Chapter 5
Pedagogical Design and Evaluation of Interactive Information Retrieval Learning Environment

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5.1 Introduction

Interactive information retrieval (IIR) has become a commonplace activity in our networked world. People constantly use various search services in order to find relevant documents to satisfy their information needs or accessing services, communities, or people to get answers or recommendations. From a pedagogical viewpoint, IIR activities have some important properties. These include firstly, task dependence of information searching. In the real world, searching is bound to various task situations. Therefore, IIR instruction is seldom successful as a decontextualized activity. Secondly, users of IR systems encounter uncertainty in various phases of searching. Searching and finding is basically motivated by uncertainty in a situation, i.e., the need to find information to reduce uncertainty. Uncertainty also relates to selection of information channels and sources, search keys, and evaluation of search results. Thirdly, although we can outline the main phases of searching, we seldom can provide definite rules on how to proceed in IIR tasks. These ill-defined rules for proceeding are important elements of IIR instruction. Learners should be supported with motivating cues and hints, without providing too ready-made solutions. IIR instruction should also equip learners with transferable skills to manage searching in different operational IR systems and interfaces (Halttunen 2004; Morville and Callender 2010).

Understanding how pedagogical solutions and technology can best support student learning in diverse learning environments remains a crucial line of educational research and development. Finding a suitable approach to rapid technological change and the identification of best practices are core ideas of "design experiments." Collins (1992) describes an educational research experiment carried out in a complex learning context, which explores how a technological innovation

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affects student learning and educational practice (see also Brown 1992; Cobb et al. 2003). The goals of design experiments are to design and implement innovative learning environments and simultaneously understand salient aspects of human cognition and learning involved in those innovations. Design experiments:

- Address learning programs involving important subject matter
- Are usually mediated by innovative technology
- Are embedded in everyday social contexts which are often classrooms, homes, and workplaces where it is hard to control unanticipated events
- Account for multiple dependent variables
- Do not attempt to hold variables constant, but rather identify many variables and the nature and the extent of their effects
- Evaluate various aspects of the design and develop a profile to characterize the design in practice

The present chapter describes continuing development of teaching practice and a research-oriented design experiment where pedagogical solutions like anchored instruction with scaffolding and fading are used. IIR instruction is also mediated with instructional software application QPA (Query Performance Analyzer). Student assessment and feedback is based on their prior conceptions, performance, learning experiences, and learning outcomes. Students' conceptual change and skills development provide base for learning outcomes assessment. The design experiment was conducted in a naturalistic educational environment of a university. The focus of the chapter is to describe design, implementation, and evaluation process in meta-level without concentrating highly on details of design and evaluation. These are described and referenced in original research articles.

5.2 Pedagogical Design of the IIR Learning Environment

Pedagogical design refers to any systematic choice and use of procedures, methods, prescriptions, and devices in order to bring about effective, efficient, and productive learning (see, e.g., Romiszowski 1981). According to Lowyck (2002), most recent models of design incorporate the following components:

- An analysis of a knowledge base of learning and instructional theories
- The frame of reference in which the design is used (i.e., elements like context, learners, and content)
- A set of validated rules or procedures to regulate and realize the design process and product

Most instructional design efforts involve a minimum of four components: namely, a specification of (1) the goals to be met, (2) materials to be used, (3) teaching strategies to be used, and (4) items and procedures for assessment. These components seem to be important for any domain of instruction imaginable. There is also a potential problem with this approach. The more complete the specification

of values for each instructional component, the less inclined teachers may be to map onto the unique features of particular students and communities (Cognition and Technology Group at Vanderbilt 1993).

Sfard (1998) points out that all our concepts and beliefs are based on a small number of fundamental ideas, which are carried from one domain to another by the language we use. She states that the current discourse of learning brings about two metaphors, which she names the acquisition metaphor (strengthening of reactions and information processing) and the participation metaphor (knowledge construction). Both of these metaphors are present in recent texts, but the former is more prominent in older writing and the latter in more recent studies. These ideas guide our pedagogical approaches, intentionally or unintentionally.

