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RESEARCH ARTICLE

Towards an idea-centered, principle-based design approach to support learning as knowledge creation

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Abstract While the importance of viewing learning as knowledge creation is gradually recognized (Paavola et al. Computer-supported collaborative learning: foundations for a CSCL community 2002; Rev Educ Res 74:557–576 2004), an important question remains to be answered—what represents an effective instructional design to support collaborative creative learning? This paper argues for the need to move away from efficiency-oriented instructional design to innovation-oriented instructional design if learning as knowledge creation is to be pursued as an important instructional goal. The rationale in support of this argument is discussed from four different theoretical perspectives and an idea-centered, principle-based design approach as an example is proposed for discussion.

Keywords Knowledge building · Knowledge creation · Principle-based design · Idea-centered design · Idea improvement · Community knowledge · Instructional design

In her work, Sfard (1998) distinguishes two metaphors of learning, which are learning as acquisition and learning as participation. Building on this work, Paavola et al. (2002, 2004) suggest a third metaphor—learning as knowledge creation. They identify Bereiter and Scardamalia's (Bereiter 2002; Scardamalia and Bereiter 2006) knowledge building theory, Nonaka and Takeuchi's (1995) knowledge-creating theory, and Engestrom's (1999) expansive learning theory as three prominent models in support of the knowledge creating community conceptualization. While the argument for "learning as knowledge creation" as a new pedagogical approach to schooling and education is well justified in their articles, an important issue remains to be explored—what represents an effective instructional design to support learning as knowledge creation?

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The purpose of this paper is to discuss two general types of instructional design approaches—efficiency-oriented and innovation-oriented. It is posited that if learning as knowledge creation is to be pursued as a new pedagogical approach, instructional design will need to move away from an efficiency-oriented to a more innovation-oriented approach. We discuss some design differences between the three learning metaphors in relation to these two types of instructional approaches from four theoretical perspectives to support this argument, and then propose an idea-centered, principle-based design approach as an example to support learning as knowledge creation.[1] Table 1 outlines these key design differences as a basis for the following discussion.

Theoretical perspectives

Pedagogical underpinnings

Of the three learning metaphors, learning as acquisition represents a traditional view according to which learning is "mainly a process of acquiring desired pieces of knowledge" (Paavola et al. 2002, p. 24). It highlights a psychological concept of knowledge (cf. Hyman 1999) and sees knowledge as possessed within an individual's mind-as-a-container (cf. Popper 1972). Learning as participation suggests learning is a process of participating in various cultural practices and shared learning activities (e.g., Brown et al. 1989; Lave and Wenger 1991). In this view, activities are regarded as the center of learning and knowledge is seen as distributed over both individuals and their environments (Hutchins 1995). In other words, the focus of learning is on activities ("knowing") more than on outcomes ("knowledge"). The creation metaphor, however, emphasizes the innovative process of inquiry where "something new is created and the initial knowledge is either substantially enriched or significantly transformed during the process" (Paavola et al. 2002, p. 24).

Consistent with the view of learning as acquisition, a conventionally held belief in education has been to learn first (e.g., through K-12 schooling), and to innovate later (e.g., during graduate study). Under this view, "efficiency" in maximizing an individual's personal knowledge becomes an important criterion in judging whether instruction is effective. To this end, early instructional design models have strongly emphasized the importance of employing well-defined procedures, clear scripts and rules, and componential tasks (e.g., see Reigeluth 1999) in order to help students master certain pre-specified knowledge/skills. Such instructional design examples include task-driven instructional design models (Dick and Cary 1990), Criterion Referenced Instruction (Mager 1975), Principles of Instructional Design (Gagne et al. 1992), and Component Display Theory (Merrill 1983). Growth of individual knowledge is usually the chief goal. Although "innovation" may still be considered important under the learning-as-acquisition view, for most conventional instructional designs, it is clearly not their primary design focus.

[1] Throughout this article, knowledge creation is conceptualized not so much from an outcome perspective but from a process perspective. As argued by Amabile (1983), if learners are not following a well-known path to solution, but instead are attempting to create the path to the solution, they are engaged in a creative process. As such, it does not really matter whether the knowledge created is genuinely new to a discipline (e.g. a new scientific theory) or only new to the learners' immediate community (see also Beghetto and Kaufman 2007); the learners are still engaging in knowledge creation.

