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An Ecosystem View on Online Communities of Practice

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ABSTRACT

A community of practice (CoP) is a group of people who share common concerns, problems, or passions for a domain, and who deepen their knowledge and expertise through interaction on an ongoing basis. People view a CoP as a wellspring of precious knowledge in the era of knowledge economy. Notably, many researchers support the notion that a CoP is not designed or made but grown. However, there is no systematic theory of online community development. Based on the properties of autotrophic and open system of online CoPs, there are several differences between traditional groups and online CoPs. Interestingly, there exists an ideal mapping between the properties of an online CoP and an ecological ecosystem. This study adopts Yin's analytic strategy of descriptive framework and Odum's ecosystem model to develop an online CoP ecosystem model to identify the evolution of an ecosystem over time. Finally, some policies implications for development of online communities of practice are proposed based on the ecosystem view.

Keywords: Online communities of practice, knowledge management, ecosystem, evolutionary model

I. Introduction

A. Research Background

A community of practice (CoP) is a group of people who share information, insight, experience, and tools about an area of common interest[1]. A CoP has been further defined as a group of people who share common concerns, problems, or passions for a domain, and who deepen their knowledge and expertise through interactions on an ongoing basis[2]. A community's focus could be on a professional discipline, a skill, or a topic, an industry, or a segment of a production process[3]. It is

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[1] *See* Etienne Wenger, Communities of Practice: Learning, Meaning and Identity (Cambridge: Cambridge University Press *1998).*

[2] *See* Etienne Wenger, Richard Mc Dermott & William M. Synder, Cultivating Communities of Practice: A Guide to Managing Knowledge *(*Boston, MA: Harvard Business School Press. 2002).

[3] *See* Richard A. Mc Dermott, *Knowing in community: 10 critical success factors in building*

loosely connected, informal, and self-managed; membership in a community depends on participation, not institutional affiliation or reporting relationships. Although they usually gel around a particular topic or domain, the specific issues they focus on change over time, as the needs and interests of their members change.

The three fundamental elements of a community of practice are: domain, community, and practice[4].

(1) Domain: A domain defines a set of issues and legitimizes the community by affirming its purpose and value to the community's members. The domain of a community of practice can range from common know-how to highly specialized expertise. It is easier to define a domain if there is already an established discourse or a professional discipline, but what brings members together is not always based on recognized topics. Members of a community may share a profession or a discipline, or play the same roles. A listserv or newsgroup, no matter how well-trafficked, is not a community of practice[5]. Without commitment to a domain, a community is just a group of friends.

The domain guides the questions they ask and the way they organize their knowledge or present their ideas. It is what inspires members to contribute and participate, moreover, helps them sort out what to share and how to distinguish between a trivial idea and one with promise.

(2) Community: A group of people who care about a specific domain formed a community through interact, learn together, and build relationships. Having others who share one's view of the domain and bring their individual perspectives on a given problem creates a social learning system. Membership may be self-selected or assigned, but the actual level of engagement depends on personal willingness; that is, participation is voluntary. Participation can be encouraged, but the kind of personal investment that makes for a vibrant community cannot be invented or forced.

(3) Practice: Practice denotes a set of socially defined ways of doing things in a specific domain. It is a set of common approaches and standards that create a basis for action, communication, problem solving, performance, and accountability. Whereas the domain denotes the topic the community focuses on, the practice is the specific knowledge the community develops, shares, and maintains. Successful practice development depends on a balance between joint activities, in which members explore ideas together, and the production of "things" like documents or tools.

CoP is not a new concept. Dating back to the Middle Ages, people gathered to form guilds for discussing practical issues, everyday problems, and exchanging resources, therefore guilds were deemed one of the ancient CoPs. Today, CoPs are still pervasive. They have continued to proliferate in various aspects of human lives. An organization or industry has its own formally recognized or invisible practice-based communities[6].

In the era of knowledge economy, the practice of online CoP is drawing more

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communities of practice, in *The International Association for Human Resource Information 1-12 (2000).*

4 *See* generally Wenger et al., *supra* note 2.

5 *See* Mark S. Schlager , Judith Fusco & Patricia Schank, *Evolution of an on-line education community of practice* in Building Virtual Communities: Learning and Change in Cyberspace 129-158 (Ann Renninger and Wesley Shumar eds., New York: Cambridge University Press, 2002).

6 *See* generally Wenger et al. *supra* note 2.

attentions as people view it as a wellspring of precious knowledge. Numerous management and design principles for online CoPs have been presented[7]. Interestingly, many researchers support the notion that a CoP is developed over time [8] and it is not designed or made but grown[9]. However, in a review recent articles by Whittaker and others[10]. Schoberth and his colleagues asserted no common theoretical model was found to explain longitudinal aspects of the users' communication activity in online communities[11]. There is no systematic theory to portray online community development[12]. Furthermore, there are many unanswered questions regarding the development process over time of online CoPs. Although the core structure of CoPs is important for their development researchers have no idea about the evolutionary process of the core structure[13]. Does the core develop early? Is the core stable or shifting over time? For the entire online CoPs, in practical situations with long term observation, CoPs' development usually endures fluctuation that some CoPs are generally prosperous but suddenly failed. What are reasons for such fluctuations? What are emerging structures contributing to a CoP's steady development? Furthermore, what are effects on members with different migration time and ages contributed to a CoP's development process? When concerning about the change over time, few field studies have been conducted to tackle the longitudinal development process of online CoPs in order to gain insights into the dominant factors or mechanisms influencing a CoP's developmental process.

Since an online CoP is formed by a group of people, existing group development models may contribute constituent constructs to understand the driving forces toward its evolution. Over the last five decades, researchers have postulated different models of how groups develop over time[14]. Chidambaram and Bostrom summarized

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[7] *See,* e.g., Amy Jo Kim, Community Building on the Web: Secret Strategies for Successful Online Communities, (2000). *See* Jennifer Preece, Online Communities: Designing Usability, Supporting Sociability (2000). *See* Mc Dermott, *supra* note 3. *See* Joe Cothrel *Five ingredients for a successful online community,* Internet Executives Club: Internet Marketing Symposium (2001).

[8] *See* Mc Dermott *supra* at note 4. *See* Schlager et al *supra* note 5. *See* Heather A. Smith, and James D. McKeen, *Creating and facilitating Communities of Practice,* 1 Handbook on Knowledge Management: Knowledge Matters 393-407, (1992).

[9] *See* Amy Jo Kim, Community Building on the Web: Secret Strategies for Successful Online Communities, (2000). *See* John Seely Brown and Paul Duguid, The Social Life of Information (Harvard Business School Press, 2002). *See* Sasha Barab & Thomas Duffy, *From practice fields to communities of practice* in Theoretical Foundations of Learning Environments, (Jonassen, D. and Land, S. M. eds., NJ: Lawrence Erlbaum Associates 2002). *See* Wenger *supra* note 1. *See* Wenger at al *supra* note 2.

[10] *See* generally Whittaker et al., *The dynamics of mass interaction, 98th* Proceedings of CSCW Seattle Washington.

[11] *See* generally Thomas Schoberth, Jennifer Preece & Armin Heinzl, *Online communities: a longitudinal analysis of communication activities,* Proceedings of the 36th Hawaii International Conference on System Sciences (2002).

[12] *See* Uwe Matzat, *Cooperation and community on the Internet: Past issues and present perspectives for theoretical-empirical Internet research* Proceedings of Conference on Trust and Community on the Internet, Center for Interdisciplinary Research, Germany (2002).

[13] *See* Heather A. Smith, and James D. McKeen, *Creating and facilitating Communities of Practice,* 1 Handbook on Knowledge Management: Knowledge Matters 393-407, (1992). *See* Avia et al., *Network analysis of Knowledge Construction in Asynchronous Learning Networks* 7(3) *Journal of Asynchronous Learning Networks* 1-23, (2002).

[14] *See* e.g., Robert F. Bales & Fred L. Strodtbeck, *Phases in group problem-solving,* 46 *Journal of Abnormal and Social PSYCHOLOGY 485*-495, (1951). *See* Warren Bennis, and H. A. Shepard. *A theory of group development,* 9 Human Relations 415-457, (1956). *See* W. R. Bion, Experiences in

these models into several categories as listed in Figure 1.[15] Nevertheless, there are some different CoP properties between traditional groups and online CoP development models. This research takes two aspects rarely addressed in prior studies into account as follows.

