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# How Can We Support Paper-centric Learning Ecologies?

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**Abstract**

Paper is an integral part of most learning settings. We advocate an ecological perspective for designing system support for technology-enhanced learning. We present the perspective and, as an example, our concept and system framework for paper-centric learning.

**Keywords**

Learning, CSCL, User Interface, Digital Paper, Ecology

**ACM Classification Keywords**

H.5.2 User Interfaces. K.3.1 Comp. Uses in Education.

**Introduction**

Although the end of paper use has been predicted, traditional paper keeps being used in a huge variety of learning contexts. This is due to the many inherent advantages of paper over digital documents. For instance, paper equally serves for deeply reading a text, annotating and making an excerpt, for brainstorming and sketching in a learning group meeting, for scribbling a note and passing it to someone else, or for integrating information from books and web pages. There exist now a considerable number of systems which integrate traditional paper with computers (e.g. [8, 2, 7]).

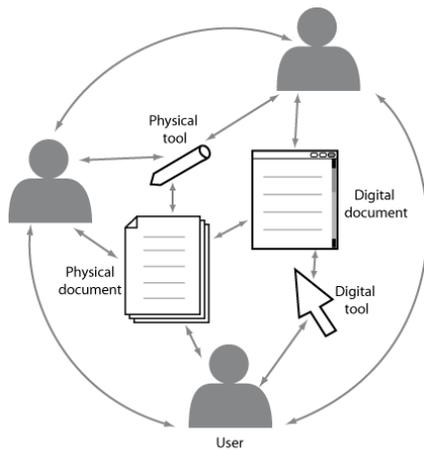
However, these previous works each support only specific workflows of working and learning with paper media. This does not respond well to the wide range of

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**Figure 1.** The ecological perspective advocates an integral view on people, artifacts, and practices in a collaborative learning setting.



**Figure 2.** Co-located collaboration with CoScribe. Each user has a personal pen to interact both with printed media and digital information on a tabletop display.

usages and the highly individual practices of using paper [3]. We argue that instead, an ecological perspective is the key for understanding and supporting learning activities in collaborative contexts.

In this paper, we discuss this perspective and its implication on the design of paper-centric systems. Next, we show how this perspective is applied in CoScribe, our concept and system for paper-centric learning.

### An Ecological Perspective on Learning

The ecological perspective advocates an *integral view* on the various interrelated elements of a collaborative setting. It is inspired by Bateson [1], Distributed Cognition [5] and Information Ecologies [4].

Distributed cognition states that cognition is not just something that happens within the self. Knowledge and competences can be inscribed into objects and cognitive work is done by using and manipulating these objects. Learning happens by using these objects and it transforms both the objects and the way they are used.

Information Ecologies model learning as a complex network of elements (users, artifacts and tools, interleaving tasks, and collaborative practices). These have strong interrelations and dependencies (Fig. 1). From this perspective learning is always situated, i.e. it is always embedded into a context or a practice.

Our particular interest lies in the way learners make use of paper artifacts within this ecology. Following Bateson we distinguish three different logical degrees of learning each being on a higher logical level than the previous one. Learning I happens within a stable context I, learning II transforms this context I but happens

itself within a stable context II etc. If we adapt this schema to learning with paper artifacts, this yields three types of learning:

- *Collecting information:* Reading or adding information, e.g. by annotating a document. The overall organization of information remains unchanged.
- *Constructing knowledge:* (Re-)organizing information for relating, structuring and abstracting information to knowledge. While the organization is transformed, the more general learning practices remain unchanged.
- *Adapting Learning Practices:* The learner consciously adapts the practices of organizing information as part of the cognitive process. Both information and practices are transformed.

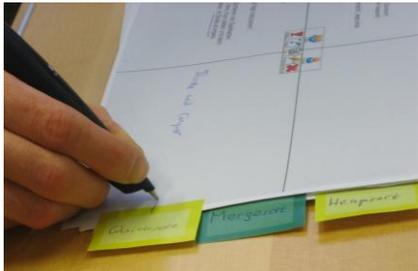
#### Implications on the Design of Paper-centric Systems

First, the system is only part of the (larger) ecology rather than the ecology being centered on a system. The interface must be *simple to use* and *integrate easily* into specific ways of organizing information and into specific learning practices. In order to identify common tasks in a specific ecology and to examine how they can be best supported by paper-centric interfaces, ethnographic field studies are an important means.