Table 1 Some design differences between the three learning metaphors

	Learning as acquisition	Learning as participation	Learning as knowledge creation
Pedagogical underpinnings	Enhancing efficiency in knowledge appropriation as a primary instructional design goal	Facilitating participation and distributed knowing as a primary instructional design goal	Promoting knowledge innovation or creation as a primary instructional design goal
	To learn in order to, potentially, innovate	To learn through participation	To innovate is to learn
Psychological underpinnings	Placing more emphasis on automatic process (as ends) than controlled process (as means)	Placing more emphasis on controlled process (as ends) than automatic process (as means)	Both controlled and automatic processes integrally regarded as means to progressive problem solving and finding/defining; there is no end to this process
Epistemological underpinnings	Towards more routine know-how and pre-defined know-that	Towards more adaptive know-how with still largely pre-defined know-that	Towards adaptive know-how and emergent know-that
	Pursuit of knowledge of promisingness not emphasized	Pursuit of knowledge of promisingness less emphasized	Pursuit of knowledge of promisingness highly supported
	Pre-determined curriculum (with clear instructional procedures)	Pre-determined curriculum (with more flexible learning process/activity)	Progressive curriculum necessary
Socio-cultural underpinnings	Community usually not emphasized	Community of learners	Knowledge-creating community
	Social activity not necessarily emphasized	Structured social activity (e.g., division of labor; scripted cooperation, reciprocal teaching, group-based collaboration)	Emergent, opportunistically structured activity
	Knowledge appropriating culture	Knowledge exchanging and collaborating culture	Knowledge innovating and creating culture
	Construction of individual knowledge highly valued; community knowledge advancement not emphasized	Social participation as means to support distributed knowing and individual knowledge growth; community knowledge advances not necessarily valued	Sustained community knowledge advancement and individual knowledge growth are both valued

Moving away from cognitive reductionism and overemphasizing mental "efficiency," instructional designs based on the view of learning-as-participation have been shifting the design focus to activity and collaboration, for example, problem-based, project-based, and inquiry-based instructional activities (see Barron et al. 1998; Edelson et al. 1999; Hmelo-Silver 2004; Krajcik and Blumenfeld 2006). Although procedures and routines are still an unavoidable part of instructional design, the primary design interest is clearly in meaningful constructivist activities to support situated learning and knowing. The design of such activities and practices are often characterized as student-centered (e.g., self directed learning, Hmelo-Silver 2004), situated (e.g., cognitive apprenticeship, Brown et al. 1989), and culturally relevant (e.g., Lee 2001). Despite success in facilitating knowing through participation, most instructional designs based on this view still fall short of seeing knowledge as a collective social product and designing activities accordingly to promote knowledge "innovation." This can be seen in the tendency of many of these approaches to formulize learning as a set of procedures that a group of students can follow. For example, in the problem-based learning approach students move through a clearly defined cycle of activity as follows: (1) identify the facts of a problem scenario; (2) generate hypotheses about the problem solution; (3) identify what knowledge needs to be gained in order to solve the problem; (4) apply the newly gained knowledge to solve the problem; and (5) abstract the knowledge gained from the entire cycle of problem solution through reflection (Hmelo-Silver 2004; see also White et al. 2000).

Arguably, in a knowledge creating community, the knowledge goal is not merely to achieve individual knowledge growth or to promote distributed knowing, but to collectively advance community knowledge as a public product (Bereiter 2002). Of the three knowledge-creating theories referenced above, a commonality among them is their emphasis on pursuing sustained knowledge advancement through collective effort. Under the learning-as-knowledge-creation view, the function of a knowledge creating community is very much like that of a research organization or a science community (Latour and Woolgar 1986; Merton 1973) where sustained collective public knowledge advancement is treated as the primary knowledge goal while personal learning and individual knowledge growth become a natural byproduct of such endeavors (Bereiter 2002). Doing so, however, requires a rethinking of the nature of designed instructional activities. We argue that rather than pre-defined activity structures (e.g., clear division of labor, fixed-group activity, and the following of a set of procedures), more emergent, self-organizing activity structures (Barab et al. 1999) are necessary in order to engender learning as knowledge creation. We provide more reasons below.

