supported collaborative learning conference* (pp. 43–50). Mahway, NJ: Lawrence Erlbaum.

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82*, 407–428.

Cress, U. (2013). Mass collaboration and learning. In R. Luckin, P. Goodyear, B. Grabowski, S. Puntambekar, J. Underwood, & N. Winters (Eds.), *Handbook on design in educational technology* (pp. 416–425). London, England: Taylor & Francis.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with Wikis. *International Journal of Computer-Supported Collaborative Learning, 3*, 105–122.

de Laat, M., Lally, V., Lipponen, L., & Simons, R.-J. (2007). Investigating patterns of interaction in networked learning and computer-supported collaborative learning: A role for social network analysis. *International Journal of Computer-Supported Collaborative Learning, 2*, 87–103.

Dohn, N. (2009). Web 2.0: Inherent tensions and evident challenges for education. *International Journal of Computer-Supported Collaborative Learning, 4*, 343–363.

Forte, A., & Bruckman, A. (2006). From Wikipedia to the classroom: Exploring online publication and learning. In S. A. Barab, K. E. Hay, & D. T. Hickey (Eds.), *Proceedings of the 7th International Conference of the Learning Sciences* (pp. 182–188). Mahwah, NJ: Erlbaum.

Forte, A., & Bruckman, A. (2008). Scaling consensus: Increasing decentralization in Wikipedia governance. In *Proceedings of the 41st Annual Hawaii International Conference on System Sciences* (pp. 157–157). Maui, HI: IEEE.

Freeman, L. C. (1979). Centrality in social networks: Conceptual clarification. *Social Networks, 1*, 215–239.

Garfield, E. (1972). Citation analysis as a tool in journal evaluation. *Science, 178*, 471–479.

Gerbaudo, P. (2012). *Tweets and the streets: Social media and contemporary activism*. London, England: Pluto Press.

Giles, J. (2005). Internet encyclopaedias go head to head. *Nature, 438*, 900–901.

Glänzel, W. (2003). *Bibliometrics as a research field: A course on the theory an application of bibliometric indicators*. Budapest, Hungary: Magyar Tudományos Akadémia Könyvtára. Retrieved from http://nsdl.niscair.res.in/jspui/bitstream/123456789/968/1/Bib_Module_KUL.pdf.

Halatchliyski, I., & Cress, U. (2014). How structure shapes dynamics: Knowledge development in Wikipedia—A network multilevel modeling approach. *PLoS One, 9*, e111958.

Halatchliyski, I., Hecking, T., Göhnert, T., & Hoppe, H. U. (2014). Analyzing the main paths of knowledge evolution and contributor roles in an open learning community. *Journal of Learning Analytics, 1*, 72–93.

Halatchliyski, I., Kimmerle, J., & Cress, U. (2011). Divergent and convergent knowledge processes on Wikipedia. In H. Spada, G. Stahl, N. Miyake, & N. Law (Eds.), *Connecting computer-supported collaborative learning to policy and practice: CSCL2011 Conference Proceedings* (Vol. 2, pp. 566–570). Hong Kong, China: International Society of the Learning Sciences.

Halatchliyski, I., Moskaliuk, J., Kimmerle, J., & Cress, U. (2014). Explaining authors' contribution to pivotal artifacts during mass collaboration in the Wikipedia's knowledge base. *International Journal of Computer-Supported Collaborative Learning, 9*, 97–115.

Halatchliyski, I., Oeberst, A., Bientzle, M., Bokhorst, F., & van Aalst, J. (2012). Unraveling idea development in discourse trajectories. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), The future of learning: Proceedings of the 10th international conference of the learning sciences (Vol. 2, pp. 162–166). Sydney, NSW, Australia: International Society of the Learning Sciences.

Hoppe, H. U., Harrer, A., Göhnert, T., & Hecking, T. (2016). Applying network models and network analysis techniques to the study of online communities. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Hummon, N. P., & Doreian, P. (1989). Connectivity in a citation network: The development of DNA theory. *Social Networks, 11*, 39–63.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Jenkins, H., Clinton, K., Purushotma, R., Robinson, A. J., & Weigel, M. (2006). *Confronting the challenges of participatory culture: Media education for the 21st century*. Chicago, IL: The MacArthur Foundation.

Kimmerle, J., Cress, U., & Held, C. (2010). The interplay between individual and collective knowledge: Technologies for organisational learning and knowledge building. *Knowledge Management Research and Practice, 8*, 33–44.

Kimmerle, J., Thiel, A., Gerbing, K.-K., Bientzle, M., Halatchliyski, I., & Cress, U. (2013). Knowledge construction in an outsider community: Extending the communities of practice concept. *Computers in Human Behavior, 29*, 1078–1090.

Konieczny, P. (2007). Wikis and Wikipedia as a teaching tool. *International Journal of Instructional Technology and Distance Learning, 4*, 15–34.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, England: Cambridge University Press.

Levy, P. (1999). *Collective intelligence: Mankind's emerging world in cyberspace*. Cambridge, MA: Perseus Books.

Lipponen, L. (2002). Exploring foundations for computer-supported collaborative learning. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community. Proceedings of the Computer-Supported Collaborative Learning Conference* (pp. 72–81). Mahwah, NJ: Lawrence Erlbaum.

Lipponen, L., Hakkarainen, K., & Paavola, S. (2004). Practices and orientations of computer supported collaborative learning. In J. Strijbos, P. Kirschner, & R. Martens (Eds.), *What we know about CSCL, and implementing it in higher education* (pp. 31–50). Boston, MA: Kluwer.

Lucio-Arias, D., & Leydesdorff, L. (2009). The dynamics of exchanges and references among scientific texts, and the *autopoiesis* of discursive knowledge. *Journal of Informetrics, 3*, 261–271.

Luhmann, N. (1984). *Soziale Systeme: Grundriß einer allgemeinen Theorie*. Frankfurt am Main, Germany: Suhrkamp.

Mali, F., Kronegger, L., Doreian, P., & Ferligoj, A. (2012). Dynamic scientific co-authorship networks. In A. Scharnhorst, K. Borner, & P. van den Besselaar (Eds.), *Models of science dynamics* (Understanding complex systems, pp. 195–232). Heidelberg, Germany: Springer.

Mathes, A. (2004). Folksonomies-cooperative classification and communication through shared metadata. *Journal of Computer Mediated Communication, 47*, 1–13.

Maturana, H. R., & Varela, F. J. (1987). *The tree of knowledge: The biological roots of human understanding*. Boston, MA: New Science Library/Shambhala.

Mercer, N. (2008). The seeds of time: Why classroom dialogue needs a temporal analysis. *The Journal of the Learning Sciences, 17*, 33–59.

Moskaliuk, J., Kimmerle, J., & Cress, U. (2009). Wiki-supported learning and knowledge building: Effects of incongruity between knowledge and information. *Journal of Computer Assisted Learning, 25*, 549–561.

Moskaliuk, J., Kimmerle, J., & Cress, U. (2012). Collaborative knowledge building with Wikis: The impact of redundancy and polarity. *Computers & Education, 58*, 1049–1057.

Niederer, S., & Van Dijck, J. (2010). Wisdom of the crowd or technicity of content? Wikipedia as a sociotechnical system. *New Media & Society, 12*, 1368–1387.

Nonaka, I., & Nishiguchi, T. (2000). *Knowledge emergence: Social, technical, and evolutionary dimensions of knowledge creation*. Oxford, England: Oxford University Press.

Oeberst, A., Halatchliyski, I., Kimmerle, J., & Cress, U. (2014). Knowledge construction in Wikipedia: A systemic-constructivist analysis. *The Journal of the Learning Sciences, 23*, 149–176.

Paavola, S., & Hakkarainen, K. (2005). The knowledge creation metaphor—An emergent epistemological approach to learning. *Science & Education, 14*, 535–557.

Paavola, S., & Hakkarainen, K. (2009). From meaning making to joint construction of knowledge practices and artefacts—A trialogical approach to CSCL. In C. O'Malley, D. Suthers, P. Reimann, & A. Dimitracopoulou (Eds.), *Computer supported collaborative learning practices: CSCL2009 Conference Proceedings* (pp. 83–92). Rhodes, Greece: International Society of the Learning Sciences.

Paavola, S., Lipponen, L., & Hakkarainen, K. (2004). Models of innovative knowledge communities and three metaphors of learning. *Review of Educational Research, 74*, 557–576.

Popper, K. R. (1968). Epistemology without a knowing subject. *Studies in Logic and the Foundations of Mathematics, 52*, 333–373.

Popper, K. R. (1972). *Objective knowledge: An evolutionary approach*. Oxford, England: Oxford University Press.

Purdy, J. P. (2009). When the tenets of composition go public: A study of writing in Wikipedia. *College Composition and Communication, 61*, 383.

Reffay, C., & Chanier, T. (2002). Social network analysis used for modeling collaboration in distance learning groups. In S. A. Cerri, G. Gouardères, & F. Paraguaçu (Eds.), *ITS 2002 lecture notes in computer science, 2363* (pp. 31–40). Heidelberg, Germany: Springer.

Reimann, P. (2009). Time is precious: Variable-and event-centred approaches to process analysis in CSCL research. *International Journal of Computer-Supported Collaborative Learning, 4*, 239–257.

Ryberg, T., & Larsen, M. C. (2008). Networked identities: Understanding relationships between strong and weak ties in networked environments. *Journal of Computer Assisted Learning, 24*, 103–115.

Saviotti, P. (2009). Knowledge networks: Structure and dynamics. In A. Pyka & A. Scharnhorst (Eds.), *Innovation networks: Developing an integrated approach* (pp. 19–41). Heidelberg, Germany: Springer.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago, IL: Open Court.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*, 265–283.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 97–118). Cambridge, England: Cambridge University Press.

Siemens, G. (2012). Learning analytics: Envisioning a research discipline and a domain of practice. In S. Buckingham Shum, D. Gasevic, & R. Ferguson (Eds.), *Proceedings of the Second International Conference on Learning Analytics and Knowledge, LAK'12* (pp. 4–8). New York, NY: ACM Press.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences*. Cambridge, England: Cambridge University Press.

Surowiecki, J. (2005). *The wisdom of crowds*. New York, NY: Anchor Books.

Susi, T., & Ziemke, T. (2001). Social cognition, artifacts, and stigmergy: A comparative analysis of theoretical frameworks for the understanding of artifact-mediated collaborative activity. *Cognitive Systems Research, 2*, 273–290.

Suthers, D. (2006). Technology affordances for intersubjective meaning-making: A research agenda for CSCL. *International Journal of Computers-Supported Collaborative Learning, 1*, 315–337.

Suthers, D., & Verbert, K. (2013). Learning analytics as a "middle space". In D. Suthers, K. Verbert, E. Duval, & X. Ochoa (Eds.), *Proceedings of the 3rd International Conference on Learning Analytics and Knowledge, LAK'13* (pp. 1–4). New York, NY: ACM Press.

Swarts, J. (2009). The collaborative construction of "fact" on Wikipedia. In *Proceedings of the 27th ACM International Conference on Design of Communication* (pp. 281–288). New York, NY: ACM Press.

Tapscott, D., & Williams, A. D. (2006). *Wikinomics: How mass collaboration changes everything*. New York, NY: Portfolio.

Theiner, G., Allen, C., & Goldstone, R. L. (2010). Recognizing group cognition. *Cognitive Systems Research, 11*, 378–395.

Viégas, F. B., Wattenberg, M., & Dave, K. (2004). Studying cooperation and conflict between authors with history flow visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 575–582). New York, NY: ACM Press.

von Foerster, H. (2003). *Understanding understanding: Essays on cybernetics and cognition*. New York, NY: Springer.

von Glasersfeld, E. (1995). *Radical constructivism: A way of knowing and learning*. Bristol, PA: Falmer Press/Taylor & Francis.

Voss, J. (2005). Measuring Wikipedia. In P. Ingwersen & B. Larsen (Eds.), *Proceedings of 10th International Conference of the International Society for Scientometrics and Informetrics* (pp. 221–231). Stockholm, Sweden: Karolinska University Press.

Wasko, M. M., & Faraj, S. (2005). Why should I share? Examining knowledge contribution in networks of practice. *MIS Quarterly, 29*, 35–58.

Wassermann, S., & Faust, K. (1994). *Social network analysis: Methods and application*. Cambridge, England: Cambridge University Press.

Wellman, B. (1997). Structural analysis: From method and metaphor to theory and substance. *Contemporary Studies in Sociology, 15*, 19–61.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, England: Cambridge University Press.

Wöhner, T., & Peters, R. (2009). Assessing the quality of Wikipedia articles with lifecycle based metrics. In *Proceedings of the 5th International Symposium on Wikis and Open Collaboration*. New York, NY: ACM Press.

Applying Network Models and Network Analysis Techniques to the Study of Online Communities

H. Ulrich Hoppe, Andreas Harrer, Tilman Göhnert, and Tobias Hecking

Network Science as Interdisciplinary Paradigm

Over the last decade, "network science" has evolved as a new interdisciplinary paradigm for studying the structure and evolution of networks of various natures, such as technical networks and their applications (including the Internet and the World Wide Web), biological networks, as well as social networks and communities. Network science provides models that simulate and thus possibly explain the emergence of certain structures in networked communities based on relations involving actors and artifacts. It also provides mathematically well-understood methods of analysis to detect such structures in existing networks. In this sense, it resonates with social theories such as actor-network theory (Latour, 2005). A well-established field application of network analysis techniques is the study of scientific cooperation and production or "scientometrics" (see e.g., Leydesdorff, 2001). Network science has the potential of providing a general formal analytic underpinning for the study of mass collaboration in networked communities.

Newman, Barabási, and Watts (2006) summarize a number of modeling approaches and analytic results that led to the notions of "scale-free" or "small-world" networks. These findings have challenged and modified the original assumptions about the evolution of dynamic networks as "random graphs," which were introduced by Erdös in the late 1950s. This strand of research is currently being integrated with the analysis and modeling of social networks pioneered by Moreno

---

H.U. Hoppe (✉) • T. Göhnert • T. Hecking
Department of Computer Science and Applied Cognitive Science,
University of Duisburg-Essen, Essen, Germany
e-mail: hoppe@collide.info; goehnert@collide.info; hecking@collide.info

A. Harrer
Department of Computer Science, Technical University of Clausthal,
Clausthal-Zellerfeld, Germany
e-mail: andreas.harrer@tu-clausthal.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_17

in the 1930s. In the 1960s, studies of citation networks (de Solla Price, 1965) made social networks a popular theme in scientometrics. More recently, many Web-based or online communities have become social networks in their own right (Twitter, Facebook, etc.). Meanwhile, social network analysis (SNA—cf. Wasserman & Faust, 1994) is a rapidly progressing branch of research at the crossroads of natural, technical, and social sciences.

The characteristic feature of SNA is the relational perspective and the view of actors as parts of a network structure. The network analysis perspective is complementary to the analysis of action sequences in terms of sequential patterns in that the structural properties of a network disregard sequential or process structures. A network consists of a set of actors and a set of ties between pair of actors (Wasserman & Faust, 1994). The kind of pairwise connections defines the nature of each social network (Borgatti, Mehra, Brass, & Labianca, 2009). Examples of different kind of ties are affiliation, friendship, professional, behavioral interaction, or information flows. The visualization of such network structures has emerged as a specific subfield (Krempel, 2005). A well-known inherent limitation of SNA is that the target representation, i.e., the network, does no longer represent temporal characteristics but aggregates data over a given time window. It has been shown that the size of the time window has a systematic influence on certain network characteristics such as subcommunity structures (Hecking, Göhnert, Zeini, & Hoppe, 2013). Of course, the dynamic evolution of networks is also of interest. To explicitly address time-dependent effects, SNA techniques have been extended to analyzing time series of networks in dynamic approaches.

In addition to social interaction, knowledge building and productive processes also involve the creation of knowledge artifacts. The relation between the actor (or author) and the artifact or product can be regarded as another basic relationship, which is captured in so-called two-mode networks. In the context of SNA, such two-mode networks are also called "affiliation networks" (Wasserman & Faust, 1994). In pure form, these networks are assumed to be bipartite, i.e., only alternating links actor-artifact (relation "created/modified") or artifact-actor (relation "created by/modified by") would be allowed. Using simple matrix operations, such bipartite two-mode networks can be "folded" into homogeneous (one-mode) networks of either only actors or only artifacts. Here, e.g., two actors would be associated if they have acted upon the same artifact. We would then say that the relation between the actors was mediated by the artifact. A typical example of such a transformation is found in co-publication networks based on coauthorship. Similarly, we can derive relationships between artifacts by considering agents (engaged in the creation of two different artifacts) as mediators.

In the last decade, we have seen an increasing number of studies of educational communities using SNA techniques in the fields of CSCL and learning analytics. In general, online communities with digital communication channels lend themselves to data-intensive analyses (Haythornthwaite, 2001). Originally, networks derived from e-mail and discussion boards were the most prominent type studied, such as the study of cohesion in learning groups using a shared forum (Reffay & Chanier, 2003). In the following years, more and more SNA techniques are also being combined with other approaches. Martínez Monés, Dimitriadis, Rubia Avi, Gómez Sánchez, and de la Fuente Redondo (2003) present an evaluation method that combines SNA with traditional sources of data and analyses in blended scenarios with face-to-face and computer-supported collaboration. Another approach of combining qualitative methods with SNA was chosen by Harrer, Zeini, and Pinkwart (2006). Here, the classification of wiki and forum usage was triangulated with network structures and statistical measures of usage of shared code management systems. Other approximations combine SNA and content analysis. Lipponen, Rahikainen, Lallimo, and Hakkarainen (2003) analyzed patterns of participation and characterized the quality of discourse. They combined density and centrality measurement with qualitative content analysis reporting clear differences on student network position and rather informative and on-topic oriented discussions. For large communities and mass collaboration, network analytic approaches are ideally suited to detect interactions between subsets of actors within the mass and to detect patterns of knowledge creation and take-up within networks of actors and artifacts. Thus, network analyses can provide insights in seemingly amorphous sets of learners and add interactional facets to other methods, such as aggregated statistical analysis of the community population.

The remaining sections of this chapter will elaborate particularly on three different standard types of methods taken from the inventory of SNA, namely, (1) the identification of central actors and roles, (2) the identification and tracking of subcommunities, and (3) techniques to characterize the evolution of ideas in actor-artifact networks. The corresponding approaches will be exemplified with recent applications to the study of networked collaboration, especially in learning contexts.

Identification of Central Actors and Roles

SNA methods can be used to identify important or also marginal or isolated actors in networks both for research purposes (i.e., understanding the nature of a collaboration network) and for regulative feedback and reflection on the part of the actors (i.e., supporting the network during interaction). Means for this are centrality measures, group detection, or positional analyses within a network. Among the most common usage types of SNA methods in community scenarios are the identification of most central actors and isolated actors. A popular approach for this end is the computation of centrality measures (Wasserman & Faust, 1994), such as the degree centrality that represents how many links an actor has to other community members. Relatively often, the interpretation of such a measure alone produced shallow insights, such as "the teacher was the most central actor of the network," which is often a natural consequence of the pedagogical design. Another common approach is to determine groups of dense interaction within a community. Different graph theoretic constructs, such as cliques, clubs, cores, k-plexes, and algorithmic methods like the clique percolation method (Palla, Derenyi, Farkas, & Vicsek,

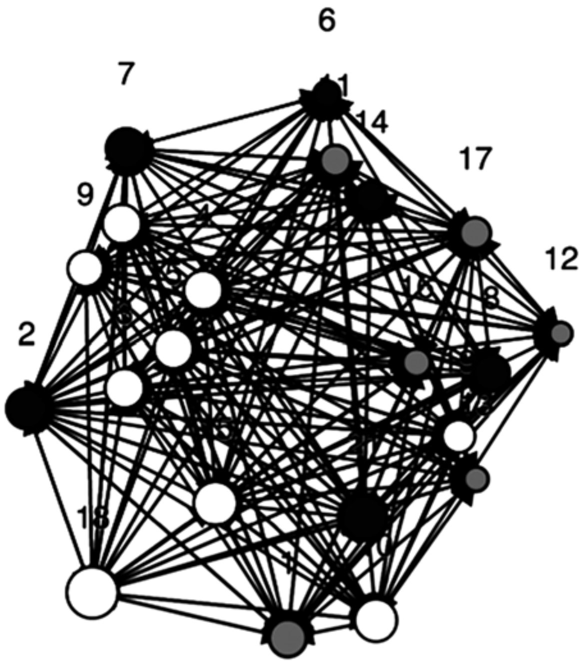


Fig. 1 Network graph with centrality and grouping information

2005), have been proposed and tested. Without complementing knowledge about the network, the interpretation of such analyses may be misleading. For example, when processing coauthorship networks, the author-author network contains cliques of n persons for each paper coauthored by n persons: a paper of $n=10$ authors thus results in a clique of ten that might indicate a very intense collaboration group, while it potentially only shows a one-time loose collaboration for one paper. Figure 1 shows a typical network representation where centrality and grouping have been used, yet with relatively limited expressiveness: because of the sheer number of edges, the relevant relations are hard to see, and the size of the nodes that represents the degree centrality has little variation; additionally, the grouping of the actors that is represented by the same color (here represented as different degrees of shading) is not easy to understand.

Thus, the isolated focus on either individual actor's centrality or membership in groupings is in most cases not sufficient to understand the nature of collaboration and quality of interaction. We will present our proposal of combining different network analytic approaches with each other to create a more comprehensive perspective of the collaboration.

Computer-supported collaboration frequently creates several distinct relations between the actors, such as direct communication using chat, knowledge co-construction using wiki, etc. The analysis of relational patterns between these different relations can be done using methods for role analysis (Wasserman & Faust, 1994). Examples of relevant patterns for CSCL scenarios might be "all students interacting indirectly on the same wiki page also communicated directly in the chat" or "students using the discussion forum to discuss with each other were not interacting directly in the lab sessions." The role analysis is more expressive if applied to a positional analysis that aggregates actors with similar network function into the same position. In contrast to a grouping that shows proximity and/or connection between actors within a group, this aggregation is along positional aspects (e.g., isolate, bridge, hub) and does not mean that actors in the same position are connected to each other.

Researchers interested in this overall structure of a network can use blockmodeling algorithms (Doreian, Batagelj, & Ferligoj, 2005) to categorize actors with a similar position/function into the same block. This creates a suitable network representation to take a look at the relations between the different blocks.

We will describe in the following our approach that uses a combination of groupings, multi-relational blockmodeling, and role analysis within an integrated visualization that has been proposed recently (Harrer & Schmidt, 2013) and integrated into the SISOB analysis workbench (Göhnert, Harrer, Hecking, & Hoppe, 2013) to allow application and convenient reuse of this complex analysis process to networks created within CSCL scenarios.

