SITUATING ALTERNATE THEORIES OF KNOWLEDGE CREATION IN THE CONTEXT OF KNOWLEDGE BUILDING

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Abstract

This paper situates three alternate theories of new knowledge creation in the context of knowledge building theory: the componential model of creativity (a generalized model of creativity); organizational learning theory, based on a business model of creativity; and the expansive learning cycle, based on activity theory, a general theory of human action. Each theory is described, and commonalities and differences among them are examined including the need to build up a store of requisite knowledge, the importance of mediational artifacts, the importance of externalizing tacit knowledge, the nature of the problem, and the need to work recursively.

Following this, there is a look at the conditions necessary to foster creativity, including the burden of knowledge, the location of the cutting in a domain of knowledge, and the role of intersections among knowledge domains. Novel ideas are most likely to be created by trained and experience innovators in fields where there is a relatively light burden of knowledge, and an in which an intersection with another knowledge domain can be found.

Introduction

Knowledge building is a process in which new understandings, paradigms, models and other forms of knowledge are produced through communal work in the manner of a research community. Typically, knowledge building proceeds in conjunction with the

Knowledge Forum knowledge building software or other groupware product that allows for online collaboration among group members. A particular strength of knowledge building is that the theory informs the practice, and both have informed the development of software tools to support the process. However, knowledge building is not the only theory about the creation of new knowledge. Variously called innovation or creativity (C. Bereiter, 2002), the process of the creation of new knowledge has in recent years been the focus of considerable research, especially as it applies in organizational settings. It is the purpose of this paper to situate three alternate theories of knowledge creation in the context of knowledge building, and to discuss what is known about the process of creating new knowledge. In particular, it will examine Teresa Amibile's *componential model of creativity* (Amabile, 1996), Nonaka & Takaeuchi's *theory of organizational knowledge creation* (Nonaka & Takeuchi, 1995), and Engeström's *expansive learning cycle* (Hakkarainen, Palonen, Paavola, & Lehtinen, 2004), based on *activity theory*, originally deriving from Vygotsky's theory of mediated thought (Engeström, 2001). Following this, we will examine what is known about the process of stimulating creative ideas, and conclude with a synthesis of the material presented. We will start with an examination of knowledge building.

Knowledge Building

Defining knowledge building, Scardamalia & Bereiter (2003) stated, "[Knowledge building] is productive work that advances the frontiers of knowledge as these are perceived by the community. Learning-–or improving the content of individual minds-

–results as a by-product. An important part of that learning is learning to be a knowledge builder" (p. 6). There are a number of aspects to this definition that need clarification.

Knowledge building is productive work, but does not produce what is conventionally thought of as a product–a material artifact such as a toaster or MP3 player. Instead, the products of knowledge building, and any other creative process, are quite broadly defined but contain common elements such as being novel and unusual; being public in the sense that the new knowledge is externalized so that other members of the community can have access to it and share it; and can take the form of physical products such as models or prototypes, etc., but often can take more abstract intellectual forms such as conceptual models, paradigms, algorithms, concept maps, simulations, or other forms of symbolic intellectual representation. In knowledge building, such external representations are often placed as digital representations in an online environment such as Knowledge Forum.

Knowledge building advances the frontiers of knowledge as perceived by the community. It is not necessary that the knowledge is new to the world at large, but that it be new to the knowledge building community. Communities engaged in solving their own particular problems take and re-shape new knowledge to their own particular ends (Rogers, 1995), and knowledge building communities are no different from other communities trying to solve problems. Thus, the perception by the community of where the frontiers of knowledge are, whether scientific researchers, workers creating a new business plan, or school children, is critical to the knowledge building process because knowledge advances from those frontiers.

The detection of such frontiers is one of the key jobs of persons engaged in knowledge creation, and involves evaluating the *promisingness* of an idea or approach. Bereiter & Scardamalia note that promisingness can be evaluated by asking: (1) does the idea have a direct match to a desired goal; (2) does the idea match the capabilites of the worker; and (3) does the idea point to any further possibilities (1993, p. 137). Thus an idea having no clear match to current goals; for which no one in the organization has the requisite skills; and for which further possibilities are unclear is an idea of low promisingness for that organization.

Finally, learning is a by-product of the knowledge building process (Scardamalia & Bereiter, 2003). Typically, learning has been the focus of schooling, but has often proceeded in the abstract without application to problems that are relevant to the student. As a result, the knowledge learned has often taken the form of easily statable, testable knowledge that is often forgotten almost as quickly as it is learned. Knowledge building, with its focus on new knowledge, forces students to learn and understand deeply what is currently known in order to advance beyond that to forge new understandings, models, etc. Thus, although learning is a by-product of the knowledge building process, it is an essential part of it, and cannot proceed without it.

In practice, knowledge building usually proceeds as follows, although it should be emphasized that this is not a recipe to be followed, but simply a typical pattern:

- The students create or discuss an idea about a problem (usually with a curricular focus);
- The idea is entered in some form into the Knowledge Forum database as an object for contemplation and reflection by all students in the class;

- Through a process of either modifying the artifact (object,) or by building onto the artifact, new knowledge or understandings are created. These are then saved to the database, becoming new objects for contemplation and reflection; and finally
- The process continues recursively with a never-ending flow of new or improved ideas until some constraint (usually time) forces the process to end.

The recursive nature of the knowledge building process should be emphasized here, as there is no definite end to the process. There is always something more to be discovered, and newer models and understandings to be created in a continuous process of innovation. The concept that every idea can be improved is central to the knowledge building process.