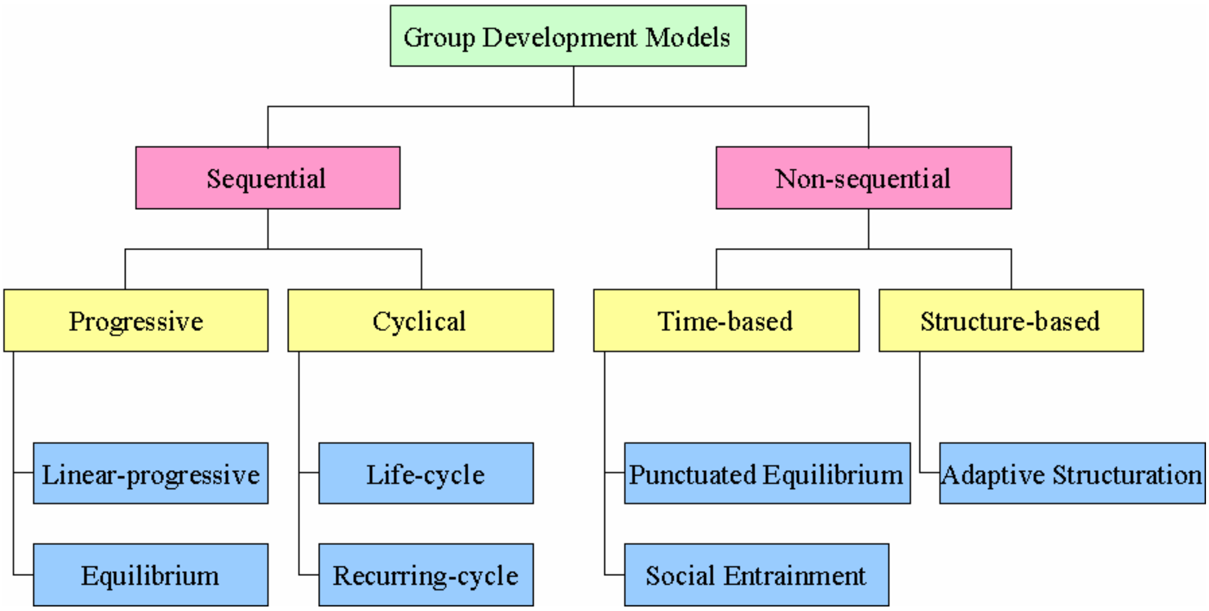

Figure 1. Group development models (Chidambaram and Bostrom, 1996)

The first aspect views an online CoP as an autotrophic system. A group has limited life span by examining group development studies; that is, a group has a fixed starting and ending point. In studies where time and deadline pressure have been explicitly recognized, the behavior change in groups is evident with the passage of time, and results in different development models[16]. In contrast, since members of an

Groups (New York: Basic Books Inc.1961). *See* Artemis Chang, *Punctuated equilibrium and linear progression: Toward a new understanding of group development*, 46 (1) Academy of Management Journal 106-117, (2003). *See* Connie J.Gersick, *Time and transition in work teams: Toward a new model of group development*, 3(1) Academy of Management Journal 9-41, (1988). *See David Johnson* and Frank Johnson, Joining Together: Group Theory and Group Skills (Boston: Allyn and Bacon 1977). *See* Roy B. Lacoursiere, *The Life Cycle of Groups: Group Developmental Stage Theory (*New York: Human Sciences Press 1980). *See* Joseph. Edward. McGrath, *Time, interaction and performance (TIP)* 23 A theory of groups Small Group Research 524-572 (1991). *See* Steven *L.* Obert, *Developmental Patterns of Organizational Task Groups: A Preliminary Study 36(1)* Human Relations 37-52, (1983). *See* Sarkar & Sahay, *Understanding virtual team development: An interpretive study,* 3 Journal of the Association for Information Systems 247-285, (2002). *See* A.Seers, *Temporal pacing in task forces: Group development or deadline pressure?,* 23(2) Journal of Management 69-187, (1997). *See* S.A Wheelan & J. M Hochberger, *Validation studies of the group development questionnaire, 27* Small Group Research 143-170, (1996). *See* Worchel, S., Coutant-Sassic, D. and Grossman, M. A developmental approach to group dynamics: A model and illustrative Research in S. Worchel, W. Wood, and J. A. Simpson , *Group Process and Productivity* 181-182 (eds., Newbury Park, CA: Sage Publications 1992).

[15] *See* Laku Chidambaram and Robert P. Bostrom, *Group Development: I A Review and Synthesis of Development Models,* (6) *Group Decision and Negotiation* 159-187, (1996).

[16] *See* Kelly Burke and Laku Chidambaram, *Developmental differences between distributed and face-to-face groups in electronically supported meeting environments: An exploratory investigation,* 4(3) Group Decision and Negotiation 213-234, (1994). *See* Laku Chidambaram and Robert P. Bostrom. *supra* at note 15. *See* R.C Ginnet *The airline cockpit crew* in J. R. Hackman, Groups That Work (and

online CoP can overcome space, time, and organizational boundaries by employing information technology, the life span lasts if intended. Besides, due to the limited life span of a group examined in prior studies, members may expect that they may not work together in the future. Expectancy theory indicates that the future expectation can influence the current behavior. Such expectation often leads to very different responses if the group has no future[17]. However, the relationship of online CoP members lasts and groups may form and reform continuously through information technology if desired.

Besides, all groups in prior studies are given specific tasks to complete[18]. Results indicated that the temporal pattern postulated in the punctuated equilibrium model reflects task pacing with a deadline, rather than the group development process[19] .

On one hand, the examination of dissimilar tasks brings conflicting results[20]. On the other hand, members in a CoP may pursue a common interest or goal within a specific domain via exchanging resources, practical knowledge, or advisory information, but not exactly perform certain tasks.

In ecological terms, an online CoP is an autotrophic system[21] namely, it is a self-supporting system. The life span of an online CoP mainly depends on members that it will collapse if no members want to participate continuously in the online CoP. On the other hand, traditional groups in prior group development studies, or online groups such as online training/learning groups, virtual teams, are all heterotrophic systems[22]. The fate of these groups hinges on outer forces rather group members themselves. They must undergo predefined life length, and major differences between them are on the group process and final outcome.

The second aspect treats an online CoP as an open system. Opposite to fixed membership in group development models, the membership is self-subscribed, and member fluidity is relatively high in an online CoP. Membership might be open to anyone interested, and they can leave in free will. Therefore, members may have to link and re-link to their social networks, and define their individual roles, repetitively. Similarly, the size of an online CoP can be very large since it is open to the public. Most of well established online CoPs are generally composed of members over ten thousands. It may be impossible to know all of the members personally. These settings are quite different from those prior studies on group development. Furthermore, these distinct features hinder the measurement of some research constructs such as trust or norm, especially when they are based on fixed membership or when it is necessary to collect perception data from members. The problem of self-selection is also obvious because the respondents of questionnaires are mostly active members. These aforementioned distinct features are less tackled in concerning online CoP development model. Furthermore, some defects in prior

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Those That Don't): Crating Conditions for Effective Teamwork,(Jossey-Bass, San Francisco: CA 1990). *See* Seers, *Temporal pacing in task forces: Group development or deadline pressure?* 23(2) Journal of Management 169-187, (1997).

[17] *See* Donald *C.* Hambrick & Richard A. D'aveni, *Top team deterioration as part of the downward spiral of large corporate bankruptcy, 38 (10)* Management Science 1445-1466, (1992).

[18] *See* Luka Chidambaram and Robert P. Bostrom. *supra* at note 15.

[19] *See* A. Sears *supra* at note 16.

[20] *See* Chidambaram & Bostrom, R. P. *supra* at note 15.

[21] *See* R.E Ricklefs Ecology (3 eds. WH: Freeman and Company 1990). *See* Peter D. Stiling Introductory Ecology (Englewood Cliffs, N.J.: Prentice Hall 1992).

[22] *See Id.*

group development studies are also deserved attention.

First, Chidambaram and Bostrom argued that most models are drawn from student groups. Several researchers pointed out that it is problematic by using zero-history groups in information systems research[23]. It raises serious concerns about the general applicability of the results from studying the behavior of groups that have never worked together before and will never work together in the future[24].

Second, prior models say little about the mechanisms of change, but it is critical to understand and manage group development[25]. A group often changes in social and work processes throughout the time of its existence. Understanding these changes, such as the consequences of these events, is important to guide the group toward high performance[26].

Third, previous research on group behavior suggests that groups change over time; group development models can be referred as patterns of change[27]. Recently, authors have recognized the existence of continuous change, and changes are ongoing, evolving, and cumulative[28]. In the virtual work environment, individuals may not only manage continuous changes, but also have potential for change which increases the complexity of the work process[29]. Most studies that acknowledge that social structures of organizations or groups are subject to change over time; however, they only consider a single snapshot of the social structures. Therefore, studies continue to rely on empirical tests associated with a given static structure[30]. Consequently, the length of a study directly influences the development pattern identified by researchers, especially among sequential models. Observing groups over different time periods may result in different models of development since these models in literatures offer snapshots of groups at different stages of their life-spans. Although the limitations of such a single snapshot approach have been recognized, financial and organizational constraints have limited efforts on the inevitable changes that occur in networks over time[31]. Miller also pointed out that the relative difficulty of studying the dynamic group processes has been a limiting factor on the amount and scope of

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23 *See* e.g., Ernest G. Bormann, *The paradox and promise of small group research,* 37(1) Speech Monographs 211-217, (1970).

24 *See* Chidambaram & Bostrom, R. P. *supra* at note 15.

25 *See* Manju J. Ahuja & Kathleen M. Carley, *Network structure in virtual organizations, 10 (6)* Organization Science, 741-757 (1999). *See* James E. McGrath, *Studying groups at work: Ten critical needs for theory and practice* in Designing Effective Work Groups, 363-392 (Goodman, P. S. and Associates eds., San Francisco: Jossey-Bass 1986). *See* Thomas Schoberth et al., *Online communities: a longitudinal analysis of communication activities* Proceedings of the 36th Hawaii International Conference on System Sciences (2003).

26 *See* D. L Miller, *The stages of group development: A retrospective study of dynamic team process* 20 (2) Canadian Journal of Administrative Sciences 121-134, (2003).

27 *See* Chidambaram & Bostrom *supra* at note 15.

28 *See* Andrew Pettigrew, Richard W. Woodman & Kim S. Cameron, *Studying organizational change and development: challenges for future research, 44(4)* Academy of Management Journal 697-713, (2001).