In many cases, instruction in IIR is based on practical hands-on exercises, which concentrate on search, interface, and document representation features of mostly operational IR systems. Instruction emphasizes active learning: doing and practicing. Learning tasks are often divided into subtasks like practicing author or title search, truncation, use of operators, etc. Exercises are done in a predefined sequence and feedback given with correct solutions. These pedagogical solutions based on strengthening of reactions are in many cases valid to support learning of the basic features of IR systems, but they may not produce transferable skills.

Pedagogical solutions adapted from the information processing metaphor stress the importance of activating long-term memory with the help of learning materials in different formats (text, image, sound). Learners are supported with flowcharts, hierarchies, and concept maps in building their mental models of study topics.

The metaphor of knowledge construction incorporates pedagogical solutions like activation and consideration of prior conceptions, as well as interaction with the environment both individually and socially. Learning is deeply rooted in interaction and participation in communities of practice.

The present learning environment is a place where learners may work together and support each other as they use a variety of tools and information sources in their guided pursuit of learning goals and problem-solving activities (Wilson 1996). In the present design experiment, learning environment has following properties:

- Place consists of classroom and networked environment
- Learners are first-year university students of information studies
- Who work both individually and in small groups
- Support is based on intentional scaffolding provided by teachers, tools, and colearners. Scaffolding and fading refers to various ways to build learning support
- Different kind of tools like operational and instructional IR systems are used
- Lectures, printed materials, and Web pages serve as information sources
- Students are guided in the learning process by teachers providing learning tasks, timelines, feedback, and scaffolding
- Learning goals are based on a curriculum
- Problem-solving activities are present constantly in classroom and Web exercises

Along with the general definition of the elements of the learning environment stated earlier, the design exploits the idea of "phenomenaria," i.e., the area of presenting, observing, examining, and manipulating the phenomena under study (Perkins 1991). Ideas of anchoring instruction to context as well as various pedagogical solutions based on situated learning and cognitive apprenticeship are utilized (Cognition and Technology Group at Vanderbilt 1990). Examples of these include modeling, coaching, and various ways to support learner, i.e., scaffolding and fading. Some of the scaffolding is implemented in the QPA, but teachers and tutors in the classroom do most of the coaching and scaffolding. The learning environment provides learning tasks, goals and activities, feedback, and information sources.

The QPA was originally developed as a rapid query performance analysis tool (Airio et al. 2007; Sormunen et al. 1998, 2002). The goal of the QPA is to provide a realistic environment for demonstrating the performance of queries in different types of search situations.

The basic idea of the QPA arose from the insight that the test collections used in the laboratory-based IR experiments could be used in instruction. A traditional test collection consists of a database, a collection of test topics (search tasks), and relevance assessments indicating which documents are relevant in respect to a given search topic.

The QPA consist of four major components (1) a set of well-specified search tasks for retrieving documents in a database, (2) relevance judgment's explicating which documents of the database match the relevance requirements of each search task, (3) a front-end system supporting and monitoring searching in all appropriate retrieval systems and databases, and (4) a feedback system for measuring and visualizing the performance of any query executed.

5.3 Description of the Learning Environment in the IIR Course

The course "Introduction to Information Retrieval" (6 ECTS credits) at the Department of Information Studies at the University of Tampere, Finland has been intended for first-year undergraduate students from 2000 onwards. They attend the basic course on information retrieval in the first semester of their studies. They are studying either IS as a major or as a minor subject. The course provides an overview of information storage and retrieval as practice and as a research area. Themes like the production and structure of databases, matching algorithms, metadata, subject representation, query languages and formulation, search strategies and tactics, and evaluation are covered in the course. Learning domain is congruent with IR curriculum described in Vilar and Zumer (2009).

The course consists of five instructional elements. First, students' prior conceptions of IR were analyzed in order to form a baseline for evaluation of learning outcomes and as tool for providing ideas for the design of IIR learning

environment. Activating these conceptions enhances learning, creates motivation, and makes it easier to concentrate on studying.

