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A Computational Tool for Lifelong Learning Through Experiencing Breakdowns and Understanding the Situations

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Abstract
Regarding a breakdown as an opportunity for learning, systems for lifelong learning need to support a learner in: (1) experiencing a breakdown, and (2) asking for information relevant to the breakdown situation. Knowledge-based critiquing systems have been studied to support the processes. Such a system monitors human performance within its computational environment, identifies a potentially problematic situation, alerts the user for the situation to make the user aware of the potential problem, and provides explanation for the criticism and information relevant to the problem. Although found effective, critiquing systems depend on knowledge-bases that need to be built by knowledge engineers prior to the use of the system. This makes them impossible to afford synchronous collaborative learning among practitioners. To complement this aspect, this paper presents the EVIDII system, which visualizes differences among associations made by individual group members between two sets, for instance, pictorial images and words. By interacting with EVIDII, a user is encouraged to experience a breakdown by encountering an unexpected association made by other group members, and to ask for more information about the association from the other members. This embraces further communication and knowledge construction among group members. A few scenarios are provided to illustrate how learning takes place in using EVIDII.

Keywords
Computer-support for lifelong learning, breakdowns, computational critiquing systems, interactive visualizations of associations, the EVIDII system

1. Support for Lifelong Learning

As technologies evolve rapidly and the world changes, life-long learning is no longer luxury but has become a must [Fischer, Nakakoji 1997]. Different from in-class learning, lifelong learning within the working context is characterized as follows:

- There are no curricula of what to learn. There is no list of items that learners have to pay attention to.
- Although lifelong learning is recognized as crucial in improving and maintaining quality of work, learning can also be avoided. In many cases, practitioners have a way to deal with most of situations with their existing skills and knowledge even if they are aware of the existence of a better way to do if they acquire new knowledge.
- Most of learning styles are constructive rather than instructive. Since there are no pre-determined agenda for lifelong learning, instruction materials cannot be prepared a priori. Instead, a practitioner learns in a constructive manner, identifying a problem, collecting information relevant to the problem, and constructing a solution to the problem. Collected information, approaches used to frame the problem, as well as the problem-solution mapping is *learned* by the practitioner and becomes *knowledge* of the practitioner.

- Such learning, therefore, is mostly situated. Learning takes place within the context of the learner's problem at hand.

Due to these characteristics, most of traditional intelligent tutoring system approaches [Frasson, Gauthier, 1990], which presuppose a set of pre-defined curricula, are not applicable to support lifelong.

To support lifelong learners, computational tools need to support learners within their working context. For this goal in mind, we have taken an approach to take breakdowns as an opportunity for learning [Fischer 1995]. A breakdown is *"not a negative situation to be avoided, but a situation of non-obviousness, in which the recognition that something is missing leads to unconcealing (generating through our declarations) some aspect of the network of tools that we are engaged in using"* [Winograd, Flores, 1986, p.165].

According to Maturana and Varela [1986], for an organism to learn means that the structure of the organism changes. Such a change is triggered by perturbations caused by interacting with external environments. However, how the structure changes is not determined by the perturbations themselves but by the structure itself; what they call a structure-determined system.

Our approach is to provide a computational environment that helps people experience *breakdowns* [Schegloff, 1991]. Breakdowns are triggers that serve as perturbations for causing structural changes of an organism; knowledge construction. Our approach is based on the following claims:

- it is possible for a computational mechanism to make users experience breakdowns;
- experiencing a breakdown is a trigger that "may" causes structural changes. What is needed for ensuring structural changes, and thereby constructing knowledge, is to provide information relevant to the experienced breakdown; and
- providing information relevant to the breakdown can be achieved through communication: communication with computers or with other people.

This paper presents our approach to support lifelong learning within the working context through experiencing breakdowns, and through understanding their situations. To do so, computational tools need to support a learner (1) when experiencing breakdowns by encouraging the learner to encounter them, and (2) when understanding the situations by providing information through communications. Note that this type of communication is not merely "transmitting information" and cannot be adequately described in terms of the communication-through-tube metaphor. *"The phenomenon of communication depends on not what is transmitted, but on what happens to the person who receives it. And this is a very different matter from 'transmitting information'"*[Maturana, p.196]. Information provided through such communication needs to be made relevant to the learner's problem situation where the breakdown was experienced.