29 *See* Mary Beth Watson-Manheim, Kevin Crowston & Katherine Chudoba, *Discontinuities and continuities: A new way to understand virtual work, 15 (3)* Information *Technology and People* 191-209, (2002).

30 *See* Shaul *M.* Gabbay & Roger Leenders J., *Social capital of organizations: From social structure to the management of corporate social capital,* 18 Social Capital of Organizations 1-20, (2001).

31 *See* Barry Wellman, J. Suitor & Morgan, D. L. *It's about time: how, why and when networks change 19* Social Networks 1-7, (1997).

the group research[32].

B. Research Questions

Many questions regarding the changes over time of an online CoP remain unanswered, and fail to address the characteristics of online CoPs. Some shortcomings identified in previous subsection inspire us to adopt an alternative perspective to understand the developmental process of online CoPs. There is a strong need to develop novel perspectives that bring insights beyond those generated and validated using the traditional theoretical and methodological perspectives. If we want to open the black box of evolutionary process, the question is, how to develop a systematic theory of online CoPs development concerning about the properties of online CoPs? In other words, how to model an online CoP so that we can thereby systematically describe the changes of online CoPs along the timeline?

To answer the research question, this study decides to adopt the ecological perspective for several reasons articulated as follows.

First, the mechanisms of change can be suitably inferred from ecological perspective. In general, development often implies that things become better. Evolution, from the Latin, "evolutio," is widely used for temporal change, that is, change with time[33]. What we are concerned about, the developmental processes over time, or, alternatively, the evolutionary process, are akin to the central theme of ecological theory. Besides, the ecological perspective is more holistic and macroscopic, where the level of analysis is the entire ecosystem, and the issues in individual member fluidity can be tackled accordingly. Actually ecologists refer to the processes that population as a whole gradually changes composition as "phyletic gradualism," namely, the gradual one-by-one selection of population members. Their focus is on how natural selection progressively transforms population over time[34].

Second, many ecological concepts are mentioned in numerous CoP-related literatures to describe CoPs, such as a community is organic CoP is much like a living organism growing and evolving over time and is organic growth[35]. Besides, being immersed in some CoPs for several years, we also found that members usually use some ecological terms such as dead, alive, energy, sustainability or evolution to describe the individuals or CoP members as a whole. This phenomenon supports that the adoption of ecological perspective is appropriate.

Third, several studies indicated that the ecological approach seems to provide a powerful framework for understanding complex human social issues[36]. Moreover,

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32 *See* David L. Miller, *The stages of group development: A retrospective study of dynamic team process,* 20 (3) Canadian Journal of Administrative Sciences 121-134, (2003).

33 *See* Eugene Pleasants Odum, Ecology and Endangered Life-Support Systems (Sunderland, MA: Sinauer Associates, Inc 1993).

34 *See* Graham W. Astley, *The two ecologies: Population and community perspectives on organizational evolution,* 30 Administrative Science Quarterly, 224-241, (1985).

35 *See* generally Robert McDermott, *Knowing in community: 10 critical success factors in building communities of practice* The International Association for Human Resource Information 1-12, 2002. *See* Barab et al., *Designing system dualities: Characterizing an online professional development. community* in Barab*, S. A., Kling, R., and Gray, J. (eds.), Designing for Virtual Communities in the Service of Learning* (Cambridge, MA: Cambridge University Press, 2004).

36 *See* generally Bronfenbrenner, The Ecology of Human Development: Experiments by Nature and Design, Cambridge (MA: Harvard University Press 1979), discussing the role of human development.

an ecological model offers two main advantages and a way of allowing for the inclusion of complexity, and, a new language and set of analytical and descriptive tools from the ecological sciences[37]. The type of ecological framework has quite successfully in several other areas including treatment of poor health[38], studies of organizational behavior[39] world politics[40], curriculum innovation[41] and a study of the effects of violence on children.

Thus, ecological perspective can structure the essential elements of group interaction in online CoPs, which may help to ensure that important elements of interaction are not ignored because they are too complex to integrate. This could potentially be helpful in accurately modeling the online CoPs and studying their development. We will further elaborate the concept of ecological perspective in the following section.

II. Ecosystem Ecology

The word "ecology" comes from the Greek "oikos," meaning "household", combined with the suffix "logy", meaning "the study of." Thus the discipline of ecology is literally the study of households, and people live together as interdependent beings. The dictionary defines ecology as "the branch of biology dealing with the relations of organisms to one another and to their physical surroundings"[42]. Ecology is also one kind of study of help for us to understand changes of populations in relation to time and space, such as (1) how many organisms, (2) how are they distributed, (3) how they changed, and (4) why they changed in that way (Ricklefs, 1990; Stiling, 1992).

A fundamental concept in ecology that enables the holistic study of both parts and wholes is hierarchy. The basic, autonomous biotic unit is *organism*. A *population* is a group of the same organisms. *Species* is a similar concept to population, which signifies groups of organisms with specific characteristics. A *community* includes all of the populations or species living in a particular area. The community and the nonliving environment function together as an *ecosystem*. Groups of ecosystems along with human artifacts make up a *landscape*. *Biosphere* is the widely used term for all of the earth's ecosystems functioning together on a global scale. Among them, an ecosystem is the lowest level in the ecological hierarchy that is complete with all the necessary components for function and survival

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See also Bronfenbrenner & Ceci *Nature-nurture reconceptualized: A bioecological model 101 (4)* Psychological Review 568-56 (1994) discussing the role of technology and literacy: *See* Bertram C Bruce and Maureen P. Hogan, *The disappearance of technology: Toward an ecological model of literacy,* In Reinking, D., McKenna, M. C., Labbo, L. D. and Kieffer, R. D., Handbook of Literacy and Technology: Transformations in a Post-Typographic World 281, (Mahwah, NJ: Erlbaum 1998).

[37] *See* Arthur Tatnall and & Bill Davey, *Improving the chances of getting your IT curriculum innovation successfully adopted by the application of an ecological approach to innovation, 7* Informing Science Journal 87-103, (2004).

[38] *See* Joseph. G. Grzywacz and Juliana Fuqua, *The social ecology of health: Leverage points and linkages*, 26(3) Behavioral Medicine 101-115, (2000).

[39] *See* William Barnett, Mischke G. A. and Ocasio, W. *The evolution of collective strategies among organizations,* 22(1) Organization Studies 325-354, (2000).

[40] *See* Simon Dalby, Ecological *metaphors of security: World politics in the biosphere, 23(3)* Alternatives: Social Transformation and Humane Governance 291-320, (1998).

[41] *See* Tatnall *supra* note 37.

[42] *See* Simon Dalby, *Ecological metaphors of security* The Oxford English reference dictionary (Oxford: Oxford University Press 1996).

over a long term. Since we view an online CoP as an ecosystem, we should pay special attentions on it.

The basic definition of the ecosystem was first proposed by Tansley[43]. He defined an ecosystem as a biotic community and its associated physical environment in a specific place. The main components of the concept are its biotic and abiotic (nonliving) features and the interactions between them. An ecosystem is an open system; that is, things are constantly entering and leaving. As shown in Figure 2, an ecosystem consists of a system, which represents the area we are interested in, and two large parts as input and output environments. Energy is a necessary input. The sun is the energy source for the biosphere, and directly supports ecosystems. Energy also flows out of the system in the form of heat and other transformed forms such as pollutants. Moreover, organisms may enter (immigrate) or leave (emigrate) as well.

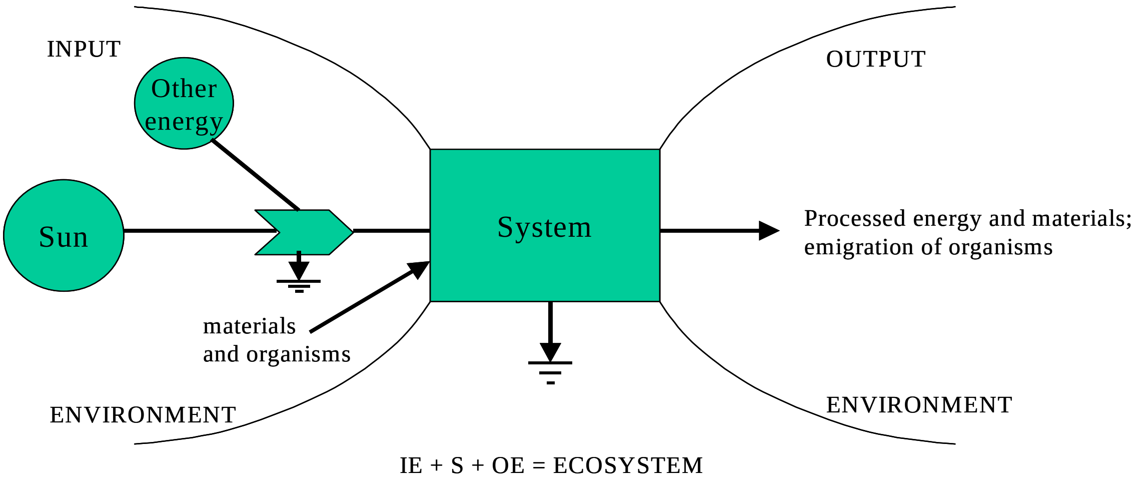

Figure 2. An ecosystem as an open system (Odum, 1993)

To further understand the components and functions of an ecosystem, we can refer to Odums ecosystem model[44], which is the most representative and has influenced a generation of ecologists[45].

