Navigational Paths and Didactical Patterns

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Investigations of E-Learning Patterns:

Context Factors, Problems, and Solutions

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Chapter 10
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ABSTRACT

This chapter focuses on a specific field of e-learning: the relationship between general didactical patterns to design teaching/learning processes on the one hand and empirical behavioral patterns of users (navigational paths) on the other hand. It is based on empirical research on the usage of a hypertextual on-line learning environment. The analyzed dataset consists of about 1500 paths containing about 4700 pages. These empirical navigational paths are analyzed in order to identify similar paths (patterns, structures and regularities), following a heuristic and inductive approach. This approach is based on the method of sequence analysis (optimal matching). The aggregation of similar paths into homogeneous groups will be discussed, as well as the identification of patterns within these aggregated groups. The inductively identified empirical patterns will be compared to deductive, theory-driven patterns. Empirical results will be presented which show the variety and complexity of empirical navigational paths and their relation to theory-driven patterns. These results will be located and discussed in a pedagogical-didactical context.

NAVIGATIONAL PATHS AND DIDACTICAL PATTERNS

This chapter refers to a specific field of e-learning: the empirical analysis of navigational processes in hypertextual on-line learning environments. As there is no predefined exclusive way to navigate a non-linear hypertext, navigation depends on the choices of every single user. The user is selecting specific links from a multiplicity of possible links (see Iske, 2002). This process of exploratory, self-directed navigation can be described as the linear unfolding of a non-linear hypertext (see Kuhlen, 1991, p. 33).

This linear unfolding will be focused as the relation between the structure of the learning environment on the one hand and the empirical navigational paths on the other hand.

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In the following the term "pattern" is used in a very general way according to every-day usage as specific regularities, i.e. in the sense of structural regularities of a wall-paper which form a specific "pattern". It is explicitly not used in the elaborated way proposed by Christopher Alexander (1979) as a method to describe, implement and evaluate design processes. More precisely I will refer to navigational paths (sequences) as behavioral patterns in hypertextual on-line environments, as a specific regularities and structures (see Baur, 2005, "Social Pattern Analysis"), which take into account a fundamental characteristic of acting: temporality.

- On the one hand, these temporal patterns refer to individual learners ("How do learner X acquire the learning environment? Which strategies of acquisition he uses?").
- On the other hand, on an aggregated level these temporal patterns refer to a group of learners ("How do group X acquire a learning environment? Which strategies of acquisition are used?").

The consideration of temporal aspects implies a specific perspective on learning: the perspective of the learner and the learning process – and not the perspective of a teacher and teaching processes (or a designer of a learning environment). From this perspective, patterns of usage are the complementary side of the structure of learning environments (which may be for example based on "design-patterns" described by Alexander): the navigational path is brought into focus.

In general, I am acting on the assumption that navigational paths in hypertextual learning environments:

- are not contingent, but contain specific patterns, structures and regularities within the action of learners (behavioral patterns);
- are an index for -implicit and explicit- strategies of learners. In this respect, navigational paths reflect a specific "habitus" which according to Bourdieu (1993) can be characterized as structured structures predisposed to function as structuring structures;
- refer to a specific context, in this case: to a specific hypertextual learning environment as the context of these navigational strategies.

Therefore, the analytical focus is on general processes of acquisition and not on processes of designing on-line learning environments by means of "design patterns" (see Kohls / Wedekind, 2008). In contrast to Alexander (1979) it can be stated that this approach does not focus on the documentation of "design patterns" but on the empirical interaction with these "design patterns" by real users, i.e. on "navigational patterns".

The analysis of navigational patterns as usage patterns gain in importance, especially in the context of standardization in e-learning (see IMS Global Learning Consortium) and the identification of "Learning Design Patterns". According to Koper (2006) this kind of analysis poses a crucial challenge for research: "The idea of learning design patterns and the possibility to recognize them automatically with pattern detection algorithms is a new field of work that is worthwhile to elaborate in future." (Koper, 2006)[1].