The latter concept distinguishes knowledge building from other organizational creativity models. In business settings, in the end, a product, process, report, etc. needs to be produced, effectively ending the knowledge creation process (see Nonaka & Takeuchi, below,) but in schools this need not be so to the same degree. In a knowledge building class, often the only product is the online database itself, which acts both as a summary of the knowledge of the community, and a map of the path by which that knowledge was achieved.

Associated with the knowledge building process are twelve characteristics or knowledge building principles often seen in functioning knowledge building communities. These are:

- *Real ideas, authentic problems*: The ideas and problems worked on by students engaged in knowledge building should be real-world and relevant to them, not invented solely for instructional purposes;

- *Idea diversity*: It is essential to avoid 'groupthink' in knowledge building classes, and to this end a diversity of ideas should be encouraged within the group. Everyone should feel free to express their ideas and receive a fair hearing;
- *Knowledge building discourse*: Either in a live setting or through an online environment, discourse about the ideas expressed is essential to understanding them. It is through this discourse that conflicts among ideas emerge and this acts as a spur to further research and idea modification;
- *Improvable ideas*: Central to the process is the concept that no idea is ever free from improvement, that everything can be improved. Thus every student knows that, although they have expressed an idea, either they or someone else will try to find flaws in it and work on those to improve the idea;
- *Constructive use of authoritative sources*: Students are encouraged to test their ideas against current best knowledge by consulting authoritative sources such as textbooks, encyclopedias, learning materials provided by the teacher and so forth. It should be noted, however, that this is under student direction, so not all students will consult the same sources all of the time. This contributes to idea diversity;
- *Symmetric knowledge advancement*: As all students work on improving their ideas and understandings, the knowledge of the group advances in a symmetric fashion, including that of the teacher;
- *Democratization of knowledge*: In knowledge building communities, it is essential that students feel free to explore their own ideas without explicit direction from the teacher. Thus, the teacher needs to step aside and not direct work in a hierarchical fashion, as this tends to stifle the flow of ideas. As a result, the

functioning of the class and the knowledge produced tends to become democratized, with student ideas being treated as equal to or better than the teacher's ideas or even those of authoritative sources;

- *Epistemic Agency*: Epistemic agency refers to the students taking charge of the course of their own inquiries. Williams (1999) notes this as a characteristic of creative teams and notes that creative teams tend to perform many of the supervisory functions usually relegated to a manager (or in this case, a teacher);
- *Rise above*: Rising above refers to students trying to transcend current models of thought and ideas to create new and original ideas. Often this involves a synthesis of current ideas and information into something new and original;
- *Community knowledge, collective responsibility*: Closely related to symmetric knowledge advancement, community knowledge, collective responsibility makes it the responsibility of all students to improve not only their knowledge but to advance the knowledge of the community by externalizing what they have learned to a public symbolic form available to others;
- *Pervasive knowledge building*: Once the students have firmly grasped the concept that all ideas are improvable, this tends to spill over into all aspects of their lives. Students tend to view everything as potentially improvable; and
- *Embedded and transformative assessment*: In order for the knowledge building process to function properly, the students and teacher need to learn how to monitor and assess their progress, and that of the group. This is done informally when students ask others to contribute more ideas to the Knowledge Forum database, and comment upon them, or more formally when the teacher and

students use the built in assessment tools in Knowledge Forum to assess various aspects of the knowledge building process.

These principles have been encapsulated in a two-tier diagram shown in *Figure 1*. Tier one principles are those that tend to appear at the beginning of a knowledge building inquiry, and tier two ideas tend to appear later on, although in a class of experienced knowledge building students tiers one and two tend to blur together. Tiers one and two feed back into each other during the knowledge building process, with students moving from one to the other continuously. Embedded and transformative assessment is external to the tiers because it acts on both at all times in the knowledge building process, providing feedback into the system in the manner described by Bonabeau for self-organizing systems (Gloor, 2006, p. 20).