Psychological underpinnings

In a review, Brown et al. (1983) describe a classic view of a two-process approach to thinking. One is an automatic process (often referred to as automaticity), which represents a fast, parallel process of mental activity, requiring less subject effort. Such a process is commonly associated with cognitive mechanisms such as chunking (Miller 1956), schemas (Anderson 2000) and scripts (Schank and Abelson 1977). The other is a controlled process, which is a comparatively slow, serial process that requires a large degree of subject control. While they are both indispensable mental mechanisms, the roles played by these two thinking processes are very different for efficiency and innovation as knowledge goals.

When efficiency is regarded as a primary knowledge goal, facilitating the development of automaticity becomes more essential as an end in and of itself. Towards this end, a controlled process needs to serve as a means to fostering automaticity. For example, in learning to drive (or to cook), effortful thinking in order to integrate necessary knowledge and know-how of driving or cooking must function as a means to gradually accomplish the automatization of driving (or cooking). Once a learning goal of being efficient is achieved to form certain automatic procedures, controlled processes become less essential as a means of accomplishing the goal. Apparently, well-defined procedures (such as those described in a manual for driving or a recipe for cooking), and/or authentic activities/practices (such as craft apprenticeship), can help with such mental practice; and with considerable cognitive and/or socio-culturally embedded practice it is possible for people to become adept at performing certain routines (e.g., driving or cooking) with great efficiency (Hatano and Inagaki 1986). Hence, both component-based and activity-based instructional designs are useful in developing automaticity or routine expertise in a given domain.

However, when innovation is prized as a primary knowledge goal, facilitating the development of a controlled process in service of innovative thinking becomes more essential as an end in itself. To accomplish this, any previously acquired automatic processes must be re-invested as a means to serving a higher goal of knowledge advancement. Doing so not only sustains knowledge creation but also helps with the gradual attainment of adaptiveness, that is, being more effective in activating and utilizing the controlled thinking process. As a related example, for professional drivers (or cooks), achieving routine efficiency in driving (or cooking), that is, automaticity, is not an end of itself. The goal is to achieve a higher-level of adaptive capacity, that is, to be able to drive (or to cook) adaptively regardless of any kind of road conditions (or cooking conditions), or in other words, to be able to problem-solve creatively across different contexts (Hatano and Inagaki 1993).

As another example, in formal schooling automaticity in reading is an important capability and one that we want all people to achieve. However, to be a great reader, one must still be adept at exerting controlled processes. To really be able to read well and understand what is being said in various texts, one must know and think about other texts in relation to the text one is reading. So, there is an effort in reading at a higher level, while the basic skill is automatic, the deeper skill is not. Also, in formal science learning, automaticity implies being able to apply known, fixed solutions or equations to solving well-structured textbook problems. But to be adaptive would imply being able to work more innovatively with knowledge in order to define and solve more ill-structured problems. To do so, however, requires a metacognitive habit of mind (Black and Wiliam 1998; Zessoules and Gardner 1991) and a progressive problem-solving approach (Bereiter and Scardamalia 1993); that is, to persistently subject oneself to a controlled thinking process for tackling gradually more difficult problems in order to advance one's expertise (rather than reducing problems to previously learned, familiar routines), and more importantly, for going beyond creative problem solving to a mode of sustained problem finding or defining. We argue that in order to achieve higher-levels of adaptiveness, a more flexible instructional design framework that can go beyond scripted procedures and ritualistic mental activities, and allow more emergent and self-organizing activities to occur is required.

Some may argue that novices are not capable of authentic problem solving, or that routine expertise must be developed first, before adaptive expertise may be developed. In our view, the relationship of routine to adaptive expertise is less of a sequential progression, than the establishment of habits of mind which predispose one to adaptive approaches to novel problems. Researchers have postulated that such habits of mind may be fostered through the design of learning technology (Lin et al. 1999) and/or specifically designed pedagogical approaches (Schwartz et al. 1999). Indeed, recent research indicates that the twin dimensions of adaptive expertise, knowledge and innovation (see Schwartz et al. 2005), may be simultaneously fostered in students with very little background in a given discipline when specific pedagogical approaches aimed at developing adaptive expertise are utilized (Martin et al. 2007).