As displayed in Figure 3, bullet-shaped units are autotrophs, hexagons are heterotrophs, tank-shaped boxes are storages, loop represents recycling materials, and arrows-into-ground are heat sinks (where heat is lost).

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43 *See* Arthur G. Tansley, *The use and abuse of vegetational concepts and terms, 16 Ecology,* 284-307, (1935).

44 *See* generally Odlums *supra* at note 33.

45 *See* generally Robert E. Ricklefs Ecology (3rd ed., WH: Freeman and Company 1990).

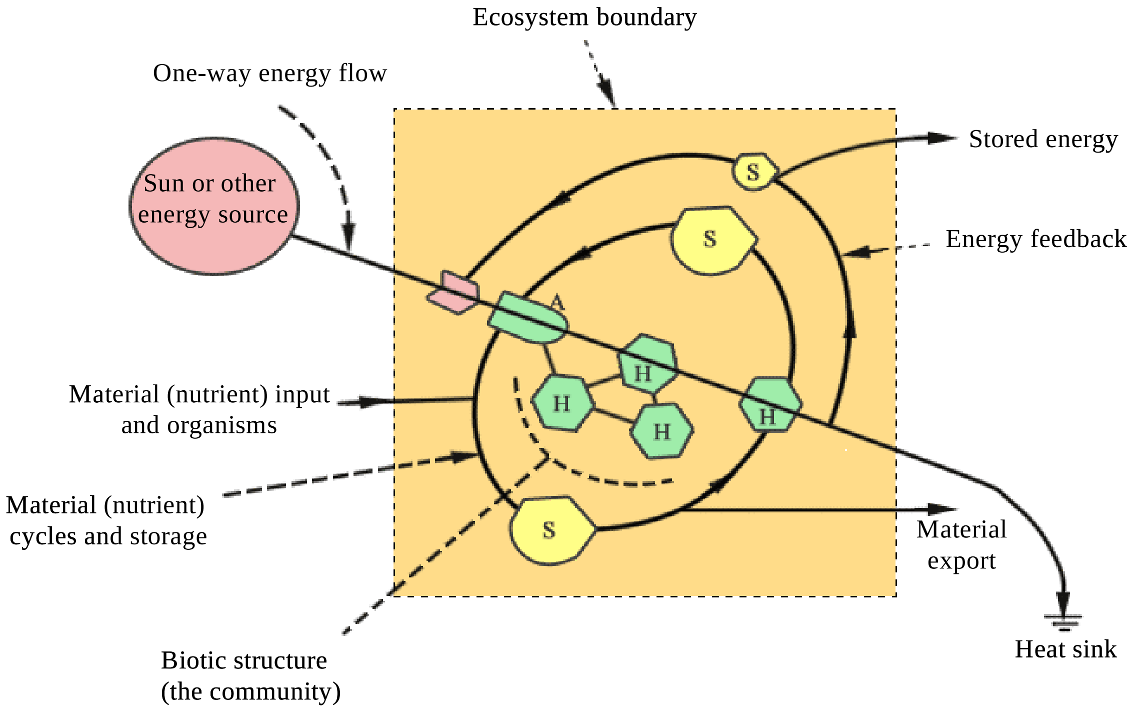

Figure 3. Odum's ecosystem model

An ecosystem has two major biotic components. First is an autotrophic component, able to fix light energy and manufacture food by the process of photosynthesis. The green plants constitute the autotrophic component. These organisms may be viewed as producers. The second major biotic unit is the heterotrophic component, which utilizes, rearranges, and decomposes materials synthesized by autotrophs. Generally, fungi, animals, including human, constitute the heterotrophs. These organisms may be thought of as the consumers or decomposers. The autotrophic and hetertrophic components depicted in Figure 3 are linked together in a network based on their interaction relationship.

Energy, materials, and pools are primary abiotic components. There are two abiotic functions that make the ecosystem operational, namely, energy flow and material cycles. Energy is defined as the capacity to do work. It is required to drive the cycling of chemical materials. Energy flow is one-way, although it may sometimes feedback through storage. It flows from the sun or another external source through the biotic community as the heat, and finally disappears. Therefore, an ecosystem demands continuous inflow of energy to sustain its lives. In contrast to energy, chemical materials, such as nitrogen or calcium, can be used repeatedly without losing utility. These materials are stored in pools. In a well-ordered ecosystem, many of these materials cycle back and forth between pools of abiotic and biotic components. These are called the biogeochemical cycles. A certain chemical materials are necessary for life. These are called nutrients and tend to be retained and recycled within living ecosystems[46].

There are five steps to establish an ecosystem model according to Pickett and

[46] *See* Odums *supra* note 37.

Cadenasso [47]:

Step 1. Identify the components of the model. The components of the models are the biological, social, or geophysical entities that are of interest—for example, species, populations, soils, patches, nutrients, energy, and various kinds of capital. The components will be included and specifies at what level of aggregation they are evaluated should also be identified[48]. For example, organisms can be considered as individuals or communities.

Step 2. State the spatial and temporal scale of the model. The second step in establishing ecosystem model is to state the spatial and temporal scale[49]. Spatially, ecosystem models can range from fine to coarse scales. Temporally, ecosystem models can have seasonal, decadal, or longer extents.

Step 3. Delineate the boundary of the ecosystem. The boundaries must be specified since an ecosystem is conceived as a spatial unit[50]. Boundaries allow ecologists to simplify their views on a system, to identify an external set of forcing functions, and to calculate changes in material and energy budgets. The boundaries of an ecosystem can be specified as a matter of convenience, to follow geomorphological divides, to understand a political entity, to recognize changes in flux rates, or to respond to changes in the frequency of some ecological process of interest. Convenience and physical borders are the most common motivations for setting ecosystem boundaries.

Step 4. Articulate relations among components. The ecosystem model must also clarify the relations among components in a system. For instance, exactly what components and entities are linked to one another? In this case, a food web is an appropriate representation of the relation between predators and preys. Further, we may also want to know which part of a system is tightly coupled and which is only weakly coupled? The relation merely indicates which components are linked, how they are linked is exposed by identifying the intervening ecological interactions and influences. Interactions that are included in the model depend on the type of model being built.

Step 5. Identify the constraints on system behavior. A model must also identify the constraints on system behavior. Depending on the processes and components included in the model, there are various principles may constrain the behavior of system components. For example, in a nutrient model that focuses on the processing of nitrogen, the availability of oxygen acts as a critical switch[51].

III. Online CoP Ecosystem Model

In science, metaphor plays a generative or creative role (Pickett, 1999). Metaphors are useful in viewing certain aspects of a complex system, but can greatly improve the understanding of complex issues. We follow Yin's (1994) analytic strategy of descriptive framework and thus use the metaphor of an ecosystem to integrate and organize sets of dimensions in relation to the evolutionary process of an

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47 *See* Stewart T.A Pickett and Mary L. Cadenasso, *The ecosystem as a multidimensional concept: Meaning, model, and metaphor,* 5 Ecosystem*s* 1-10, (2002).

48 *See* Jax, K.Jones & Stewart T. A Pickett, *The self-identity of ecological units* 82 Oikos, (82) 253-264.

49 *See* generally Odum *supra* note 37.

50 *See* Gene E. Likens, Excellence in Ecology, III: The Ecosystem Approach: Its Use and Abuse (Oldendorf/Luhe (Germany): Ecology Institutem1992).

51 *See* Jones et al., *supra* note 48. *See* Odums *supra* note 37.

online CoP.

Mappings between ecological and online CoP entities are listed in Table 1. Among them, because an ecosystem is the lowest level in the ecological hierarchy that is complete with all the necessary components for function and survival, this study views an online CoP as an ecosystem, and its members are organisms that interact based upon practical knowledge and exchange resources.

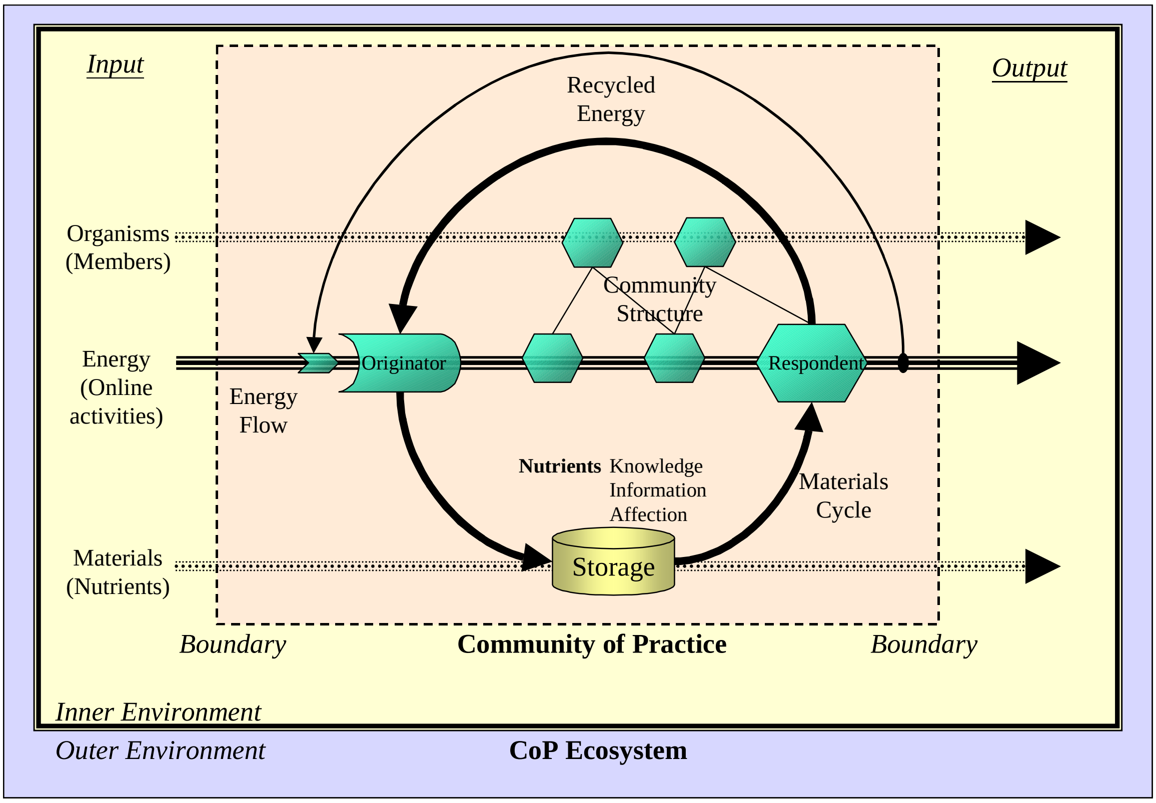
Table 1. The mapping of hierarchical ecological entities to online CoPs entities