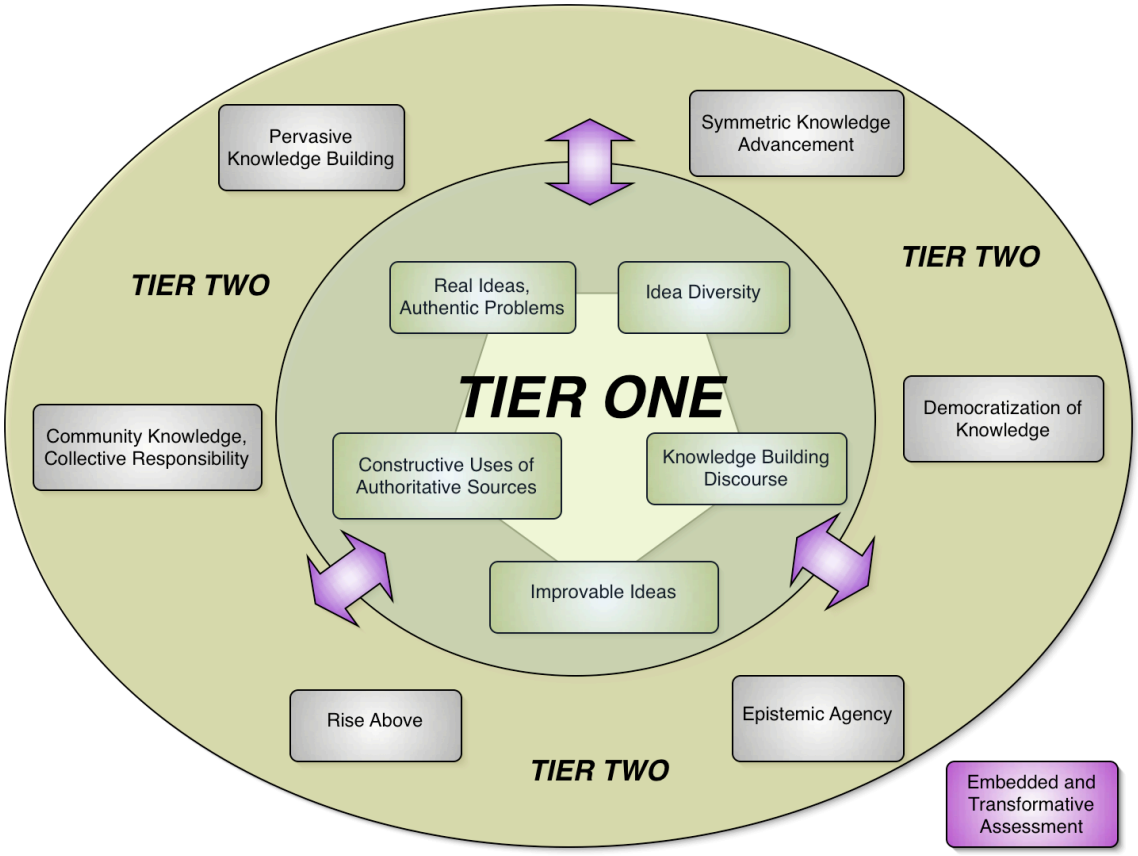

Figure 1. A diagram showing the knowledge building principles arranged in two tiers. Tier one principles tend to occur earlier in the knowledge building process than tier two principles, with assessment occurring at any time in the process. (Image courtesy of Chris Teplovs.)

Componential Model of Creativity

The second model of creativity we will examine is Teresa Amibile's (1996) componential model of creativity. Arising from a long period of research into the nature of creativity, the model is expressed diagrammatically in *Figure 2*.

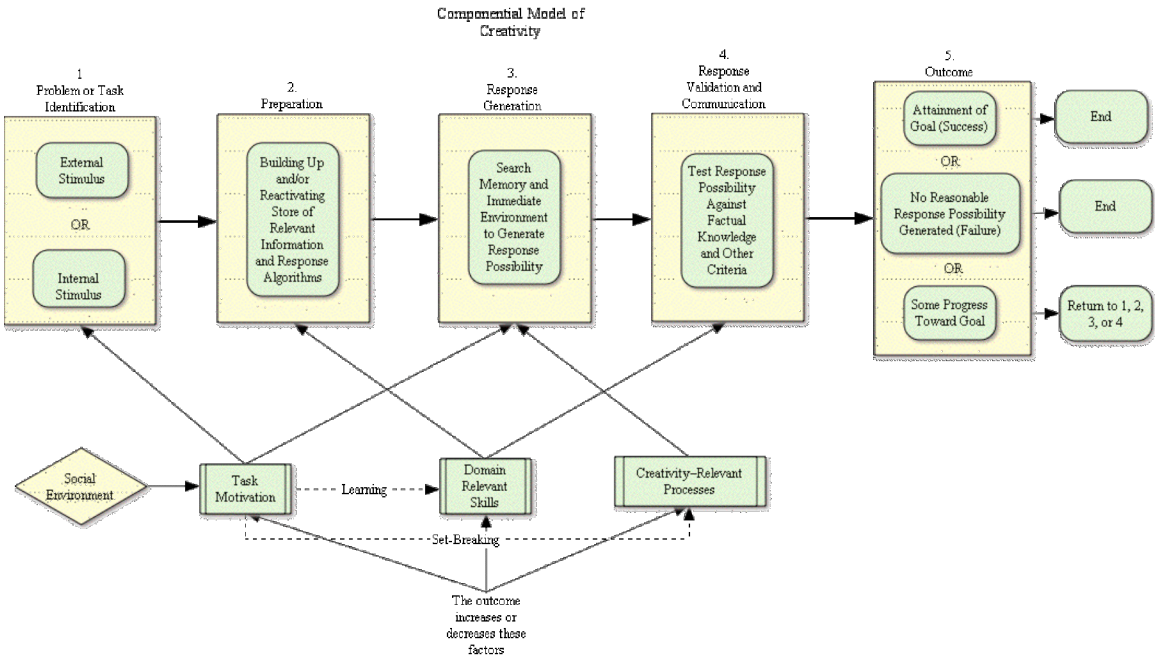

Figure 2. Amibile's componential model of creativity. Although there are five basic stages in the process, the stages also act recursively, returning to steps 1, 2, 3, or 4 if the outcome of the process is not successful.

Amibile's model starts with stage one in which the identification of a problem or task initiates acts as an internal or external stimulus to action. Stage two is a preparatory phase in which the individual or group gathers relevant information about the problem or task. In stage three, the knowledge obtained in stage two is used in conjunction with the local environment to generate some possible responses. It should be noted that the environment can include online systems in which individuals have placed information for the group. During stage four, the various responses that have been generated are tested against factual knowledge, either from authoritative sources, other group members, or external sources of various kinds. Finally, in stage five, there are three possible outcomes: the problem can be solved, in which case no further action need be taken; the problem

can prove intractable, in which case the problem may be abandoned (possibly due to lack of time or resources); or there may be some progress towards the goal, but the group needs to work recursively back to a previous step in order to make progress. It is this latter outcome that is most common in creative processes. The social surround affects task motivation, the presence of domain relevant skills, and of the skills with creativity-relevant process within the group.