2. Computational Tools for Lifelong Learning

2.1 Computational Critiquing Systems

We have studied computational critiquing systems in a variety of domains; KID for kitchen designs [Nakakoji, Fischer 1995], eMMaC for designing colors in computer graphics [Nakakoji et al. 1995], and IAM-eMMa in image selections [Takashima, et al. 2000]. A computational critiquing system (critics, for short) is a knowledge-based human-computer cooperative problem-solving system. Such a system monitors human performance within its computational environment, identifies a potentially problematic situation, alerts the user for the situation to make the user aware of the potential problem, and provides explanation for the criticism and information relevant to the problem as requested [Fischer et al. 1998].

Our studies [Nakakoji, Fischer, 1995; Takashima, et al. 2000] have identified that a critics supports life-long learning by *making breakdowns as an opportunity for learning*. A problematic situation that a critics identifies is a *breakdown*.

Two types of learning have been found evoked by using the critics [Nakakoji, Fischer, 1995]. First, the user learns when the critics explains why a certain situation is found problematic by the critics. It provides argumentation about the situation, pros and cons of alternative solutions and possible effects.

Second, the user learns by arguing back against the critics explanation. When being critiqued, especially an expert argues against the system's behaviour trying to justify why the user's action should not be critiqued. This served as a knowledge elicitation mechanism [Nakakoji, Fishcer 1995, Nakakoji et al. 1998] as the user articulated otherwise tacit arguments regarding the situation. This often gives the user to reflect on what has been done and helped them externalize knowledge relevant to the situation.

Having observed these situations, the critics have been found very effective supporting lifelong learners [Fischer 1995]. However, the obvious shortcoming of this approach is that critics works only when it has pre-defined critiquing rules, or knowledge that the critics can base its behavior on. The system can identify possible breakdowns only if the system has a prior understanding about how to analyze the task. The arbitrary identification of a trivial problem without using knowledge-bases has already been found less effective in supporting learning [Owen, 1986]. Although we have built a mechanism to allow a user to add and modify critiquing rules as the user uses the system [Nakakoji, Fishcer 1995], the core knowledge should be fed by system builders prior to the usage of the critiquing system.

2.2 A Complement to Critiquing Systems: The EVIDII System

To complement this knowledge-based critiquing approach, we have built a computational environment with which practitioners can talk about breakdowns they experience. Using the system, communication among the practitioners serves as critics. That is, by using the computational environment, a practitioner identifies a breakdown, and by talking about the breakdown, individual practitioners are given opportunities to learn.

EVIDII (an Environment for VIsualizing Differences of Individual Impressions) is an interactive tool that visualizes differences of individual associations between two data sets on multiple two-dimensional spaces [Ohira et al. 1999]. EVIDII first asks collaborating group members to associate each object in one set with object(s) in the other set. Then, the system provides interactive interfaces that visualize the relationships among the two sets of data - objects in one set, and those in the other set - in terms of persons. Group members operate the EVIDII system together during their collaborative task. Communications are encouraged among the members based on what they find interesting and question-provoking using EVIDII. The visualisation causes breakdowns during a group discussion making the group members acquire knowledge about one another resulting in new understanding about the problem, solutions, and the language they use to communicate [Clark 1991].

In the next section, we present a few scenarios of how EVIDII is used among practitioners and how learning takes place. The following section then discusses underlying models of learning supported by EVIDII.

3. Scenarios of Using EVIDII

Five kitchen designers use EVIDII talking about a new kitchen design targeted for young couples. They have brought eight kitchen example pictures and twenty affective adjectives illustrating aspects of people's preferences and life-styles, such as urban, casual, pretty, rich, or cool.

Each of the five designers associates one or more word with each kitchen picture. Figure 1-(a) illustrates one of the designers, Shingo, is associating words from a list on the right to each of the kitchen pictures listed on the left. The other four designers make associations in the same manner.

When all are done with making associations, they sit together in a meeting room and the EVIDII system is shown on a computer-projected large screen. One of them is operating EVIDII and the other four look at the EVIDII's visualizations of associations (Figure 1-(b), (c) and (d)).