Epistemological underpinnings

The two types of knowledge most frequently discussed are know-that and know-how (Ryle 1949). In various terms, they are also referred to as learning and use (Brown et al. 1989), replicative and applicative knowledge (Broudy 1977), or declarative and procedural knowledge (Anderson 2000). An example of know-that may be learning the multiplication table, number facts, or chemistry formulae and that of know-how may be using the multiplication table to answer a math question or using the chemistry formulae to solve a scientific problem. There is, however, a third type of knowledge, which all too often is neglected in formal schooling. This type of knowledge may be called knowledge of "promisingness." It is a specific type of "tacit knowledge" (Polanyi 1967; Nonaka 1994), i.e., knowledge that people carry in their minds, which can be valuable to others in a community once shared or codified. Such knowledge of promisingness is found to be especially important as a resource of creative expertise (Bereiter and Scardamalia 1993). For example, after continuously solving many problems in their area of expertise, experts are found to possess a stronger sense of what is promising (or problematic) as a solution to a problem, and/or of how to improve, refine, or re-design that solution in order to better solve that problem.

There are important relationships between the above three types of knowledge. According to Hatano and Inagaki (1986) know-how can be categorized into two subcategories. One is routine know-how and another is adaptive know-how. An example of routine know-how is being able to solve a science problem by applying a set of well-specified, textbook-defined procedures. In contrast, an example of adaptive know-how may be solving the same science problem by trying to design a better solution and keep improving, refining, or re-designing it. In correspondence with these two types of know-how, the role of know-that can be very different. When routine know-how is pursued as an important knowledge goal, know-that is more likely to be specifiable content knowledge that can be used to fulfill the routine know-how. As such, know-that and know-how are both ends of learning, and typically in many school settings they are reified as textbook knowledge guided by a well-structured and circumscribed curriculum. Normally, when curriculum is structured in this way (with routine know-how and specifiable know-that), little room is left for students to develop the third kind of knowledge of "promisingness."

On the other hand, when adaptive know-how is the primary knowledge goal, know-that becomes less likely to be specifiable. As such, know-that and know-how become emergent knowledge and their content can only be gradually defined in a developing course of knowledge building. Arguably, knowledge practice, as such, would give more opportunities for students to develop the kind of knowledge of "promisingness" that is important for knowledge creation. Correspondingly, the kind of curriculum required would be a progressive one (Caswell and Bielaczyc 2002) that would be allowed to unfold and emerge as inquiry progresses, so as to foster the development of such knowledge of "promisingness." Thus, while it is important to refer to curriculum guidelines when designing instruction, it will be equally important to allow more design flexibility so that instructional activities can be more adaptive and can go beyond curricular and disciplinary boundaries. If knowledge creation is to be pursued as an essential instructional goal, design flexibility is needed to foster the kind of knowledge of "promisingness."

Socio-cultural underpinnings

Where the emphasis of instructional design is placed on knowledge acquisition and distribution rather than on knowledge innovation in a community, a culture that facilitates efficiency in mastery of a corpus of knowledge predefined in the curriculum becomes essential. To initiate members into such a culture, it is necessary to create a well-organized community that favors effective division of labor and well-structured group activities in facilitating such a process. An example of collaborative learning through repetitive activity structures in the classroom is the jigsaw method (Aronson and Patnoe 1997). As the authors note in their book, “The Jigsaw Classroom:”

> Every member of every group was responsible for learning all the curriculum material, but individual students had direct access to only their part of the material—the part they were to teach others. Since they had to depend on groupmates for access to the rest of the materials, it became essential for all groupmates to do a good job of communicating their parts of the material…In essence, the students in each group were putting their knowledge together a piece at a time, each student contributing a piece of the jigsaw puzzle of material. (p. 91)

Brown et al. (1993) also highlight the importance of repetitive activity structure:

> The repetitive, indeed, ritualistic nature of these activities is an essential aspect of the classroom, for it enables the children to make the transition from one participant structure (Erickson and Schultz 1977) to another quickly and effortlessly. As soon as students recognize a participant structure, they understand the role expected of them. Thus, although there is room for individual agendas and discovery in these classrooms, they are highly structured to permit students and teachers to navigate between repetitive activities as effortlessly as possible. (pp. 200–201)

The chances are the more defined a community’s division of labor, the more likely a community will be aligned with an efficiency-oriented instructional design and be able to achieve an overarching goal of knowledge acquisition and distribution. Arguably, this typifies a learning community (Brown 1997) and the kind of culture valued in such community is a culture of knowledge sharing and construction based on a pre-defined curriculum. Although innovation may still be held with high value within such a community, the focus of innovation is likely to be on the process of how to best achieve knowledge acquisition and distributed knowing (e.g., learning how to learn individually or collaboratively), but not necessarily community knowledge advancement. For example, in a discussion of the anchored instruction design model, collaboration is seen not only as allowing students to “…discuss and explain, and hence learn, with understanding,” but also to serve a monitoring function so that “Students in groups can also monitor one another and thereby help keep one another from going too far off track.” (CTGV 1990). The monitoring function of collaboration seems to be viewed as a strategy for achieving knowledge acquisition.