Amabile (1996, p. 82) also notes that the creative process is a continuum from low levels of creativity to groundbreaking and significant work (noted also by Buchanan (2002)); that individuals have degrees of creativity within their corpus of work; and that this, "…implies that it is possible for anyone with normal cognitive abilities to produce work that is creative to some degree in some domain of endeavor" (Amabile, 1996, p. 82). Taken together, these three factors are important because some critics of knowledge building theory insist that school-aged children cannot be innovative, but this would appear to fly in the face of the evidence.

Although Amabile notes that innate talent plays a role in creativity, she further notes that (p. 82), "[F]ormal education seems essential in most outstanding creative achievements (Feldman, 1980)". This stresses the importance of stage two in the componential model, and the importance of the use of authoritative sources in knowledge building. Amabile (1996) also comments on the importance of intellectual playfulness and the freedom from external constraints such as artificial deadlines (p. 83). In knowledge building terms, students have to be free to play with and transform their ideas without too much external interference if they are to be creative. As well, Amabile stresses the importance of the appropriate cognitive style, idea generation strategies, and

work style, all of which are the product of training in idea generation, experience in idea generation (both of which are under the control of the teacher,) and personality characteristics (which is not.) Carl Bereiter (2002, p. 361) echoes the importance of training in creativity when he notes that, "If an educational goal is to equip students for thinking in adult life, then discourse in school ought progressively to approximate the discourse adults engage in when they are seriously trying to understand something, to reach a decision, to solve a problem, or to produce a design", which would include appropriate cognitive styles, ideas generation strategies, and work strategies.

The Theory of Organizational Knowledge Creation

Many businesses, due to competitive pressure from developing countries such as China and India (Uhalde, Strohl, & Simkins, 2006) and offshoring (Friedman, 2005; Roberts, 2006) are finding that they have to structure their method of working towards continuous innovation.

Against this background, Nonaka and Takeuchi (1995) have created their theory of organizational learning as it applies to business settings. *Figure 3* shows their theory diagrammatically:

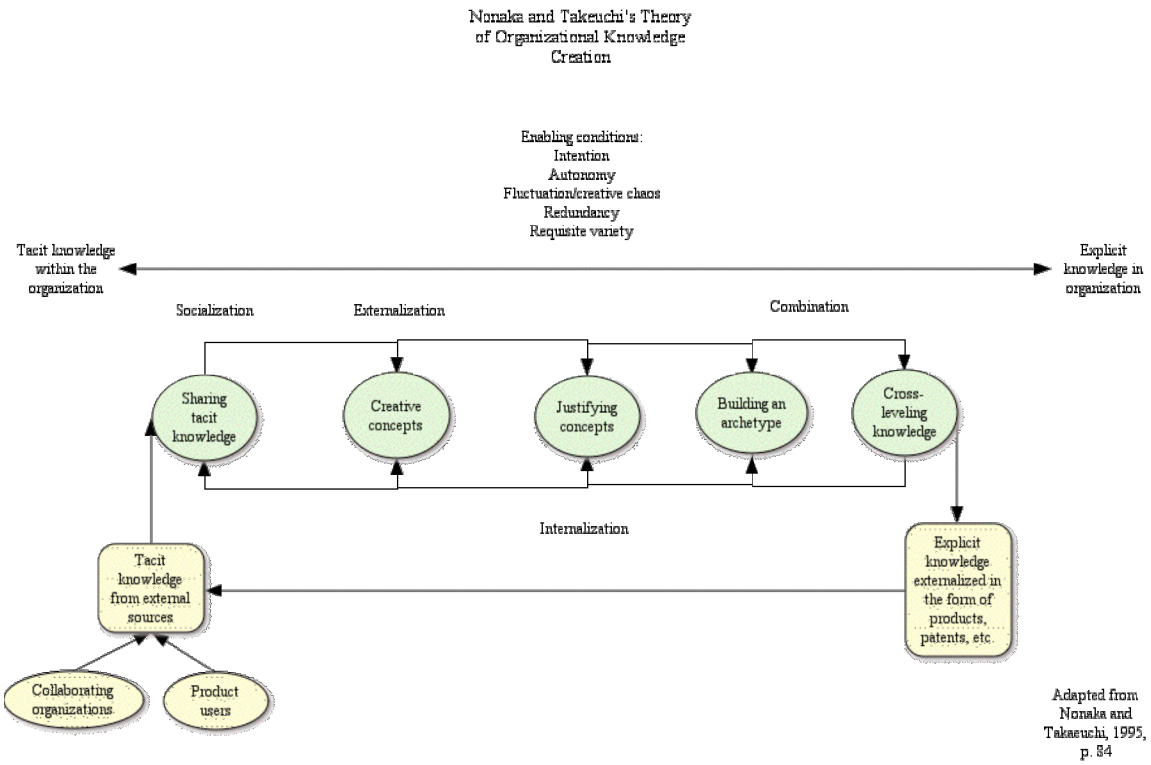

Figure 3. Nonaka and Takeuchi's organizational learning theory. Note their emphasis on the externalization of tacit knowledge and the recursive nature of the process.

Nonaka and Takaeuchi's (1995) theory, like Amabile's, has five stages. However, having assumed a business setting, it is presumed that the problem has already been identified, and given to a work group (often similar in size to a school class.) Their model identifies a continuum from tacit knowledge within the organization to explicit knowledge after a creative process. The explicit knowledge is then fed back into the system recursively and the process repeated as necessary.