Second, lectures are given on basic concepts of information storage and retrieval. Along with the themes covered earlier, lectures present visual and textual advance organizers of topics to be studied and provide interactive feedback and summaries of exercises and learning tasks completed during the course. Mind maps and charts are used as introductory material to form conceptual understanding and serve as advance organizers. They enhance student learning and make it easier to connect new knowledge to prior conceptions and mental models (Ausubel 1960).

Third, weekly Web exercises concentrate on putting the themes covered in lectures into practice. Every participant is working on these exercises making use of Web-based tools and resources. Exercises are reported on the Moodle learning management system. Feedback on these tasks was given during the lectures.

Fourth, tutored exercises in the classroom covered various aspects of information retrieval systems and their effective use. In these sessions, groups of 8–12 students work in pairs. Various kinds of search services are used (OPACs, union catalogs, article reference databases, full text databases, Internet search engines and directories). Performance feedback of the QPA is used in several exercises as well as log-file analysis.

Fifth, a course feedback Web form is filled out at the end of the course. This feedback covered three main areas (1) course design and teaching methods, (2) the learner's self-evaluation and role in the course, and (3) the teacher's role in the course. The course feedback is an integral part of the course and it provides questions to support learners' self-evaluation and reflection. Feedback is also gathered with empathy-based stories, as discussed later in the chapter.

About 85–120 students attend this course, and a lecturer and two to three tutors take care of a part of the tutored sessions' provided instruction. The course outline, material, exhaustive handouts covering the lecture material, a bulletin board and exercises are provided via the University Moodle. Despite of the number of participants, the course can be regarded as highly interactive and task oriented. The learning-by-doing approach is used in several situations. The assessment of learning outcomes is based on weekly Web exercises, tutored exercises, and final examination. The grading one to five is used to indicate how a student has fulfilled the learning objectives.

5.4 Supporting the Learning Process with Anchoring, Scaffolding, and Fading

Anchored instruction is strongly associated with situated learning and constructivist learning environments. A major goal of anchored instruction is to overcome the problem of inert knowledge by teaching problem-solving skills and independent thinking. The Cognition and Technology Group at Vanderbilt (1993) states that an

anchored learning environment permits sustained exploration by students and teachers. Furthermore, it enables them to understand the kinds of problems and opportunities that experts encounter and the knowledge that experts use as tools.

Anchored instruction was used to create a macro-context for IIR activities. We used the full-text database of a local newspaper, an image database of a national press agency, and a national bibliographic database on journal and newspaper articles. Based on these tools we created a context of journalistic practice. In other words, IR activities were situated in a simulated work-task situation (Borlund 2000), where search tasks were based on the idea of a journalist searching the text and image databases available in order to find information on certain topics for a forthcoming article. In addition, some topics required the reporter to search national databases on certain topics.

Scaffolding occurs when a student, with the help of an expert, carries out a task that is too difficult for the student to cope with independently. The concept originates from idea of the zone of proximal development introduced by Vygotsky (1978). The metaphor of scaffolding comes from house construction, in which the house is built with the help of the surrounding scaffolding. When the house is complete, the scaffolding can be taken away. In cognitive apprenticeship, the tutor's withdrawal is called fading. Fading consists of the gradual removal of supports until students are completely on their own (Halttunen 2003b). Scaffolding was offered both by tutors and the QPA. Examples of scaffolding in the classroom are presented in Table 5.1.

The teacher can model the search process by providing examples focusing not only on end products (efficient query formulations), but also on the search process. The teacher provides hints, either initially or on an ongoing basis, on query formulation. The provision of examples of possible search keys serves as a scaffold in certain situations. Coaching comments are intended for motivation, providing feedback and advice on performance, and provoking reflection. Different kinds of questions can be set to enhance reflection, for example, pointing out weaknesses and asking about motivation.