In each of the visualization window, a set of words are positioned in a two dimensional space (in the middle window of Figure 1-(b)). The positioning is done by one of the designers who put words with similar meanings close to each other.

The operator clicks on a kitchen image icon one by one in upper-right of Figure 1-(b). The system shows who associated which kitchens with each word by displaying kitchen images on top of assigned words. By looking at Figure 1-(b), the designers become aware that only Shingo (represented with a face icon with yellow hair) associated a certain kitchen to a word differently; the rest of the designers associated with the same word. Selecting a different kitchen changes the visualization as EVIDII displays who selected the kitchen with which word (Figure 1-(c)). Selecting a face icon in lower-right makes EVIDII displays which kitchen designs are associated with which word by this particular designer (in this case, by Shingo) (Figure 1-(d)).

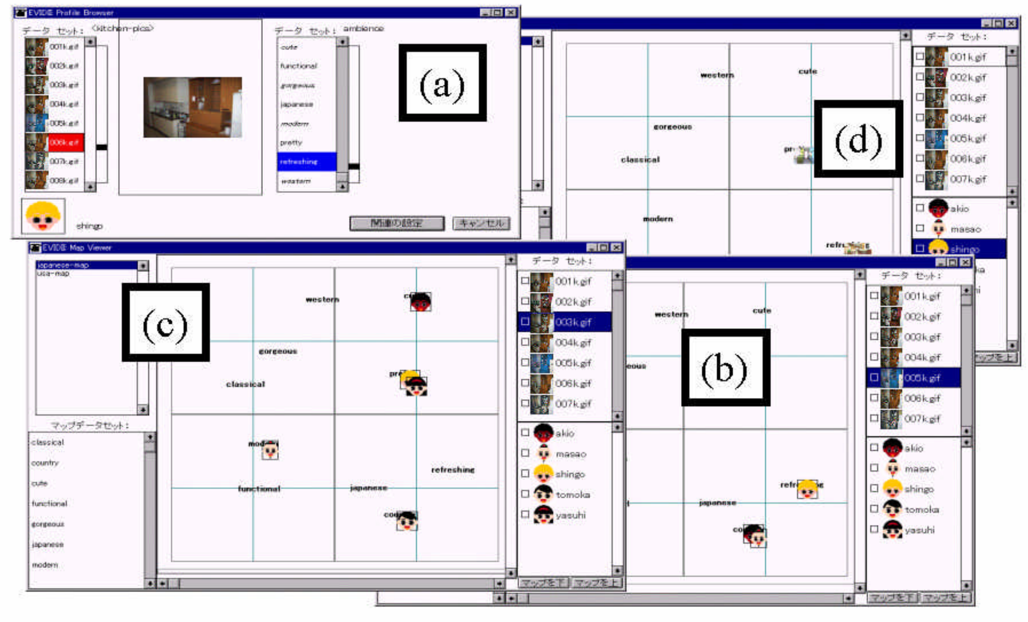


Figure 1: The EVIDII System

The two scenarios below are created based on parts of the actual transcripts we have taken from user studies [Ohira, et al. 2000].

> (1) A kitchen #1 is associated with seemingly opposite words. Shingo associated with “cool” while Tomoka associated with “warm.” When they find this difference in viewing EVIDII visualizations, Tomoka asks a question to Shingo:
>
> > Tomoka: *Why do you think this kitchen (kitchen #1) “cool?”*
> >
> > Shingo: *Why? because it* ***is*** *cool*.
> >
> > Tomoka: *I found Kitchen #1 has kind-of warm and has family-oriented atmosphere*.
> >
> > Shingo: *Oh that’s why you said its “warm.” You see, this picture (kitchen #1) has shadow in it. I think everything that has shadows and dark places is “cool.”*

In this scenario, Shingo and Tomoka find how they felt kitchen #1 have conflicts. By communicating about this breakdown, however, they can describe how they use words such as “cool” and “warm.” This results in their mutual understanding that how they use those two words.

Through this conversation, Tomoka learns that having shadows in a picture may cause a person to think that it is “cool.” Not only Tomoka, but all the other designers learn that “cool” and “warm” are not necessarily conflicting associations.