On the other hand, when a community not only values efficiency in the growth and exchange of individual knowledge, but highlights a higher aim of creating an innovative community (Hargreaves 1999; Zhang et al. 2007, 2008), a different community culture would be required. Such a culture would encourage members to collaboratively contribute knowledge to the community and persistently build-on and improve one another’s individual ideas towards advancing collective knowledge in the community (Hong and Scardamalia 2008). To initiate members into such a culture is to create a community, whose chief function is not to pursue ideal learning procedures and/or optimal distributed social activities for the growth of individual knowledge. Instead, it is to encourage members to work with knowledge creatively by allowing knowledge building processes and activities to emerge. The more adaptive and flexible a community’s activity structure, the more likely members would be able to design their own course of knowledge work; and the more likely they will be able to work opportunistically to connect diverse ideas and collaborate with one another for sustained knowledge advancement (for example see

Hong et al. 2007, 2008; Zhang et al. 2009). Arguably, this represents a knowledge-creating community and the kind of culture valued in such a community is similar to the kind of knowledge-innovating culture that is commonly observed in research, science, technology, and business communities (Evans and Wolf 2005; Gloor 2006; Latour and Woolgar 1986; Merton 1973; Nonaka 1994; Nonaka and Takeuchi 1995). In these cultures, community knowledge advancement is the highly valued, primary goal. For example, new technologies are increasingly created by self-organizing knowledge workers (Rycroft 2003) such that the open source operating system, Linux, has been developed and continues to evolve through an essentially volunteer, self-organizing community of thousands of programmers who collaborate on diversified ideas through constant exchange of open source code (Evans and Wolf 2005).

Needless to say, the two kinds of communities (learning community versus knowledge-creating community) described here are very different in nature and would require different instructional design support. It is evident that an efficiency-oriented design is a better candidate than an innovation-oriented design for sustaining a culture that values efficiency for knowledge acquisition and/or distributed knowing in a learning community. On the other hand, to foster a knowledge-creating community would require a high degree of flexibility and adaptability in the design of activity structures in order to support self-organization of knowledge. It is therefore posited that an innovation-oriented design is a more effective design approach to supporting learning-as-knowledge-creation.

An idea-centered, principle-based design approach

As an example of innovation-oriented design, we describe an idea-centered (Scardamalia 1999), principle-based (Hong et al. 2008; Scardamalia 2002) approach that supports learning as knowledge creation. Underlying this design approach is knowledge-building theory (Bereiter 2002) and Knowledge Forum (KF) technology—which enables a computer-supported knowledge building environment (Scardamalia and Bereiter 2006).

Principle-based design

Knowledge building is a social process focused on the production and continual improvement of ideas of value to a community (Scardamalia and Bereiter 2006), and guided by a set of knowledge-building principles (see Scardamalia 2002, for detail). For example, the principle of 'Epistemic Agency' highlights the importance of setting forth ideas and negotiating a fit between personal ideas and ideas of other community members, using contrasts to spark and sustain knowledge advancement rather than depending on others to chart that course for them. One way to support "Epistemic Agency" in Knowledge Forum is the use of theory-building scaffolds. It is designed to support more spontaneous knowledge work and idea improvement using incomplete sentence prompts such as "My theory is…", "I need to understand…", "This theory cannot explain…", and "A better theory is…" to help students become more self-directed knowledge workers.

As another example, the principle of "community knowledge, collective responsibility" emphasizes that contributions to shared, top-level goals of the community be prized and rewarded as much as individual achievements (Hong and Scardamalia 2008; Hong et al. 2007; Scardamalia 2002) and that team members produce ideas of value to others and share responsibility for the overall community knowledge advancement. To support this principle, a recently developed design feature has been a semantic overlap tool. This tool can be used to compare key terms extracted from any two sets of notes or texts and to identify overlapping words in those two sets of notes or texts. Thus overlap between terms entered early or late into the knowledge spaces, or between student notes and discipline-based resources, can be easily compared and identified. Using this tool, learners are thus able to monitor and reflect more frequently on who has worked on which ideas (or sets of ideas), so members can share a meta-perspective on their work. More effectively distributed knowledge-building processes and shared cognitive responsibility can thus be effectively facilitated (Hewitt and Scardamalia 1998; Hong and Scardamalia 2008).