Hierarchical Entities	Description	Mapping Entities	Explanation
Organism	The basic, autonomous biotic unit.	Individual member	Every member is a freewill, autonomous agent, who can choose to participate actively, dormant or leave.
Population	A group of the same organisms.	A group of members.	Two or more members form a population.
Species	A group of organisms with specific characteristics.	Members play the same ecological roles.	There can be various characteristics to judge members whether belong to the same species or not.
Community	Including all of the populations living in a particular area.	Members participate in the same online community of practice.	All members with various roles or domains in an online CoP form the community.
Ecosystem	The community and the nonliving environment function together.	Online community of practice	The ecosystem is composed of biotic and abiotic components.
Landscape	Groups of ecosystems along with human artifacts.	Platform (*i.e.*, SCTNeT)	The habitat of online CoPs.
Biosphere	The widely used term for all of the earth's ecosystems functioning together on a global scale.	The whole educational environment.	Refer to the universal and general surrounding of online CoPs, including invisible culture and physical environment.

A. Identify the model components

The components of an online CoP ecosystem are listed in Figure 4. There are biotic and abiotic components in an ecosystem. Pools, nutrients and energy are all abiotic components. All interaction data between members are stored in the system; thus, the system storage acts as pools for later access by members.

Figure 4. Components of an online CoP ecosystem



Nutrients are materials regarding members' survival cycling between pools of abiotic system and biotic members within the online CoP. They can be used repeatedly without loss of utility. In an online CoP ecosystem, nutrients can be domain knowledge. This study identified five categories of domain knowledge shared in online CoPs. As shown in Figure 5, there are content knowledge, manipulation knowledge, exercise knowledge, conviction knowledge, and context knowledge. Descriptions and examples of these categories of domain knowledge shared in online CoPs are further elaborated in Table 2. Knowledge once articulated and shared in an online CoP as the nutrient, and can be used repeatedly without loss of utility because they are stored in the system.

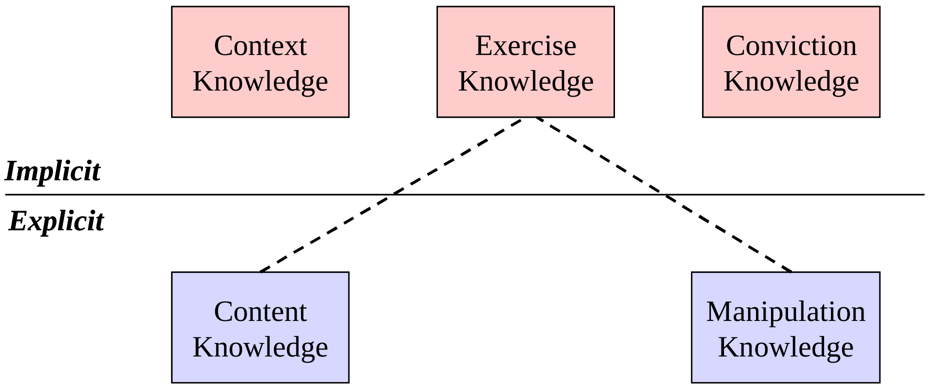


Figure 5. Categories of domain knowledge of online CoPs

Table 2. Descriptions for categories of domain knowledge of online CoPs

Classification	Categories	Descriptions	Examples (in the domain of education)
Explicit	Content knowledge	The codified body of knowledge for specific domain, including knowledge structures and contents.	The schemas and contents of environmental education.
	Manipulation knowledge	The knowledge of applying content knowledge.	How to teach environmental education?
Implicit	Exercise knowledge	When applying content or manipulation knowledge in real world, there are some gaps and adjustments learnt.	How to represent and organize the teaching materials, so that students can easily understand?
	Conviction knowledge	Personal beliefs or values toward the domain.	1. What is a good scientific teacher? 2. Are teachers professionals?
	Context knowledge	The knowledge of context around the domain.	1. The level of individual students. 2. The context of equipments and classrooms. 3. The newly educational policies.

Moreover, information regarding the focal domain of online CoP is exchanged frequently. For instance, information about on-job training is welcome for most of domain experts. Sometimes members may post news in relation to their domain. These kinds of information may attract members to join the online CoP. Furthermore, affection interflowing between members is another important type of nutrient. Some members may share their practical situation and anticipate for emotional supports from others within the same domain. This kind of care is also an important inducement for members to participate in a CoP because they may share the same professions and own enough knowledge to understand key points. All nutrients may keep attracting members to come back to the online CoP. Without these nutrients, members may go dormant or even leave the online CoP. When some nutrients are deleted by leader or posters, they are discharged from the ecosystem.

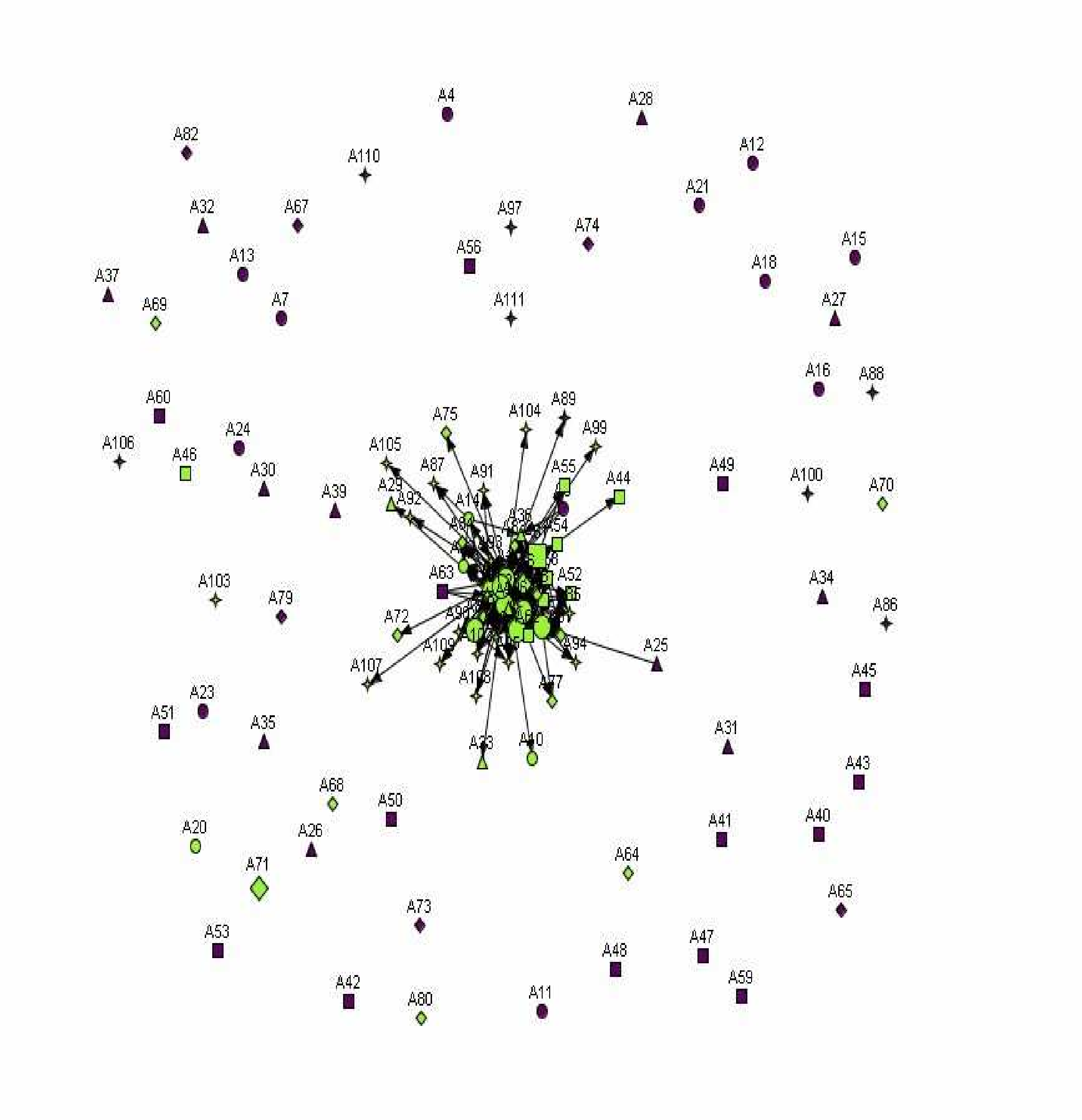
This study analogizes the *energy* as online activities performed by members. Because energy is the capacity to drive the nutrients cycle between organisms, and an ecosystem demands continuously inflow of energy to sustain its life. Energy is a necessary input that directly supports the life of an ecosystem. If there were no any online activities for certain periods within the online CoP ecosystem, members would judge the CoP was lifeless and never come back again. These online activities include the post or response to a topic discussion, the uploading or downloading of resources, logging into the online CoP, or any kinds of actions that can be perceived by others. Some online activities may carry nutrients and help the cycling of nutrients while some are irrelevant to nutrients. For instance, responding to a practical issue with personal experiences is good for the cycling of knowledge; whereas posting house keeping messages is a helpless effort.