As an overall consideration, we tried to design an approach that scales also to large networks, such as the ones that typically occur in mass collaboration scenarios. For this end, we chose as our grouping approach the k-core measure (Batagelj & Zaveršnik, 2003), since a clique analysis is not well suited for larger networks. The k-core metrics assigns an actor to level k if the actor has at least k edges to other members of this core level. Thus, it embeds all cliques of size k + 1, because in a strict clique of size k + 1, all actors have k links to the other clique members. As one drawback of the core metrics, the members of the same core level are not necessarily connected with each other at all, but a connectivity check can be performed easily if needed. For our purpose, the core level each actor belongs to is good enough as a measure how connected the actor is.

The second information we use in our approach is the position the actor belongs to across the multiple relations. In comparison with single-relational blockmodeling, the challenge is to produce a fitting model for actors to positions that takes into account both relations at the same time. Because a complete test for the best model is computationally heavy and just impractical for larger networks, we derived a randomized optimization algorithm based on the principles of the single-relational blockmodeling algorithm proposed by Doreian et al. (2005). To achieve a good result (not necessarily the optimum), the procedure uses repeated iterations for a number of times that should be chosen according to the size of the network. This algorithm assigns each actor to a block/position that is characteristic for both relations at the same time. Together with the resulting block matrix that shows the coarser relationships between positions, this can result in interpretations, such as "the actor belongs to the network center of forum usage but is isolated in chat usage" if the block matrix for forum usage has multiple receiving and sending links for the specific position the actor belongs to and the block matrix for chat has no links to other positions. Such a position could potentially be labeled "asynchronous contributor."

The third information we obtain is the dependencies that hold across the different network relations. While in principle this can be done at the network level, for large networks this is computationally impractical, and the general nature of relations between positions makes the role analysis based on the block matrix suitable for this type of analysis. The algorithm we chose to compute the relational dependencies is well described in the literature (Wasserman & Faust, 1994). As a result of this algorithm, we obtain equalities of relational combinations (e.g., "posting relations between the blocks is similar to the chatting behavior between the blocks") and inclusion dependencies (e.g., "collaborating in the wiki is a smaller relation than posting with each other," which means additionally that positions collaborating in a wiki also post with each other).

The three types of information of groups, positions, and roles are brought together in an integrative visualization we call PRoG diagram (position, role, group). It represents each position as a large circle where the actors assigned to the position are placed inside. To reduce the number of edges that have to be drawn and thus avoid the literal "Death Star" of network visualization (similar to Fig. 1, when drawn in a circular network layout), we only represent edges between the positions as the block matrix describes. An important difference to actor networks is here that self-ties have the meaning that actors within a position interact with each other. Since different relational combinations usually share some links, we create one diagram for each chain of relational combinations that include other combinations. Common edges for several combinations are only shown for the smallest relation, because all the including combinations also contain that link. Thus, the larger combinations only show the additional links that the lower ones don't have. The colors of combinations and edges are used consistently to highlight the relational dependencies. The grouping information is included only at a coarse level, because the detailed information of k-core level across multiple relations and a comparison with minimum and maximum values for each would clutter the diagram. Our decision was to highlight actors that belong to the maximum core in all relations in red color, actors that belong to the minimum core in at least one relation in black, and all others in gray. Thus, red actors are very central across all relations, while black actors might be isolated in some relation, pinpointing potentially interesting behavior and actionable results for instructors, such as "the actor has a position of project manager but is interacting only very little" which might require an intervention to help the student solving the task properly.

Figure 2 shows an example of our visualization for a small network from the literature that uses a friendship (F) and an advice relationship (A). This kind of semantic difference between relations can also be found frequently in social software systems, virtual learning environments, and co-constructive spaces. As interesting relational structures, we can detect in the diagram that "friend-of-a-friend relation is larger than friendship alone" (F*F>F in the lower right) and especially "advice relationship and friend-of-an-advisor do not share any edges but create the maximum relation together," which might indicate that actors advising are typically not befriended with actors that are themselves advisors. These antagonistic tendencies can be seen with relative ease in the diagram, while in the original data, this was

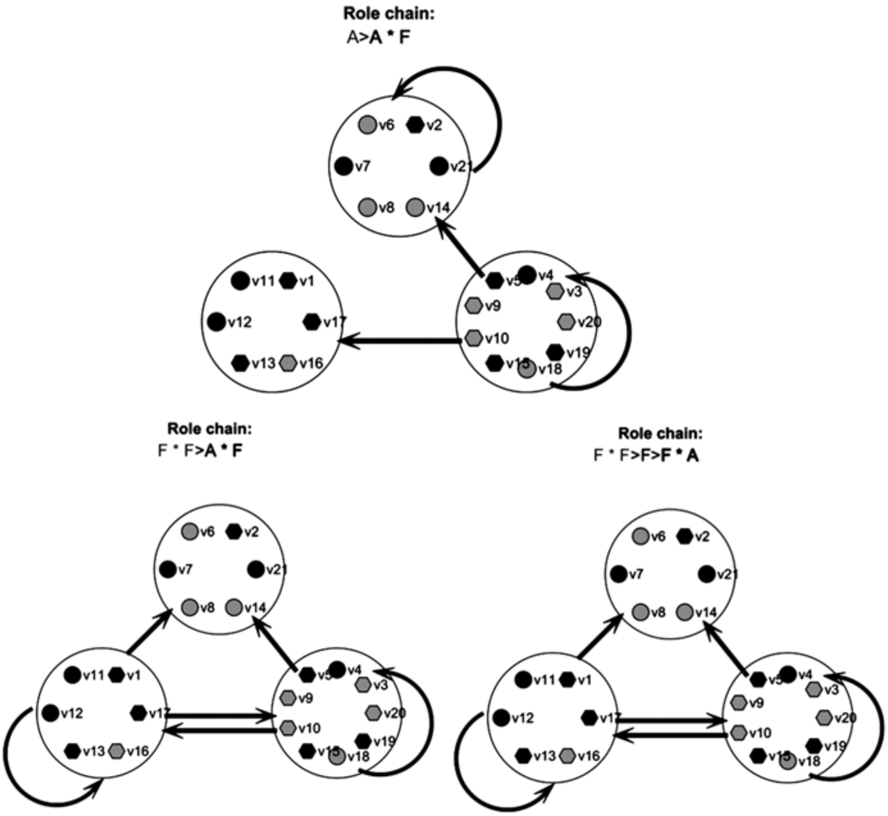
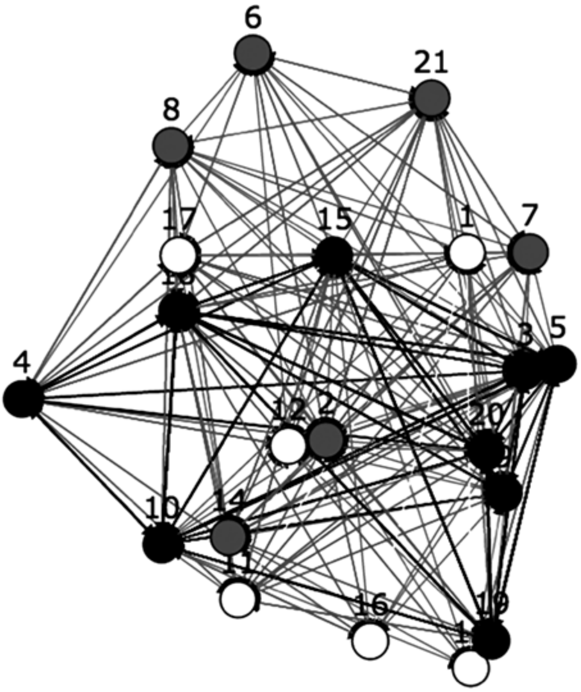


Fig. 2 PRoG diagram of a two-relational network and its role relations

not visible at all. Still we would like to raise a caveat that the interpretation of these networks and analysis results on a substantial level is difficult and requires in-depth knowledge of the network to create reliable interpretations. Even labeling a position with a meaningful name has interpretation and subjectivity in it.

The proposed method has been applied to well-researched data in the field of SNA, such as the Krackhardt's high-tech manager network as a benchmark test. This brought interesting new insights (Harrer & Schmidt, 2013) both with respect to the positional system and relational dependencies in comparison with earlier research (Wasserman & Faust, 1994). We also applied it to a Facebook dataset with buddies and "game friends" that we had in-depth knowledge of (to allow interpretation at the substantial level) and to a large set of randomly generated networks to test the performance of the different algorithms. We currently plan to apply it to a full-fledged large-scale online scenario where different relations can be captured through usage of different collaboration tools. Since all of our practical considerations (core metrics efficient also for large networks, randomized optimization algorithm for blockmodeling, role analysis on blocks instead of actors) were made with scalability in mind, we are optimistic that the approach can also be used for real networks with

Fig. 3 Combination of network graph with analysis results of multi-relational analysis



several thousand actors and interpreted together with experts of the specific network community.

Originally, the whole analysis approach has been implemented as a collection of R-scripts to be used by expert analysts. To allow re-usage of the whole quite complex analysis workflow and also to support the combination with other SNA techniques (e.g., other grouping methods and additional visualizations), we integrated the R-scripts technically into the SISOB analysis workbench (Göhnert et al., 2013). This enables us to combine the complex multi-relational analysis with other more usual visualization approaches such as in Fig. 3. In this representation, the positional information computed by multi-relational blockmodeling is color-coded, and the links that are between nodes in the same position are in the same color, thus highlighting intra-positional connectivity.

This network representation complements the PRoG diagram in its visual expression of the links that have been left out on purpose in the other diagram. Bringing both visually together and using all the results of analysis in a combined way allow an improved interpretation of the social interaction within the network and across different relations.

While the method presented in this section is prepared algorithmically for large networks and thus mass collaboration, the choice of parameters, such as the number of positions the blockmodeling is fit to and the criterion to define the block matrices, is a challenge and requires some expertise to achieve expressive results. Additionally, the nature of data in large online communities (often following the

Pareto distribution of 1 % active users, 9 % casual users, and 90 % passive users) might result in sparsely connected networks of actors and artifacts which possibly create problems to find well-defined and coherent positions. As mentioned before, the combination of network analysis with other analytic methods amplifies the potential to understand learning and collaboration, especially if experts knowledgeable about the nature of the community are involved in the combined interpretation of the analytic results.

Identification and Tracking of Subcommunities in Networks

Social networks usually develop cohesive substructures (also called subcommunities). This means that certain subsets of actors tend to be more densely connected to each other than to outsiders (Backstrom, Huttenlocher, Kleinberg, & Lan, 2006; Watts & Strogatz, 1998). The detection of such cohesive subgroups also referred to as subcommunities of actors in a social network is a standard task in SNA (Fortunato, 2010). Subcommunity detection is especially relevant for the analysis of collaborating communities because they allow for the identification of subcommunities of actors who tend to interact more closely (or intensively) compared to the overall interactions. Concerning the diffusion of information in a social network, subcommunities can be considered as modules in which information is circulated internally with limited access from outside. There are several methods with different properties which should be chosen carefully according to the goal of the analysis. Many methods aim to partition a graph into disjoint sets of nodes while maximizing the modularity (Girvan & Newman, 2002). In simplified terms, modularity measures the fraction of edges that occur between members of the same subcommunity and the expected number of edges between them after random rewiring of the network. Its value rises with the number of intra-community edges. Modularity-optimizing methods are especially suited to identify highly separated groups of actors keeping information within their circle.

On the other hand, there are also methods that do not cluster all nodes exhaustively and allow for overlaps in the sense that actors can belong to more than one subcommunity. A prominent example for methods that detect overlapping subgroups is the clique percolation method (CPM—cf. Palla et al., 2005). Overlapping subcommunities can be of particular interest in the domain of collaboration since actors who appear in the overlap between subgroups, or bridge between them, play a special role in this model as information brokers because of their ability to spread information across different subcommunities (Vedres & Stark, 2010).

Apart from the complexity of analysis, the identification of subcommunities is a challenging task from the algorithmic point of view. The task becomes even more complicated in evolving networks where time is an important factor. In those networks, subcommunities evolve over time and thus undergo certain life-cycle events. In particular, these events can be described according to Palla, Barabasi, and Vicsek (2007) as:

- Birth: A subcommunity is identified the first time.
- Growth: A subcommunity acquires new members but core stays the same.
- Contraction: A subcommunity loses members over time.
- Merge: The members of distinct subgroups merge to one subgroup at later point in time.
- Split: One subcommunity splits into two new born subcommunities.
- Death: A subcommunity disappears over time.

The identification of these events is another active area of research in network science. The goal is to identify relationships between subcommunities in different time slices of an evolving network. Re-identification of subcommunities across subsequent time slices is often done by matching. Matching can, for example, be based on Jaccard similarity (Greene, Doyle, & Cunningham, 2010) or measures of the inclusion of one cluster into another (Takaffoli, Sangi, Fagnan, & Zâiane, 2011). There are also hybrid measures as defined by Bròdka, Saganowski, and Kazienko (2013) where inclusion is combined with the social position of the cluster members in social networks. If an evolving network is not sampled into time slices but modeled as a stream of atomic events like appearance and disappearance of one edge or node, it is possible to update the community structure incrementally and no matching is necessary (Nguyen, Dinh, Xuan, & Thai, 2011). This, however, results in much more computational effort than the matching-based approaches.

When evolving networks are sampled into time slices according to nodes and edges that were present in certain time windows, the problem of choosing an appropriate time window size arises. The length of a time window has a huge effect on the number and the size of subgroups detected in a network and thus on the analysis result. This problem has been clearly addressed by Zeini, Göhnert, Hecking, Krempel, and Hoppe (2014), and indicators for proper time window sizes were investigated. However, these indicators differ across different subgroup detection methods (Hecking et al., 2013). Thus, one has additionally to consider the goal of the analysis. The analysis task influences the method that should be applied, and both task and method determine a proper time window size. The choice of a suitable size of a time window depends on the method that is used for subcommunity detection, the analysis task (Hecking et al., 2013).

Dynamic Subcommunity Detection in Affiliation Networks

Even in collaborative online environments, immediate relationships between actors like social relations or knowledge exchange are often not directly observable from the data. However, in the absence of direct communication channels such as forums or mailing lists, it is still possible to infer indirect relations between actors mediated by artifacts. For example, based on the log protocols of actors and the resources they accessed or edited, it is possible to derive bipartite or “two-mode” networks where actors are affiliated to artifacts, while there are no direct connections between the actors or the artifacts themselves. According to the concept of social-thematic navigation through the sharing of learner-created “emerging learning objects,” relations between groups of people induced by thematically related objects indicate actors with a common interest (Hoppe et al., 2005). Interaction can then take place indirectly mediated by those objects without necessarily implying a person-to-person communication. Typical examples for bipartite networks in collaboration scenarios are users and forum topics, researchers and their affiliations to conferences, or wiki editors and articles they modified.

It is always possible to derive unipartite (one-mode) networks between entities of the same type from those bipartite (or two-mode) networks based on mutual affiliations to nodes of the other type. This is reasonable since mutual connections often imply connections between the nodes of one type itself. For example, a common paper of two scientists constitutes a coauthorship connection between the authors. On the other hand, the projection of two-mode networks into one-mode networks always loses the information about one type of nodes. If the detection of subgroups as described above is performed on the bipartite network itself, the resulting clusters comprise nodes of both types. This allows for identifying actors with similar affiliations to certain objects by keeping the objects themselves as part of the cluster and vice versa.

In dynamic affiliation networks, the problem of “tracking” subgroups as described in the previous section has to be addressed. For example, it has to be decided if certain clusters are almost identical to previous ones, or if they are results of mergers and splits, or if they have just been newly formed. In a static snapshot of an affiliation network, a cluster contains two groups of nodes for the two node types each. However, regarding the evolution of bipartite clusters over time, these two node groups have to be considered separately. Figure 4 (left) depicts an example where an evolving affiliation networks have two clusters at time *t–1*. At time *t* two other clusters can be detected, which cannot be matched to the previous clusters as a whole. However, it is possible to match the clusters partially to the previous ones since the different groups of nodes reoccur as part of different clusters. In this view, the events

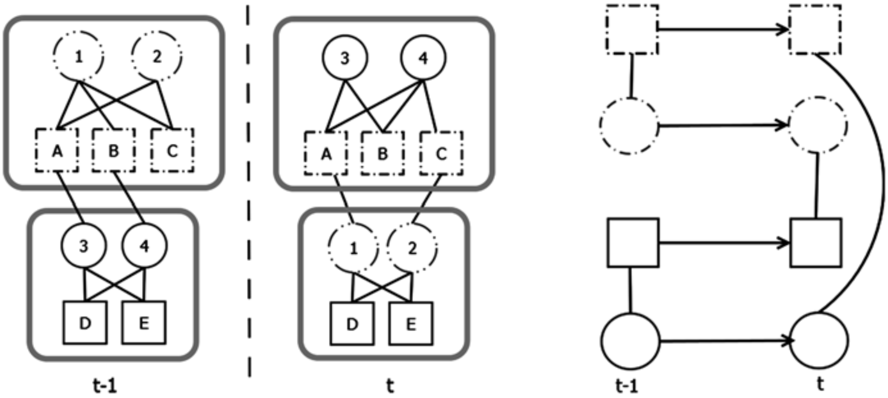


Fig. 4 Evolving bipartite clusters (*left*) and the corresponding swim lane diagram (*right*)

described in the previous section can be detected for each of the two node groups of a bipartite cluster. On the right side of Fig. 4, the situation is depicted as a swim lane diagram. A node in the swim lane diagram represents a group of nodes of one or the other type in the original affiliation network. In one time slice, two groups of different types are linked by a vertical edge indicating that these two groups form a bipartite cluster at that time. Horizontal edges appear across time slices and link two groups of the same type indicating group similarity. This approach has been applied in the work of Hecking, Ziebarth, and Hoppe (2014) where affiliation networks were built based on students' affiliations to learning resources they used in interdisciplinary university classes. In two case studies, one on a small blended learning course on interactive learning and teaching technologies with 44 participants and on a large purely online lecture with 173 participants on computer-mediated communication, the bipartite clustering approach could give surprising insights into the patterns of resource usage over time. Both courses were resource intensive in the sense that the traditional lecture was accompanied by a variety of additional learning resources like lecture videos, slides, serious games, as well as a glossary of important concepts created by the students themselves as a wiki.

For the sake of a clear and explanatory presentation in the following, the possible applications of the method are outlined along the example of the small blended learning course. However, as mentioned earlier, the approach can easily be extended toward much larger scenarios where actors and their affiliations to resources of various kinds can be modeled as a bipartite network.

Students and resources were simultaneously grouped into mixed and overlapping clusters as explained above. Those clusters can be interpreted as a group of students who have a common interest in a group of learning resources but not necessarily having social connections. A typical example cluster is depicted in Fig. 5.

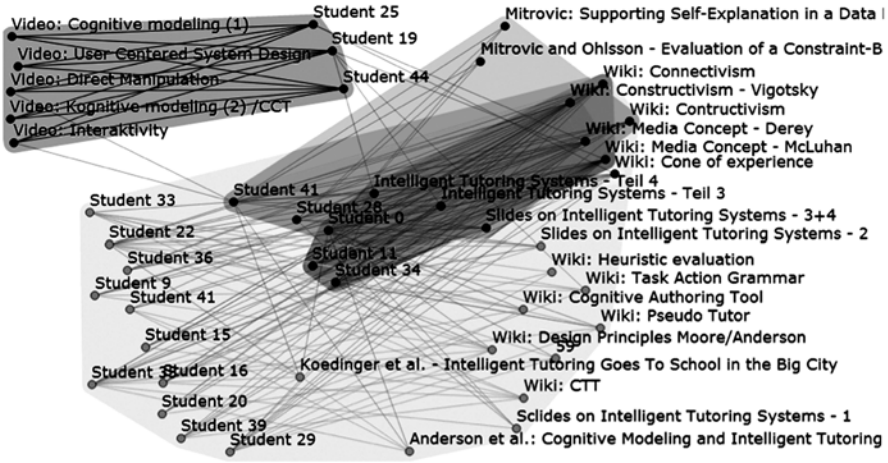


Fig. 5 Bipartite clusters of students and learning resources. *Black* nodes belong to more than one cluster

In order to find clusters in such affiliation networks, the biclique communities method (Lehmann, Schwartz, & Hansen, 2008) was applied. The method adapts the CPM. CPM builds overlapping subcommunities in one-mode networks based on the presence of cliques (fully connected subgraphs). Since in affiliation networks cycles of odd length are impossible, not even a nontrivial clique with more than two nodes can be found in those networks. Therefore, the biclique communities method adapts the original CPM in the sense that it operates on bicliques which are maximal connected subgraphs in bipartite networks.

By applying the method to the student—resource networks of particular weeks during the lecture period—this analysis reflects certain groupings induced by explicit assignments but also yielded some surprising insights regarding the usage materials. This can be, for example, seen in Fig. 2 where the orange-colored cluster comprises lecture videos and students that seem to have distinct interest in learning resources compared to the others.

In addition to that, the tracking of bipartite student—resource cluster—was used to investigate the resource access behavior during exam preparation of the students after the last lecture. This period is particular interesting because at that time the entire learning material that had been successively added every week to the course was present. This includes the wiki articles created by the students. The swim lane diagram in Fig. 6 depicts the resource access patterns found in the course during this phase. Time slices where build based on a time window size of 4 days. The oral exams were distributed over 2 weeks for most of the students, while for another study program, the examination phase began 6 weeks after the last lecture. One

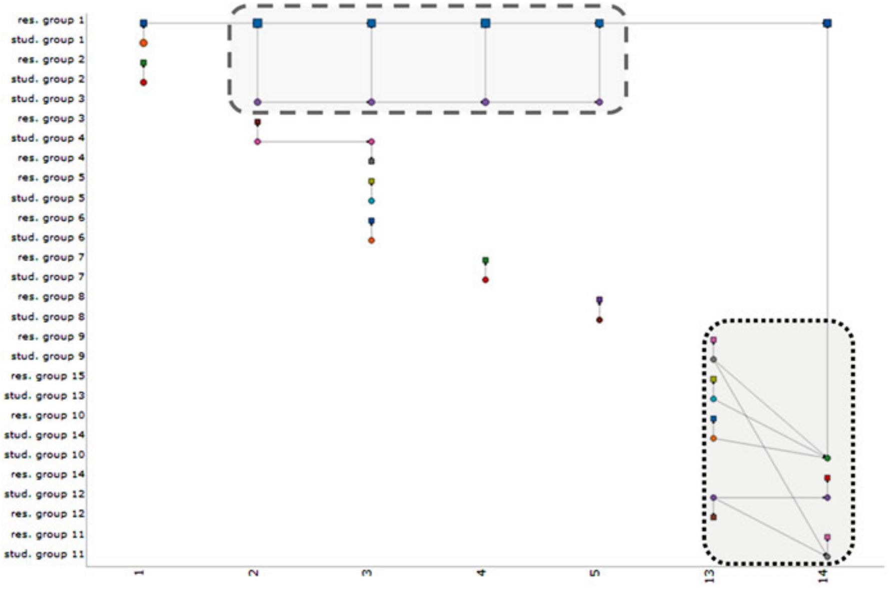


Fig. 6 Swim lane diagram of the evolving student—resources cluster during the exam preparation phase

finding is that a large majority of students accessed large proportions of the learning material over several time slices which resulted in the pattern highlighted in the gray dashed box. In particular, resource group 1 which includes most of the lecture slides but also the learner generated wiki articles occurs in nearly every time slice. Between time slices 2 and 5, there was a stable set of students (stud. group 3) using this material for exam preparation. In contrast to that, the students of a study program who had their oral exams later than the others had a more diverse resource access behavior (black dotted box). It is also suspicious that they began their exam preparation much closer to the exam compared to the other study programs. In the last time slice, three of the four student groups merged to a larger group who was then more affiliated to the core learning material (res. group 1).