Idea-centered design

Idea generation

In a knowledge-building environment, knowledge advancement usually starts with idea generation, for example, using authentic problems and scaffolds to help students form ideas. Once generated, ideas are captured and contributed to a KF database in the form of a note. In other words, these ideas become public knowledge as they are permanently recorded in the database. And once recorded, they can be treated as what Popper (1972) called conceptual objects or artifacts for further collective improvement (Bereiter 2002). Figure 1 shows some selected design features in a KF note to support idea generation, including: (1) using customizable scaffolds to frame ideas; (2) using authentic problems to guide the generation of real ideas and improvable ideas; (3) using the text body to elaborate ideas; (4) using key words to help search for and relate to other ideas.

Idea improvement

Ideas can be improved in two dimensions: depth and breadth (Hong et al. 2007; Fig. 2). From a social perspective, improving the depth of an idea is a function of how knowledge

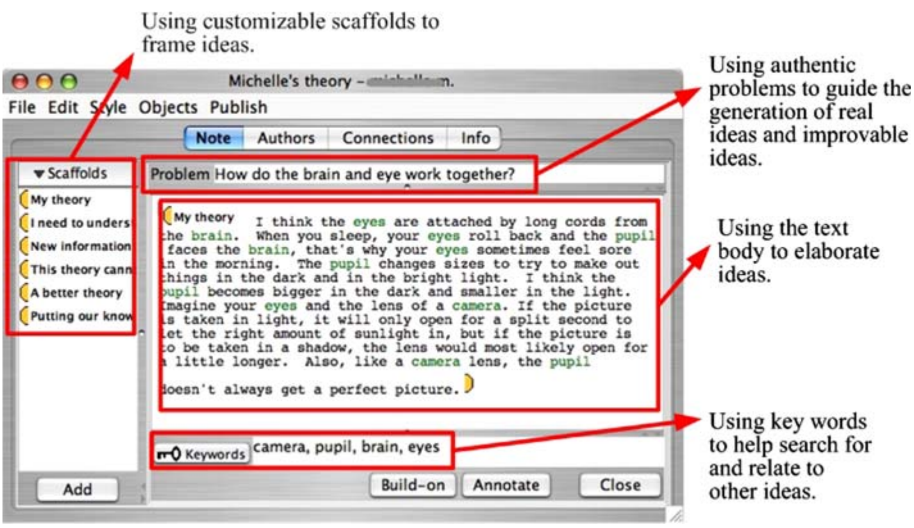

Fig. 1 Some design features in a Knowledge Forum note (*source*: adapted from Knowledge Forum 4.6 online manual at http://ikit.org/kf/46/help/)

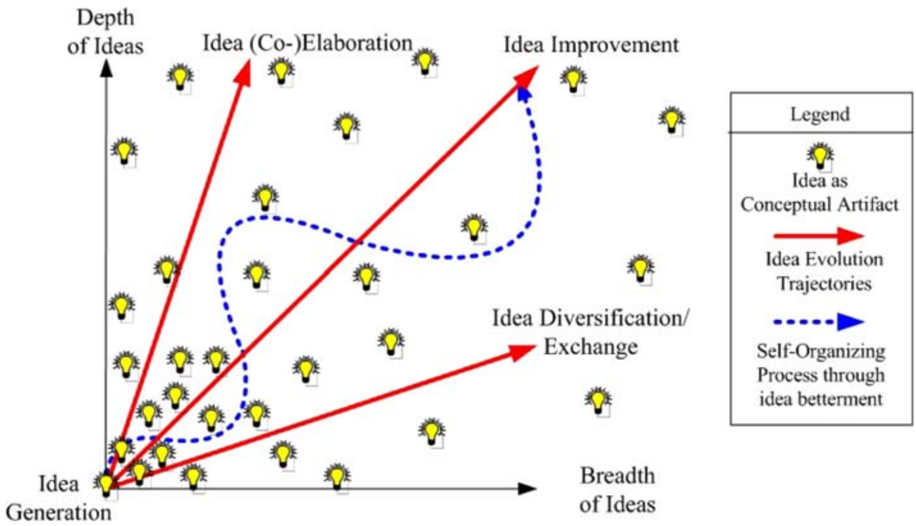

Fig. 2 An evolutionary view of idea improvement (*source*: adopted from Hong et al. 2007)