> (2) When a kitchen #2 is examined, Yasuhi finds that Tomoka associated two words with the kitchen: “family-oriented” and “commercial.” Yasuhi thinks that those two words are conflicting and associating those two words to a single kitchen is not understandable.
>
> > Yasuhi: *Wait wait wait, … (pause) … don’t you think that Tomoka (‘s association) is a little strange that he associated this kitchen (kitchen #2) with “family-oriented” and “commercial,” which are two contradictory words?*
> >
> > Tomoka: *I like the color of this kitchen (kitchen #2) because it provides family-oriented atmosphere. However, the shape of this handle of the drawers is kind of commercial-like and I do not like the shape.*

In this scenario, the experienced breakdown is also conflicting words but this time associated by a single person, Tomoka. Yasuhi, who experiences this breakdown, poses a question to the group. Then the designers all discover that it is due to different aspects Tomoka looked at. For Tomoka, its color is family-oriented but the shape of drawer handles is commercial-like. Yasuhi has never paid attention to the shape of drawer handles till this moment and Yasuhi learns the existing of a new aspect based on the communication. Tomoka, who made the two seemingly-conflicting associations has not thought that these associations conflict to each other because it was so obvious to him. Tomoka learns by himself and becomes able to articulate why he made certain associations.

4. Discussion

The scenarios provided in the previous section illustrate how the EVIDII system supports lifelong learners in experiencing breakdowns and in understanding the situations. This section illustrates the EVIDII approach with computational critiquing systems by using a model of a lifelong learning process. We then discuss crucial design elements provided and not provided in the current EVIDII.

4.1 A Model of a Learning Process

Figure 2 illustrates how lifelong learning through experiencing breakdowns and understanding the situations takes place.

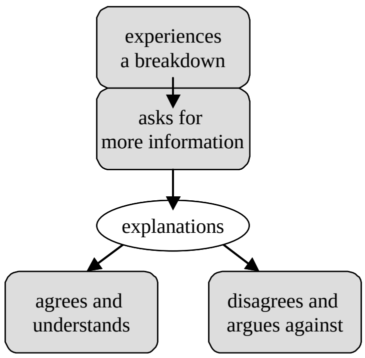


Figure 2: Lifelong Learning through Experiencing Breakdowns and Understanding the Situations

First, a learner experiences a breakdown. This makes the learner aware of the need for more information relevant to the situation that has caused the breakdown. Obtaining the information, or knowledge, the learner may be convinced why the breakdown happened and become able to integrate newly acquired information with pre-existing knowledge about the domain. This is one type of learning.

Given the information, the learner may not agree with the information (i.e., the way the breakdown situation was described) and become able to argue about the information provided. This is another type of learning. If the arguments articulated by the learner had not been explicitly mentioned before, then this is a situation when the learner’s tacit knowledge is partially externalised [Polanyi 1966]. The experiential knowledge of the learner becomes the reflective knowledge through the process of learning [Norman 1993].

Based on the model depicted in Figure2, as we argued in Section 1, computer environments can help life-long learners in the process of breakdown-based learning in two ways: when experiencing a breakdown, and when requesting relevant information.

Critiquing systems support the both aspects (Figure 3-(a)). Critics monitors while a user makes a move in a solution space. The system continuously analyses each move made by the user using its knowledge-base and as soon as it detects a problematic situation, the system presents a critiquing message to the user. This causes the user to experience a breakdown. When the user clicks on the critiquing message, the system can provide the user with explanations why the system fired the critiquing message; that is, which rules were used to identify possible problematic situations. The user may be able to further obtain relevant argumentation about the critiquing rule. When presented with such relevant information, the user either is convinced and understand the situation or the user argues against the system's behaviour often justifying why the situation should not have been judged as problematic. The user learns about the situation and is given an opportunity to reflect on otherwise tacit knowledge used in solving the problem.

The EVIDII system also supports the both aspects (Figure 3-(b)). However, the role distribution between people and the computer is a little different from that of the critiquing systems. With EVIDII, each of users make associations among two sets; for instance between a set of words and a set of kitchen pictures. EVIDII then provides visualizations of collected associations. When a user interacts with the visualization, the user may experience a breakdown; for instance, by finding that a certain user made an association that is very different from the rest of the users. Then, the user asks for information relevant to the breakdown situation by directly asking the group member who made the interesting association. The user being asked, as well as other participating users, will talk about why such interesting phenomena have been created. The user is given an opportunity to become aware of new perspective for the domain or unfamiliar opinions about the domain that are being talked by the participating users. This gives the user an opportunity to learn about the domain as well as learn about the other participating users. They become collaborative learners.