The term *tacit knowledge* requires some clarification. Tacit knowledge is the result of the internalization of *complex knowledge*. It is knowledge expressed in an agent's actions and is difficult or impossible to articulate in words. Playing a musical instrument is a good example of tacit knowledge. A person may know everything that can be

articulated *about* playing the violin, but may not know *how* to play it. van Merriënboer and Sweller (2005) note that complex knowledge is composed of large numbers highly interactive elements that have not yet been assimilated into schemata in long-term memory. The large number of elements puts a strain on working memory, therefore causing an increased cognitive load. Once assimilated into schemata in long-term memory (becoming tacit knowledge,) the strain on working memory is reduced. These interactive elements may include words, images, or, as in the case of playing an instrument, muscular actions that all need to be integrated into fluid action in real time. In contrast to tacit knowledge, explicit knowledge is easily stated and is closer to information than knowledge.

With that in mind, we can look more closely at the stages and see that tacit knowledge comes from multiple sources–product users, collaborating organizations as well as from inside the company–and feeds into the innovation system through a process of socialization in which tacit knowledge is shared. In the process of generating creative concepts, the externalization of tacit knowledge occurs, usually in the form of reports, prototypes, models, etc.

The stage in which concepts are justified is similar to Amabile's (1996) response validation stage. The building of an archetype refers to a formal conceptualization of the proposed solution, in the form of reconstructions of existing perspectives, frameworks, or premises (Nonaka & Takeuchi, 1995, p. 46).

Finally, the cross-leveling of knowledge is the process in which externalized knowledge feeds back into the system and becomes tacit knowledge among company members and others. This process of internalization of the explicit knowledge also feeds

back recursively into all stages of the innovation process, implying, although not explicitly stated, that there may be multiple iterations of the process.

Nonaka and Takeuchi (1995) also note the importance of a nurturing environment in creativity. They state that experimentation should be encouraged and mistakes not punished if creativity is to become the norm. As well, they support the idea that creativity can be formally trained.

The Expansive Learning Cycle

Yrjö Engeström, a Finnish researcher, through studies of innovation in organizational settings has come up with a different model of the knowledge creation process. His work is grounded in *activity theory* in which an individual is viewed as being situated in a complex activity system involving the individual, mediating artifacts, their community, the way labour is divided within that community, the community rules, and externalized mental objects that interact with the entire activity system and those of other individuals. More details about this can be found in Engeström's writings about activity theory (Engeström, 2001). From this work, he has created an *expansive learning model*, shown in Figure 4.

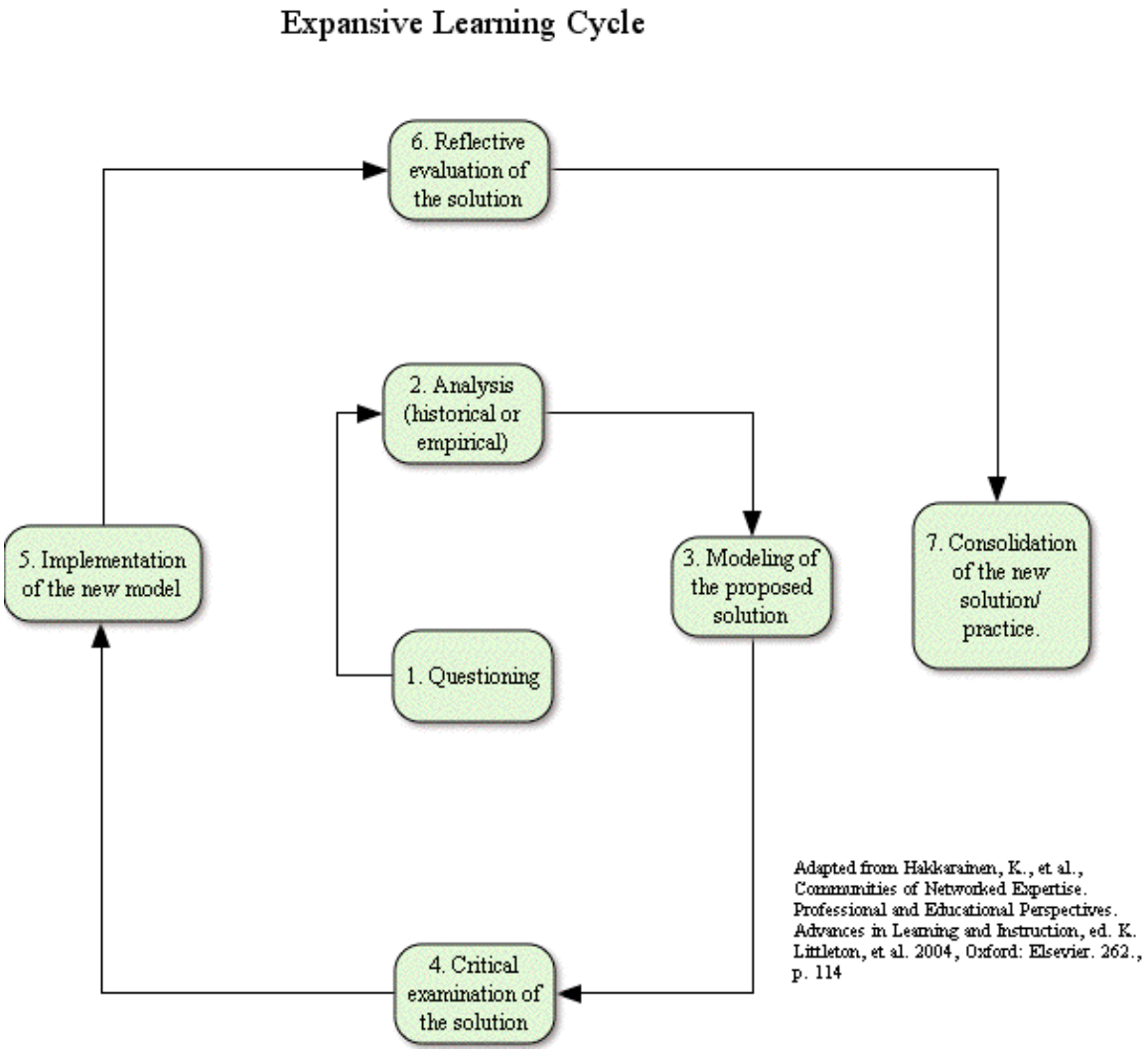

Figure 4. Engestöm's expansive learning cycle.