Analyzing the Evolution of Ideas in Knowledge-Building Communities

Scientific production can be seen as a prototypical case of knowledge building in communities. For example, the knowledge-building pedagogy introduced by Scardamalia and Bereiter (1994) is essentially based on this analogy. Accordingly, methods that have been developed to analyze scientific production ("scientometric methods") can plausibly also be used to analyze other types of knowledge building in networked communities. Scientometric methods are tailored to the analysis of the interrelation between actors (authors) and knowledge (most prominently publications).

Hummon and Dereian (1989) have proposed the method of "main path analysis" (MPA) to detect the main flow of ideas in citation networks with scientific publications as nodes connected by citations. The original paper uses a corpus of publications in DNA biology as an example. Chapter "Theoretical and Empirical Analysis of Networked Knowledge" by Halatchliyski (2016) presents a study on the application of the MPA method in order to analyze the evolution of externalized knowledge in the Web-based educational community of Wikiversity (Halatchliyski, Hecking, Göhnert, & Hoppe, 2014). This section focuses on the adaptation of MPA method to hyperlinked environments from a computational perspective. The original MPA method relies on the acyclic nature of citation graphs. Since a publication can only cite already published and hence older publications, in a corpus of documents, there always exist documents that are not cited by other as well as documents that do not cite other documents in the corpus. Consequently, if the direction of the relations between the documents is modeled according to the flow of information, namely, from the cited to the citing publication, there will be information sources (nodes with no ingoing edges) and information sinks (nodes with no outgoing edges). The idea of MPA is to find the most used edges in terms of the information flow from the source nodes to the sink nodes. One common method to find these edges is the "search path count" SPC method (Batagelj, 2003). All sources in the network are connected to a single artificial source and all sinks to a single artificial sink. SPC assigns a weight to an edge according to the number of path from the source to the

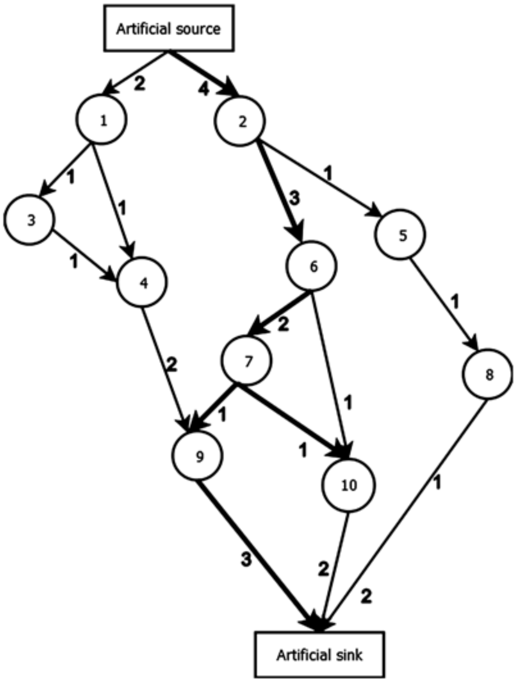


Fig. 7 Example network. Edge weights were calculated according to the SPC method. (*Thick* edges indicate the main path edges)

sink on which the edge occurs. The main path can then be found by traversing the graph from the source to the sink by using the edges with highest weight as depicted in Fig. 7.

In wikis as hyperlinked environments, a hyperlink between two articles can be considered as a citation. However, MPA cannot be applied because the premise of directed acyclic graphs (DAGs) is usually not fulfilled. Since the content of articles in a wiki is dynamic, hyperlinks between two articles do not induce a temporal order between them, and cycles become possible. Thus, the adapted MPA method considers the particular revisions of an article rather than the articles themselves. Revisions of an evolving wiki article are artifacts with stable content as scientific publications. In a network with article, revisions as nodes connections can be established between successive revisions of the same article. Further, revisions that introduce a link to a revision of another article can be connected by a directed edge. The resulting graph is a DAG as depicted in Fig. 8. The direction of the interpage hyperlinks points from the linked to the linking revision and thus can be interpreted as an uptake of an idea. Chapter “Theoretical and Empirical Analysis of Networked Knowledge” by Halatchliyski (2016) describes the application of the method to the online teaching and learning community of Wikiversity. As a further application, the coincidence of articles with identified main paths has been used as a basis to judge the importance or “weight” of Wikiversity contributions and to characterize author profiles.

In another study, we have combined MPA with existing approaches to the analysis of chat interactions. Here, we had to take into account the characteristic of chat as a

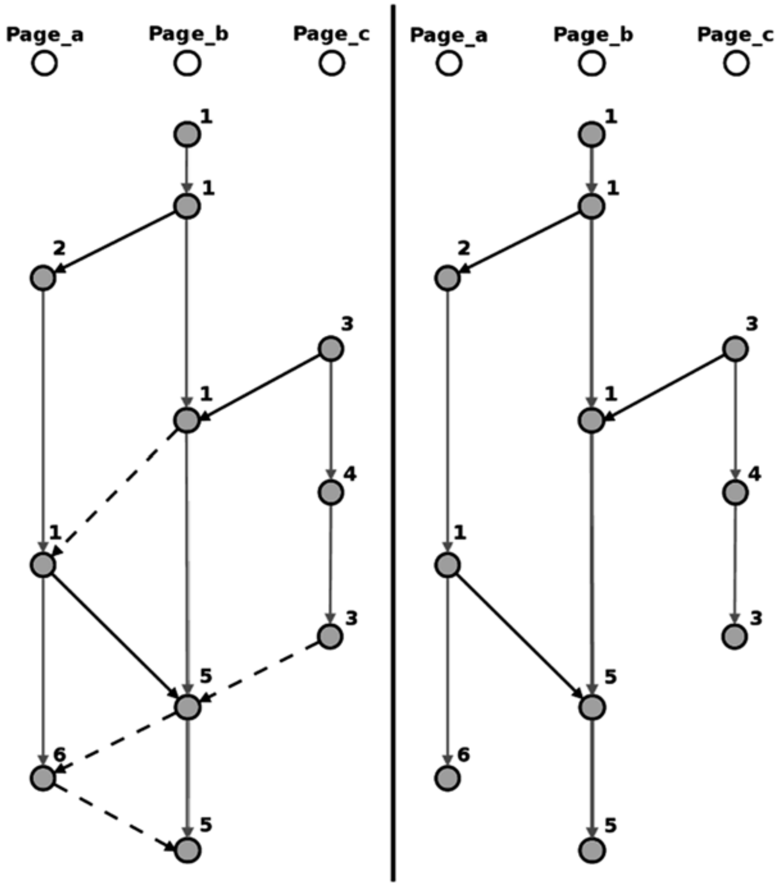
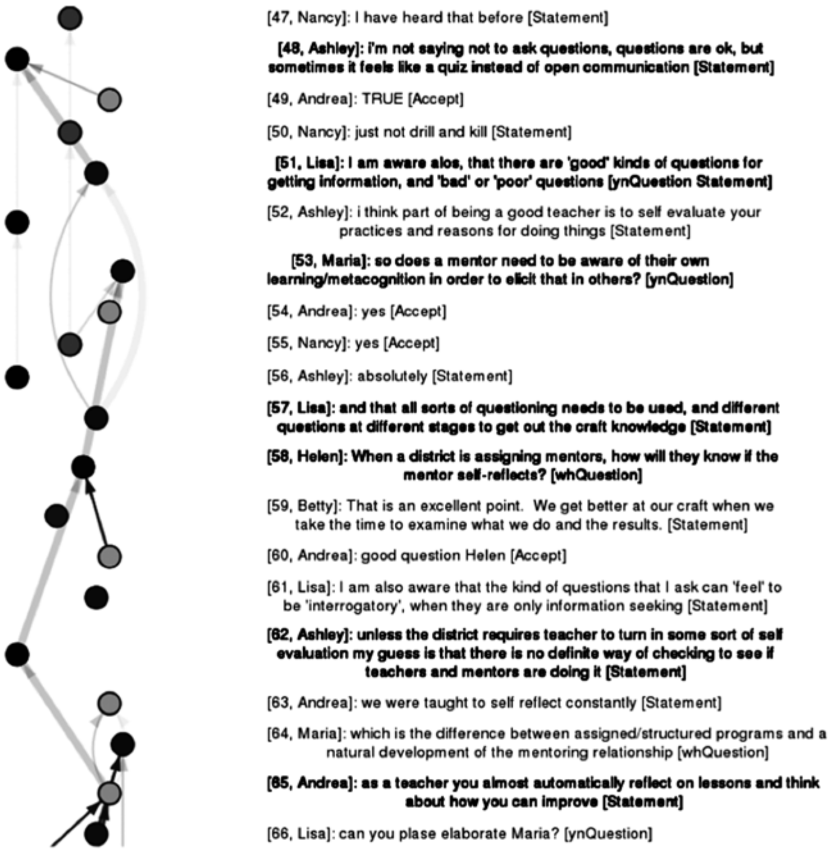


Fig. 8 (*Left*): DAG comprising the revisions of articles a, b, c. (*Right*): with redundant links filtered

synchronous communication medium, especially regarding turn-taking, possible parallel threading, and interactional coherence. We took the "contingency analysis" approach (Suthers, Dwyer, Medina, & Vatraou, 2010) as a fundamentum and base line to detect general dependencies based on operational rules. We reconstructed and refined this approach by using the concept of dialogue act tagging (Wu, Khan, Fisher, Shuler, & Pottenger, 2005) to enrich the basic set of indicators. Our implementation and extension of the method have been integrated with the SISOB analytics workbench to allow for a visual representation and reuse of specific analysis workflows (Hoppe, Göhnert, Steinert, & Charles, 2014). We have tested our method using several examples of chat protocols from a teacher community as benchmarks. This allowed us to assess the agreement between the contingency links generated by our method with previously hand-coded contingencies (Suthers & Desiato, 2012) based on the *F*-score (a measure used in information retrieval combining precision and recall). The automatically generated contingencies reached an *F*-score similarity of 83–97 %, which is comparable to the pairwise *F*-score similarity of manually ana-



[47, Nancy]: I have heard that before [Statement]

[48, Ashley]: i'm not saying not to ask questions, questions are ok, but sometimes it feels like a quiz instead of open communication [Statement]

[49, Andrea]: TRUE [Accept]

[50, Nancy]: just not drill and kill [Statement]

[51, Lisa]: I am aware alos, that there are 'good' kinds of questions for getting information, and 'bad' or 'poor' questions [ynQuestion Statement]

[52, Ashley]: i think part of being a good teacher is to self evaluate your practices and reasons for doing things [Statement]

[53, Maria]: so does a mentor need to be aware of their own learning/metacognition in order to elicit that in others? [ynQuestion]

[54, Andrea]: yes [Accept]

[55, Nancy]: yes [Accept]

[56, Ashley]: absolutely [Statement]

[57, Lisa]: and that all sorts of questioning needs to be used, and different questions at different stages to get out the craft knowledge [Statement]

[58, Helen]: When a district is assigning mentors, how will they know if the mentor self-reflects? [whQuestion]

[59, Betty]: That is an excellent point. We get better at our craft when we take the time to examine what we do and the results. [Statement]

[60, Andrea]: good question Helen [Accept]

[61, Lisa]: I am also aware that the kind of questions that I ask can 'feel' to be 'interrogatory', when they are only information seeking [Statement]

[62, Ashley]: unless the district requires teacher to turn in some sort of self evaluation my guess is that there is no definite way of checking to see if teachers and mentors are doing it [Statement]

[63, Andrea]: we were taught to self reflect constantly [Statement]

[64, Maria]: which is the difference between assigned/structured programs and a natural development of the mentoring relationship [whQuestion]

[65, Andrea]: as a teacher you almost automatically reflect on lessons and think about how you can improve [Statement]

[66, Lisa]: can you plase elaborate Maria? [ynQuestion]

Fig. 9 Fragment of a chat protocol with inferred contingency links (main path contributions and links indicated in *bold*)

lyzed graphs. Figure 9 shows a fragment of a chat sequence with contingency links indicated on the right hand side, main path contributions highlighted in bold, and the message categories resulting from dialogue act tagging (e.g., "Statement" or "ynQuestion") added in brackets.

The main path information should be interpreted as an indicator for the relevance of contributions in the evolution and progress of the overall discourse. This relevance measure for contributions can in turn be used to estimate the influence of participants in the discourse. Since we did not have human ratings for this feature, we have compared the measure "percentage of contributions on main path" (*%MainPath*) per actor to other influence rankings based on the well-established *PageRank* and *Indegree* measures. We applied these measures to different versions of the contingency graphs resulting from human and automatic coding. As a result, we found a 0.82 (0.82) correlation of *%MainPath* with *PageRank* and a 0.69 (0.88) correlation with *Indegree*. Per se, *%MainPath* is just another competing indicator.

However, it is different from the other measures since it takes into account the flow of arguments in the discourse and not only local (*Indegree*) or globally weighted prestige (*PageRank*). As can be seen in Fig. 9, MPA also allows for filtering the discourse for main threads of argument. This is promising, but further investigation is needed to validate these constructs.

Conclusion

Network models and network analysis techniques can reveal various structural facets in online communities. In this chapter, we have concentrated on characterizing important techniques and possible insights. An ensuing question is how these insights can be used in certain practical contexts and application scenarios. Regarding learning communities, network-based approaches are now conceived as part of the repertoire of learning analytics techniques. Accordingly, network characteristics and visualizations can support the supervision of learning communities as well as self-reflection on the part of the learners.

The general prospect is that analytic methods can support community (self-) organization and management by providing relevant information on the ongoing social and content level processes, allowing the actors to make more informed decisions.

References

Backstrom, L., Huttenlocher, D., Kleinberg, J., & Lan, X. (2006). Group formation in large social networks: Membership, growth, and evolution. In *Proceedings of the 12th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* (pp. 44–54), Philadelphia, PA. doi:10.1145/1150402.1150412.

Batagelj, V. (2003). Efficient algorithms for citation network analysis. In *arXiv preprint cs/0309023*. Retrieved from http://arxiv.org/abs/cs/0309023.

Batagelj, V., & Zaveršnik, M. (2003). An o(m) algorithm for cores decomposition of networks. *arXiv preprint cs/0310049*. Retrieved from http://arxiv.org/abs/cs/0310049.

Borgatti, S. P., Mehra, A., Brass, D. J., & Labianca, G. (2009). Network analysis in the social sciences. *Science, 323*, 892–895.

Bròdka, P., Saganowski, S., & Kazienko, P. (2013). GED: The method for group evolution discovery in social networks. *Social Network Analysis and Mining, 3*, 1–14.

de Solla Price, D. J. (1965). Networks of scientific papers. *Science, 149*, 510–515.

Doreian, P., Batagelj, V., & Ferligoj, A. (2005). *Generalized blockmodeling*. Cambridge, England: Cambridge University Press.

Fortunato, S. (2010). Community detection in graphs. *Physics Reports, 486*, 75–174.

Girvan, M., & Newman, M. E. J. (2002). Community structure in social and biological networks. *Proceedings of the National Academy of Sciences, 99*, 7821–7826.

Göhnert, T., Harrer, A., Hecking, T., & Hoppe, H. U. (2013, August). A workbench to construct and re-use network analysis workflows: Concept, implementation, and example case. In *Proceedings of the 2013 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining* (pp. 1464–1466). New York, NY: ACM.

Greene, D., Doyle, D., & Cunningham, P. (2010). Tracking the evolution of communities in dynamic social networks. In *International Conference on Advances in Social Networks Analysis and Mining (ASONAM)* (pp. 176–183).

Halatchliyski, I. (2016). Theoretical and empirical analysis of networked knowledge. In U. Cress, J. Moskaliuk, & H. Jeong (Eds.), *Mass collaboration and education*. Cham, Switzerland: Springer.

Halatchliyski, I., Hecking, T., Göhnert, T., & Hoppe, H. U. (2014). Analyzing the path of ideas and activity of contributors in an open learning community. *Journal of Learning Analytics, 1*, 72–93.

Harrer, A., & Schmidt, A. (2013). Blockmodeling and role analysis in multi-relational networks. *Social Network Analysis and Mining, 3*, 701–719.

Harrer, A., Zeini, S., & Pinkwart, N. (2006). Evaluation of communication in web-supported learning communities—An analysis with triangulation research design. *International Journal of Web Based Communities, 2*, 428–446.

Haythornthwaite, C. (2001). Exploring multiplexity: Social network structures in a computer-supported distance learning class. *The Information Society, 17*, 211–226.

Hecking, T., Göhnert, T., Zeini, S., & Hoppe, H. U. (2013). Task and time aware community detection in dynamically evolving social networks. *Procedia Computer Science, 18*, 2066, Proceedings of the International Conference on Computational Science, 2013, Barcelona, Spain, 5–7 June, 2013.

Hecking, T., Ziebarth, S., & Hoppe, H. U. (2014). Analysis of dynamic resource access patterns in a blended learning course. *Journal of Learning Analytics, 1*, 34–60.

Hoppe, H. U., Göhnert, T., Steinert, L., & Charles, C. (2014). A web-based tool for communication flow analysis of online chats. *LAK 2014—Workshop Proceedings* (CEUR Vol-1137 urn:nbn:de:0074-1137-8). Retrieved from http://ceur-ws.org/Vol-1137.

Hoppe, U., Pinkwart, N., Oelinger, M., Zeini, S., Verdejo, F., Barros, B., & Mayorga, J. I. (2005). Building bridges within learning communities through ontologies and thematic objects. In *Proceedings of the 2005 Conference on Computer Support for Collaborative Learning (CSCL 2005)* (pp. 211–220), Taipei, Taiwan, June 2005.

Hummon, N. P., & Dereian, P. (1989). Connectivity in a citation network: The development of DNA theory. *Social Networks, 11*, 39–63.

Krempel, L. (2005). *Visualisierung komplexer Strukturen—Grundlagen der Darstellung mehrdimensionaler Netzwerke*. Frankfurt, Germany: Campus.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford, England: Oxford University Press.

Lehmann, S., Schwartz, M., & Hansen, L. K. (2008). Biclique communities. *Physical Review E, 78*, 016108. doi:10.1103/PhysRevE.78.016108.

Leydesdorff, L. (2001). *The challenge of scientometrics: The development, measurement, and self-organization of scientific communications*. Leiden, The Netherlands: Universal.

Lipponen, L., Rahikainen, M., Lallimo, J., & Hakkarainen, K. (2003). Patterns of participation and discourse in elementary students' computer-supported collaborative learning. *Learning and Instruction, 13*, 487–509.

Martínez Monés, A., Dimitriadis, Y., Rubia Avi, B., Gómez Sánchez, E., & de la Fuente Redondo, P. (2003). Combining qualitative evaluation and social network analysis for the study of classroom social interactions. *Computers & Education, 41*, 353–368.

Newman, M. E. J., Barabási, A.-L., & Watts, D. J. (2006). *The structure and dynamics of networks* (Princeton studies in complexity). Princeton, NJ: Princeton University Press.

Nguyen, N. P., Dinh, T. N., Xuan, Y., & Thai, M. T. (2011). Adaptive algorithms for detecting community structure in dynamic social networks. In *INFOCOM, 2011 Proceedings IEEE* (pp. 2282–2290). doi:10.1109/INFCOM.2011.5935045.

Palla, G., Barabasi, A. L., & Vicsek, T. (2007). Quantifying social group evolution. *Nature, 446*, 664–667.

Palla, G., Derenyi, I., Farkas, I., & Vicsek, T. (2005). Uncovering the overlapping community structure of complex networks in nature and society. *Nature, 435*, 814–818.

Reffay, C., & Chanier, T. (2003). How social network analysis can help to measure cohesion in collaborative distance-learning. In B. Wasson, S. Ludvigsen, & H. U. Hoppe (Eds.), *Designing for change in networked learning environments* (pp. 343–352). Dordrecht, The Netherlands: Springer.

Scardamalia, M., & Bereiter, C. (1994). Computer support for knowledge-building communities. *The Journal of the Learning Sciences, 3*, 265–283.

Suthers, D. D., & Desiato, C. (2012). Exposing chat features through analysis of uptake between contributions. In *Proceedings of HICSS 2012* (pp. 3368–3377). New Brunswick, NJ: IEEE Computer Society.

Suthers, D. D., Dwyer, N., Medina, R., & Vatraou, R. (2010). A framework for conceptualizing, representing, and analyzing distributed interaction. *International Journal of Computer-Supported Collaborative Learning, 5*, 5–42.

Takaffoli, M., Sangi, F., Fagnan, J., & Zâiane, O. R. (2011). Community evolution mining in dynamic social networks. *Procedia: Social and Behavioral Sciences, 22*, 49–58.

Vedres, B., & Stark, D. (2010). Structural folds: Generative disruption in overlapping groups. *American Journal of Sociology, 115*, 1150–1190.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge, England: Cambridge University Press.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*, 440–442.

Wu, T., Khan, F. M., Fisher, T. A., Shuler, L. A., & Pottenger, W. M. (2005). Posting act tagging using transformation-based learning. In T. Y. Lin, S. Ohsuga, C.-J. Liau, X. Hu, & S. Tsumoto (Eds.), *Foundations of data mining and knowledge discovery* (Vol. 6, pp. 319–331). Berlin, Germany: Springer.

Zeini, S., Göhnert, T., Hecking, T., Krempel, L., & Hoppe, H. U. (2014). The impact of measurement time on subgroup detection in online communities. In F. Can, T. Özyer, & F. Polat (Eds.), *State of the art applications of social network analysis* (pp. 249–268). Cham, Switzerland: Springer.