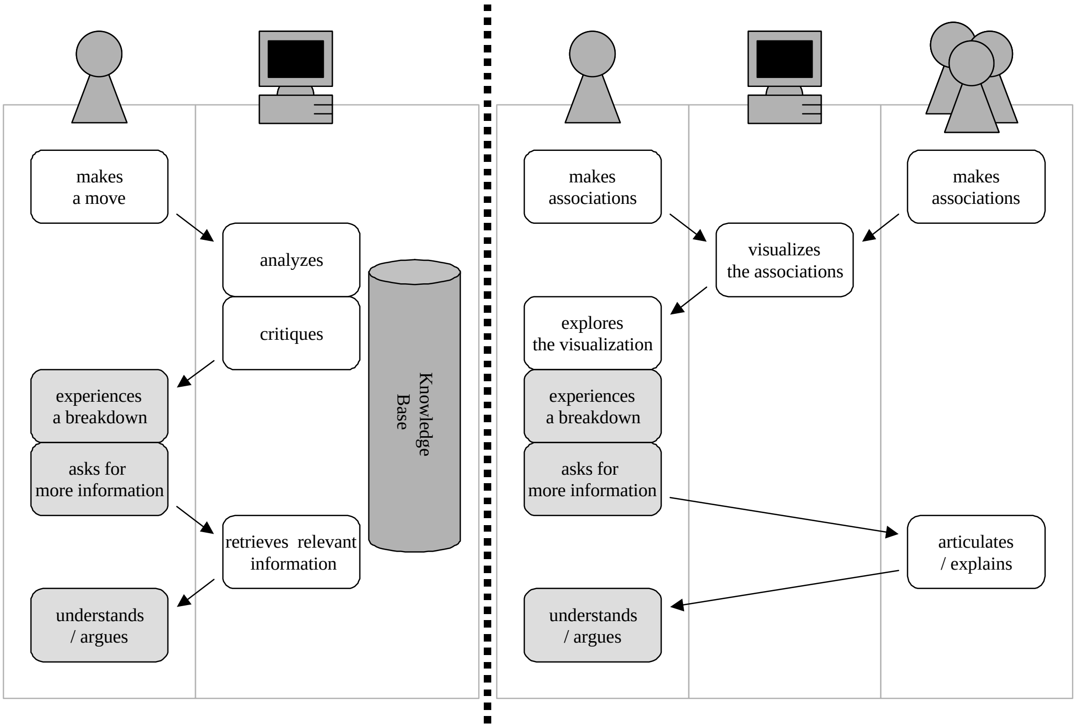
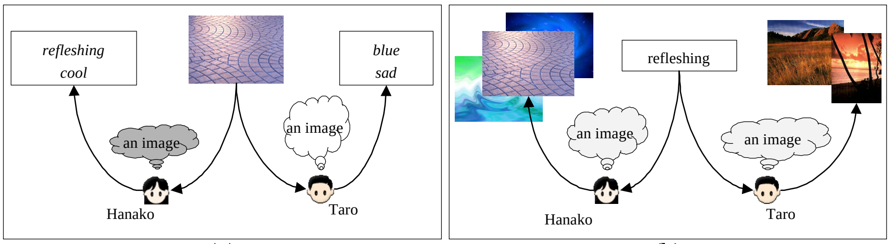


Figure 3: Support for Lifelong Learning:
left: (a) the Critiquing Systems Approach; right: (b) the EVIDII Approach

The key difference between the critiquing system approach and the EVIDII approach is twofold. First, the way that a user is helped experiencing a breakdown is different. With critics, the system continuously monitors the user's performance and actively notifies the user of potential breakdowns. With EVIDII, on the other hand, the system simply provides visualizations, and it is the user who needs to interact with the visualization and to discover a breakdown situation by him/herself. The EVIDII approach needs the user to take a more active role in experiencing a breakdown. With critics, the user can stay more in a passive mode in terms of experiencing a breakdown.