The provision of a timeline with fixed timing and goals provides support for goal direction and reflection. The gradual removal of scaffolding, i.e., fading, was based

Table 5.1 Scaffolding implemented in the classroom

Scaffold	Implementation in classroom
Providing examples	Teacher models a search process
Providing hints	Suggesting parts of query formulation
Giving away parts of the solution	Suggesting search terms
Cueing/hinting	Giving cues/hints on operators, syntax
Providing coaching comments	Commenting, for example: "Why did this happen?"
Asking questions	Asking, for example: "How does that effect?" "What problems may that cause?"
Providing a timeline	Presenting a search process timeline

Table 5.2 Software-based scaffolding implemented in the QPA

Scaffold	Implementation in the QPA
Giving away parts of solution	Query performance feedback, relevance information, and search topics
Providing clues	Give a hint on relevant documents
Providing examples	Showing hall of fame containing queries
Providing comparison	Others' queries, p/r curves

on student performance in the exercises. When the students were able to construct queries, scaffolds such as examples and hints were removed. Coaching comments and questions were used throughout the exercises to improve reflection and articulation. Performance feedback provided by the QPA was removed in one of the search tasks, when students selected their own viewpoints on the topic. Table 5.2 describes the instructional scaffolds implemented in the QPA.

The basic idea and functionality of the QPA is that the query performance feedback scaffolds the learner by providing information on query performance. The learner receives feedback on query construction, which enables her/him to evaluate different search strategies and tactics. Learners can concentrate on the analysis of effective query formulation without spending lots of time in analyzing results. The "give a hint" function provides the learner with one nonretrieved relevant document. This document serves as a cue to the selection of appropriate search keys or document structures usable while searching. The possibility of identifying the retrieved relevant documents also serves as a cue in the same respect. The hall of fame provides examples of best queries on the current topic over time. The opportunity to see one's own performance compared to the performance of other users provides an area of comparison and feedback. Search topics can serve as a scaffold, providing examples of search keys and informing searchers about applicable restrictions.

The software-based scaffolds in the QPA are based on the basic idea of "knowing the right documents" for each topic. In a way this approach pays attention to the end product of the process, to effective query formulation with good precision and recall, but not interactive learning process support as such. The face-to-face scaffolding described earlier is needed in this situation (Halttunen 2003a).

5.5 Data Collection for Evaluation and Feedback

In order to evaluate students' prior conceptions and the effect of anchored instruction, scaffolding, fading, and the use of the QPA on learning experiences (student feedback), performance and outcomes, multiple evaluation and feedback data collection and analysis methods were used.

First, prior conceptions represent learners' understanding and experiences of IR know-how at the very beginning of formal instruction. Students' prior conceptions form the basis for learning. Conceptions cover elements of IR skills (e.g., information

sources, search engines), phases of the search process (e.g., analysis of information needs, evaluation of results), and background factors (e.g., searcher characteristics, IT skills). Students wrote essays and filled out the questionnaire on conceptions of IR know-how as an in-class assignment in the very beginning of the first lecture. The instruction for essay writing was presented as: "Write an essay-type text, in which you present your own description of information retrieval know-how. You can approach the topic by identifying different kinds of skills, knowledge, elements, etc. which, in your opinion are part of IR know-how." After writing the essay, students filled out the questionnaire, which presents visual analog scales (VAS) of different kinds of conceptions of IR. They presented their views from three different perspectives (1) what the important aspects of IR know-how are; (2) what their present knowledge about these aspects is; and finally, (3) what they expected as the important aspects of IR on the course they were attending. VAS was used because we did not want to categorize the levels of importance in advance, but direct students to form their own categorizations (Halttunen 2003b, 2007; Halttunen and Järvelin 2005).

Second, learning experiences represent students' reactions and feedback to the instruction. These experiences form a basis for the evaluation of instruction as a whole. Students describe their learning experiences concentrating on the elements of learning environments which were felt to be either positive or negative, i.e., factors enhancing or inhibiting learning. (Halttunen and Sormunen 2000). Students described their learning experiences in texts written based on the method of empathy-based stories (MEBS) and in answers to the course feedback questionnaire. There were seven major themes of learning experiences, namely: study orientation, domain of study, instructional design, teachers, other students, computer skills, and factors of everyday life (Halttunen 2003a, 2007).