Although Engeström has worked extensively with businesses, he also has research roots in educational research and education for innovation. His model has seven stages, envisioned as cyclic:

1. Questioning, in which accepted practices or knowledge are questioned by an individual;
2. Analysis of the problem identified in the questioning stage;
3. Modeling of the proposed solution;

4. Critical examination of the solution;
5. Implementation of the new model;
6. Reflective evaluation of the proposed solution; and
7. Consolidation of the new solution into some form of practice.

Although the process begins within the activity system of an individual, his model is social in its essence, as the activity system of individuals are always embedded in a social context. In simpler terms, he envisions the process as happening in learning communities or teams. Therefore by stage two, there is room for the activities of other members of the learning community, and the process would involve other team members from there on, creating a group activity system focused on solving the problem.

Engeström does not envision this process as having a fixed order, despite the numbering of the stages. Instead, it is viewed as an ideal version of what might happen (Hakkarainen et al., 2004, p. 115). Reality may differ, and the process can start at any point in the cycle. This is similar to knowledge building theory, for which no set of stages have been put forward, because of the fear that the stages would be viewed as a rigid set of steps that must be followed in order.

Commonalities Among the Theories

We have looked at four theories of new knowledge creation: knowledge building theory, the componential model of creativity, the theory of organizational learning, and activity theory.*Table 1* shows a comparison among the four models of knowledge creation that have been examined.

Table 1.

Table 1 compares the four models of innovation on five dimensions: the source of the problem, preliminary activities, the process by which innovative ideas are generated, the validation of those ideas, and the endpoint of the process.

	Componential Model	**Organizational Learning Theory**	**Expansive Learning Cycle**	**Knowledge Building**
Problem Source	Internal or External Stimulus	External from some source usually higher in the hierarchy	Questioning (internal)	Real idea/authentic problem. In practice, this is often based on a curricular objective (external), but students generate ideas as well (internal)
Preliminary activities	Build up or reactivate relevant information	Activation of tacit knowledge from a variety of sources	Analysis (historical or empirical)	Use of authoritative sources, ideas of other students, notes in an online learning environment
Innovation process	Search memory and environment to generate creative ideas	Externalization of tacit knowledge among the group	Modeling of the proposed solution	Synthesis of ideas; 'rising above'.
Validation	Creative ideas are tested against factual knowledge, etc.	Justify concepts; build an archetype	Critical examination of the proposed solution.	Other students comment upon, modify idea in an ongoing process
Endpoint	Success or an impasse creates an endpoint; limited progress causes a return to some stage in the process	Cross-leveling knowledge and further externalization of explicit knowledge. This leads to internalization of knowledge that then feeds back into the tacit knowledge store	Implementation and reflective evaluation of the proposed solution.	There is no real endpoint–ideas are continuously improved as long as possible

Depending on the setting in which innovation is to occur, the source of the problem can be internal (such as the innate drive to understand proposed by activity theory,) or external, such as the problems assigned to work teams in business settings.

The componential model acknowledges both, and knowledge building finds both in practice, although prefers to use student ideas (an internal source) as a starting point. In two cases, knowledge building and organizational learning theory, the problems are always authentic and real world.

Knowledge building notes the role of mediational artifacts in building up a store of requisite knowledge, as does the expansive learning cycle through its activity theory roots, and this is implied in the componential model. In the case of knowledge building, this is through authoritative sources and other students (often via notes in the online learning environment.) In the case of the expansive learning cycle/activity theory, it is through any form of tool (cognitive or physical,) interactions with others, etc. Organizational learning theory does not discuss explicit knowledge too much, preferring to focus on the problem of externalizing tacit knowledge. It should be noted that organizational learning theory assumes that the persons assigned to a work group have a store of relevant explicit knowledge available to them. Finally, the componential model discusses building up a store of relevant information, but is not specific as to how. It would be safe to assume some form of mediating artifacts (such as books) would be used.

In terms of generating innovative ideas, the componential model notes the role of memory and the environment. Since the environment would include people, artifacts, etc. this is similar to activity theory–inevitably there would be an overlap among these that would produce ideas. Organizational learning theory emphasizes the externalization of tacit knowledge among group members. This is similar to the knowledge building concept of symmetric knowledge advancement. The expansive learning cycle emphasizes the role of analyses. Finally knowledge building finds new ideas arising from the

synthesis of old ideas, creating new understandings that rise above (are at a higher conceptual level than) previous ideas.

In terms of validation, the componential model notes that ideas should be validated against factual knowledge. Organizational learning theory and activity theory note the creation of some form of artifact or tool. The expansive learning cycle promotes critical examination of the proposed model. Knowledge building notes the role of other persons in the knowledge building community in testing and commenting upon new ideas.