Mass Collaboration on the Web: Textual Content Analysis by Means of Natural Language Processing

Ivan Habernal, Johannes Daxenberger, and Iryna Gurevych

Mass Collaboration from the Natural Language Processing Perspective

Mass collaboration on the web, as a practice with far-reaching implications for a knowledge society, promotes communication, collaborative authoring, and information sharing (Cress et al., 2013). This phenomenon has been investigated from many perspectives, such as knowledge management and collaborative learning (Cress & Kimmerle, 2008; Su & Beaumont, 2010), information quality (Ferschke, 2014; Kane, 2011), knowledge construction (Moskaliuk, Kimmerle, & Cress, 2012; Stahl, Cress, Law, & Ludvigsen, 2014), or design processes (Kim, Lee, Maeng, & Lee, 2011). The main four principles of the mass collaboration paradigm are openness, peering, sharing, and acting globally (Tapscott & Williams, 2007, p. 20). In contrast to existing works, this chapter presents a novel viewpoint that targets mass collaboration from the natural language processing (NLP) perspective and explores corresponding methods that are able to cope with the current information overload. As an example domain, we focus on education as its breadth attracts not only researchers but also practitioners or policy-makers. We discuss specific NLP methods and their suitability and reliability within that domain.

I. Habernal (✉) • I. Gurevych
Ubiquitous Knowledge Processing Lab, Department of Computer Science,
TU Darmstadt, Darmstadt, Germany

German Institute for Educational Research, Frankfurt am Main, Germany
e-mail: habernal@ukp.informatik.tu-darmstadt.de; gurevych@ukp.informatik.tu-darmstadt.de

J. Daxenberger
Ubiquitous Knowledge Processing Lab, Department of Computer Science,
TU Darmstadt, Darmstadt, Germany
e-mail: daxenberger@ukp.informatik.tu-darmstadt.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported
Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_18

Collaborative learning and mass collaboration are popular educational strategies that encourage learners to engage not only in social activities and knowledge sharing but also to actively construct new knowledge (Eryilmaz, Pol, Ryan, Clark, & Mary, 2013). Onrubia and Engel (2009) examined phases of collaborative knowledge construction and found that each phase represents a higher level of cognitive complexity than the previous one, more in-depth study, more convergence, and more shared understanding of the meanings constructed by the members of a group. In a review of research examining social, cognitive, and teaching presence in online learning environments, Garrison and Arbaugh (2007) conclude that collaborative learning can help learners to retain learned information longer and foster their higher-order thinking skills. In the field of computer-supported collaborative learning, asynchronous online discussions (Eryilmaz et al., 2013) and wikis (Larusson & Alterman, 2009; Wheeler, Yeomans, & Wheeler, 2008) are widely used tools. They can facilitate a natural setting for collaborative knowledge construction, e.g., by offering students the opportunity to reflect on peers' contributions and analyze their own ideas before articulating them (Pena-Shaff & Nicholls, 2004). According to Lund and Rasmussen (2010), for teachers it is becoming increasingly important to develop competence in designing technology-mediated and collaborative tasks. Their findings reveal the need to examine the complex relationships between methods, tasks, activities, and assessment in order to develop teaching with the help of Web 2.0 applications.

Among the knowledge-oriented platforms, there are numerous scenarios that approach collaboration from other directions. For instance, computer-supported argumentation facilitates communication and argumentation between multiple, and perhaps distant, participants (Scheuer, Loll, Pinkwart, & McLaren, 2010). Debate platforms are tailored for the purpose of education, but serve a wide audience beyond traditional classrooms and across regional borders.

One of the main challenges that education-related mass collaboration has to face is the huge amount of textual content generated by users. As a consequence, learners may not be able to effectively process the massive load of textual material in which to look for relevant information, and the work overload of instructors increases.

Information scattered across multiple locations, difficulty to keep an overview, or abundance of non-relevant or low-quality content are among the main obstacles to easily access and make use of the required information. Furthermore, current platforms for mass collaboration in education do not offer intelligent tools that would support users in their information needs and help to overcome the information overload. To tackle this issue, NLP is the key technology that enables extracting, analyzing, and utilizing valuable information from textual data. This article presents NLP perspectives for the field of mass collaboration in education and educational research.

The main trends in the current NLP research can be characterized with the following key phrases: (1) data driven, meaning that the methods learn from human-annotated data using various statistical models from the machine learning area (Smith, 2011); (2) semi-/unsupervised, so the costly and error-prone human

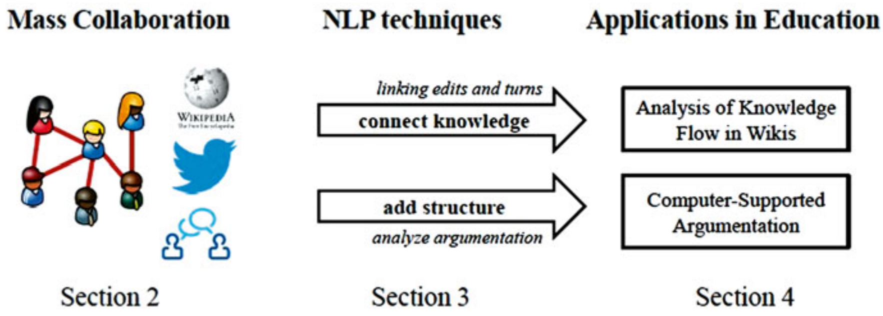


Fig. 1 Outline of this chapter

annotations are minimized by employing methods that utilize large amounts of unlabeled data (Søgaard, 2013); and (3) resource driven, which means that various existing resources are combined together in order to boost the prior knowledge of the methods (Gurevych et al., 2012). Whereas the performance of some methods achieves almost humanlike results, such as in part-of-speech tagging (Moore, 2014), syntax parsing (Krishnamurthy & Mitchell, 2014), or named entity recognition (Che, Wang, Manning, & Liu, 2013), more complex tasks remain challenging. These are, for instance, discourse processing (Ji & Eisenstein, 2014), sentiment analysis (Habernal, Ptáček, & Steinberger, 2014), question answering (Yih, Chang, Meek, & Pastusiak, 2013), or argumentation mining (Stab & Gurevych, 2014b), among others. One limitation of many current NLP methods is task dependency in terms of, e.g., task-specific features, limited domains, or language-dependent resources. To tackle these issues, recent attempts have tried to rely solely on the data without any prior task-specific information (Collobert et al., 2011).

Figure 1 gives an overview of the contents of this chapter and explains our view on mass collaboration on the web. We have selected two use cases of NLP techniques which can be applied to a range of resources for online mass collaboration. Some of these resources are discussed in section "Web-Based Resources of Mass Collaboration and Their Properties." As displayed in Fig. 1 and explained in detail in section "Recent Advances in NLP for Mass Collaboration," we use NLP techniques to (a) connect knowledge by linking edits and discussion turns and (b) to add structure to natural language texts by analyzing argumentation. Finally, in section "Toward NLP for Mass Collaboration in the Educational Domain," we show how these techniques can be applied to mass collaboration in the educational domain.

Web-Based Resources of Mass Collaboration and Their Properties

This section discusses several types of web-based resources which we think are particularly useful for the study of mass collaboration. For each of the resources, we also refer to related work. Later, in section "Recent Advances in NLP for Mass

Collaboration," we demonstrate the usage of our recently developed NLP techniques which process data from two of these resources. Typical properties of the presented resources will be summarized in a tabular form at the end of this section.

Wikis

Wikis are a popular tool to present content which should be easily accessible and editable (Leuf & Cunningham, 2001). The open encyclopedia Wikipedia, which can be edited by anybody, is probably the best known example for a wiki. However, wikis are not necessarily open to everybody. Companies often use wikis to maintain internal documentation, as many wikis allow a fine-granular access right management. Independent of whether they are closed to the public or open to everybody, wikis are always designed to facilitate collaboration on content which is shared among many or few editors and readers. Hence, wikis typically offer technologies to support online collaboration. One helpful tool is the revision history which is maintained for each page of the wiki, so that everybody can follow its entire development (Ferschke, Zesch, & Gurevych, 2011). To enable open discussion about the content of a page, many wikis additionally offer a dedicated discussion forum, in the form of a normal wiki page, used exclusively to discuss issues about the associated main content page (Viegas, Wattenberg, Kriss, & van Ham, 2007).

Data extracted from wikis is usually rather clean in a grammatical sense. Most editors are eager to add content with a certain level of quality, as other readers and editors are able to track back each change to its author. However, wikis offer limited possibilities to structure content below the page level. Large projects such as Wikipedia often have developed guidelines and best practices to ensure coherent structures across pages, e.g., infoboxes (Wu & Weld, 2010). Nevertheless, such practices are not enforced technically and consequently ignored by many users.

As mentioned above, an important piece of information which is usually made available by wikis is the revision history of a page. In addition, the discussion pages, which are bound to main content pages and are available in some wikis, offer valuable information not just about the development of an article but also about the—potentially controversial—discourse with respect to the page content (Ferschke, Gurevych, & Chebotar, 2012). As a consequence, discussion pages might contain implicit knowledge about a topic which is not visible within the article itself. The size of data extracted from wikis obviously varies a lot depending on the project. By the end of 2014, the English Wikipedia, as one of the largest wikis, contains 4.7 million content (article) pages, which approximately receive three million edits each month. Whereas the number of pages is growing rather slowly, the evergrowing revision history for the English Wikipedia is a very large resource for NLP researchers. All of Wikipedia's content is open and licensed under the permissive Creative Commons License.

To manage the size of the data, in particular the revision history of the larger Wikipedias, sophisticated data structures and algorithms are required. One disadvantage of the openness of many wikis and the fact that anyone can edit its contents is the lack of quality control and the danger of vandalism (Potthast, Stein, & Gerling, 2008; Priedhorsky et al., 2007). The many-eyes principle only works for pages with a minimum number of readers and editors, whereas many unpopular pages remain untouched for years. Many edits with malicious intentions can be detected by automatic programs and are deleted quickly. However, some vandalism may go unnoticed for a long time, so that users cannot be fully sure about the quality of what they are reading (Priedhorsky et al., 2007).

Wikipedia's revision history data has been used for several NLP applications, including spelling error correction, paraphrasing, or information retrieval (Ferschke, Daxenberger, & Gurevych 2013). Since the revision history stores all edits including metadata such as the names of the authors, comments, and timestamps, it is a very promising resource to analyze collaborative writing processes (Daxenberger & Gurevych, 2012). Additionally, Wikipedia covers more than 250 languages and is thus a valuable resource for research in languages which otherwise offer little user-generated content on the web. Ferschke, Daxenberger, and Gurevych (2013) present an extensive survey summarizing studies and applications about the dynamic contents in Wikipedia.

In section "Connecting Knowledge in Wikis," we will show how the Wikipedia revision history and the discussion pages can be linked with each other, enabling a detailed analysis of the knowledge flow from the discussion to the article contents. Based on the findings from section "Connecting Knowledge in Wikis," we will discuss applications of wiki mass collaboration in education and educational research in section "Analyzing Collaboration and Knowledge Creation in Wikis."

Discussion Forums

Online forums belong to the family of social media sites whose main purpose is to mediate discussions within a certain community. In the educational domain, forums can also facilitate a natural setting for collaborative knowledge construction (Eryilmaz et al., 2013). In contrast to wikis, where the emphasis is put on creating knowledge in the form of consistent and coherent articles, information in forums is usually implicitly spread across the discourse within a thread.

Taking into account the educational domain, discussion forums have played a dominant role when exploring collaborative learning and critical thinking in the past decade (Du, Zhang, Olinzock, & Adams, 2008; Gilbert & Dabbagh, 2005; Guzdial & Turns, 2000; Hrastinski, 2008; Niu & Van Aalst, 2009; Perkins & Murphy, 2006).

Whereas in threaded discussions the flow of dialog can be explicitly followed, many forums rely on a linear order of entries. This results into implicitly encoded flow of simultaneous discussions (i.e., using quotations). Restoring the context must rely on, e.g., thread disentanglement techniques (Elsner & Charniak, 2010; Jamison & Gurevych, 2013).

The content, as in many social media platforms, is usually very noisy. This may involve unusual spelling, irregular capitalization, and idiosyncratic abbreviations (Bontcheva & Rout, 2014) as well as non-dictionary slang, wordplay, or censor avoidance (Clark & Araki, 2011). Moreover, the temporal nature of the data, the social context, and implicit information about the participants represent an under-researched problem (Bontcheva & Rout, 2014).

The abovementioned properties of nonstandard language in social texts pose challenges to many NLP methods. For example, automatic tokenization is difficult because the majority of tokenizers are trained on newswire texts and perform poorly on social media, where punctuation plays a different role, e.g., in emoticons, hashtags, etc. (O'Connor, Krieger, & Ahn, 2010). Consider the following example by Yang and Eisenstein (2013): "gimme suttin 2 beleive innnn." These custom abbreviations, phonetic substitution, or slang affect the vocabulary size and introduce many infrequent words. Saif, He, and Alani (2012) show that 93 % of words in their Twitter corpus (1.6 million Tweets) occur less than ten times. This causes data sparsity problems in many machine learning approaches.

Therefore, text normalization is often considered as one of the first tasks when dealing with social media texts. The previous example would be normalized to "Give me something to believe in." (Yang & Eisenstein, 2013). Recent work on text normalization handles the problem by mapping the noisy words to their normalized counterparts in a dynamically generated lexicon in an unsupervised manner. Han, Cook, and Baldwin (2012) create the lexicon using distributional and string similarity. Hassan and Menezes (2013) acquire the lexicon from unlabeled data using random walks on a contextual similarity graph which is constructed from n-gram sequences obtained from large unlabeled corpora. Yang and Eisenstein (2013) propose a log-linear unsupervised model to capture the relationship between standard (normalized) and non-standard tokens, reaching state-of-the-art F_1 score of about 0.73–0.82.

Debate Platforms

A specific type of discussion forums are debate platforms that explicitly deal with one (mostly controversial) topic and allow users to add their opinions either on the *for* side or the *against* side. The debate topic is usually expressed in the form of a statement and is accompanied by a final voting of all pros and cons. From the collaboration perspective, users contribute their arguments on the issue, and the final product is usually a two-sided summary of the main arguments. The scope of discussed topics ranges from very general ones (including religion[1], vegetarianism[2], etc.) to very narrowed ones, e.g., for particular policy-making (such as "weapon inspectors leaving Syria"[3]).

---

[1] http://undergod.procon.org/

[2] http://vegetarian.procon.org/

[3] http://idebate.org/debatabase/debates/international/house-would-have-weapons-inspectors-leave-syria

The degree of moderation and involvement of editors varies. Whereas many portals do not put any restrictions on the content and structure, some of them rely on heavy post-editing and even involve academics from the field to curate the final debate (such as idebate.org). Each discussion is then also provided with objective background information about the issue and justifies the propositions by linking to their respective sources (comparable to the Wikipedia citation conventions).

Similar to a practice used in general online discussions, some debate portals provide mechanisms for voting (positive and negative votes for particular posts; see, e.g., www.createdebate.org). The votes are then used to rank best arguments as well as to evaluate the dispute and display the winning position.

Although these portals provide mostly structured and high-quality content in terms of topic relatedness or argumentativeness, they have not yet been heavily exploited in NLP approaches. Gottipati, Qiu, Sim, Jiang, and Smith (2013) try to predict positions of posts and external articles toward the proposed topic on Debatepedia[4]. Using the same source, Cabrio and Villata (2012) analyze relations between pairs of posts from the argumentation perspective. They automatically examine whether a particular post either supports or attacks another post, which later results into instantiation of a full argumentation graph over the topic debate.

Argumentation mining is becoming an emerging subfield of NLP (Habernal, Eckle-Kohler, & Gurevych, 2014; Stab & Gurevych, 2014a). Since creating annotated resources for argumentation mining is costly and error prone, debate portals may serve as an additional data source and thus facilitate semi-supervised scenarios, such as active learning (Settles, 2009) or co-learning (Zhu & Goldberg, 2009).

Blogosphere and Microblogging

Blogging and especially microblogging platforms, a subfield of social media, represent another growing field for the study of mass collaboration (Carroll et al., 2011; Zhao, Rosson, Matthews, & Moran, 2011). Blogs might not be considered as resources to study collaboration as they are usually written by only one author. However, popular blogs often receive several hundred comments, which either refer to the text initially posted by the author of the blog or to other comments. Interaction among bloggers facilitates networking with unique characteristics, where individuals experience a sense of community (Agarwal & Liu, 2009). This kind of collaboration has become even more popular with the rise of microblogs such as Twitter. Twitter users retweet posts from others and respond to tweets.

From the educational and mass collaboration research point of view, blogging and microblogging have drawn much attention in recent years (Cakir, 2013; Chu, Chan, & Tiwari, 2012; Deng & Yuen, 2011; Ebner, Lienhardt, Rohs, & Meyer, 2010; Kim, 2008; Robertson, 2011). All phenomena of language common to discussion forums (cf. Section "Discussion Forums") can be also applied to blogosphere.

---

[4] Now accessible under idebate.org

An additional property is the brevity of texts published in microblogging platforms, as the content is usually limited to a few hundreds of characters (140 for Twitter). Also, the trend of following particular authors is present both in blogosphere (using, e.g., RSS subscriptions) and microblogging platforms (e.g., following mechanism on Twitter) (Kwak, Lee, Park, & Moon, 2010).

Given the amount of constantly growing content, one of the main challenges is viable processing of this kind of data, for such purposes as information retrieval, blog post search, information extraction, or network analysis (Agarwal & Liu, 2009; Santos, Macdonald, McCreadie, Ounis, & Soboroff, 2012). Parallel computing architectures which can handle such massive data volumes (Tjong Kim Sang & van den Bosch, 2013) are required to do so.

Table 1 summarizes typical properties of all resources introduced in this section.

Recent Advances in NLP for Mass Collaboration

Given the growing number of resources to study online mass collaboration presented in the last section, we will now turn to discuss some of our recent advances and ongoing efforts in NLP operating on these resources. To a limited extent, the approaches presented in the following are dependent on the type of resource they are applied to (e.g., wikis or debate platforms). This can be seen as a side effect of the type and aspect of mass collaboration inherent to each of the discussed resources (see Table 1). In wikis, the collaboration is made explicit by the revision history of articles, whereas in other resources such as blogs or debate platforms, collaboration is rather implicit in the sense that the attribution of contributions to individual users or the order of contributions might be harder to reproduce. Different kinds of collaborative aspects require different web environments and technologies and thus different methodologies to be analyzed. For example, the revision history of a wiki page can be used to analyze the collaborative construction of knowledge, whereas online debate platforms can facilitate better understanding of collaborative argumentation. An analysis of knowledge construction requires different methodologies as compared to the analysis of argumentation.

NLP methods typically deal with this problem in two steps. First, the text at hand needs to be prepared in order to serve as input for more sophisticated processing tools. This step is often referred to as linguistic preprocessing. Linguistic preprocessing typically involves basic NLP tasks such as the cleaning of noisy text or normalization (cf. Section “Discussion Forums”), the segmentation of text into smaller units such as sentences or words, and syntactical parsing. In Table 1, the properties referred to as text quality, challenges for NLP, and morphological and syntax processing are important parameters for linguistic preprocessing. Second, once the raw text has been prepared, it can be further processed with NLP methods targeted toward specific research questions. This is where the collaborative aspects and potentially higher-level NLP applications need to be considered.

Table 1 Language resources discussed in this chapter and their values of selected properties

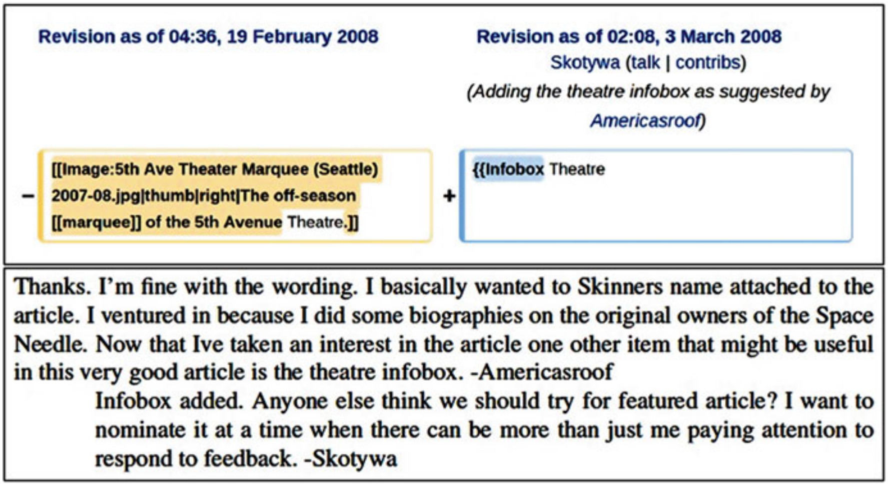
	Wikis	Discussion forums	Debate platforms	Blogs	Microblogging
Collaborative type	Explicit	Implicit	Implicit	Implicit	Implicit
Collaborative aspect	Knowledge construction	Information exchange	Argumentation	Information exchange	Information exchange
Text quality	Edited	Noisy	Noisy, edited	Noisy	Noisy
Challenges for NLP	Vandalism	Noise, implicit discussion flow	Noise, argument relevance	Meta-text/comments	Noise, little context
Morphological and syntax processing	Easy	Medium	Medium	Medium	Hard
License	Creative commons	Various	Creative commons, copyrighted	Copyrighted	Copyrighted
NLP applications	Information extraction, text classification	Discourse analysis, information extraction	Argumentation mining, stance classification	Information extraction, text classification	Opinion mining

We have discussed the properties of mass collaboration resources which need to be considered for linguistic preprocessing in section "Web-Based Resources of Mass Collaboration and Their Properties" (see Table 1 for an overview). In the following, we turn to two novel approaches which reflect the usage of NLP methodology to answer questions about collaborative aspects in mass collaboration. Two particular examples are (a) how to connect the knowledge in Wikipedia articles and discussion pages and (b) how to deal with argumentation and controversies in online discussion forums. For both use cases, we apply supervised machine learning classifiers, i.e., we use human-labeled data for training a model which can be used to automatically label further data. To do so, we have to define a set of features, tailored for the task at hand. These features abstract over the actual document contents and thus enable the model to generalize and identify the relevant pieces of information, depending on the classification task. For example, a textual document can be represented by the frequency of each word it contains (the so-called bag-of-words model).

Connecting Knowledge in Wikis

Many platforms used for collaborative writing, including wikis, do not explicitly allow their users to interact directly, so that the implicit effort of coordination behind the actual writing is not documented. As explained in section "Wikis," Wikipedia offers its users a platform to coordinate their writing, called discussion pages. Numerous studies have analyzed the nature of collaborative knowledge construction using wikis and their various properties. These include, e.g., the role of discussion pages (Hadjerrouit, 2013; Meishar-Tal & Gorsky, 2010), the impact of redundancy and polarity (Moskaliuk et al., 2012), or scripting for supporting collaborative writing (Wichmann & Rummel, 2013). In our recent study (Daxenberger & Gurevych, 2014), we analyzed links between edits in Wikipedia articles and turns (discourse segments) from their discussion pages. Our motivation is to better understand implicit details about the writing process and the knowledge flow in collaboratively created resources. Direct links between the article text (e.g., a controversial paragraph) and the discussion going on in the background of the article text can help the readers to understand the development of an article up to the point of time when they are accessing it. If new Wikipedia editors were able to directly access a past discussion thread about the piece of text they are about to edit, the organizational overload for senior editors pointing new users to the relevant parts of the discussion might be lowered.