MEBS was used for collecting data on students' learning experiences related to the instructional design. This method involves writing short essays according to instructions given by the teacher or researcher. In MEBS, the respondent is given some orientation, which is called the script. This script should be used in conjunction with the respondents' imagination in the writing of the story. The author of the story either continues the situation detailed in the script or describes what must or may have taken place prior to that situation. Variation is crucial to the use of this method, and there are at least two different versions of the same script, which vary with regard to a certain key issue. Such variation distinguishes the MEBS from many other methods of acquiring data (Eskola 1988, 1998). Variation of the scripts was based on good and poor learning experiences. Also a course feedback Web form was filled out at the end of the course. Feedback covers three main areas (1) course design and teaching methods, (2) the learner's self-evaluation and role in the course, and (3) the teacher's role in the course. There were 21 questions out of which 16 were open questions and five were multiple option questions.

Third, performance in IR learning environment covers learners' search sessions, i.e., performance feedback provided by the QPA on four exercises in the course. Student performance was analyzed with the following data: (a) the number of queries, (b) the number of search keys, (c) the average number of search keys per query, (d) qualitative evaluation of use of operators, truncation and field searching,

and finally (e) the overall efficiency of best queries based on precision/recall measures provided by the QPA (Halttunen 2003a, 2007).

Log files were gathered in several search exercise sessions. First, search sessions in the QPA were logged within the application. Log files were downloaded from the QPA and converted into spreadsheets. Second, the Dialog system was used in the last search exercise session for the performance assessment of IR skills. These sessions were logged with the aid of the search history of Dialog. Search histories were saved as HTML files and converted into spreadsheets.

Fourth, learning outcomes represent what a student knows and/or what she is able to do as a result of an educational experience. Learning outcomes indicate the change in the knowledge, understanding, skills, capabilities, and values that a student has gained by completing an instructional episode. In the present case, learning outcomes are evaluated on two levels. First, conceptual change is analyzed by comparing students' conceptions of IR know-how at the beginning and at the end of the course. At the end of the course the students were again asked to write an essay-type text on their conceptions of IR know-how in the same manner as at the beginning of the course. Second, the development of IR skills is analyzed by identifying improvement and errors in query formulation in 24 search sessions. The conceptual change consists of the introduction, modification, and neglect of concepts presented in student essays along with enrichment or revision of conceptual structures. The development of IR skills is based on an analysis of query formulation, error types, and effectiveness of queries (Halttunen and Järvelin 2005; Halttunen 2007).

5.6 Analysis of Evaluation and Feedback Data

IIR learning environment is evaluated at three levels: students' learning experiences, performance, and learning outcomes. In order to describe and analyze these different levels, several datasets were gathered as described earlier. The analytical methods for assessment and feedback and corresponding datasets are outlined later.

First, students' subjective learning experiences concerning the learning environment and the QPA are studied using the MEBS (Eskola 1988, 1998) and the course feedback questionnaire. Stories and course feedback were analyzed qualitatively by theme coding, categorization, and with the aid of matrices (Eskola 1998; Miles and Huberman 1994).

Second, student performance in the IIR learning environment was analyzed by assessing their search sessions both in terms of query construction and modification and the overall effectiveness of queries. Query construction and modification was analyzed with the scheme concentrating on (1) the construction of facets and the use of operators, (2) the use of truncation and masking, and (3) the use of field restrictions. The overall effectiveness of best queries of each student within the four exercises was measured by average precision and recall.

Third, learning outcomes were analyzed on two levels, namely, conceptual change and skills development. Conceptual change was assessed with essays and questionnaire. The essays were first analyzed through the phenomenographic approach (Marton 1988, 1994) in order to ascertain students' conceptions of IR and how it may affect the design of learning environment. These conceptions were also used as a baseline for the evaluation of learning outcomes. The analysis of the essays was based on a grounded theory approach, which is common due to the fact that phenomenography is clearly an approach, not a solid method, in the analysis phase (Richardson 1999). The teacher collected all the statements concerning conceptions of IR know-how from each essay and compared the statements between and within essays. In the analysis we were primarily looking for qualitative differences in the way in which students experienced the phenomenon of IR know-how. The evolving pattern of differences and similarities was then captured in a set of categories of description. The categories of description were again applied to the data, which resulted in modification of categories. Prior conceptions of information retrieval were also studied through the questionnaire, which presents VAS of different kinds of conceptions of IR. VAS results are based on the measurement of the point on an axis (0–6 cm). Measurements were categorized into six classes. Student learning benefits from activating prior conceptions. This activation may be used as an advance organizer for learning (Ausubel 1960). Student generated visual representations of IR systems serve well for this purpose (Hendry and Efthimiadis 2008).