Lastly, the expansive learning cycle posits reflective evaluation as the final stage, but, as noted above, Engeström is careful to note that this is not restrictive and represents an ideal, rather than actual practice (Hakkarainen et al., 2004). The componential model states two: one resulting from success, and one from failure. Limited success results in a return to some previous stage of the process, feeding the new knowledge back into the system. Organizational learning theory notes that the externalized knowledge becomes tacit knowledge, and that this can feed back into the process at any point. Knowledge building notes the recursive nature of the innovation process, and that the process could theoretically continue indefinitely.

Differences Among the Theories of Knowledge Creation

One striking aspect of the comparison of the theories of creativity is that they aren't more similar. The source of the initial problem differs to a great degree among the theories, ranging from internal stimuli in the case of the componential model, to an external

hierarchy in the case of organizational learning theory (business superiors) and knowledge building (school curricula), to a process of questioning in the case of of the expansive learning cycle.

While the preliminary activities are very similar, often re-statements of the same kind of process of consulting authoritative sources or knowledgeable others, the process during which new creative ideas are generated is somewhat vague in all cases. This is a case where the role of the individual versus others is unclear. In organizational learning theory, the group is emphasized, with creativity arising from the externalizing of tacit knowledge within a group setting. The componential model emphasizes the searching of memory and the environment, but is not clear on whether this is an individual or group process. Proponents of collective intelligence (Smith (1994); Lévy (1998)) would argue that groups can be involved, but many would disagree and focus on the individual's role in the process. The knowledge building idea of synthesis of ideas, implying that one individual or group puts together the ideas of other individuals or groups is perhaps the clearest here.

Finally, the very great differences in all of the stages envisioned by the different theories imply that the process is not as clearly understood as we would wish. Certainly, there would appear to be quite different emphases in each theory that need to be resolved.

Conditions for the Generation of Creative Ideas

Additional to the process of creativity *per se*, there has been considerable work done on the conditions needed for the generation of creative ideas.

Jones (2005) notes a concept he calls the *burden of knowledge*. Shown in *Figure 5*, the burden of knowledge is the distance from the common core of public knowledge to the cutting edge of some specialized knowledge domain (physics being an example.) Because of the time and effort required to be able to understand the cutting edge of such a domain, innovation is not possible in some cases for many years. Jones has found that the age of first innovation has been increasing; the average creative team size has been increasing (17 percent per decade); specialization in increasingly narrow fields is increasing (6 percent per decade); and there is a drop in patent production per worker (Jones, 2005).

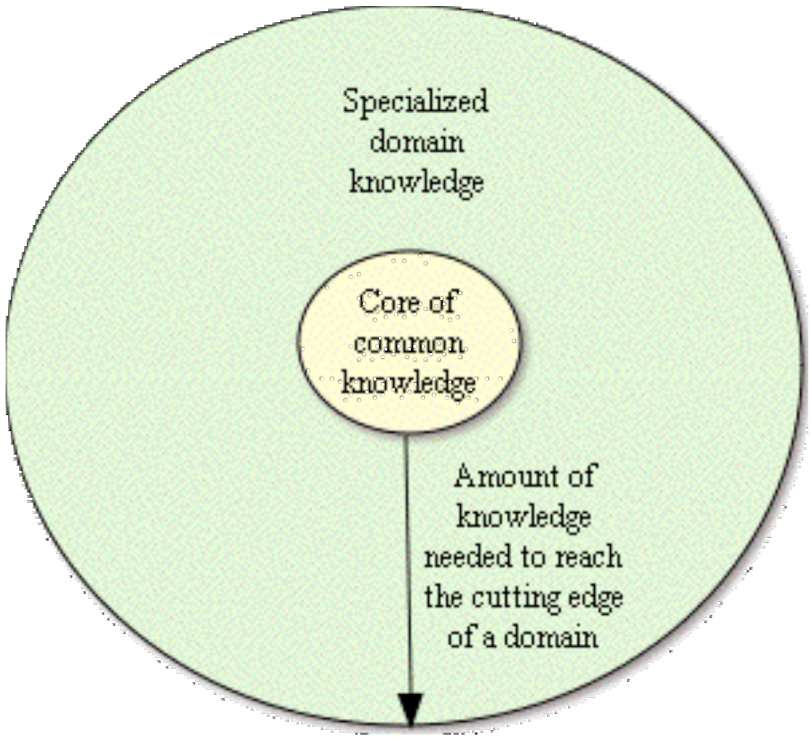

Figure 5. The burden of knowledge. This distance from the core of common knowledge to the cutting edge of many knowledge domains is daunting, and takes many years to master. Hence creativity in those domains is difficult.

However, (and this is where the author disagrees with Jones,) this is not quite what really happens in a domain. *Figure 6* shows something more like the actual case. Knowledge domains are not entirely uniform in the amount of knowledge it takes to reach the cutting edge. Again using physics as an example, it certainly does take a very long time to master the domain in something like particle physics. But in recent years, complexity theory has come to the fore in physics. Those who studied it early had a much, much smaller distance from the core to the cutting edge of knowledge and innovation happened very quickly. Therefore, innovation will tend to happen more quickly in the valleys of knowledge domains, and more slowly in the peaks.

The earlier discussion of the promingness of an idea has relevance here. Individuals wishing to make a contribution to a domain may need to look at point (2): does the worker have the requisite skills. If these will take many years to develop, then there may be other more promising directions to take.