However, in more complex learning processes, the ecology of which the interface is a part will itself be transformed. The learner will not only edit contents, but also her learning practices themselves. Paper-centric user interfaces that seek to support such learning processes must offer ways to *be adapted and transformed* by the learners. They must therefore be modular and designable by the end-user.



**Figure 3.** Mobile use of digital pen and paper with CoScribe.



**Figure 4.** Tagging printed documents with Digital Paper Bookmarks.



**Figure 5.** Creating a cross-media hyperlink using a pen gesture.

Additionally the functionality offered by the systems modules must be so *generic* that people, artifacts and practices can change and the user interfaces still fits into the ecology as it evolves.

### **CoScribe: Paper-centric Learning Ecology**

CoScribe [6] is a concept and system for paper-centric learning with documents that consistently follows the ecological perspective. Its design is based on the results of three field studies on how students learn in lectures, seminars, and in learning groups. The system leverages Anoto Digital Pen-and-Paper technology. Anoto pens can be used on paper like ordinary ballpoint pens but additionally capture and transfer to a computer what has been written or sketched.

#### *Ecology: Users, Practices, and Artifacts*

Following the ecological perspective, CoScribe offers support for a set of collaborative practices. Learners use Anoto pens to annotate, reference, and tag documents. These are rather generic activities, all highly important for understanding contents and constructing knowledge. Several users can collaborate in a co-located setting, each having an own Anoto pen (Fig. 2); new visualizations of ink-based user generated content provide for remote asynchronous collaboration. CoScribe can be used at various physical places of a learning ecology, such as at home, at a library, in public transport, or in a lecture hall (Fig. 3).

A wide variety of typical artifacts used in learning ecologies are supported. This comprises paper-based documents (printed PDF and PPT files, books), digital documents (PDF, web pages), as well as paper tools (e.g. folders and index stickers). Besides paper and Anoto

pens, CoScribe leverages traditional computer screens and tabletop displays.

#### *Ease of Use*

The ease of use of paper is one of the main reasons why it can be so easily integrated into many different information ecologies. The following four design concepts ensure that this advantage is maintained by the digital paper-centric user interface of CoScribe.

First, CoScribe maintains the *interactional freedom* of traditional pen and paper in many respects. For instance, users can freely annotate, write and sketch on printed documents at any position. User-adaptable layouts of printed pages ensure that there is enough space available for writing.

Second, all interactions are designed by combining several core interactions, defined by our *systematic model* of paper-centric interaction [6]. Each core interaction is simple to memorize and to perform.

Third, CoScribe leverages simple, well-known *metaphors*. For instance, users can create cross-media bookmarks by attaching physical index stickers to printed documents (Fig. 4). A digital counterpart of a bookmark is automatically added to the digital version of the document and can be shared with collaborators.

Fourth, the interaction with paper and digital contents is *unified*. The same digital pen as on paper can also be used on an interactive table to work with digital documents. For instance, this enables an easy and intuitive interaction technique for creating and following cross-media hyperlinks. A hyperlink is defined by one single



**Figure 6.** Tagging printed and digital documents with Tag Menu Cards.

pen gesture that connects both link anchors and that spans paper and a display (Fig. 5).

### Modularity

As discussed above, complex learning activities imply that the learner transforms the practices of learning. In CoScribe, a modular interface design is the key for enabling the user to adapt the practices. The system is not monolithic and static, designed once for all times, but is a set of building blocks to support a continuous evolution of use. These building blocks are diverse tangible tools made of paper (including printed tool-bars, paper cards, adhesive stickers and folders), printed documents, and various digital visualizations. The end-user acts as a designer for her own environment, flexibly composing modules or choosing between alternative ones, thereby transforming the interface to fit her current practices. For instance, for organizing information, the learner can choose between creating hyperlinks using a pen gesture (Fig. 5), creating tangible bookmarks with adhesive stickers (Fig. 4), or creating free tags with Tag Menu Cards (Fig. 6).

By distributing the user interface of CoScribe on an ensemble of many paper surfaces and interactive displays, the system is physically integrated into the learning ecology. CoScribe has been implemented and evaluated with students in several settings (see [5] for more details on the concepts and the evaluation).

### Challenges

A main challenge for future research on paper-centric learning ecologies concerns the aspects of digital feedback. In contrast to current systems where paper is an interactive input channel but provides only static output, new technologies such as ePaper, Anoto pens with

an integrated display and mobile projectors enable new forms of real-time digital feedback on paper. Future research must carefully examine which novel interactive elements can be integrated how and for what purposes to optimally support the learning ecology.

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