Currently this identification and documentation of patterns is conducted following either a deductive or an inductive approach (vgl. Brouns u.a., 2005): Following the deductive approach, patterns are developed by experts (see 'Instructional Design', Reigeluth, 1999), whereas the inductive approach analyses the didactical structure of learning environments or online-courses – in the majority of cases "best-practice-scenarios" - in order to identify and to extract empirically approved solutions for recurrent problems.

The methodological approach described in this chapter is to analyze navigational paths by means of optimal matching (with subsequent cluster analysis) and therefore refers to an inductive approach. But it is extending the inductive approach essentially: not alone the structures rather the usage of structures is the main analytical unit of analysis – "learning patterns" are focused, and not primarily "teaching patterns".

This chapter falls into 4 parts: (1) Data collection and data set, (2) applied methods, (3) empirical results and (4) summing up conclusions.

DATA COLLECTION AND DATA SET

Generally the usage of on-line learning environment often documented automatically by server-sided log files (documents requested by a specific user from a server). These log files are a specific form of transcription of the user – on-line environment interaction. But in contrast to widespread analysis of log file data, the following analysis is not based on aggregated but on sequenced log file data. This means that the temporal information of the succession of visited pages is documented and analyzed. This succession of visited pages represents the navigational path of each user. Within the scope of this chapter, only a small part of the overall data set is analyzed, which documents the navigational processes in four specific learning units ("Lerneinheiten") of the learning environment, which all belong to the field of descriptive statistics (measures of central tendency). The analyzed learning environment is structured in a specific way according to the didactical ontology of Web-Didaktik (Meder, 2006); the content as well as the links is typified by didactical metadata.

Figure 1 illustrates the structure and layout of *lerndorf* as the analyzed hypertextual on-line learning environment[2]. On the left hand side, a table of content is located (navigational tree). The right hand frame contains the content and above this content-frame different knowledge units are located (from left to right: "orientation", "action", "explanation", "resources", "exercise", "discovering exercise" and "discussion" as the descriptors of the didactical ontology), which are related to specific learning unit (in this case the learning unit "measures of central tendency". The analyzed navigational path refers to the choice of knowledge units within a learning unit (micro-navigation).

Users accessed the learning environment over the Internet, so the data represent actions of users in authentic situations. This form of data collection is characterized as unobtrusive, detailed, objective and non-reactive (see Web, Campbell, Schwartz, Sechrest, 1966)]. In contrast to forms of retrospective data collection (i.e. interview, questionnaire) it is characterized as process-generated data (see Bergmann, 2000).

The resulting data set consists of about 1500 paths (sequences) containing about 4700 pages (knowledge units) and is based on usage data of the hypertextual on-line learning environment over the period of about one year (06/2005 – 06/2006).

Table 1 illustrates the data set and shows the number of knowledge units which are contained in each learning unit as well as the number of sequences, the number of elements within these sequences and the average length of these sequences. In general, the length of the analyzed sequences vary form 1 to 24 elements and consist of the combination of 8 distinct elements (knowledge units, see Figure 1).

METHODS

Two different methods were used to analyze the described data set. First, the sequences of the data set are analyzed by quantitative descriptive statistics: Frequencies of sequences, frequencies of elements as well as frequencies of identical sequences are calculated.

Second, navigational sequences (paths) where analyzed in order to identify similar paths (patterns, structures and regularities), following an

Figure 1. Screenshot: Learning unit "measures of central tendendy"; www.lerndorf.de)

Table 1. Data set (overview)

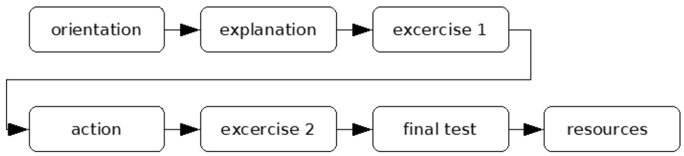
	learning unit 513	learning unit 515	learning unit 516	learning unit 517	total
Number of "knowledge units"	8	8	9	8	8,25
Number of sequences	1542	1638	602	896	4680
Number of elements	475	526	212	309	1522
Average length of sequences	3,25	3,11	2,84	2,90	3,07

heuristic and inductive approach. This approach is based on the quantitative approach to sequence analysis and is called Optimal-Matching (see Sankoff / Kruskal, 1983; Abbott / Forrest, 1986; Baur, 2005). The transfer and application of sequence analysis by means of optimal matching in the field of e-learning is described in more detail in Iske (2007, 2008).