Essays written at the beginning and end of the course were analyzed with the aid of concept maps. These maps describe the essence of concepts, and the number of, and connections between, concepts (Kankkunen 1999; Novak and Musonda 1991; Novak 1998). Though concept maps were introduced as vehicles for instruction, studying, and assessment in the situations where they are used by teachers or students, they can also be used as analytical methods by researchers in qualitative inquiry (Miles and Huberman 1994). Concepts referring to IR know-how were extracted and labeled in the essays, likewise the connections between concepts. Top-level concepts are identified within essays as new themes, which did not consist of examples or enriched definitions or descriptions of concepts presented earlier in the essay. Assessment framework for structure of observed learning outcomes (SOLO taxonomy) would also contribute to this approach (Biggs and Collis 1982).

The development of IR skills was analyzed with performance assessment criteria based on search-logs in an assessment situation during the last tutored exercises. This assessment was based on analyzing problems and errors in queries and the effectiveness of queries. A scoring scheme was devised for log-file analysis. It identified all possible errors, which students had made during each session. This raw data was categorized with the aid of previous research on interaction problems in IR and OPAC systems and knowledge types in human–computer interaction (see, for example, Borgman 1996; Shneiderman 1992; Sit 1998). Because of the instructional performance assessment we excluded several factors of previous studies of operational environments, for example, database selection and information need

formulation to search task, and concentrated on factors directly present in our learning assignments. The analysis scheme contains the following dimensions: (1) semantic and syntactic knowledge; (2) topical and functional knowledge.

5.7 Reflections on the Design, Evaluation, and Feedback

Writing an essay on prior conceptions of IR at the beginning of the course served as an orientation, and it created an interest in the topic at hand. In this way, writing assignments were used as advance organizers and as a means to bridge and activate prior knowledge and conceptions of the new area of study. Search histories were used to reflect the searching processes and to analyze errors in queries as natural phenomena. The second essay on conceptions of IR know-how was used as reflection and self-evaluation of student learning. Empathy-based stories and the course feedback questionnaire served as tools for course feedback and evaluation as well as instruments for self-reflection. The chosen approach to integrate evaluation and feedback data gathering as an integral part of learning activities seems to work well.

The design and evaluation of IIR learning environment in the present design experiment was highly intuitive but same at the same time innovative for at least two reasons. First, there were few published, available up-to-date models of IR instruction design and evaluation (see, e.g., Fernández-Luna et al. 2009; Lucas and Topi 2005). Second, the design experiment was implemented in a natural setting, with resources and tools available at the time in the course. The strength of the natural setting is the applicability of the pedagogical solutions. The pedagogical design was mainly based on the teacher's understanding of the central problems of IIR instruction, which they have encountered during their own teaching careers. The identification of a need for research and development was motivated by the research on conceptions of learning and learning environments. Anchored instruction was found to be a promising strategy to overcome the problem of decontextualized IIR instruction and ideas from scaffolding provided explicit tools to support learners in their information searching.

The evaluation of learning environment was based on various datasets, containing material on learning experiences, performance, and outcomes. Data gathering was integrated into course activities and also served as an instructional element itself, as described earlier. This approach was highly successful. After collecting and analyzing these datasets, the teacher could reflect the work done by following recommendations or reconsiderations for future: first, allocate more time for essay writing in order to activate prior conceptions. Visual tools and techniques are worth considering. Second, collect some performance data – for example, observations, texts, and interviews – to enrich the log data. Collaborative work by students should be used more and more. Third, develop data collection methods for evaluating learning outcomes. Weekly learning tasks and final examination could

be enriched with various ways to make learners work visible to colearners and tutors.

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