Second, the relevant information provided by the system is different. Most of critics depend on the existence of pre-constructed knowledge-bases. With critics, it is not the critiquing message itself that the user learns but information retrieved relevant to the situation [Fischer, et al. 1998]. Such knowledge-bases need to be built prior to the use of the system by domain engineers. In this sense, the user of critics cannot obtain information that is not included in its knowledge-base unless the user him/herself comes up with new thoughts or becomes able to articulate a part of previously tacit knowledge. With EVIDII, the relevant information provided to the



(a) (b)

Figure 4: Differences of Individual Impressions

learner is coming not from a computer, but from other users using the EVIDII at the same time. It embraces a live exchange of knowledge among the participants. The use of EVIDII often encourages people to articulate knowledge and thoughts that have never been externalised before.

4.2 How EVIDII Helps Learners Experience Breakdowns

In the previous section, we argue that critiquing approach and EVIDII nicely complete each other. While critics embraces a user to learn pre-stored knowledge through asynchronous communication, EVIDII embraces a user to learn "live knowledge" through synchronous face-to-face communication. Critics actively helps a user experience a breakdown while EVIDII needs a user to actively experience a breakdown.

It is a challenging task to design a system that motivates a user to actively interact with the system and actively experience a breakdown. We have chosen an approach to use interactive visualizations of individual differences with other users to make the user motivated to participate in the discovery process. Association is a simple but powerful scheme to illustrate individual differences.

Figure 4 illustrates how associations are used in EVIDII. Take an association between pictures and words, for instance. There are two cases when a difference emerges. First, two users may feel the same picture differently. Second, two users may use the same word in a different manner even if the two feel the picture in the same manner. In the beginning of our studies with EVIDII, we anticipated that the only first type of difference will be discussed. In the studies, however, interesting discussions and more learning opportunities were identified when users found that different people used the same word in different manners. The scenarios illustrated in Section 3 provide nice examples. It is not that designers feel the same kitchen design in different ways but that designers used the same word quite differently resulting in different associations between a kitchen design and a set of words. It turns out that the use of EVIDII helps users develop shared ontology among the group members.

If associations are such an interesting scheme, we could just use a simple table format to illustrate associations and give the table to the users. A table is a simple, compact, yet precise format to illustrate associations. However, we argue that interactive visualization of associations is another essential element of the design of EVIDII. EVIDII provides many views in visualizing associations. In observing users, we have found that users of EVIDII always browse through different visualizations by clicking on each of the users, or of the pictures, or of the words, one by one in order. By repeating this process, users often found something interesting visually.

In the current EVIDII, we use face-like icons to represent users. In one of our user studies when we used simple numbers to represent different users, not much lively discussions took place. Although we have not identified what factors were critical to make people really "in" to interacting with visualizations and experiencing breakdowns, subtle design decisions, such as using friendly face-icons rather than numbers to designate users, do matter. Representational issues need more careful attention in supporting this type of learning [Yamamoto et al. 2000].

5. Conclusion

In summary, through our user studies, we have found effects of EVIDII including:

- users become aware of other aspects/perspectives; their perspectives have been widened;
- the system prevents them from suffering from having tunnel-visions or fixed-viewpoints;

- users have learned how to look at a certain picture or an artifact; and
- the use of system evokes a user's mental simulation by making a user try to understand why a particular person has a different point of view.

Throughout the case studies, we have observed situations similar to the scenarios presented in Section 3. Each of such conversations often started with phrases such as "*Really*?" or "*Wao*," which indicates that there has been a breakdown experienced by the users while interacting with the system. Most of such breakdowns were identified when a subject found differences or seemingly conflicting associations among the user and the other participants, among multiple participants, or even within a single participant. We have not observed any cases where the participants could not describe (verbalize) why a certain association was made. Once a breakdown was observed, communication regarding the breakdown was embraced, which triggered the participants to rationalize and verbalize why a certain action (association) was taken (made).

It is this rationalization process that the structural change occurs in a single person's mind. Once rationalized and verbalized, then such knowledge can be shared among participating collaborators and most of all, help the user him/herself to have better understanding about how he/she has seen and will see the problem and solution.

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