Energy is a one-way flow that is finally degraded as heat and then disappeared. Popular issues may earn aggregated energy that accelerates the cycling of nutrients between members and system. Sometimes energy may recycle and feedback when stored online activities are brought up, such as old postings re-mentioned by members. It happens occasionally because certain topics within a professional domain are rather important and may be taken repeatedly at some intervals. Sometimes members may have new experiences toward old discussions, or new members may dig out historical topics and infill their opinions as well. However, although past online activities may reappear, it is the nutrient rather the energy that recycles between members.

Besides, members whether playing important roles or not are all biotic components or *organisms* that form the community of the ecosystem. In an online CoP ecosystem, there can be two types of biotic components. People that initiate a topic for discussion or contribute related resources are originators, while those who respond to originators are respondents. The former are akin to autotrophic component or producers, because they spend energy on bringing in or manufacturing nutrients. The latter are similar to heterotrophic component or decomposers since they may utilize and rearrange the nutrients brought in by the autotrophs. These two components trigger the cycling of nutrients. There is another type of heterotrophic component; that is consumer. Consumers consume nutrients only but irrelevant to the cycling of nutrients, just like some members gain valuable knowledge or information but contribute nothing. All members are autonomous agents because they can join or leave the online CoP ecosystem, and participate proactively or passively.

B. Steps 2, 3, and 4

In step 2, we state the spatial and temporal scale of the model. Spatially, the ecosystem of online CoP resides in a system platform. An online CoP is a distinct ecosystem. Temporally, the extent of the ecosystem can be unlimited if the online

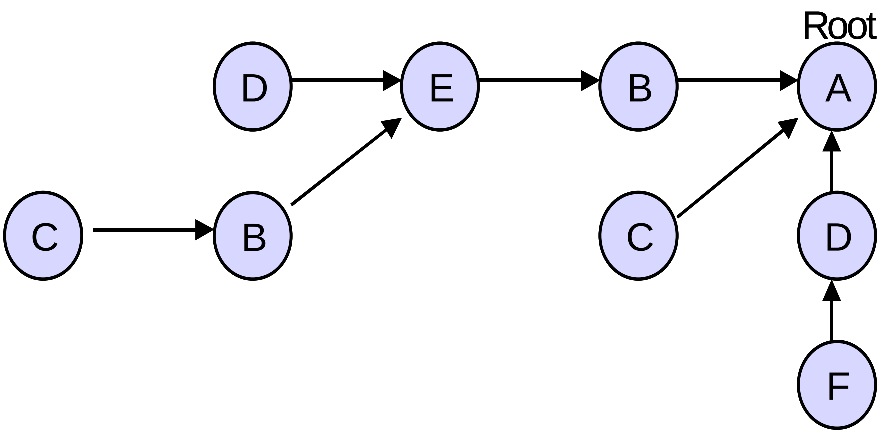


CoP is sustainable. We measure targeted online CoPs since their initiation for three years.

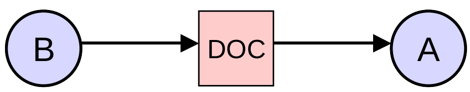
In step 3, we delineate the boundary of the ecosystem. Each online CoP has its innate and discrete boundary. In other words, unless people self-subscribed and are granted permission to join the online CoP, they cannot login the online CoP, let alone interact with members or access the resources of the online CoP. A CoP ecosystem consists of a CoP, input and output environments. Members may join to (immigrate) or quit from (emigrate) the CoP. Nutrients can be brought into the CoP by members' online activities and excluded when deleted. Energy is imported when members perform certain online activities, but flowed out when the utilities of online activities disappeared. Besides, every online CoP has its own domain or goal of setting up, in ecological perspective, it is the ecological niche of the online CoP that distinct it from others and thus establish an invisible boundary.

In step 4, we articulate the connections among the components. Network analysis has been used to develop ecosystem theory[52]. In the last fifteen years, ecologists have developed a theoretical approach and a set of computational methods, called the ecological network analysis. Mathematically and conceptually, the ecological network analysis is similar to work in the domain of social network analysis[53]. Much like a food web, which is a representation of various paths of energy flow through populations in the community, the originators and respondents are linked together in a social network based on their interaction relationship. As shown in Figure 6, a link between two nodes denotes interactions between these two members. A dark node symbolizes a dormant member (*i.e.*, a member falls into inactive state that is motionless.), and a light one is a biomass (*i.e.*, a member is active within specific time). Various shapes of nodes signify members joining at different time periods, and a large node denotes a core member of the last period.

Figure 6. An example of network structure of an online CoP in a specific time period



(a) Direct Interactive Network



(b) Indirect Interactive Network

Figure 7. Two types of interactive networks

Various types of information technologies can be utilized to support the interaction between members of an online CoP. In our viewpoint, no matter which kind of interaction mechanisms is adopted, they only contribute to two types of networks: direct and indirect interactive networks. A direct interactive network is

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[52] *See* Joseph. J. Luczkovich, S. P Borgatti, Johnson, and M. G. Everett, *Defining and measuring trophic role similarity in food webs using regular equivalence, 220(3) Journal of Theoretical Biology* 303-321, (2003).

[53] *See Id.*

composed of an originator and several follow-up respondents; therefore, their connections can be conceptualized as a tree structure[54]. Their connections are immediate, and they all have knowledge about who responds to whom. For example, in Figure 7(a), each node represents a respondent. Member A initiates a topic, and then members B, C, and D share their knowledge with member A. Then, member E decomposes member B's response and contributes his/her opinions. We can derive their social networks by analyzing such responsive structures[55]. Discussion and message boards are primary information technologies leading to a direct interactive network.

Instead, resource exchange and site recommendation are functions leading to the formation of indirect interactive networks, because an originator uploads documents but has no idea who will download them. They may have interactions but the relationships are indirect. As a consequence, the network is composed of one-to-one links without follow-up connections. As demonstrated in Figure 7(b), member A downloads resources provided by member B, and there are no proceeded respondents. To construct such kind of networks, we can draw a directed link from member B to A. In practice, we observed some members seem voiceless but actually quite active in exchanging resources.

Besides, the tight connection between members forms the core structure, and reveals some sort of ecological patterns. We can articulate the connections through sociograms of social network analysis and analyze the evolution of core structures, namely, keystone structures, as demonstrated in dotted box of Figure 8. Moreover, as Luczkovich[56] and his colleagues suggested, we analyzed the interaction relationship through structural equivalence or regular equivalence of network analysis[57]. We identified ecological roles every member played and understood the role distribution in an ecosystem, as delineated in Figure 9, where nodes with the same color denote equivalent ecological roles.

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[54] *See* generally Avia, R., Erlich, Z., and Ravid, G. *Network analysis of Knowledge Construction in Asynchronous Learning Networks*, 7(3) Journal of Asynchronous Learning Networks 1-23, (2003).

[55] *See Id.*

[56] *See* Luczkovich et al., *supra* note 52.

[57] *See* Martin G. Everett and Steve P. Borgatti, *Role coloring a graph,* 21 Mathematical Social Sciences 183-188, (1991).

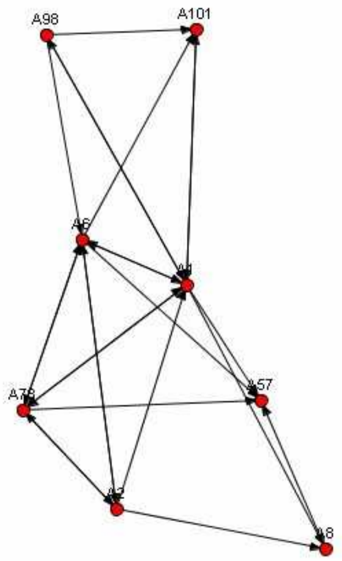

Figure 8. An example of keystone structure of an online CoP in a specific time period

C. Identify the constraints on system behavior

Step 5 identifies the constraints on system behavior. There are various factors may constrain the behavior of system components. For example, some constraints may limit the inflowing of energy and cycling of nutrients. Based on the CoP ecosystem model, we can systematically identify five categories of constraints on the source of outflows as shown in Figure 10.

The ecosystem concept has proven to be immensely flexible and productive[58]. It supports researches of individual processes[59] and studies of the reciprocal interactions between disparate organisms and their effects on particular sites[60]. Further, ecosystem can be an analytic or a synthetic concept and can support an impressive variety of kinds of models[61]. It is also proved to be useful for understanding system

change and institute policies of adaptive management[62]. Moreover, the ecosystem metaphor integrates social capital based on sociobiology[63]. Members perpetuate their genes by supporting members of their clan or share resources driven by reciprocal altruism. In other words, members invest in each other because of their shared interests or because of the realization that they all need helps some day.