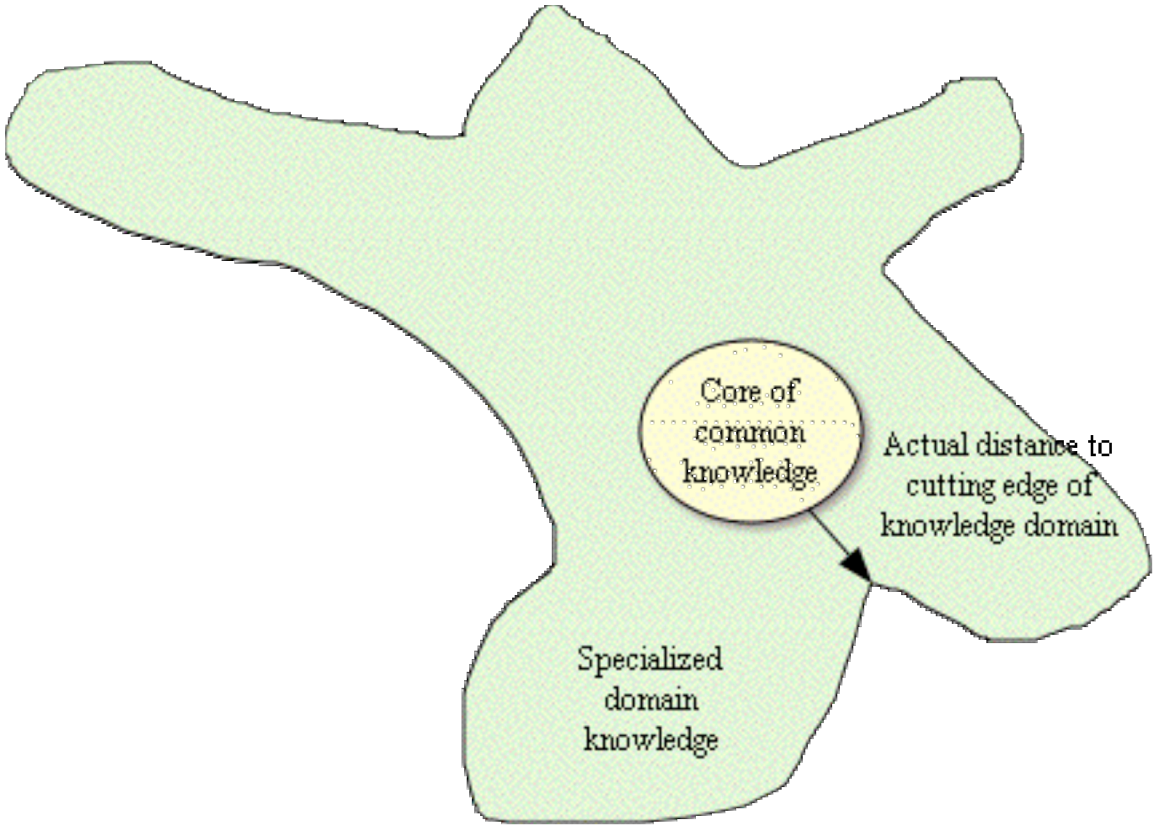

Figure 6. The burden of knowledge is not uniform across domains. There are places where knowledge is shallower than others, and therefore less time is needed to master those sub-domains, allowing for innovation to happen more quickly.

Amabile (1996) noted the importance of creativity-relevant skills: cognitive style, knowledge of heuristics for generating novel ideas, and a conducive work style. These are products of training, experience, and personality. Therefore, students need to have both training and experience in generating novel ideas if they are to produce important novel ideas later on. Innovative ideas will be produced more easily and quickly if the experience and training in innovation are provided.

Finally, Johansson (2006) notes the importance of what he terms intersectional ideas, created most often by the intersection of two different fields of expertise. He identifies three forces that can create such intersections:

1. The movement of people creating cross-cultural intersections;
2. The convergence of science creating intersections among different areas of science; and
3. The leap in computational power creating new possibilities.

He states, "Because the effect of these three forces are so pervasive, your understanding of a field is likely to become intersected many times during your lifetime. The individuals or teams who find these intersections are likely to be the ones who radically change our world" (p. 32).

Juxtaposing the burden of knowledge concept with the intersectional idea concept gives the following: peak-to-peak intersections will be the most difficult and slow to produce innovations; peak-to-valley will be less difficult and slow; and valley-to-valley intersections will produce innovations the most easily and quickly.

Thus, innovative ideas are most likely to be generated by students who have been trained and prepared for innovation, in areas where the burden of knowledge is not too great for them, and in fields where intersectional ideas are possible, happening most easily with valley-to-valley intersections.

Summary

This paper has examined four theories of knowledge creation: knowledge building theory, the componential model of creativity, organizational learning theory, and the

expansive learning cycle. Commonalities among these theories included the importance of building up a store of requisite knowledge, of interactions with mediational artifacts and other people, of validating the newly created knowledge, of externalizing tacit knowledge, and of allowing for recursiveness in the process. Although implied by organization learning theory and the componential theory, and only explicitly stated by knowledge building theory, the nature of the problem (real and authentic) is important to motivation among the innovators.

The conditions under which novel ideas are more likely to be generated include the presence of trained and prepared (experienced) innovators, a light burden of knowledge in the domain(s), and the nature of the intersection among fields of knowledge.

Although the different models of knowledge creation vary depending on the base assumptions and circumstances in which the innovators find themselves, they have strong similarities. Knowledge building contains the key elements (externalizing of tacit knowledge, the use of mediational artifacts, building up a store of knowledge, and allowing for recursive work with ideas) that characterize other knowledge creation models. As well, it fulfills the condition of training and preparing students to be innovators. The burden of knowledge in a domain and the nature of the intersection would be under the control of the teacher in most educational settings.

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