We use the concepts of edits and turns developed in previous work (Daxenberger & Gurevych, 2012; Ferschke et al., 2012). Edits are local modifications extracted from consecutive Wikipedia revisions, e.g., spelling corrections, content additions, or referencing. Each revision of a Wikipedia article consists of one or more edits and may be accompanied by a comment, in which the author of this revision explains the edit(s). Turns are segments from Wikipedia discussion pages. A turn is part of a



Revision as of 04:36, 19 February 2008

Revision as of 02:08, 3 March 2008
Skotywa (talk | contribs)
(Adding the theatre infobox as suggested by Americasroof)

− [[Image:5th Ave Theater Marquee (Seattle) 2007-08.jpg|thumb|right|The off-season [[marquee]] of the 5th Avenue Theatre.]]

\+ {{Infobox Theatre

Thanks. I’m fine with the wording. I basically wanted to Skinners name attached to the article. I ventured in because I did some biographies on the original owners of the Space Needle. Now that Ive taken an interest in the article one other item that might be useful in this very good article is the theatre infobox. -Americasroof

Infobox added. Anyone else think we should try for featured article? I want to nominate it at a time when there can be more than just me paying attention to respond to feedback. -Skotywa

Fig. 2 An edit (*top*) as displayed on an English Wikipedia diff page along with two corresponding turns (*bottom*)

topic, similar to a thread in a discussion forum, and can be attributed to a unique author. An edit-turn-pair is defined as a pair of an edit from the article’s revision history and a turn from the discussion page bound to the same article. We consider an edit-turn-pair to be corresponding if the turn contains an explicit performative and the edit corresponds to this performative. For example, a Wikipedia user might suggest adding information to an article and announce the lack of information on the discussion page as displayed in Fig. 2 (lower box, first turn). Another user adds the missing information to the part of the article in question (upper box) and leaves a report about the action on the discussion page (lower box, second turn). Both the turn which announces the missing link and the edit which adds the link, as well as the turn which reports the addition of the link and the edit to the article page, are corresponding edit-turn-pairs.

We collected and annotated a corpus of 636 edit-turn-pairs using the crowdsourcing platform Amazon Mechanical Turk. For mature Wikipedia articles, combining each edit with each turn results in a very large search space for corresponding edit-turn-pairs. We therefore limited the time span between edits and turns considered for correspondence to 24 h. Despite this limitation, the number of noncorresponding edit-turn-pairs still outscores the number of corresponding pairs by far, resulting in great class imbalance. To tackle this problem, we manually picked about 250 pairs of corresponding turns and revisions from a random sample of English Wikipedia articles. The resulting edit-turn-pairs were used as positive seeds in the Mechanical Turk annotation study, to keep the workers from labeling all given pairs as noncorresponding. We collected five crowdsourced votes for each edit-turn-pair and created the final labeling via majority voting. On a randomly selected subset of 100 pairs, the agreement with expert annotations is Cohen’s $k = 0{:}72$, showing that the corpus can be used to draw conclusions (Artstein & Poesio, 2008).

The resulting corpus contains 128 corresponding and 508 noncorresponding edit-turn-pairs.

We used the DKPro TC framework (Daxenberger, Ferschke, Gurevych, & Zesch, 2014) to train a model on the annotated data. The model was trained on various features including textual features (such as similarity features between the turn and the edit) and metadata features (such as the username or the time difference). With the help of this model, a machine learning classifier can automatically recognize corresponding and noncorresponding edit-turn-pairs in Wikipedia articles. Despite the small size of our corpus, a random forest classifier (Breiman, 2001) achieved 0.79 macro F_1 score. One particular application of our system is that a possibly controversial discussion about, e.g., the neutrality of an article can be associated with the edits that were triggered by this particular discussion.

Argumentation Mining in Online Media

Argumentation mining deals with automatically identifying argumentative structures within natural language texts. Despite its strong background and long history in philosophy and logic (Toulmin, 1958; Walton, 2012), practical NLP approaches to argumentation have gained attention just recently (Feng & Hirst, 2011; Mochales & Moens, 2011). In its very simplistic and abstract form, an argument consists of a claim that the author wants to persuade the readers about, accompanied by one or more reasons that are put forward to support the claim.

In an ongoing study, we investigate how argumentation is conveyed across online media, such as forums, blogs, or comments to newswire articles. With a focus on controversies in education (such as single-sex schools, mainstreaming, or homeschooling), we collected a dataset containing 5444 documents from various web sources. A subset of this collection (990 documents) was manually labeled by three independent annotators with respect to its persuasiveness and argumentativeness, discarding non-relevant documents on the document level. We achieved moderate agreement (Fleiss' $k=0{:}59$) based on three expert annotators.

In the next step, the structure of the argumentation is being further investigated in a more fine-grained manner. Relying on an adapted argumentation model by Toulmin (1958), each document is annotated on the statement level with its corresponding functional argumentation concepts, such as the claim, the grounds, the backing, etc. Consider the following actual example from a discussion forum that argues about public versus private schools.

The annotation spans correspond to the argument components in the scheme, which can be also demonstrated in a diagram as in Fig. 3, where the content of individual components was manually rephrased and simplified.

Such a detailed discourse annotation brings many challenges. First, proper boundaries of argument components (where the component begins and ends) must be identified. The boundaries might occur on the sentence level or an arbitrary phrase level. Second, the granularity of the argument components must be

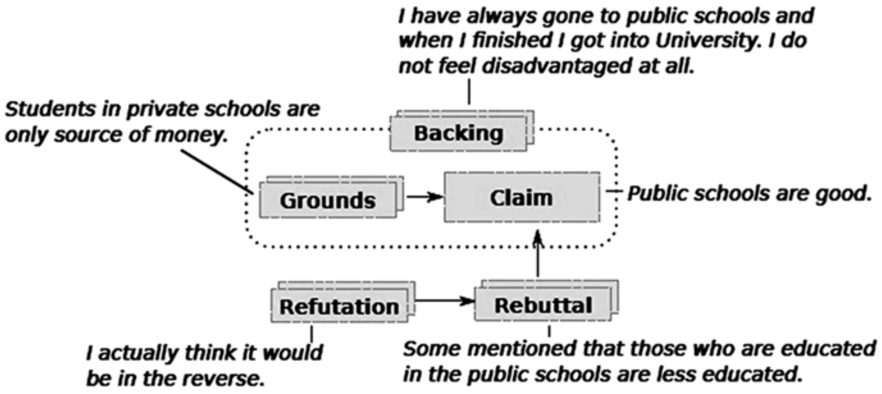


Fig. 3 Extended Toulmin's scheme used for annotation of arguments with an instantiated example from a single *public* vs. *private school* discussion forum post

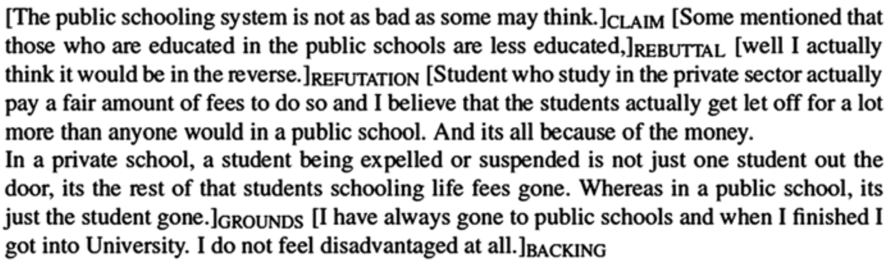

[The public schooling system is not as bad as some may think.]$_{\text{CLAIM}}$ [Some mentioned that those who are educated in the public schools are less educated,]$_{\text{REBUTTAL}}$ [well I actually think it would be in the reverse.]$_{\text{REFUTATION}}$ [Student who study in the private sector actually pay a fair amount of fees to do so and I believe that the students actually get let off for a lot more than anyone would in a public school. And its all because of the money.
In a private school, a student being expelled or suspended is not just one student out the door, its the rest of that students schooling life fees gone. Whereas in a public school, its just the student gone.]$_{\text{GROUNDS}}$ [I have always gone to public schools and when I finished I got into University. I do not feel disadvantaged at all.]$_{\text{BACKING}}$

Fig. 4 Example of annotated text with argument components

considered, for instance, whether the GROUNDS component in the previous example (Fig. 4) should be kept as a single component or split into multiple components. Third, assigning the proper role of a particular component depends on the overall context, such as the case of REFUTATION in the example in Fig. 4. Furthermore, not only is the user-generated discourse noisy (in terms of grammatical errors and other social media-related phenomena), but the main difficulty is that the argumentation is not well articulated. This means that the argumentation structures are often implicit and require complex inference. In contrast to argumentative essays (Stab & Gurevych, 2014a) or the legal domain (Mochales & Moens, 2011), user-generated texts often lack qualities typical to proper argumentation (Schiappa & Nordin, 2013). Particular challenges are, e.g., implicit claims, unclear stance toward the controversy, off-topic text unrelated to the argument, or appeal to emotions and other fallacies.

Using the extended Toulmin's model, three independent annotators labeled 340 documents (total 84,673 tokens, average 249.04 tokens per document, total 3890 sentences). Annotations were performed in three steps with discussions, updating the annotation guidelines, and clarifying unclear cases. In the final step, the interannotation agreement reached 0.481 Krippendorff's unitized alpha a_{U} (Krippendorff, 2004) across all registers (blogs, newswire articles, forum posts, and article comments). However, when considering only article comments and forum posts, the agreement was significantly higher (0.603 a_{U}). This difference has multiple reasons. First, we observed that the obtained agreement negatively correlates with the length of the document (p-value ≤ 0.05) and blog posts and articles tend to be much longer than comments or forum posts. Second, some topics were inherently challenging to annotate. We observed that in the case of the private versus public schools domain, the agreement negatively correlates with the text readability (tested on four different readability measures, p-value ≤ 0.05). Third, newswire articles and blogs employ various literary devices, such as quotations, narratives, or interviews, which cannot be easily modeled by Toulmin's scheme, given its inherent limitations (see, e.g., van Eemeren et al., 2014, p. 233, for a theoretical discussion of applications of the model).

Using the annotated corpora, we developed and evaluated a supervised machine learning system. We treat the problem of finding argument component spans in the text as sequence labeling, where each token is labeled either as (1) COMPONENT14 B for the beginning of the component (e.g., CLAIM-B), as (2) COMPONENT-I where the token is inside the component span (e.g., CLAIM-I), or (3) "O" as other, meaning that the token is not part of the argument. An excerpt of such BIO coding is shown in Fig. 5, which corresponds to the previous example in Fig. 3.

As a classifier, we employ SVM$^{\mathrm{hmm}}$ framework for sequence labeling (Joachims, Finley, & Yu, 2009), DKPro TC for feature extraction and experiment setup (Daxenberger et al., 2014), and DKPro Core for linguistic annotations (de Castilho & Gurevych, 2014).

We experimented with many different types of features. The baseline feature set contains only binary features denoting presence of unigrams, bigrams, and trigrams in a sentence. The system trained using these features and default hyper-parameter settings yields 0.156 macro F_1 score in the tenfold cross validation scenario. The richest feature set incorporates morphological features, syntactic features, coreference features, features obtained from semantic frames, features based on sentiment analysis, features exploiting unsupervised models (LDA and word embedding), and features produced by a discourse parser. With this configuration, the performance reaches macro F_1 score of 0.220 and significantly outperforms the baseline setting (p-value < 0.001), Liddell's exact test (Liddell, 1983).

The$^{\text{CLAIM-B}}$ public$^{\text{CLAIM-I}}$ schooling$^{\text{CLAIM-I}}$ system$^{\text{CLAIM-I}}$ is$^{\text{CLAIM-I}}$ not$^{\text{CLAIM-I}}$ as$^{\text{CLAIM-I}}$ bad$^{\text{CLAIM-I}}$ as$^{\text{CLAIM-I}}$ some$^{\text{CLAIM-I}}$ may$^{\text{CLAIM-I}}$ think$^{\text{CLAIM-I}}$.$^{\text{CLAIM-I}}$ Some$^{\text{REBUTTAL-B}}$ mentioned$^{\text{REBUTTAL-I}}$ that$^{\text{REBUTTAL-I}}$ ...
... disadvantaged$^{\text{BACKING-I}}$ at$^{\text{BACKING-I}}$ all$^{\text{BACKING-I}}$.$^{\text{BACKING-I}}$

Fig. 5 BIO annotation of the example text shown in Fig. 3

One of the causes explaining the low macro F_1 score is the skewed distribution of the classes in the labeled data. As REBUTTAL-B, REBUTTAL-I, REFUTATIONB, and REFUTATION-I represent only 3.7 % of the data, the model cannot learn these classes and their F_1 score is mostly zero. This negatively affects the macroaveraged overall F_1 score. Furthermore, the evaluation on the token level is very strict as it penalizes also wrongly identified boundaries of the argument component. If the results are measured using Krippendorff's a_U, the system achieves 0.30 score, which is in the middle between the baseline (0.11) and the human performance (0.48). Further investigation of the error types is currently in progress.

Toward NLP for Mass Collaboration in the Educational Domain

The NLP methods presented in section "Recent Advances in NLP for Mass Collaboration" can be utilized to foster intelligent and informed mass collaboration in education. They either directly cover the educational domain (argumentation mining in section "Argumentation Mining in Online Media") or can be adapted to it (wiki-based collaboration in "Connecting Knowledge in Wikis"). In this section, we will discuss the benefits emerging from incorporating such methods into mass collaboration in educational scenarios.

Analyzing Collaboration and Knowledge Creation in Wikis

The use of wikis in education, and in particular in teaching (Forte & Bruckman, 2006), has several advantages. Due to the nature of wikis, editing one's own or other people's text is simple and very well documented. This enables a detailed analysis of the collaborative writing process.

Several studies have analyzed the user network to get insights about collaboration in wikis (Brandes, Kenis, Lerner, & van Raaij, 2009; Laniado & Tasso, 2011). The networks in these studies are made up of nodes representing authors and edges representing collaboration. Collaboration can be defined in various ways, e.g., as editing the same article or the same sentence within an article. Such networks are also known as coauthorship networks (Newman, 2004). Coauthorship networks typically only record the existence of interaction between users, but do not take into account the context of edits. Like this, information about whether an edit modifies the text base (i.e., a change which has an effect on the meaning of the text, e.g., addition of information) or the text surface (a change which does not change the meaning, e.g., a spelling correction) is lost (Faigley & Witte, 1981).

Daxenberger and Gurevych (2013) present a system to automatically classify edit operations such as grammatical error corrections or additions of information to Wikipedia pages. This tool can be used to add more specific information about the collaboration of users in wikis. In large-scale scenarios, groups of users based on edit behavior (content adders, cleaners, all-round editors) can be identified (Liu & Ram, 2011). Using additional information about the quality of the final text product (which in educational settings is often available through grading), computers could assist writers to find more successful ways of collaboration, based on the order and preference of different kinds of revision. The intuition behind this is explained in the following example: after several iterations of content addition, it might be necessary to back up the existing information in the text with references and apply factual or grammatical corrections, rather than adding more information to the article text.

The information about the writing process which is implicitly documented in wikis becomes even more useful when additional resources such as underlying discussion pages are taken into account. By automatically linking issues raised on discussion pages to edit operations in wikis (Daxenberger & Gurevych, 2014), fine-grained information can enrich the data under investigation as well as bring completely new insights when these methods are applied to large data collections (cf. Section "Connecting Knowledge in Wikis"). While analyzing the revision history helps to understand which changes were made, linking discussion segments to edits helps to understand why changes were made. This information can be very valuable to teachers in wiki-based education (both in classroom as well as in mass collaboration settings), as it helps to understand potentially hidden collaborative processes and communication not documented in the revision history of the final product. For the same reason, linking edits and discussion segments can also be a useful tool for educational research, as it might reveal deeper insights about the success and failure of collaborative tasks. It also helps to address possibly controversial issues (Kittur, Suh, Pendleton, & Chi, 2007). Linking discussions and revision history makes it possible to understand which knowledge in the main text has been created through discussion in the background (Cress & Kimmerle, 2008).

Computer-Supported Argumentation

Apart from the NLP approaches to argumentation mining, research on computer-supported argumentation has been also very active, as shown by Scheuer et al. (2010) in their recent survey of various models and argumentation formalisms from the educational perspective. Noroozi, Weinberger, Biemans, Mulder, and Chizari (2013) describe collaborative argumentation as engaging a group of learners in dialogical argumentation, critical thinking, elaboration, and reasoning so that they can build up a shared understanding of the issue at stake instead of merely convincing or changing their own and each other's beliefs.

Existing tools for collaborative argumentation rely on scripts to support student discussions by way of dialog models that describe desirable discussion moves and sequences (Dillenbourg & Hong, 2008; Scheuer, McLaren, Weinberger, & Niebuhr, 2014). Fischer, Kollar, Stegmann, and Wecker (2013) outline a script theory of guidance in computer-supported collaborative learning. Many studies employ extensions or modification of the argument model proposed by Toulmin (1958). Noroozi et al. (2013) investigate the formal-argumentative dimension of computer-supported collaborative learning by letting learners construct single arguments and exchange them in argumentation sequences to solve complex problems. Weinberger and Fischer (2006) analyze asynchronous discussion boards in which learners engage in an argumentative discourse with the goal to acquire knowledge. For coding the argument dimension, they created a set of argumentative moves based on Toulmin's model. Stegmann, Weinberger, and Fischer (2007) experiment with template-based methods that allowed to enter a claim, grounds, and qualifications.

The abovementioned tools and approaches to computer-supported argumentation can eminently benefit from NLP techniques for an automatic argument analysis, classification, and summarization. Instead of relying on, e.g., scripts (Dillenbourg & Hong, 2008; Fischer et al., 2013; Scheuer et al., 2010) or explicit argument diagramming (Scheuer et al., 2014), collaborative platforms can provide scholars with a summary of the whole argumentation to the topic, reveal the main argumentative patterns, provide the weaknesses of other's arguments, as well as identify shortcomings that need to be improved in the argumentative knowledge construction. Automatic analysis of micro-arguments can also help to overcome the existing trade-off between freedom (free-text option) and guidance (scripts) (Dillenbourg & Hong, 2008). Moreover, discovering fallacies in arguments (Schiappa & Nordin, 2013) might also have a positive impact on the learner's ability to construct reasonable argumentative discourse. Visualization of argumentation, e.g., using graphical connections that indicate arguments and the corresponding counterarguments, may further support learners to refine their argumentation (Kirschner, Shum, & Carr, 2003).

Conclusions

As mass collaboration is shifting rapidly toward the big data paradigm, the massive amount of unstructured, textual data being produced represents one of the main challenges. In order to utilize this knowledge and information, new techniques are required that are capable of processing, extracting, and understanding the content in an automatic and intelligent manner. We believe that NLP is a key technology to support mass collaboration and the research based on the resulting content. The benefits are wide ranging. In the educational domain, for example, learners can be directly supported as they are provided with access to automatically generated, structured information and feedback about the knowledge creation process of themselves and their fellow learners. Furthermore, with the help of deep analysis, new patterns and behavior in mass collaboration platforms can be explored and might foster further research in the field.

This chapter demonstrated how recent advances and ongoing efforts in NLP can boost research into mass collaboration. We have presented NLP methods capable of linking discussions in wikis with the actual undertaken actions (see section "Connecting Knowledge in Wikis") and approaches to analyzing argumentation in user-generated web discussions (see section "Argumentation Mining in Online Media"). Apart from the examples shown here, there exist other scenarios dealing with the information overload that benefit from utilizing NLP, e.g., question answering in online communities (Gurevych, Bernhard, Ignatova, & Toprak, 2009), or MOOCs—massive open online courses (Shatnawi, Gaber, & Cocea, 2014).

In section "Web-Based Resources of Mass Collaboration and Their Properties," we reviewed several types of mass-collaborative resources and their properties. Such a wide range of text registers, genres, and quality pose challenges to NLP in terms of domain adaptation. The majority of data-driven NLP approaches (and their underlying machine learning models) are trained and tested under bias by sampling from a particular restricted domain or register (Søgaard, 2013). Experiments show that, for instance, applying a part-of-speech tagging or named entity recognition model (traditionally trained on newswire corpora) to Twitter significantly degrades the performance (Finin et al., 2010; Gimpel et al., 2011). Although the approaches presented in section "Recent Advances in NLP for Mass Collaboration" have been tested in a cross-domain setting to some extent, drawing hard conclusions about their adaptation to a very different register (refer to Table 1) would require additional experiments. Apart from adapted linguistic preprocessing, adapting the presented approaches to different domain might involve creating new annotated resources in order to evaluate the models in the target domains. However, given the labor intensity and difficulty of annotating, e.g., argument components, the task of a broad domain-independent evaluation remains fairly challenging. Adapting existing models to other domains with different distribution of features and/or classes is current research in NLP.

There are several directions for the future work. Apart from the obvious one (e.g., domain adaptation as discussed above and other NLP-specific research questions), one particular area worth investigating is how the presented methods could be applied in other nonexpert communities, for instance, computer-supported collaborative learning. Bridging the gap between NLP and other communities requires innovative technical solutions with emphasis on usability, reproducibility, flexibility, and interactivity (de Castilho, 2014). One successful example of this endeavor is the DKPro framework (de Castilho & Gurevych, 2014) which integrates a multitude of linguistic tools, yet provides a user-friendly API and facilitates its adoption by nonexpert users.

Acknowledgments This work has been supported by the Volkswagen Foundation as part of the Lichtenberg-Professorship Program under grant No. I/82806 and by the German Institute for Educational Research (DIPF).

References

Agarwal, N., & Liu, H. (2009). *Modeling and data mining in blogosphere* (Synthesis lectures on data mining and knowledge discovery). San Rafael, CA: Morgan & Claypool.

Artstein, R., & Poesio, M. (2008). Inter-coder agreement for computational linguistics. *Computational Linguistics, 34*, 555–596.

Bontcheva, K., & Rout, D. (2014). Making sense of social media streams through semantics: A survey. *Semantic Web, 5*, 373–403.

Brandes, U., Kenis, P., Lerner, J., & van Raaij, D. (2009). Network analysis of collaboration structure in Wikipedia. In *WWW'09, Proceedings of the 18th International Conference on World Wide Web* (pp. 731–740). New York, NY: ACM.

Breiman, L. (2001). Random forests. *Machine Learning, 45*, 5–32.

Cabrio, E., & Villata, S. (2012). Combining textual entailment and argumentation theory for supporting online debates interactions. *Proceedings of the 50th Annual Meeting of the Association for Computational Linguistics, 2*, 208–212.