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58 *See* Frank B. Golley, A History of the Ecosystem Concept in Ecology: More Than the Sum of the Parts, (New Haven: Yale University Press 1993).

59 *See* G. Agren and E. Bosatta, Theoretical Ecosystem Ecology: Understanding Element Cycles, (New York: Cambridge University Press 1996).

60 *See* Buzz Holling, *What barriers? What bridges?* in *Gunderson, L. H., Holling, C. S., Light, S. S. Barriers and bridges to the renewal of ecosystems and institutions* (New York: Columbia University Press 3-34, 1995).

61 *See Frank B. Golley, A History of the Ecosystem Concept in Ecology: More Than the Sum of* the Parts, (New Haven: Yale University Press 1993).

62 *See* Holling *supra* at note 60.

63 *See* Anderson K. Frank, *The dynamics of social capital Paper* presented at the Annual Meeting of the International Social Networks Association, (New Orleans, Louisiana 2002).

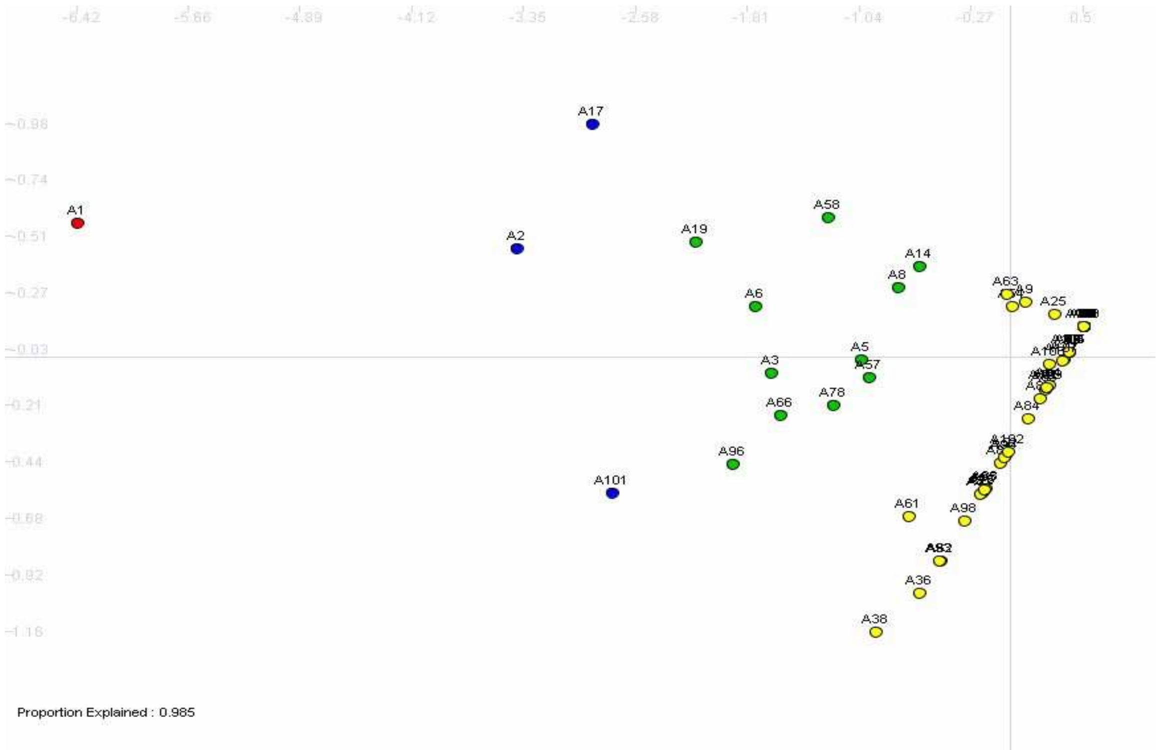

Figure 9. An example of ecological role distribution of an online CoP in a specific time period

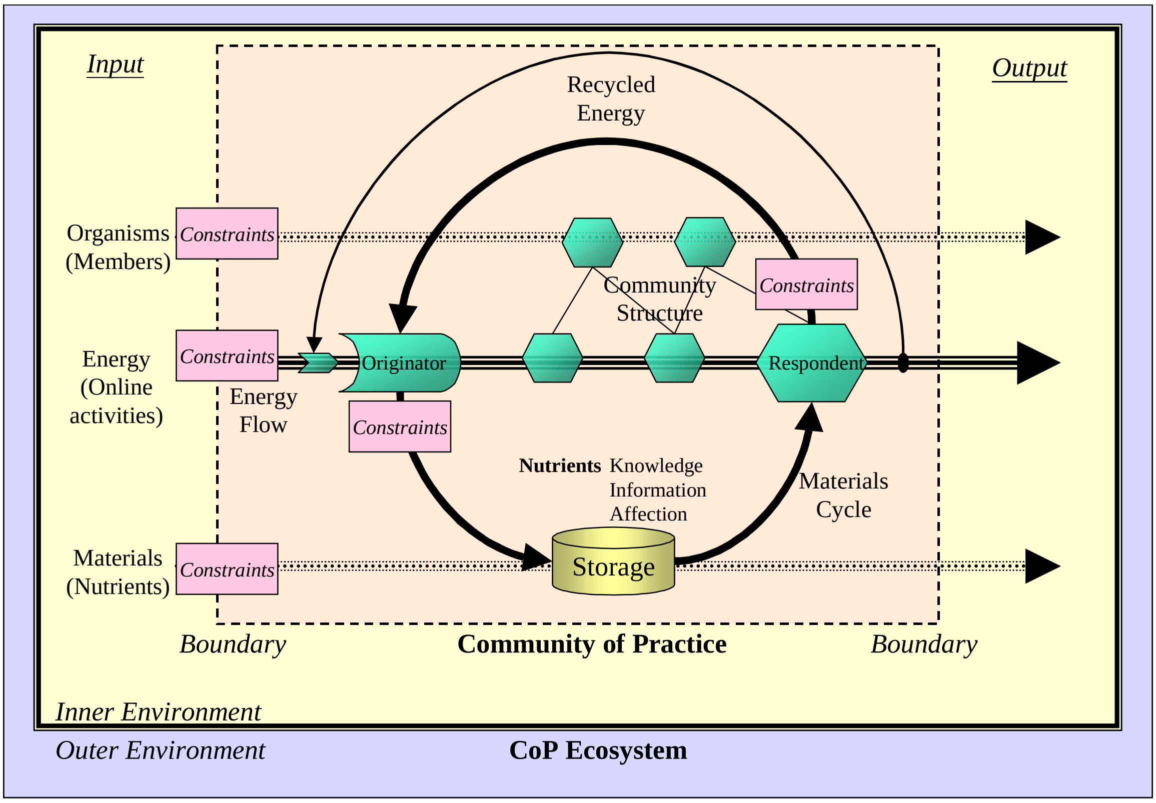

Figure 10. Constraints in an online CoP ecosystem

In this study, the online CoP ecosystem model serves as a conceptual framework for understanding the evolutionary process of an online CoP. Based on Odum's ecosystem model, this study proposes a descriptive framework to model CoPs. There are primarily three *components*: organisms, energy, and nutrients; and three types of *connections*: network configuration, keystone structure, and ecological role distribution. There are also five categories of *constraints* on the ecosystem functioning. They serve as our dimensions of describing changes within an online CoP ecosystem over time. The detailed tabular model of the online CoP ecosystem evolution is listed in the Appendix.

IV. Policy Implications for Development of Online Communities of Practice

This study aims at modeling an online CoP in order to systematically analyze the changes within an online CoP over time. This study identifies an ideal mapping between online CoPs and ecological ecosystems, and develops an online CoP ecosystem model based on Odum's model of ecosystem to layout the dimensions of describing changes within an ecosystem over time. Based on the ecosystem view on communities of practices, we can derive several valuable hints regarding development of online communities of practice for CoP managers. For online CoPs to be functioning well, we'll draw policy implications according to five categories of constraints, since these constraints should be systematically located and managed for the development of online CoP.

(1) Build more connections between immigrants of different times: This type of constraints may hinder the new members to join the online CoP. If the rate of member loss is faster than that of member sign-in, the online CoP is obviously in danger. Niche overlapping, for instance, could be one of the possible reasons. Each online CoP has its own focal domain. When established, the articulated domain immediately drew invisible boundary around the online CoP. In other words, the niche of this online CoP is determined. Nevertheless, when the niche is overlapped with other online CoPs, some constraints on development emerged. For CoP managers, the deliberation of CoP niche is a critical issue due to its the startup. Furthermore, since online CoPs are open to public and could have large size of member bases, they often have immigrants of different times. CoP managers should take notice of how to build more connections between immigrants of different times, because the inter-linkages could have associations with the development and perpetuation of online CoPs.

***(2) Strengthen the image of ongoing movement of online CoP*:** Continuous input of energy is prerequisite for the survival of an ecosystem. If there are very few online activities in an online CoP, then members would perceive this online CoP to be dead, and forget it very soon. Some factors may hinder members from coming and performing online activities in online CoPs. For example, limited information literacy of members is a possible reason contributing to such a situation. Some members may not be capable to interact online or maintain the habit of participation, and thus remain the status of dormancy. An important task for CoP managers is to establish a mechanism to strengthen the image of ongoing movement of online CoP, which is essential for attracting members to come. For instance, active delivery of weekly report on new topics discussed may be a trigger for inviting members' further participation. Besides, CoP managers may arrange certain periodic activities in online CoP to get focused.