workers (epistemic agents) collaborate (i.e., the intensity of collaboration or co-elaboration of ideas). Improving the breadth of an idea is a function of how ideas (conceptual/epistemic artifacts) interact with each other (i.e., the extent of knowledge-interaction). Building on evolutionary epistemology (Popper 1972) and social epistemology (Fuller 1988), ideas can be improved by means of two fundamental evolving trajectories: idea co-elaboration and idea diversification. Depending on how ideas are transformed, ideas may be substantially refined by means of co-elaboration or significantly enriched by means of idea diversification. Neither, however, represents an optimal approach to sustained idea improvement. For example, research has indicated that withholding ideas as valuable intellectual properties (e.g., a business secret) without sharing with, and/or obtaining new perspectives from others (e.g., other disciplines) can hinder knowledge innovation (e.g., see Granovetter 1983; Chubin 1976). On the other hand, simply exchanging ideas (e.g., information-sharing) does not guarantee the transformation of ideas into deeper understanding (Kling and Rosenberg 1986). Ideally, the process of idea-improvement requires transformation both in depth and breadth, and there is no end to this evolutionary, collaborative, and innovative process, i.e., a self-organizing process initiated by the two simple communal behaviors of idea co-elaboration and idea diversification to form a complex system of ideas—what Popper (1972) calls the third world.

An adaptive design space for knowledge self-organization

To sustain an endless knowledge-building process, knowledge-building principles are employed as ideal conditions and constraints that constitute an optimal knowledge-building community (Scardamalia 2002). Using only principles as guidance without pre-specifying activity structures, a “design space” (e.g., a KF View, see Fig. 3) is intentionally created as a meta-design scheme to allow community members (e.g., the teacher and students) to collectively improve (i.e., to design, perform, and re-design/refine) their knowledge works (e.g., theories) in order to advance community knowledge. Accordingly, knowledge-building activities become adaptive rather than routine or ritualistic. As shown in Fig. 3,

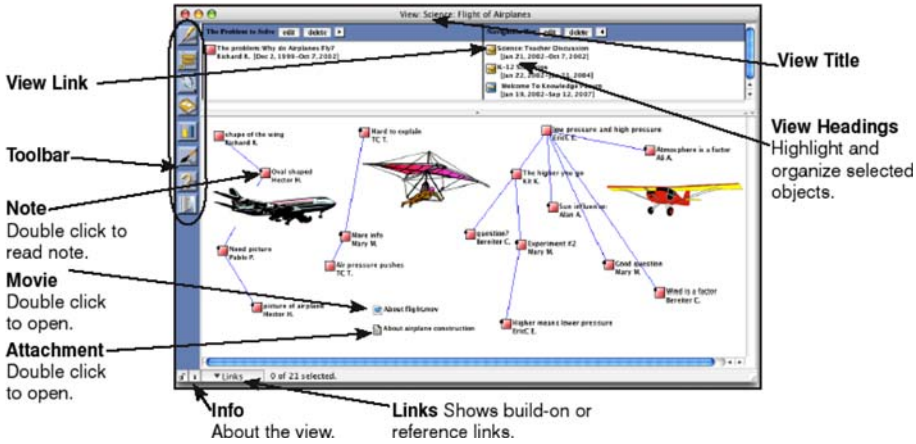

Fig. 3 An example of a KF view as a design space (*source*: adopted from Knowledge Forum 4.7 Reference Card)

a Knowledge Forum view represents a problem and design space created by community members to host diversified ideas. Members can make use of graphics palettes, linked views, header space, and other supports to collectively organize and re-organize, elaborate, and refine their ideas for community knowledge building.