Cakir, H. (2013). Use of blogs in pre-service teacher education to improve student engagement. *Computers & Education, 68*, 244–252.

Carroll, J. M., Jiang, H., Rosson, M. B., Shih, S. I., Wang, J., Xiao, L., & Zhao, D. (2011). Supporting activity awareness in computer-mediated collaboration. In *Proceedings of the 2011 International Conference on Collaboration Technologies and Systems (CTS)* (pp. 1–12).

Che, W., Wang, M., Manning, C. D., & Liu, T. (2013). Named entity recognition with bilingual constraints. In *Proceedings of the 2013 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies* (pp. 52–62).

Chu, S. K. W., Chan, C. K. K., & Tiwari, A. F. Y. (2012). Using blogs to support learning during internship. *Computers & Education, 58*, 989–1000.

Clark, E., & Araki, K. (2011). Text normalization in social media: Progress, problems and applications for a pre-processing system of casual English. *Procedia, 27*, 2–11.

Collobert, R., Weston, J., Bottou, L., Karlen, M., Kavukcuoglu, K., & Kuksa, P. (2011). Natural language processing (almost) from scratch. *Journal of Machine Learning Research, 12*, 2493–2537.

Cress, U., Barron, B., Halatchliyski, I., Oeberst, A., Forte, A., Resnick, M., & Collins, A. (2013). Mass collaboration—An emerging field for CSCL research. In N. Rummel, M. Kapur, N. Nathan, & S. Puntambekar (Eds.), *To see the world and a grain of sand: Learning across levels of space, time and scale: CSCL 2013 Proceedings* (Vol. 1, pp. 557–563). Madison, WI: International Society of the Learning Sciences.

Cress, U., & Kimmerle, J. (2008). A systemic and cognitive view on collaborative knowledge building with Wikis. *International Journal of Computer-Supported Collaborative Learning, 32*, 105–122.

Daxenberger, J., Ferschke, O., Gurevych, I., & Zesch, T. (2014). DKPro TC: A Java-based framework for supervised learning experiments on textual data. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics System Demonstrations* (pp. 61–66).

Daxenberger, J., & Gurevych, I. (2012). A corpus-based study of edit categories in featured and non-featured Wikipedia articles. In *Proceedings of the 24th International Conference on Computational Linguistics* (pp. 711–726).

Daxenberger, J., & Gurevych, I. (2013). Automatically classifying edit categories in Wikipedia revisions. In *Proceedings of the Conference on Empirical Methods in Natural Language Processing* (pp. 578–589).

Daxenberger, J., & Gurevych, I. (2014). Automatically detecting corresponding edit-turn-pairs in Wikipedia. *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, 2*, 187–192.

de Castilho, R. E. (2014). *Natural language processing: Integration of automatic and manual analysis*. Unpublished doctoral dissertation, TU Darmstadt, Darmstadt, Germany.

de Castilho, R. E., & Gurevych, I. (2014). A broad-coverage collection of portable NLP components for building shareable analysis pipelines. In *Proceedings of the Workshop on Open Infrastructures and Analysis Frameworks for HLT* (pp. 1–11).

Deng, L., & Yuen, A. H. (2011). Towards a framework for educational affordances of blogs. *Computers & Education, 56*, 441–451.

Dillenbourg, P., & Hong, F. (2008). The mechanics of CSCL macro scripts. *International Journal of Computer-Supported Collaborative Learning, 3*, 5–23.

Du, J., Zhang, K., Olinzock, A., & Adams, J. (2008). Graduate students' perspectives on the meaningful nature of online discussions. *Journal of Interactive Learning Research, 19*, 21–36.

Ebner, M., Lienhardt, C., Rohs, M., & Meyer, I. (2010). Microblogs in higher education—A chance to facilitate informal and process-oriented learning? *Computers & Education, 55*, 92–100.

Elsner, M., & Charniak, E. (2010). Disentangling chat. *Computational Linguistics, 36*, 389–409.

Eryilmaz, E., Pol, J., Ryan, T., Clark, P., & Mary, J. (2013). Enhancing student knowledge acquisition from online learning conversations. *International Journal of Computer-Supported Collaborative Learning, 8*, 113–144.

Faigley, L., & Witte, S. (1981). Analyzing revision. *College Composition and Communication, 32*, 400–414.

Feng, V. W., & Hirst, G. (2011). Classifying arguments by scheme. *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies, 1*, 987–996.

Ferschke, O. (2014). *The quality of content in open online collaboration platforms: Approaches to NLP-supported information quality management in Wikipedia*. Unpublished doctoral dissertation, TU Darmstadt, Darmstadt, Germany.

Ferschke, O., Daxenberger, J., & Gurevych, I. (2013). A survey of NLP methods and resources for analyzing the collaborative writing process in Wikipedia. In I. Gurevych & J. Kim (Eds.), *The peoples web meets NLP: Collaboratively constructed language resources, theory and applications of natural language processing*. Heidelberg, Germany: Springer.

Ferschke, O., Gurevych, I., & Chebotar, Y. (2012). Behind the article: Recognizing dialog acts in Wikipedia talk pages. In *Proceedings of the 13th Conference of the European Chapter of the Association for Computational Linguistics* (pp. 777–786).

Ferschke, O., Zesch, T., & Gurevych, I. (2011). Wikipedia revision toolkit: Efficiently accessing Wikipedia's edit history. In *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies* (pp. 97–102).

Finin, T., Murnane, W., Karandikar, A., Keller, N., Martineau, J., & Dredze, M. (2010). Annotating named entities in Twitter data with crowdsourcing. In *Proceedings of the NAACL HLT 2010 Workshop on Creating Speech and Language Data with Amazon's Mechanical Turk* (pp. 80–88).

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*, 56–66.

Forte, A., & Bruckman, A. (2006). From Wikipedia to the classroom: Exploring online publication and learning. In *Proceedings of the 7th International Conference on Learning Sciences* (pp. 182–188).

Garrison, D. R., & Arbaugh, B. (2007). Researching the community of inquiry framework: Review, issues, and future directions. *The Internet and Higher Education, 10*, 157–172.

Gilbert, P. K., & Dabbagh, N. (2005). How to structure online discussions for meaningful discourse: A case study. *British Journal of Educational Technology, 36*, 5–18.

Gimpel, K., Schneider, N., O'Connor, B., Das, D., Mills, D., Eisenstein, J., … Smith, N.A. (2011). Part-of-speech tagging for Twitter: Annotation, features, and experiments. In *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies* (pp. 42–47).

Gottipati, S., Qiu, M., Sim, Y., Jiang, J., & Smith, N. A. (2013). Learning topics and positions from Debatepedia. In *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing* (pp. 1858–1868).

Gurevych, I., Bernhard, D., Ignatova, K., & Toprak, C. (2009). Educational question answering based on social media content. In *Proceedings of the 2009 Conference on Artificial Intelligence in Education: Building Learning Systems That Care: From Knowledge Representation to Affective Modelling* (pp. 133–140).

Gurevych, I., Eckle-Kohler, J., Hartmann, S., Matuschek, M., Meyer, C. M., & Wirth, C. (2012). UBY—A large-scale unified lexical-semantic resource based on LMF. In *Proceedings of the 13th Conference of the European Chapter of the Association for Computational Linguistics* (pp. 580–590).

Guzdial, M., & Turns, J. (2000). Effective discussion through a computer-mediated anchored forum. *The Journal of the Learning Sciences, 9*, 437–469.

Habernal, I., Eckle-Kohler, J., & Gurevych, I. (2014). Argumentation mining on the web from information seeking perspective. In *Proceedings of the Workshop on Frontiers and Connections between Argumentation Theory and Natural Language Processing* (pp. 26–39).

Habernal, I., Ptáček, T., & Steinberger, J. (2014). Supervised sentiment analysis in Czech social media. *Information Processing and Management, 50*, 693–707.

Hadjerrouit, S. (2013). Collaborative writing with Wikis: Pedagogical and technological implications for successful implementation in teacher education. In D. G. Sampson, P. Isaias, D. Ifenthaler, & J. M. Spector (Eds.), *Ubiquitous and mobile learning in the Digital Age* (pp. 173–189). New York, NY: Springer.

Han, B., Cook, P., & Baldwin, T. (2012). Automatically constructing a normalisation dictionary for microblogs. In *Proceedings of the 2012 Joint Conference on Empirical Methods in Natural Language Processing and Computational Natural Language Learning* (pp. 421–432).

Hassan, H., & Menezes, A. (2013). Social text normalization using contextual graph random walks. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics* (pp. 1577–1586).

Hrastinski, S. (2008). The potential of synchronous communication to enhance participation in online discussions: A case study of two e-learning courses. *Information & Management, 45*, 499–506.

Jamison, E., & Gurevych, I. (2013). Headerless, quoteless, but not hopeless? Using pairwise email classification to disentangle email threads. In *Proceedings of the International Conference on Recent Advances in Natural Language Processing* (pp. 327–335).

Ji, Y., & Eisenstein, J. (2014). Representation learning for text-level discourse parsing. *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, 1*, 13–24.

Joachims, T., Finley, T., & Yu, C. N. J. (2009). Cutting-plane training of structural SVMs. *Machine Learning, 77*, 27–59.

Kane, G. C. (2011). A multimethod study of information quality in Wiki collaboration. *ACM Transactions on Management Information Systems, 2*, 1–16.

Kim, H. N. (2008). The phenomenon of blogs and theoretical model of blog use in educational contexts. *Computers & Education, 51*, 1342–1352.

Kim, D., Lee, S., Maeng, S., & Lee, K. P. (2011). Developing idea generation for the interface design process with mass collaboration system. In A. Marcus (Ed.), *Design, user experience, and usability. Theory, methods, tools and practice* (Lecture notes in computer science, Vol. 6769, pp. 69–76). Heidelberg, Germany: Springer.

Kirschner, P., Shum, S. B., & Carr, C. (2003). *Visualizing argumentation*. London, England: Springer.

Kittur, A., Suh, B., Pendleton, B. A., & Chi, E. H. (2007). He says, she says: Conflict and coordination in Wikipedia. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 453–462).

Krippendorff, K. (2004). Measuring the reliability of qualitative text analysis data. *Quality and Quantity, 38*, 787–800.

Krishnamurthy, J., & Mitchell, T. M. (2014). Joint syntactic and semantic parsing with combinatory categorial grammar. *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, 1*, 1188–1198.

Kwak, H., Lee, C., Park, H., & Moon, S. (2010). What is Twitter, a social network or a news media? In *Proceedings of the 19th international conference on World wide web* (pp. 591–600).

Laniado, D., & Tasso, R. (2011). Co-authorship 2.0: Patterns of collaboration in Wikipedia. In *Proceedings of the 22nd ACM Conference on Hypertext and Hypermedia, HT'11* (pp. 201–210).

Larusson, J. A., & Alterman, R. (2009). Wikis to support the "collaborative" part of collaborative learning. *International Journal of Computer-Supported Collaborative Learning, 4*, 371–402.

Leuf, B., & Cunningham, W. (2001). *The Wiki way: Quick collaboration on the web*. Boston, MA: Addison-Wesley.

Liddell, F. D. (1983). Simplified exact analysis of case-referent studies: Matched pairs; dichotomous exposure. *Journal of Epidemiology & Community Health, 37*, 82–84.

Liu, J., & Ram, S. (2011). Who does what: Collaboration patterns in the Wikipedia and their impact on article quality. *ACM Transactions on Management Information Systems, 2*, 1–23.

Lund, A., & Rasmussen, I. (2010). Tasks 2.0: Education meets social computing and mass collaboration. In *Proceedings of Society for Information Technology & Teacher Education International Conference 2010* (pp. 4058–4065).

Meishar-Tal, H., & Gorsky, P. (2010). Wikis: What students do and do not do when writing collaboratively. *Open Learning: The Journal of Open, Distance and e-Learning, 25*, 25–35.

Mochales, R., & Moens, M. F. (2011). Argumentation mining. *Artificial Intelligence and Law, 19*, 1–22.

Moore, R. (2014). Fast high-accuracy part-of-speech tagging by independent classifiers. In *Proceedings of COLING 2014, the 25th International Conference on Computational Linguistics: Technical Papers* (pp. 1165–1176).

Moskaliuk, J., Kimmerle, J., & Cress, U. (2012). Collaborative knowledge building with Wikis: The impact of redundancy and polarity. *Computers & Education, 58*, 1049–1057.

Newman, M. E. J. (2004). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the United States of America, 101*(1), 5200–5205.

Niu, H., & Van Aalst, J. (2009). Participation in knowledge-building discourse: An analysis of online discussions in mainstream and honours social studies courses. *Canadian Journal of Learning and Technology, 35*, 1–18.

Noroozi, O., Weinberger, A., Biemans, H. J., Mulder, M., & Chizari, M. (2013). Facilitating argumentative knowledge construction through a transactive discussion script in CSCL. *Computers & Education, 61*, 59–76.

O'Connor, B., Krieger, M., & Ahn, D. (2010). TweetMotif: Exploratory search and topic summarization for Twitter. In *Proceedings of International AAAI Conference on Weblogs and Social Media* (pp. 384–385).

Onrubia, J., & Engel, A. (2009). Strategies for collaborative writing and phases of knowledge construction in CSCL environments. *Computers & Education, 53*, 1256–1265.

Pena-Shaff, J. B., & Nicholls, C. (2004). Analyzing student interactions and meaning construction in computer bulletin board discussions. *Computers & Education, 42*, 243–265.

Perkins, C., & Murphy, E. (2006). Identifying and measuring individual engagement in critical thinking in online discussions: An exploratory case study. *Journal of Educational Technology & Society, 9*, 298–307.

Potthast, M., Stein, B., & Gerling, R. (2008). Automatic vandalism detection in Wikipedia. In *Advances in Information Retrieval: Proceedings of the 30th European Conference on IR Research* (pp. 663–668).

Priedhorsky, R., Chen, J., Lam, S. T. K., Panciera, K., Terveen, L., & Riedl, J. (2007). Creating, destroying, and restoring value in Wikipedia. In *Proceedings of the 2007 International ACM Conference on Supporting Group Work* (pp. 259–268).

Robertson, J. (2011). The educational affordances of blogs for self-directed learning. *Computers & Education, 57*, 1628–1644.

Saif, H., He, Y., & Alani, H. (2012). Alleviating data sparsity for Twitter sentiment analysis. In *CEUR Workshop Proceedings of the 2nd Workshop on Making Sense of Microposts (#MSM2012): Big Things Come in Small Packages at the 21st International Conference on the World Wide Web (WWW'12)* (pp. 2–9).

Santos, R. L. T., Macdonald, C., McCreadie, R., Ounis, I., & Soboroff, I. (2012). Information retrieval on the blogosphere. *Foundations and Trends in Information Retrieval, 6*, 1–125.

Scheuer, O., Loll, F., Pinkwart, N., & McLaren, B. M. (2010). Computer-supported argumentation: A review of the state of the art. *International Journal of Computer-Supported Collaborative Learning, 5*, 43–102.

Scheuer, O., McLaren, B., Weinberger, A., & Niebuhr, S. (2014). Promoting critical, elaborative discussions through a collaboration script and argument diagrams. *Instructional Science, 42*, 127–157.

Schiappa, E., & Nordin, J. P. (2013). *Argumentation: Keeping faith with reason* (1st ed.). London, England: Pearson.

Settles, B. (2009). *Active learning literature survey* (Tech. Report No. 1648). Madison, WI: University of Wisconsin-Madison.

Shatnawi, S., Gaber, M. M., & Cocea, M. (2014). Automatic content related feedback for MOOCs based on course domain ontology. In E. Corchado, J. A. Lozano, H. Quintin, & H. Yin (Eds.), *Intelligent data engineering and automated learning—IDEAL* (Vol. 8669, pp. 27–35). Cham, Switzerland: Springer.

Smith, N. A. (2011). *Linguistic structure prediction*. San Rafael, CA: Morgan & Claypool.

Søgaard, A. (2013). *Semi-supervised learning and domain adaptation in natural language processing*. San Rafael, CA: Morgan & Claypool.

Stab, C., & Gurevych, I. (2014a). Annotating argument components and relations in persuasive essays. In *Proceedings of COLING 2014, the 25th International Conference on Computational Linguistics, Technical Papers* (pp. 1501–1510).

Stab, C., & Gurevych, I. (2014b). Identifying argumentative discourse structures in persuasive essays. In *Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing* (pp. 46–56).

Stahl, G., Cress, U., Law, N., & Ludvigsen, S. (2014). Analyzing the multidimensional construction of knowledge in diverse contexts. *International Journal of Computer-Supported Collaborative Learning, 9*, 1–6.

Stegmann, K., Weinberger, A., & Fischer, F. (2007). Facilitating argumentative knowledge construction with computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning, 2*, 421–447.

Su, F., & Beaumont, C. (2010). Evaluating the use of a Wiki for collaborative learning. *Innovations in Education and Teaching International, 47*, 417–431.

Tapscott, D., & Williams, A. D. (2007). *Wikinomics: How mass collaboration changes everything*. New York, NY: Penguin.

Tjong Kim Sang, E., & van den Bosch, A. (2013). Dealing with big data: The case of Twitter. *Computational Linguistics in the Netherlands Journal, 3*, 121–134.

Toulmin, S. E. (1958). *The uses of argument*. Cambridge, England: Cambridge University Press.

van Eemeren, F. H., Garssen, B., Krabbe, E. C. W., Snoeck Henkemans, A. F., Verheij, B., & Wagemans, J. H. M. (2014). *Handbook of argumentation theory*. Berlin, Germany: Springer.

Viegas, F. B., Wattenberg, M., Kriss, J., & van Ham, F. (2007). Talk before you type: Coordination in Wikipedia. In *Proceedings of the 40th Annual Hawaii International Conference on System Sciences* (pp. 78–88).

Walton, D. (2012). Using argumentation schemes for argument extraction: A bottom-up method. *International Journal of Cognitive Informatics and Natural Intelligence, 6*, 33–61.

Weinberger, A., & Fischer, F. (2006). A framework to analyze argumentative knowledge construction in computer-supported collaborative learning. *Computers & Education, 46*, 71–95.

Wheeler, S., Yeomans, P., & Wheeler, D. (2008). The good, the bad and the Wiki: Evaluating student-generated content for collaborative learning. *British Journal of Educational Technology, 39*, 987–995.

Wichmann, A., & Rummel, N. (2013). Improving revision in Wiki-based writing: Coordination pays off. *Computers & Education, 62*, 262–270.

Wu, F., & Weld, D. S. (2010). Open information extraction using Wikipedia. In *Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics* (pp. 118–127).

Yang, Y., & Eisenstein, J. (2013). A log-linear model for unsupervised text normalization. In *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing* (pp. 61–72).

Yih, W., Chang, M. W., Meek, C., & Pastusiak, A. (2013). Question answering using enhanced lexical semantic models. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics* (Vol. 1, pp. 1744–1753). Sofia, Bulgaria: Association for Computational Linguistics.

Zhao, D., Rosson, M. B., Matthews, T., & Moran, T. (2011). Microblogging's impact on collaboration awareness: A field study of microblogging within and between project teams. In *2011 International Conference on Collaboration Technologies and Systems* (pp. 31–39).

Zhu, X., & Goldberg, A. B. (2009). *Introduction to semi-supervised learning* (Vol. 6). San Rafael, CA: Morgan & Claypool.

Identification of Causal Effects in the Context of Mass Collaboration

Olga Slivko, Michael Kummer, and Marianne Saam

Using Quasi-Experimental Methods to Analyze Mass Collaboration

Mass collaboration on the Internet creates massive amounts of data. These data are characterized by a high degree of complexity, a scale that is large by the standards of social science research, by the presence of network effects, and by causal mechanisms that often act in multidirectional ways. All these characteristics represent specific challenges to the computational and statistical methods that social sciences can use to better understand the patterns and drivers of mass collaboration. In this chapter, we review approaches that have been used in economic research to tackle the last challenge: the difficulty to disentangle cause and effect when using observational data. For example, consider a specific set of articles of an online encyclopedia, where the articles tend to have longer texts when they have more central positions in the hyperlink network. One would ask then whether more central articles receive more contributions or whether longer articles become more central. Such reverse causality is one instance of what economists call “endogeneity” (Angrist & Pischke, 2009; Wooldridge, 2013). With a standard statistical regression analysis, it is hard to determine the causal impact of the position in the hyperlink network on the text length.

One way to avoid the challenge of disentangling cause and effect would be to move the research into the laboratory. By manipulating one factor, an experiment would reveal its causal effect on the outcome of interest. However, data from the laboratory might suffer from “in lab biases” and low external validity, as they are taken from a smaller and typically less representative population of individuals. Moreover, a lab experiment would eliminate essential motivational and organizational

O. Slivko (✉) • M. Kummer • M. Saam
Centre for European Research (ZEW), Mannheim, Germany
e-mail: slivko@zew.de; kummer@zew.de; saam@zew.de

U. Cress et al. (eds.), *Mass Collaboration and Education*, Computer-Supported Collaborative Learning Series 16, DOI 10.1007/978-3-319-13536-6_19

characteristics of the process of online mass collaboration. Therefore, researchers get increasingly interested in developing methods for treating the population in the field and then handling observational data accordingly.

An increasingly widespread solution to the endogeneity problem lies in the use of quasi-experimental methods. These allow dealing with endogeneity in observational data, so this is a setting that appeals to many important research questions on mass collaboration. We will focus on two quasi-experimental methods. These methods are "natural experiments" and "instrumental variables." They are similar to an experimental design, except that the random assignment to treatment or control group cannot be controlled ex ante by the researcher. Instead, in a good quasi-experimental design, the researcher hopes to exploit a quasi- or perfect randomization in the assignment to treatment by unpredictable shocks. For instance, weather conditions could be considered as such a treatment. When and where weather conditions change is random or, at least, hardly predictable. Surprisingly, such treatments can be related to content generation in certain contexts and can be used as a quasi-experimental setting to study the effects that are of interest in mass collaboration. Alternatively, it may be possible to use a suitable measure that controls the assignment to the treatment. In recent years, such methods have been further developed and popularized in econometric research.

In our review, we will focus on how quasi-experimental methods, "natural experiments" and "instrumental variables," can be applied in the analysis of some settings of online mass collaboration of information goods. Actually, these methods have been applied in a range of disciplines. Especially, the logic and concepts used in the natural experiments approach have long been familiar to the educational and psychological literature (cf. Campbell & Stanley, 1963). Still, the degree, to which they are spread, and also the terminology used to describe them, varies across disciplines. The terms "regression" and "instrument" have distinct meanings in the economic context, while in other instances, a different term refers to similar techniques. We will relate the terminologies of different social science disciplines in what follows. In all of them, quantitative research and statistical design became so important, that "econometrics" has emerged into a specific subdiscipline. On the one hand, some researchers specialize into methodological contributions to econometrics; on the other hand, any empirical economist has nowadays to be able to follow the state-of-the-art development in econometrics and to apply modern econometric techniques.