(3) Create and promote the sense of clan: CoP managers should pay attention to factors inhibiting sharing of five categories of domain knowledge in online CoPs. The competition between organisms is one obvious constraint on inflowing of nutrients. Although Kropotkin suggested organism vs. environment may lead to mutualism or reciprocal altruism[64], however, since members usually share the same profession in an online CoP, as a result may lead to competing relationship. In ecology, we see organisms of the same clan help each another to perpetuate the gene line. Although they joined the same online CoP, nevertheless, they don't perceive other organisms as their clans. Thus, how to create and promote the sense of clan is an important task for CoP managers. Besides, balanced nutrients are required to develop well in ecology. There could be five types of domain knowledge as demonstrated in Figure 5. CoP managers should beware of balanced nutrients could have associations with the development and perpetuation of online CoPs.

(4) Facilitate outflows of originators: As we described in Section 1, open system is one of the characteristics of online CoP. There can be a big member base with many members unknown. This may hinder members from talking about something at their free will. Moreover, people may not pay attention to what others have said, but they always remember and care about what they propose and to what others respond. It may be more apparent in an online CoP. Because they share the same profession and

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[64] *See* Richard Dawkins, The Selfish Gene, (Oxford: Oxford University Press 1989). *See* Robert Wright, R The Moral Animal: The New Science of Evolutionary Psychology, (New York: Vintage Books 1994).

codified body of knowledge, and don't have many chances to meet face-to-face, they tend to judge others from their online behavior, especially their statements. Therefore, some members think passively that they have nothing valuable to contribute, or would write once and edit several times before and after their statements posted on their CoPs. They do care about what others will react to their posts, and employ the characteristics of rehearsability and reprocessability of electronic medium very well. Comparing with most entertainment-oriented online communities, this is quite an interesting but common phenomenon in an online CoP. It will be of help to the refinement of knowledge; however, this also constrains the knowledge flowing between members because some members would rather not to run the risks of being scorned and reduce the frequency to express their opinions.

(5) Encourage outflows of respondents: One constraint is resulting from miscommunication. The constraint is originated from the synchronous and asynchronous nature of the online CoPs. Some members may meet frequently online or face-to-face, but fail to inform other members. This makes other members think that their arguments are ignored. They are unaware of the status of interrelation among members, and even worse they may cease to continue sharing knowledge. Moreover, sometimes, the discontinuity of nutrients cycle results from the similar situation, where part of members communicate through discussion board, but latter they choose email to communicate between themselves, which misleads others to perceive that the interaction has ended. Furthermore, among various available communication tools, they have no idea which one their partners are using, or whether they have received messages passed through either one of communication tools.

The conversation in an online CoP is not perceived continuity as we usually do in physical settings. Conversions in the physical discussion, we have the sense of phase. After one person proposes his argument, we know it's another person's turn to make a statement to form a discussion, and the conversation continues iteratively. In an online CoP, again, due to the synchronous and asynchronous natures, the turn of taking concept is unobvious. The originator states his/her arguments, and passes the right of speech to indeterminate others, and waits for responses. In most cases, no one is psychologically obliged to react to the posted items. They feel that they are sitting in front of the computer, and individually interacting with the whole group's writings on the monitor. They have no obligation to read, or to answer the received messages. As a result, some posted items do not receive any feedbacks because they have never been viewed by others and remain untouched, or somebody reads it, but gives no comments due to unable to answer or reluctant to share knowledge. These hinder the flow of knowledge circulating between members.

Circulated organisms are organisms involved in the nutrient cycling. If the average circulated organisms in an online CoP are around two or three, which means every discussion thread has two or three members participated in the discussion in average. If the number of average circulated organisms in an online CoP is always low, then it would be not ideal for professional dialogues. In a discussion, each member plays the role as a decomposer to dissociate nutrients in former arguments and integrate new nutrients based on his own specialty. If fewer members involved, the circulated nutrients supposed to be limited. For CoP managers, above-mentioned are all critical points to address for online CoP development.

V. Future Research

In the near future, the authors plan to conduct a longitudinal exploratory study on online CoPs for a long period of time, for example, three years. Three years of longitudinal study may prevent the biases drawn from single snapshot and limited life span. We'll categorize online CoPs based on the statistics of the group member interaction and select some representative cases. Every six months the aggregated data of targeted online CoPs are treated as the unit of analysis. The whole life span of an online CoP under study will be analyzed in order to avoid the problems of zero-history groups and drawn bias conclusion from observation of groups over different time periods. We attempt to detect and analyze the changes of community structures in the ecosystem using social network analysis tools. Moreover, since quantitative data may fail to capture some interaction modes, we'll employ content analysis and semi-structural interviews to gain insights from the evolutionary process. We hope we can gain valuable insights into the development of online communities of practice through ecological perspectives.

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Appendix. The descriptive framework of ecosystem evolution

Categories	Attributes	Descriptions	Methodology and Measurements
Components			
Organisms	Immigration	The movement of individuals into an ecosystem. Number of new members approved to join the online CoP.	System logs analysis.
	Emigration	The movement of organisms out of an ecosystem. Number of approved members choose to leave the online CoP.	System logs analysis.
	Habitant	Organisms living in a particular area. Number of approved members remained in the online CoP.	System logs analysis. Habitants = Habitants (last periods) + Immigration – Emigration
	Biomass	The size of living weight or organisms. Number of approved members remain alive in the online CoP.	System logs analysis. Members come to this online CoP within six months.
	Dormancy	Organisms fall into an inactive state that is not dead but motionless. Approved members but are not biomass, that is, they haven't login the online CoP for certain time.	System logs analysis. Members didn't come back to this online CoP within six months. Dormancy = Habitant - Biomass
	Macrobiosis	Members keep coming to this online CoP since joined the online CoP.	System logs analysis.
Energy	Gross production	All kinds of online activities performed by members within the online CoP.	System logs analysis.
	Primary production	Production by autotrophs, which signifies the nature of some online activities are playing the role as initiators and having the potential to attract following energy concentrated. Such as topic initiated, and resource uploaded.	System logs analysis.
	Secondary production	Production by hetertrophs, which denotes the innate characteristics of certain online activities that cannot exist single-handed, but have to accompany with primary productions. Board reply and resource download are online activities fall in the category.	System logs analysis.
	Direct interactive production	Connections of direct interaction are immediate, and organisms have knowledge about who responses to whom.	System logs analysis.
	Indirect interactive production	They have interactions between organisms but the relationships are indirect. Resource exchange and site recommendation are online activities belong to this kind of interactive production.	System logs analysis.
	Production rate	Average productions within certain time.	Productions / Time (Half Year)
	Production discontinuity	Average days between two productions.	Time (Half year) / Productions
Nutrients	Conservation	Number of nutrients retained in the online CoP.	System logs analysis and content analysis.

	Circulated organisms	Number of organisms involved in each thread of discussion.	Content analysis.
	Discontinuance of cycling	Frequencies of discontinuance of cycling identified. Proposed problems or requests remain unanswered, or targeted member didn't response.	Content analysis.
Connections			
Interactive network	Density	Density of the network is the proportion of possible lines that are actually present in the each group. It is the ratio of the number of lines present to the maximum possible.	Social network analysis. Identified through network properties analysis in NetMiner.
	Inclusiveness	The number of connected points expressed as a proportion of the total number of points.	Social network analysis. Identified through network properties analysis in NetMiner.
	Reciprocity	The ratio of the maximum number of reciprocated ties to the total number of ties.	Social network analysis. Identified through network properties analysis in NetMiner.
	Hierarchy	This measure is to calculate how much network have hierarchical character.	Social network analysis. Identified through network properties analysis in NetMiner.
	Block density	To understand the interactions between immigrants of different times.	Social network analysis. Block Density Table in Netminer
Keystone structure	Size	Number of organisms belong to the core..	Sociogram and social network analysis. Identified through K-core in NetMiner
	Density	Density of the core structure is the proportion of possible lines that are actually present in the each group. It is the ratio of the number of lines present to the maximum possible.	Social network analysis. Identified through K-core in NetMiner. We set K = 5 in this study.
	# Cliques	Clique is a maximal complete subgraph of three or more nodes. It consists of a subset of nodes, all of which are adjacent to each other, and there are no other nodes in the network that are also adjacent to all of the members of the clique.	Social network analysis. Identified through clique analysis in NetMiner. We set n=3 in this study.
	Max Clique size	Clique size with max cohesion index.	Social network analysis. Identified through clique analysis in NetMiner.
	Keystone organisms	Core organisms. We identified them and recorded their shift over time.	Sociogram and social network analysis.
Roles distribution	Network roles	Proposed by Wasserman and Faust (1994). They classified organisms as isolate, transmitter, receiver, carrier, and ordinary, based on their in-degree and out-degree behavior.	Social network analysis.
	Ecological roles	Ecological roles, such as producers, decomposers, or consumers.	System logs analysis and content analysis.
	Species equitability	The apportionment of organisms among the species.	Structural equivalence and Social network analysis.
Constraints			

Organisms		Constraints on the immigration of organisms.	Interviews and content analysis.
Energy		Constraints on the inflowing of energy.	Interviews and content analysis
Nutrients		Constraints on the inflowing of nutrients.	Interviews and content analysis
Originators	Direct network	Constraints on the organisms to play the role as originators.	Interviews and content analysis
	Indirect network		
Respondents	Direct network	Constraints on the organisms to play the role as respondents.	Interviews and content analysis
	Indirect network		