A case example

As an example, in a recent study in a grade 5/6 knowledge-building class where students (10 girls and 12 boys) were collectively inquiring about the "human body system" (Hong et al. 2008), we have observed a more opportunistically structured activity pattern. In this particular study, the collective knowledge goal decided by the whole class together was to gain a deeper understanding, from an interdisciplinary perspective, of the internal body as a system (e.g., studying how the brain, nerves, blood and cells work together) and the physical body as a system (e.g. studying how the head, hands, legs, knees and feet coordinate to enable long jumps). At a quick glance, it appears that students are involved in activities similar to an ordinary student-centered class, for example, small-group or whole-class discussion, watching videos, computer use, library search, reading, writing, conducting experiments, and working in front of a computer, etc. However, these activities do not fall into any ritualistic practice that can be observed on a regular basis. Instead, students work around ideas, by opportunistically forming collaborations and by employing any meaningful activities considered beneficial at the moment when in need of idea improvement. Further, increasing student agency and collective responsibility (as guided by the above mentioned principles of "Epistemic Agency" and "Community Knowledge, Collective Responsibility") was also observed. Many notes clearly demonstrated that students were able to constructively evaluate their knowledge work for further idea improvement. For example, a student wrote in one note, "I figured out that putting your legs forward and swinging your body over your legs help a lot." (Hong et al. 2008, p. 380). These notes also demonstrated that students were able to monitor other students' knowledge progress by contrasting each other's ideas. For example, in another note, a student wrote, "My idea for improvement early this week was: PUSH KNEES TO 45 DEGREE ANGLE. I tested it out and it really didn't work, although with M.C., who's [whose] long jump I have studied many times, it worked perfectly" (Hong et al. 2008, p. 380). Collectively, it was clear that students were deeply engaged in designing, performing, and re-designing/refining their knowledge work, and had increased their progressive problem-solving ability, as well as their knowledge or sense of "promisingness." To further exemplify, in investigating how the human body functions as a system to perform a long jump, a student summarized the process of his idea improvement (and knowledge building) as follows:

> My original theory wasn't very successful. For my normal jump [as compared with the experimental jump] I got 2.20 m and for when I used running in the air my results were 1.48 m. So don't run in the air… but it might only be for me so you could try it…so I am going to try something the opposite of that. I am going to try not moving in the air. Also I am going to keep my legs tucked in too (but at the end stick them out so I will go higher. I think that is going to work because I will go high and you want to go high because then you won't touch the ground sooner.

As demonstrated here, an idea-centered, principle-based design has helped students to work more comfortably with idea generation, and more adventurously and adaptively in advancing their community knowledge as guided by the principles. In other words, they become more accustomed to making their tacit ideas explicit, transforming them into public objects, and putting them in the center stage of the community for sustained improvement.

Conclusion

In this paper, we have identified the need for a new, innovation-oriented, instructional design framework that addresses the conceptualization of learning as knowledge creation. To highlight the need for this new idea-centered and principle-based framework, we have contrasted it with efficiency-oriented instructional design frameworks including component-based and participation-based models. We have argued for the need for the innovation-oriented framework from pedagogical, psychological, epistemological and socio-cultural perspectives. In the following paragraphs, we discuss areas of future research from these four perspectives that will aid in the development of innovation-oriented instructional designs.

The learning as knowledge creation metaphor represents not only a shift in conceptualizing how people learn, but also in what the outcomes of learning should be and what conditions are best for fostering such learning outcomes. The idea-centered, principle-based instructional design approach emphasizes self-organization as a guiding pedagogical principle for engendering innovation and knowledge creation. Research agendas that focus on the classroom conditions, pedagogical approaches and policy decisions that affect self-organizing activity in a classroom are needed to advance our understanding of how to create innovation-oriented instructional designs for knowledge creation. An important psychological aspect of innovation is adaptiveness, meaning developing the capacity to perform at a high level in any situation through metacognitive control processes. Investigating more fully the mechanisms and conditions that make possible adaptive expertise (Hatano and Inagaki 1986) is a particularly important area of future research for those interested in creating innovation-oriented instructional designs.

We have theorized that in order for students to develop the knowledge of "promisingness" they would need to be immersed in a curriculum that holds adaptive know-how as the primary learning goal. In such a curriculum, know-that, or declarative knowledge, becomes less specifiable ahead of time. Therefore, the curriculum would need to be spacious enough to allow the know-how and know-that knowledge needs to emerge as a function of collective inquiry. The role of the teacher in facilitating movement through such a spacious curriculum is an important area of future research. Finally, our conceptualization of the knowledge creation community highlights the importance of the public advancement of community knowledge. This view of collaboration goes beyond small group work and whole class discussions, to the notion of a professional research community where an individual's interests are pursued through evolving and continuing intellectual relationships with others (Hong and Lin 2008) towards the end of advancing public knowledge. Understanding how to create the conditions for such relationships to develop overtime in a classroom is an important area of future research.

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