Our aim in this chapter is to give an overview of how quasi-experimental methods have been used recently in econometric research to analyze online mass collaboration of information goods. From the point of view of economists, learning and creativity are essential characteristics in production of information goods. Our main empirical example is Wikipedia, an online encyclopedia, which nowadays plays a significant role in informal education and to some extent is also used in formal education (e.g., by high school students). In section "The Economics of Mass Collaboration," we start off introducing econometric methods that may be useful in the field of social sciences with a focus on mass collaboration. The section "A Remark About Terminology" focuses on natural experiments and presents a summary of recent applications in selected studies in detail. The section "Establishing Causality in Online Mass Collaboration" reviews the instrumental variable approach and, using examples from some empirical studies, highlights its benefits and caveats. Thus, combining statistical methodology aspects with empirical applications, our review offers useful applications for researchers who study mass collaboration within a range of social science disciplines.

The Economics of Mass Collaboration

Though popularized through a book called "Wikinomics" (Tapscott & Williams, 2010), the notion of mass collaboration is not an established concept in economics. The growing number of economists working on phenomena that could be labeled as mass collaboration would rather use the notion of "peer production" or "open-source production." Benkler (2002) provides an extensive definition and discussion of the notion of peer production. He is a legal scholar working on intellectual property, which is symptomatic of the fact that the economic study of peer production lies at the boundary of academic disciplines rather than at the core of traditional microeconomics. Still, the way Benkler defines peer production, which is based on the costs of establishing organizations and property rights versus the benefits, represents a reasoning that is typical of economics, building on Coase's famous work on the theory of the firm (Coase, 1937) and Demsetz's work (Demsetz, 1967) on the theory of property rights. Benkler explicitly contrasts his explanation with more detailed sociological and cultural explanations of peer production. From his point of view, it is "more important to establish its baseline plausibility as a sustainable and valuable mode of production within the most widely used relevant analytic framework than to offer a detailed explanation of its workings." (Benkler, 2002, p. 401). Hence, according to his definition, "peer production" refers to a large number of individuals who work on self-identified tasks, usually without remuneration. The tasks are aggregated by a mechanism established by the platform. In the case of Wikipedia, these tasks are contributors' edits of articles, and the aggregation of tasks is made transparent in the articles' revision history.

The notion of "commons" refers to the fact that no one can appropriate the resource and exclude others from its use. "Commons-based peer production" and the exchange of productive services (e.g., labor services) on markets share the absence of hierarchical organization and command that organizes production within a firm. Contrary to market exchange, commons-based peer production, however, operates without property rights on productive resources. Commons-based peer production is the most efficient mode of production in cases where establishing property rights and a hierarchical organization entails more costs than benefits for society. The notion of commons is not trivial one. It is sometimes used with respect to physical properties of goods that prevent exclusion and congestion in use; sometimes, the term refers to the absence of private property rights (Hess & Ostrom, 2003).

In this chapter, we are only concerned with information goods, which are always non-excludable[1] and non-rival.[2] We thus use the term "commons" with respect to the property regime. "Commons-based peer production" is peer production under an open access regime, where access to the information good is not restricted. An alternative case is a common-property regime: Such a regime and firm production both have the characteristic that property rights, though shared, are confined to an organized body of individuals with the possibility to exclude others. In what follows we will understand by peer production commons-based peer production. A notion that is often used in a synonymous way in the context of software production is "open-source production."

According to Benkler, "the phenomenon of large- and medium-scale collaborations among individuals that are organized without markets or managerial hierarchies is emerging everywhere in the information and cultural production system" (p. 375). Four main properties of information and cultural production make peer production often a socially efficient mechanism in that domain: (1) Information is non-rival. (2) The capital that is required to process large amounts of information is cheap nowadays. (3) Human creativity as an input is highly variable across individuals and over time. (4) Contributors themselves know best about their talents and motivation to perform specific tasks. Areas of information production that are particularly suitable for peer production are in general those where tasks are modular and small, and the granularity of contributions can be heterogeneous (Benkler, 2002). In this characterization of peer production, we clearly see a reference to mass collaboration, since small contributions are made in a decentralized way. To our knowledge, economic research on peer production has not considered formal contexts of learning yet. Meanwhile, a lot of work has been done on Wikipedia, open-source software production, and open collaborative innovation (Baldwin & von Hippel, 2011), which we consider as contexts of informal learning. Since there is quite a large range of economic work on classroom settings (e.g., on class size, student heterogeneity, etc.), we also see a fruitful avenue for future econometric research in exploiting the use of mass collaboration settings in formal education. Meanwhile, our own research so far focuses on informal contexts.

Economic research on peer production is, in our view, always situated in an interdisciplinary realm at the frontier to psychology, sociology, and legal studies on the one side and to information systems research and computer science on the other. Many authors contributing to mass collaboration research have interdisciplinary backgrounds. Still, we consider that there is a distinct body of work within economics and management science that is characterized by a focus (1) on the quantity and level of quality of the peer-produced good (2) on the kind of self-interested behavior and learning that contributors pursue and (3) the patterns of collaboration as a feature of a production process.

---

[1] If information is around, it is impossible to exclude anyone completely from its use, though partial exclusion, e.g., through patents, is possible.

[2] Many people can use the same piece of information at the same time.

In the course of this chapter, we will discuss in more detail the following research questions, including examples from our own research:

- When there are more readers of the content, is the incentive to contribute to an article higher (because the audience is larger) or lower (as there are more potential other contributors)?
- Does the hyperlink network of an article influence the frequency and the length of additional contributions to it?
- How does the activity of peers of Wikipedia influence contributions?

Mainstream economics often analyzes work as an activity performed for monetary rewards or for other well-known motivations. The motivations for individuals to participate in peer production are only partly known today, and they are expected to vary across contexts. For instance, for the case of open-source software, the recent literature provided a rationale for the developers' incentives to invest their time and effort in the absence of monetary compensation (a salary or a license fee). Producing open source allows developers to benefit from the learning process and from others developers' participation effort in fixing bugs and developing new functionality. Moreover, participation in open-source software projects might act as a positive signal for the reputation of the developer, thus leading to higher future monetary compensation (Lerner & Tirole, 2002). In contrast to open-source projects, in Wikipedia the potential gains of signaling are limited. Therefore, incentives explained by other social and psychological factors (altruism, socialization) become more important there (Algan, Benkler, Morell, & Hergueux, 2013; Osterloh & Rota, 2007).

In addition to distinct user motivations, platforms for peer production differ in their purpose and organization of the content generation process, thus suggesting large scope for economic research. For example, open-source software requires little communication between code developers due to its modular structure, while creating encyclopedic content often induces lengthy discussions among contributors. Since any revision can be reverted, contributors have to reach an agreement on the article content, explicitly or implicitly. Thus, some platforms provide a rich environment for the analysis of learning and communication in the process of mass collaboration.

A Remark About Terminology

Before going into detail on the specifics of the two econometric methods, we would like to relate statistical terminology used in econometric and psychological research. For the comparison, we rely on the definitions from the classical work by Campbell and Stanley (1963). First, the terms "instrument" and "regression" seem quite similar between the disciplines, but they sometimes have different meanings in econometrics and in the psychological literature. While an "instrument" in Campbell's and Stanley's sense refers to the variable that is used to measure the concept under study, an econometric "instrument" or an "instrumental variable" is a term for the specific variable that is used to obtain exogenous variation in an otherwise confounded explanatory variable. This will be explained in detail below, but the essential idea is that the instrumental variable, by nature, influences the input of interest, but cannot affect the outcome variable. Econometricians frequently use instruments that are not of any special interest as concepts, except for the fact that they are generating random variation. Still, the choice of instruments affects the external validity of the study, meaning that the choice of the variable generating random variation may create a context that is different from others.

"Regression" as it is used in Campbell and Stanley (1963) refers to a confounding factor that is known to economists as a combination of "selection on outcomes" and "reversion to the mean." In econometrics, "regression" or "regression analysis" refers to an approach of modeling the relationship between a dependent and one or several explanatory variables using a most often linear predictor function.

Moreover, we would like to clarify a parallel between two estimation methods that will be used in the section "Natural Experiments" and well-established approaches in the quasi-experimental repertoire of psychologists. What we will refer to as "before and after" is essentially implemented in the same way as a "time-series experiment" (cf. Campbell & Stanley, 1963), and a difference-in-differences design is based on the same idea as the "pretest-posttest control group design" or the "non-equivalent control group design." Also when multiple periods can be observed ("the multiple time-series design"), it is called (multi-period) difference-in-differences. Before moving on, we would like to stress an important difference though: While the implementation in natural experiments is the same as in these quasi-experimental setups, the measurement is based on observational data, and researchers aim at finding exogenous shocks in this data, which are outside the researcher's control and arguably randomly administered by nature. However, it remains the duty of the researcher (and lastly in the eye of the beholder) to provide convincing arguments and evidence that the shocks were indeed administered in a random fashion. The systematic quest for randomizing circumstances in observational data (even observational data not generated for scientific purposes) is in our view a research strategy that is currently most widely employed in econometrics, though the methodology is not restricted to our discipline.

Establishing Causality in Online Mass Collaboration

Confounding correlation in observational data interferes with establishing a causal impact of one factor of interest on another one. In some cases, everyday knowledge helps us not to make strong causal claims based on correlation, like in the often-cited example of a correlation between the number of storks and the birthrate in a set of regions (e.g., Matthews, 2000). In other cases, it is more difficult, since the research hypothesis often assumes causality behind an observed correlation.

Consider researching whether additional hyperlinks (x) to articles on the online platform breed more content (y). In econometrics, we would usually use regression

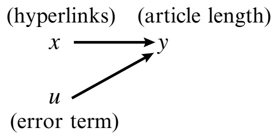


Fig. 1 Scheme of causal relationship between variables

analysis in order to determine the effect of independent variable x on dependent variable y, u being a random error term, as in Fig. 1.

Formally, the causal effect of the number of hyperlinks pointing to an article on the length of the article can be expressed through a naïve statistical model:

$$\text{length}_i = a + b \times \text{hyperlinks}_i + c \times \text{controls}_i + u_i \tag{1}$$

The length of article i would be linearly regressed on a constant a and the number of hyperlinks pointing to the article. This specification also should include a set of control variables that are expected to have an additional impact on the article length. The error term u_i captures the difference between the value of the estimated regression function and the observed value of the article length. Once we have specified the econometric model, the effect of the amount of hyperlinks on the article length captured by the coefficient b could be estimated using the method of ordinary least squares (OLS).

Note that this "regression analysis" is not the same as what is termed "regression" in Campbell and Stanley (1963). Imagine that such a regression analysis shows that articles with more links are longer and also receive more edits. This correlation alone does not allow for easy inference, because the sources of endogeneity are ubiquitous.

In fact, the OLS estimation of our effect of interest recovers the causal impact of hyperlinks on the content only under very restrictive conditions, or identification assumptions. First, the model should be correctly specified and all the factors that affect the dependent variable length_i should be included in the regression equation. Second, the error term u_i should, among other conditions, be independent from the regressors, in our example, $\text{hyperlinks}_\text{i}$ and controls_i (as illustrated on Fig. 1), and independently and identically distributed (for further details see Wooldridge, 2013).

In the example presented above, some of identification assumptions are most likely violated. The most obvious problem is "reverse causality": do articles receive more edits because they receive more links, or do they have more links because authors who edit an article might also place links to it? But there are also other sources of bias. In violation of our assumptions, we might fail to observe some factors that affect the article length, for instance, interest or relevance of the topic among general public. This problem is known to economists as "omitted variable bias." In our example, the relevance of the article's topic would probably be correlated with both the number of hyperlinks and with the article length. Therefore, omitting this variable induces correlation between hyperlinks and the error term (see Fig. 2). In that case, what would the regression results mean to us if some unobserved underlying factor drives both the number of hyperlinks and the article length?

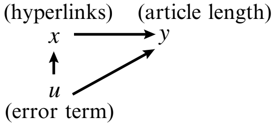


Fig. 2 Scheme of spurious relationship between variables

In the remainder of the section, we introduce two quasi-experimental methods that come from economic literature and can be useful for establishing causality in studies on mass collaboration, concretely, (1) *natural experiments* and (2) *instrumental variables*. These methods have been popularized in the book *Mostly Harmless Econometrics* by Angrist and Pischke (2009), and we will base our presentation on similar and relatively nontechnical expositions. Finally, not all possible econometric methods for addressing endogeneity were covered by this chapter for reasons of space, but we would like to briefly mention these approaches to further reference to the interested reader: Specifically in networks, matching (Aral, Muchnik, & Sundararajan, 2009) and sensitivity analysis (VanderWeele, 2011) can also be used. More methodological aspects on instrumental variables in networks are discussed by Bramoullé, Djebbari, and Fortin (2009). Finally, a very recent, but quite involved, literature focuses on methods that allow estimation of peer effects and other social influences on networks that have endogenously formed (Goldsmith-Pinkham & Imbens, 2013; Graham, 2015; Jackson, 2014).

Natural Experiments

In this section, we describe two studies that use quasi-experimental setups to study mass collaboration more in detail: First is the paper by Zhang and Zhu (2011), which uses a clearly defined natural experiment and was published in the American Economic Review. This is a very influential journal in economics and, hence, the article received a lot of attention. The second example is a recent paper from our own research in Kummer (2013). The discussion of this research will add a focus on potential avenues or further questions that were considered but eventually not pursued. This is intended to illustrate additional considerations that need to be borne in mind, when "designing" natural experiments.

A regression based on a natural experiment is a technique that aims at working with observational data from a real-world environment. It occurs when the environment that we study (in the economical field, this could be a labor market, an industry, or an online platform, say, Wikipedia, etc.) experiences a large and unpredictable shock. Such a shock is considered as a "truly exogenous" variation in the explanatory variables, which allows analyzing how they affect the dependent variables. Hence, natural experiments do not take place in the lab, but should have occurred naturally and during a time window that can ex post be traced out on observational data.

Two examples of such sources of exogenous variation in the context of mass collaboration (Wikipedia) are the communist party's decision to block access to Chinese Wikipedia from mainland China (exploited in Zhang & Zhu, 2011) and natural disasters with sudden onset, which drastically increase the number of readers and the need for updating on a small number of pages (Kummer, 2013). These will be presented in greater detail later on. Ideally, natural experiments combine the virtues of exploiting experimental variation and using real-world observational data. Observational data are considered preferable over data from the laboratory, because the latter have frequently turned out to suffer from "in-lab biases," and they are taken from a smaller and typically less representative population of individuals.

The term "natural experiment" consists of two parts, which deserve further explanation. To qualify as "experimental variation," the exogenous shock should be as close as possible to the setup in a laboratory in several important ways. First, it is required that the shock cannot be influenced by the economic agents in the system under study. Second, like a lab experiment, a natural experiment must contain an element of randomness. This randomness must either leave a part of the unobserved individuals untouched or come from the fact that it is arguably completely impossible to predict the event or at least its timing. Finally, the experiment will be even cleaner if it is hard or impossible to anticipate the shock, because such suddenness allows simply focusing on the difference between the behavior before and after the shock.

The reference to nature in "natural experiment" is due to the fact that economists, like many other social scientists, cannot or do not wish to run large-scale economic experiments in real-world environments. The questions that are important for economists often concern issues of unemployment, educational outcomes, or economic growth. At the difference of the natural sciences, where an experimental setup affects atoms or molecules, economic questions touch upon highly sensitive areas of policy making that directly impact on the livelihood of citizens. Consequently, while it is already hard to design the best possible policies, it is often undesirable to knowingly subject some individuals to less than optimal policies or to randomize who gets the best thinkable education and who gets a less than optimal one. Similarly, simply varying the interest rate in several countries, but not in others, to understand the effect of the interest rate on economic growth or the failure rate of firms merely for the purposes of intellectual curiosity is neither feasible nor desirable.

However, sources of such shocks can be found in natural forces. But also drastic changes in a policy, the unexpected bankruptcy of a major firm in a market, and similar "exogenous influences" with an element of randomness might be considered in a natural experiment. The decisive ingredient would be that the behavior of the agents did arguably not anticipate the shock when they made earlier decisions, which have a long-lasting impact and are harder to undo (e.g., investment decisions, location decisions, educational choices, family planning, choice of citizenship, etc.).

If the randomization by nature is undeniably perfect, then a simple "before and after" estimation can be applied. With only two periods of observation (before and after the shock), this estimation is implemented like a "one-group pretest-posttest design" in the terminology Campbell and Stanley (1963). With multiple periods, the estimation corresponds to a "time-series experiment." Alternatively, if a control group is available, a (multi-period) difference-in-differences can be used. This is to be implemented like the "pretest-posttest control group design," the "nonequivalent control group design," or "the multiple time-series design" (cf. Campbell & Stanley, 1963). Note that, given the implementation, the strength of a natural experiment hinges on the crucial assumption that the randomization by "nature" is undeniably perfect. It is the researcher's obligation to make the case that this assumption is credible. In the examples below, the randomness comes from nature and the (unfortunate) fact that to humanity it is "like random" when and where an earthquake strikes (Kummer, 2013) and from the unpredictability of the Chinese government's block (in Zhang & Zhu, 2011).

Goldfarb and Tucker (2014) discuss eight ingredients, which are needed for successful quasi-experimental research. We will summarize them here, but recommend reading the original, which we believe is an extremely useful guide in any discipline. According to their "diff-in-diff etiquette," (a) the first step is to carefully explain and defend the "experiment." Next, (b) a lot of effort should be made to show whether treatment and control groups are similar before the shock in terms of their observable characteristics and (c) to investigate pretreatment patterns. The main part (d) should be devoted to presenting the raw data around the intervention/experiment in terms of a graph and to (e) show the baseline estimates (clustering the standard errors as appropriate). After that (f) it is important to demonstrate, in multiple robustness checks, that the effect does not depend on the specific set of observations and that it can also be found when using different assumptions in the estimation. Finally, (g) it is necessary to carefully discuss the assumptions required to obtain external validity and/or explain why the treated population is inherently interesting and (h) to explicitly explain all remaining caveats and apologize for all that is still unproven. In Kummer (2013), these points are followed carefully, and the central element of the paper is indeed a figure that illustrates how activity on Wikipedia drastically increased on the days of the disasters, both for directly affected and also for neighboring articles.

Figure 3 illustrates the key features of a natural experiment, with a difference-in-differences estimation. Ideally two very similar groups are observed before and after the event. Moreover, the identification of the effect is based on "randomization by nature," i.e., before the event happened (ex ante), it was humanly impossible to predict which of the groups was more likely to be treated.

However, before discussing concrete examples of natural experiments, we would like to remind the reader that economists are inclined to prefer working with observational data that are not generated in the lab but at the same time are concerned

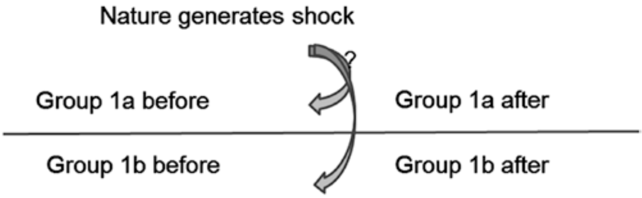


Fig. 3 Illustration of natural experiment

with potentially spurious correlations (endogeneity) that stand in the way of causal inference. This concern is similarly important in the context of a mass collaboration platform, like Wikipedia. Imagine, for example, observing that articles which receive more links also receive more edits and get contributions from more authors. This correlation alone does not allow for an easy inference, because the sources of endogeneity are ubiquitous. The most obvious of them is “reverse causality”: Do articles have more edits, because they receive more links, or do they have more links because authors that edit an article might also add links on other pages? Another source of endogeneity is “omitted variable bias”: Is there an unobserved variable, such as relevance, that drives both, links and edits? Similar problems pertain when observing that the peers of more active authors are also themselves more active.

These problems are massive and they stand in the way of real insight even when the most interesting and vast sources of observational data are available. If all the data are generated in a large process of mutually dependent variables, then “everything is endogenous,” and disentangling cause and effect becomes virtually impossible. Natural experiments can be a credible way out of this dilemma, and the careful reader will note that they share the main characteristic of a good instrument: Apart from being sudden and unpredictable, they ideally affect one variable (the independent variable), without affecting the other (dependent) one. Moreover, we would like to point out that the effect of a good natural experiment seems to be “obvious,” but that the trick really consists in being aware of an opportunity to exploit them.

Examples of Natural Experiments in Massive Online Collaboration

A good example of a natural experiment in studying mass collaborative environments is the study of Zhang and Zhu (2011) on the effects of the group size on the incentives to contribute to Wikipedia. The source of exogenous variation in this natural experiment at Chinese Wikipedia was the communist party’s decision to block access to Chinese Wikipedia from mainland China. Arguably, a single user and contributor could not easily influence whether Wikipedia was going to be blocked and especially not when exactly it would be blocked. Moreover, this block occurred very suddenly and was not announced ahead of time. Hence, the users and contributors could not anticipate the block. This impossibility to anticipate the shock is important to guarantee that the behavior that is observed before the block can serve as a valid counterfactual for how we believe the affected users would have behaved in the absence of the shock.

Zhang and Zhu (2011) use the block of Wikipedia on mainland China as a drastic exogenous shift of the group size of contributors and readers. With the mainland Chinese shut off, the majority of the mass collaborators and their audience suddenly had no access to the jointly produced information good. This variation can be used to study how the remaining contributors react when the number of contributors and readers is drastically reduced. Zhang’s and Zhu’s (2011) specification is based on the assumption that authors would not have changed their contributions absent the mainland's block of Chinese Wikipedia. Hence, they can estimate a very simple "before-after":

$$\text{Contributions}_{it} = \alpha + \beta \times \text{After Block}_t + \text{Control Vars}_{it}{}' \times \gamma + v_{it}$$

where i denotes the contributor and t denotes the week. The dependent variable $\text{Contributions}_{it}$ represents the weekly contributions of each unblocked contributor to Wikipedia articles. The variable After Block_t is a dummy that equals one if the time period is after the block and zero otherwise (cf. Zhang & Zhu, 2011). Looking at the individual Chinese author *outside* mainland China is theoretically interesting, because there are several economic theories that would predict opposite reactions. Hence, depending on the applicable theory, the shock could lead them either to increase or to decrease their contributions. For example, if the public good was suffering from free-riding (author A does not edit an article and hopes for author B to do the work), then existing authors might increase their contributions, and new authors might join. No change in behavior or decreasing the contributions would point toward competing theoretical conceptualizations of altruistic behavior. It turns out that the remaining Wikipedia editors reduce their contributions, as a consequence of the shock, which is in line with altruistic theories of warm glow giving. It is important to point out that the main purpose of the article is not to analyze the consequences of the Chinese blocking of Wikipedia. Though the study provides important insights about this event, the event is mainly instrumental in generating the random variation needed to establish more general insights on contributions on Wikipedia

Another example of an economic paper that uses natural experiments in a mass collaborative setting is Kummer (2013). This paper aims at measuring how much attention is channeled by the links between articles and how many additional contributions can be generated as a result of attention that spills across links. The paper uses sudden-onset natural (and technical) disasters, such as earthquakes and plane crashes, and shows that about 70 % of the readers of an article click on a link to another article. This pseudo-experimental variation is used to inform a more structured model on attention spillovers and to back out how much attention articles receive from the average attention on their neighbors.

The paper differs from a classical experimental setup for two important reasons: First, it uses not only one natural experiment, but 23, and second it analyzes a network of articles rather than just one treated group and one control group. Specifically, the paper exploits the variation that is due to the exogenous and unpredictable shocks to identify how attention spills from the shocked page to its neighbors (and how this attention converts to edits). The counterfactual observation is obtained from a different set of articles related to a different disaster, or from analyzing the content growth of the same set of pages several weeks before the disasters. Hence, the identification of the event is based on the idea that the timing is unpredictable, and we use the fact that an earthquake in Japan was equally likely any other day a few weeks earlier. A difference-in-difference estimation generally takes the following form:

$$\text{Views}_{it} = \alpha + \alpha_1 \times \text{Treatment Group}_i + \alpha_2 \times \text{After Treatment}_t + \beta \times \text{Treatment Group}_i \times \text{After Treatment}_t + \text{Control Vars}_{it}{}' \times \gamma + \nu_{it}$$

where Views_{it} is the outcome of interest, the views of an article. The index i represents the individual, t represents the time, and ν_{it} represents the error (cf. Goldfarb & Tucker, 2014). The focus in this regression is on β, which measures the effect of the treatment on the treated pages (or subnetwork of pages). The variable $\text{Treatment Group}_i \times \text{After Treatment}_t$ is a simple dummy, which takes the value 1 for the articles that are linked to an ongoing disaster. Since it is 0 for both, the unaffected articles and the affected articles before the disaster happened, this variable really indicates the observations where natural experiment took place. The Control Vars_{it} can help avoiding omitted variables concerns, such as an observed covariate that differs between treatment and control groups and is relevant of the effect of the treatment. Kummer (2013) has access to a 29-day time series for each observation and can hence estimate a panel regression with fixed effects α_i, which accounts for any observed and unobserved article differences (as long as they are stable over time and during treatment). Hence, the representation of the estimation becomes even simpler:

$$\text{Views}_{it} = \alpha_i + \alpha_2 \times \text{After Treatment}_t + \beta \times \text{Treatment Group}_i \times \text{After Treatment}_t + \nu_{it}$$

As before, the focus of this estimation lies on β. We would like to use this paper to highlight the previously discussed traps to successful causal inference, even in an experimental design. Moreover, we would like to offer a discussion about possible alternative setups that were considered in the research process, but then discarded in favor of the current implementation. To do so, we will revisit each important aspect of natural experiments and show how it was addressed in the paper. Hopefully, this discussion of challenges and difficult decisions is helpful to highlight that a lot of care is needed in studying natural experiments and that even then, it is not always possible to answer all questions unambiguously.

First, we would like to point out that the questions how the link network channels users' attention and contributions are very difficult to answer in the lab: The participants of the study may not be representative of the population, and they might also surf the web differently when they are in a lab situation. Similarly, it is very difficult to use observational data without exogenous variation to answer these questions, for the very reasons that were discussed earlier: There are many possible explanations for a correlation of viewership patterns between articles. The most important challenge in this context is that the presence of the link might actually be symptomatic for the fact that both pages are much frequented, or more relevant. Also clustering of pages from the same category might drive the result: Soccer is more frequented than medieval poetry, but two medieval poets are more likely to link to each other than to a soccer player (and vice versa).

Exogeneity and Randomness: Kummer (2013) uses sudden-onset natural (and technical) disasters to circumvent all of these challenges. Such events tend to motivate a large number of readers to consult the articles about the affected venues, companies, or people. The important aspect here is that, when they occur, the shocks are not related to the link structure: The variation in the attention to the pages is unpredictable, it occurs at random time, and nobody could know beforehand, for which pages the next disaster will be relevant. Earthquakes are also clearly not related or even a result of the activity on Wikipedia, so reverse causality cannot play a role. Hence, the shocks shift attention in a quasi-random location of the network, and this occurs much faster than the network of links of articles can be changed or adapted to the new situation. In that sense, the shocks are independent from the link structure and can be used to estimate how attention spills across links.

No Anticipation: Another previously mentioned challenge to natural experiments comes from anticipation. If it were possible to anticipate the shock, then some authors (or readers) might go to the relevant pages before the event. This would make it harder to measure the true increase in attention and the related spillovers. Examples were pages about volcanoes and hurricanes, where it turns out that the activity increased gradually as these events built up. Some very experienced authors already understood what was happening, before the event was on the news or before it was classified a major event. These authors also started following and updating the pages already before the events were understood to be catastrophic by the wider public. As a result, it is ambiguous to which levels of activity the post-shock activity should be compared in order to quantify the effects. The researcher can then try to make "reasonable" assumptions or, as in Kummer (2013), may decide to focus on sudden-onset events only and forgo additional statistical power in exchange for a clear-cut research design.

Experiment Affects Only One Side of the Equation: That said, it is important to point out that within a day, the link network will change due to the event, and it is important to take this into account when measuring attention spillovers. A (previously considered) weekly design would probably not work, because of the above-mentioned changes in the network structure. Similarly, it is not necessarily valid to look at all the neighbors or determine the set of neighbors at the end of the period of observation, because at that point the shock had enough time to influence the set of neighbors. In the present situation, these traps were taken into account, a.) by focusing on the day of the event and b.) by considering the spillover to pages where the link was established long before the shock occurred.

Finally, in this specific condition, it is important to note that the effect on the content generation cannot be unambiguously determined before ruling out that the contributions (even on the neighboring pages) are due to the shock itself. To give an example, a supplier of important components to the crashed airplane will be linked to that manufacturer, and if their component is also linked to the crash, then there is a need to update the supplier's Wikipedia page. This content generation is not exclusively due to increased readership; it is related to the event. Hence, the natural experiments allow a clean identification of attention spillovers on the same day, but the measures of content generation cannot be used without further ado: One way to account for the possibility that certain neighbors were directly affected is to use the link structure a year after the event and argue to find such pages. By that time, they should have a direct link to the event. Another, maybe more rigorous, way of achieving the same goal would be to obtain additional data on direct searches on the topics of the neighbors. If Wikipedia activity went up, but without an increase in related web searches, then the increase is plausibly caused by the link, whereas simultaneous increase of web searches and Wikipedia readership suggests that the shock simply raised attention to the linked article directly.

Instrumental Variables

When the observational data available to the researcher do not contain any natural experiment, but the problem of correlation between the input variable and the output variable biases the effect of interest, there is still a method that allows to eliminate or to substantially reduce the endogeneity bias in the estimated effect of interest. This method is called "instrumental variables" or IV approach.

Explanation of the instrumental variables approach in this section will be further based on Angrist and Pischke (2009). For the illustration of how to apply this method we will turn to two studies that use instrumental variables for the analysis of the role played by social ties in motivating individuals to participate in content generation. The first study is performed by Shriver, Nair, and Hofstetter (2013) and published in the highly influential journal *Management Science*. It tackles a research question that would face a similar problem as the one discussed in our first example on how setting additional hyperlinks to articles affects the amount of user-generated content. Shriver et al. (2013) hypothesize that a desire to increase social status within a peer group may cause users to add more content when they have more social (or "friendship") ties. For identifying causal effects, they apply an instrumental variable approach. The second study, Slivko (2014), represents our own research on Wikipedia. It analyzes whether the activity of peers, who collaborate with an individual contributing to the same articles, affects the amount of content generated by this individual. In this study, the endogeneity bias cannot be completely eliminated, but using instrumental variables allows better understanding whether this bias blows up or mitigates the resulting effect of peer activity.

The instrumental variable approach relies on the fact that the endogenous explanatory variable contains both useful and confounding variation. The useful part helps identify the causal effect of interest, whereas the confounding variation impedes identification of the true causal effect (Wooldridge, 2013). For example, consider a regression equation, in which the outcome variable y_i can be described as a function of the regressor x_i and other controls. Assume further that we want to estimate the true causal effect of x_i on y_i, here expressed by β:

$$y_i = \alpha + \beta \times x_i + \tau \times \text{other controls}_i + u_i \tag{2}$$

Here, x_i is a regressor and u_i is the error term, which contains a part of y_i unexplained by the regressor. If x_i is a truly exogenous regressor, the coefficient of interest β can be retrieved by an estimation using OLS. However, the research on online mass collaboration often tackles questions, in which it is impossible to have regressors that are completely exogenous to the system. This is because actors and artifacts on platforms represent a tightly interconnected system with all elements influencing each other. If x_i is endogenous, for example, because u_i contains an unobserved variable that is correlated to x_i (but uncorrelated to the other explanatory variables in Eq. (2)), the estimation of Eq. (2) by OLS would yield a biased effect of x_i on y_i.

In order to find an unbiased effect of interest, one can use variable z_i, which is called an instrumental variable, or an instrument, that satisfies two conditions. First, it should be uncorrelated to u_i and any other determinants of the dependent variable y_i. Second, there should be a relationship between z_i and an endogenous regressor x_i such that there exists a linear projection of x_i onto all the exogenous variables:

$$x_i = \gamma + \delta \times z_i + \nu \times \text{other controls}_i + \varepsilon_i \tag{3}$$

The key condition of z_i to be a relevant instrument for x_i is that its coefficient δ is nonzero. Once we have an appropriate instrument, we can plug Eq. (3) into Eq. (2) to obtain a new equation for y_i with an unbiased effect of an endogenous regressor:

$$y_i = \theta_0 + \theta_1 \times \mathrm{z}_i + \theta_2 \times \text{other controls}_i + \eta_i \tag{4}$$

Note the error term in Eq. (4), $\eta_i = \beta \times \varepsilon_i + u_i$, so now it is uncorrelated with all explanatory variables in Eq. (4), and OLS yields an unbiased effect of interest θ_1. We should stress the importance of assumptions that enable to recover the correct causal effect. The instrument z_i must clearly affect the regressor x_i. Moreover, and this is in general the more problematic condition, z_i should not be independently correlated to y_i, and the only reason why z_i can affect y_i is the relationship between x_i and z_i.

In a regression with more than one endogenous regressor, one can use in principle multiple instrumental variables. But finding good instruments for the IV approach can be tricky. One should think of the institutional context of the studied problem and try to find processes that might govern agents' behavior. More details on the techniques of applying instrumental variables are explained in Angrist and Pischke (2009) and Wooldridge (2013). In addition, for the overview on how this method was developing, please, also refer to Stock and Trebbi (2003).

Now, we will see how this technique is applied on an example in a context that is highly relevant to mass collaboration. Shriver et al. (2013) focus on one of the largest sports-based online communities in Switzerland, Soulrider.com, where users post content about their surfing activity, reporting wind speeds and conditions at specific surfing locations. Their question is twofold: do social ties motivate the

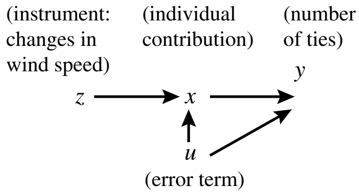


Fig. 4 Scheme of instrumental variable approach

amount of knowledge generated by individuals? And, turning the coin, does the amount of content that an individual contributes improve the social position of this individual, expressed in terms of the number of social ties, or “friends,” on the social network? The major challenge that a researcher faces conducting such research is, again, limited information about individuals available. For example, individuals have different motivations to be part of a platform. The level of individual participatory motivation would affect both, the amount of content a user contributes and the intensity of establishing social ties with other platform users. Moreover, in social sciences, it is very challenging to establish any objective measure for individual intrinsic motivation or social skills. Therefore, one would inevitably face the need to tackle this endogeneity problem.

In order to eliminate the confounded variation in an explanatory variable, i.e., the amount of content generated by an individual, Shriver et al. (2013) use the fact that surfing is only possible when wind speeds are greater than a threshold value. They show that wind speeds indeed significantly explain part of the variation in content posting on the web platform. This justifies usage of the changes in the wind speed as an instrument for the amount of generated content (see Fig. 4), where, again, an instrument is a source of variation in users’ propensity to post content on the web that may not directly affect tie formation. Indeed, the identifying assumption in their approach is that there are no other ways in which wind could affect the creation of social ties except via content generation.

Choosing an instrument, it is important for the researcher to properly justify why this instrument satisfies the required assumptions for instrument validity. In the study of Shriver et al. (2013), one could still be concerned with the fact that the geographical location of individuals might be related to both wind speeds experienced by windsurfers and to the social ties formation. To address this concern, Shriver et al. (2013) show that friendship ties are not distributed geographically.

More generally, Goldfarb and Tucker (2014) describe the strategy, which should be adopted to support that the instruments chosen for a particular research context are valid. The main steps include reporting the first stage and the F-statistic of the excluded instruments. Then, a researcher should compare OLS and instrumental variable estimation results. If the results change, one should carefully assess whether they change in a direction that makes sense. The effect of the instrument directly on the output should be checked with OLS regression. Finally, multiple robustness checks should be conducted in order to show that the found impact is not driven by some particular choice of the specification. Meanwhile, the condition that the instrument be uncorrelated with the regression error cannot be statistically tested in any strict sense. It ultimately relies on argumentation.

In Shriver et al. (2013), after instrumenting the endogenous variable “the number of friendship ties,” the resulting impact of the number of friends on the content posted increases because the endogeneity possibly acted in a negative direction to the magnitude of this effect. This is only one particular result from this ample study that, in fact, addresses a set of interaction effects between the content generated and friendship ties, which are very relevant for mass collaboration studies.

Now, we will have a look at another application for instrumental variables based on our own research, where we study peer effects on Wikipedia (Slivko, 2014). We analyze whether peer performance, which can be measured as the amount of content contributed by peers, affects the size of individual contributions of knowledge to Wikipedia.

As there are no explicit social, or “friendship,” ties on Wikipedia, we need to define which individuals will be considered as peers. Editors who contribute to the same articles and exchange comments on articles’ talk pages work in a collaborative manner engaging in communication about their work. Hence, we consider them as peers who are likely to influence each other. More precisely, we define peers as contributors who make at least two revisions of the same article and at least one revision on an article talk page each during a short period (in our study, 4 weeks).

After defining peers, we can tackle our research question, whether peers’ activity yields spillovers to the amount of content contributed by an individual. It is a relevant question for understanding how the community works and whether exogenously enhancing the activity of some community members would yield spillovers to the activity of their peers. The regression equation for this question is given by Eq. (5):

$$\text{contribution length}_i = \alpha + \beta \times \text{peer contribution length}_i + \tau \times \text{controls}_i + u_i \tag{5}$$

With such a model, one could face with a number of challenges to econometric identification. One of them is endogeneity of the independent variable. One potential source of endogeneity could be external shocks to the Wikipedia content. For example, assume that individual and her peers are connected due to editing some articles on the country’s economy. They all started editing these articles because, on some day, the country’s economy was discussed on the news channel. In this case, the news affects both the amount of individual contributions and peer contributions on the set of articles. In this case we would say that peer contributions are endogenous to individual contributions. In addition, there is a lot of information on contributors that is not available to the researcher and cannot be included into the regression equation, bearing omitted variable bias. Together, all these sources of endogeneity would bias the estimated peer effects if the standard OLS is applied. Therefore, along with OLS, the instrumental variable approach can be useful.

Here, we have to shortly notice that another potentially large issue, the endogeneity of editor network formation, which might lead to self-selection of productive editors to be connected to their productive peers, is tackled as follows. Assume that potential contributors get on the pages according to their interests and independently of the current editor network structure. In Wikipedia, individuals come to read articles, and their decision to contribute is most likely related to the content of an article rather than to other editors' characteristics. What they observe most are contributions of each other. In this case, after observing contributions of others, one might choose to remain peers with them. However, learning about "key" productive users takes time. Therefore, the study makes an analysis examining the peer impact only during the first-month performance of individuals who just joined Wikipedia. More generally, identification in networks has its specific methods that are much less standard. An exemplary application of such a method based on Kummer (2013) is described in detail in the previous section. Other econometric methods for addressing endogeneity in networks are matching (Aral et al., 2009) and sensitivity analysis (VanderWeele, 2011).

How do we choose an instrumental variable in such a context? Due to the network structure, we can use the number of peers (we label them as indirect peers or excluded peers) as an instrument for peer activity. The number of indirect peers is correlated with the direct peer number but assumed to be uncorrelated with external shocks to the articles shared by the peer group of the focal individual and with her own performance. As a result, the estimates, obtained using an instrumental variable approach, suggest that endogeneity drives the magnitude of positive peer effects down when not properly accounted for. In this study, the standard OLS approach underestimates spillovers due to peer activity. Using the IV approach, we obtain that a 1 % increase in peer activity can yield a positive effect of 0.2 % to individual monthly contributions to Wikipedia.

In both empirical examples, using an instrumental variable approach allows better assessing potential endogeneity biases and the causal effects in mass collaboration.

Conclusion

In this chapter, our main aim was to provide an overview and an intuitive explanation of some methods in economic research that help to improve econometric identification. These methods have seen a fast development over the last two decades. Especially, they can be relevant for the research on mass collaboration because online platforms represent very sophisticated systems, in which every element affects others and is affected by others.

The methodology used in this study is similar to other quasi-experimental methods, which have been applied before in economic research on formal education (e.g., in research on the relation between class size and school performance). To our knowledge, economists have not yet explicitly introduced the notion of mass collaboration to their research on education, but this could be a fruitful avenue for further interdisciplinary cooperation.

Our brief description of the identification methods, including the quasi-experimental and the instrumental variable approaches, highlights many caveats that one should bear in mind when applying them to the study of specific questions of mass collaboration. Mass collaboration is extremely difficult to analyze, and the difficulty of distinguishing cause from mere correlation may sometimes seem insurmountable. This has especially to do with the network effects present. Yet, whenever a "force majeure" can be found that interferes with the collaborators' activity, their actions, or their choices, a new opportunity for "a clean shot" might arise by generating a natural experiment or an instrumental variable.

While sophisticated statistical and experimental analysis has been used in a wide range of social sciences, we consider that the use of natural experiments and instrumental variables has in recent years been advanced most actively in economics. Other disciplines might benefit from the systematic quest for exogenous variation in observational data and from the development of statistical methods in econometrics when analyzing mass collaboration. Within econometrics, the identification of suitable quasi-experimental designs represents an art rather than a science following a specific procedure, so the recommendation at this point is learn from examples. A few cases which regularly generate quasi-experimental variation can be named: natural events, disasters, and administrative rules that generate very different outcomes for otherwise similar objects (e.g., class size limits). The presence of network effects represents an important additional challenge in both online and learning contexts. Therefore, this area will remain very active in statistical research within social sciences.

References

Algan, Y., Benkler, Y., Morell, M. F., & Hergueux, J. (2013, July). Cooperation in a peer production economy experimental evidence from Wikipedia (Working paper). In *NBER Workshop on the Economics of IT and Digitization*, Milan, Italy.

Angrist, J., & Pischke, J.-S. (2009). *Mostly Harmless Econometrics*. Princeton, NJ: Princeton University Press.

Aral, S., Muchnik, L., & Sundararajan, A. (2009). Distinguishing influence-based contagion from homophily-driven diffusion in dynamic networks. *Proceedings of the National Academy of Sciences, 106*, 21544–21549.

Baldwin, C., & von Hippel, E. (2011). Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. *Organization Science, 22*, 1399–1417.

Benkler, Y. (2002). Coase's Penguin or Linux and the nature of the firm. *The Yale Law Journal, 112*, 369–446.

Bramoullé, Y., Djebbari, H., & Fortin, B. (2009). Identification of peer effects through social networks. *Journal of Econometrics, 150*, 41–55.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Chicago, IL: Rand McNally College.

Coase, R. (1937). The nature of the firm. *Economica, 4*, 386–405.

Demsetz, H. (1967). Toward a theory of property rights. *The American Economic Review, 57*(2), 347–359.

Goldfarb, A., & Tucker, C. (2014). *Conducting research with quasi-experiments: A guide for marketers* (Working paper No. 2420920). Rotman School of Management/SSRN. Retrieved from http://ssrn.com/abstract=2420920.

Goldsmith-Pinkham, P., & Imbens, G. W. (2013). Social networks and the identification of peer effects. *Journal of Business & Economic Statistics, 31*, 253–264.

Graham, B. S. (2015). Methods of identification in social networks. *Annual Reviews of Economics, 7*, 465–485. doi:10.1146/annurev-economics-080614-115611.

Heckman, J. (2000). Causal parameters and policy analysis in economics: A twentieth century retrospective. *Quarterly Journal of Economics, 115*, 45–97.

Hess, C., & Ostrom, E. (2003). Ideas, artifacts, and facilities: Information as a common-pool resource. *Law and Contemporary Problems, 66*, 111–145.

Jackson, M. O. (2014). Networks in the understanding of economic behaviors. *The Journal of Economic Perspectives, 28*, 3–22.

Kummer, M. (2013). *Spillovers in networks of user generated content—Evidence from 23 natural experiments on Wikipedia* (ZEW Discussion Paper No. 13-098). Mannheim, Germany: SSRN.

Lerner, J., & Tirole, J. (2002). Some simple economics of open source. *The Journal of Industrial Economics, 50*, 197–234.

Matthews, R. (2000). Storks deliver babies (p = 0.008). *Teaching Statistics, 22*, 36–38.

Osterloh, M., & Rota, S. (2007). Open source software development—Just another case of collective invention? *Research Policy, 36*, 157–171.

Shriver, S. K., Nair, H. S., & Hofstetter, R. (2013). Social ties and user-generated content: Evidence from an online social network. *Management Science, 59*, 1425–1443.

Slivko, O. (2014). *Peer effects in collaborative content generation: The evidence from German Wikipedia* (ZEW Discussion Paper No. 14-128). Mannheim, Germany.

Stock, J. H., & Trebbi, F. (2003). Retrospectives: Who invented instrumental variable regression? *Journal of Economic Perspectives, 17*, 177–194.

Tapscott, D., & Williams, A. D. (2010). *Wikinomics: How mass collaboration changes everything*. New York, NY: Portfolio.

VanderWeele, T. J. (2011). Sensitivity analysis for contagion effects in social networks. *Sociological Methods & Research, 40*, 240–255.

Wooldridge, J. M. (2013). *Introductory econometrics: A modern approach* (5th ed.). Mason, OH: Cengage Learning.

Zhang, X. M., & Zhu, F. (2011). Group size and incentives to contribute: A natural experiment at Chinese Wikipedia. *The American Economic Review, 101*, 1601–1615.