The initial questions of optimal matching analysis are: How can similarities of sequences be detected? And how can the degree of similarity be defined? First of all every sequence of the data set is compared pairwise to every other sequences. Similarity is defined by the number of operations which are needed to align every two sequences. Valid operations for alignment are to insert, delete or substitute elements of the sequences. The fewer operations are needed for alignment, the more similar are the compared sequences. The lowest number of operation which are needed for alignment result in a measured value called Levensthein-Distance (Levenshtein, 1966).

Based on this Levenshtein-Distance, sequences of the data set are sorted by similarity using

Figure 2. Classical design - explanation driven (Web-Didaktik, Meder 2006)



methods of cluster analysis (more specific: the cluster algorithm developed by Ward). A 28 cluster solution was identified as most appropriate to the data set, as regards interpretation of content and form. The resulting 28 cluster of homogeneous sequences were described and interpreted (Figure 2).

Finally these clusters were compared to theory-driven learning strategies as described in Web-Didaktik (Meder, 2006). Basically, Web-Didaktik represents a specification of General Didactics facing the conditions of the hypertextual structures of the World Wide Web and refers to a long lasting didactical tradition of structuring knowledge and learning / teaching processes. Web-Didaktik is based on a didactical ontology, i.e. knowledge units and their relations are typified by didactical metadata. This knowledge of learning and teaching processes is documented as specific strategies (micro-strategies), as general didactical patterns, which will be compared to empirical navigational paths. Strategies covered by Web-Didactics are for example: theory-driven strategy; rule-driven; example-driven; exploratory design; assignment-oriented; example-oriented; orientation only; goal-based scenario.

RESULTS

In this chapter, results of the analysis of navigational paths are outlined: First the analysis of identical sequences by means of descriptive statistics. Second the analysis of similar sequences by means of optimal matching.

Descriptive Statistics: Identical Sequences

In the following section, results of the analysis of navigational paths will be presented, which result from quantitative descriptive statistics: the most outstanding result is the plurality and heterogeneousness of navigational paths. From a mathematical point of view, these navigational paths are based on a combination of 8 (respectively 9) different elements, whereas these elements can be selected several times. Table 2 illustrates the results of the analysis of identical navigational paths. The first row refers to the length of the sequence (i.e. the number of elements). Row 5 to 6 refer to different analyzed learning units. Numbers in the different cells refer to the number of identical sequences: for example, learning unit 513 contains 8 different types of identical sequences (all of a length of 2 elements). The figures in brackets ("[4/2/6/10/6/7/6/7"]) refer to the number of identical sequences: Learning unit 513 contains 8 groups of respectively identical sequences; the first group contains 4 similar sequences, the second group contains 2 similar sequences, the third group contains 6 similar sequences and so on.

Additionally, one overall characteristic of the data set has to be considered: it contains the navigational paths of users, who were following a guided tour (as a predefined succession of elements, which is implemented in the learning environment). Navigational paths which were caused by this guided-tour are marked by a circle.

Table 2. Number of identical sequences (overview)

	Number of identical sequences			
length of sequence (elements)	learning unit 513	learning unit 515	learning unit 516	learning unit 517
2	8 [4/2/6/10/6/7/6/7]	11 [2/5/5/6/6/18/7/2/10/2/2]	12 [11/2/5/2/4/2/3/4/2/5/5/9]	6 [7/4/6/3/5/6]
3	5 [3/2/4/4/2]	9 [2/2/2/2/2/3/4/2/5]	2 [2/3]	2 [3/2]
4	2 [2/3]	3 [3/2/2]	1 [2]	4 [3/2/2/2]
5	3 [2/3/5]	2 [2/2]	2 [2/2]	-
6	1 [4]	2 [2/3]	-	-
7	2 [3/2]	3 [2/3/9]	-	1 [3]
8	1 [4]	-	-	-
9		-	1 [5]	-

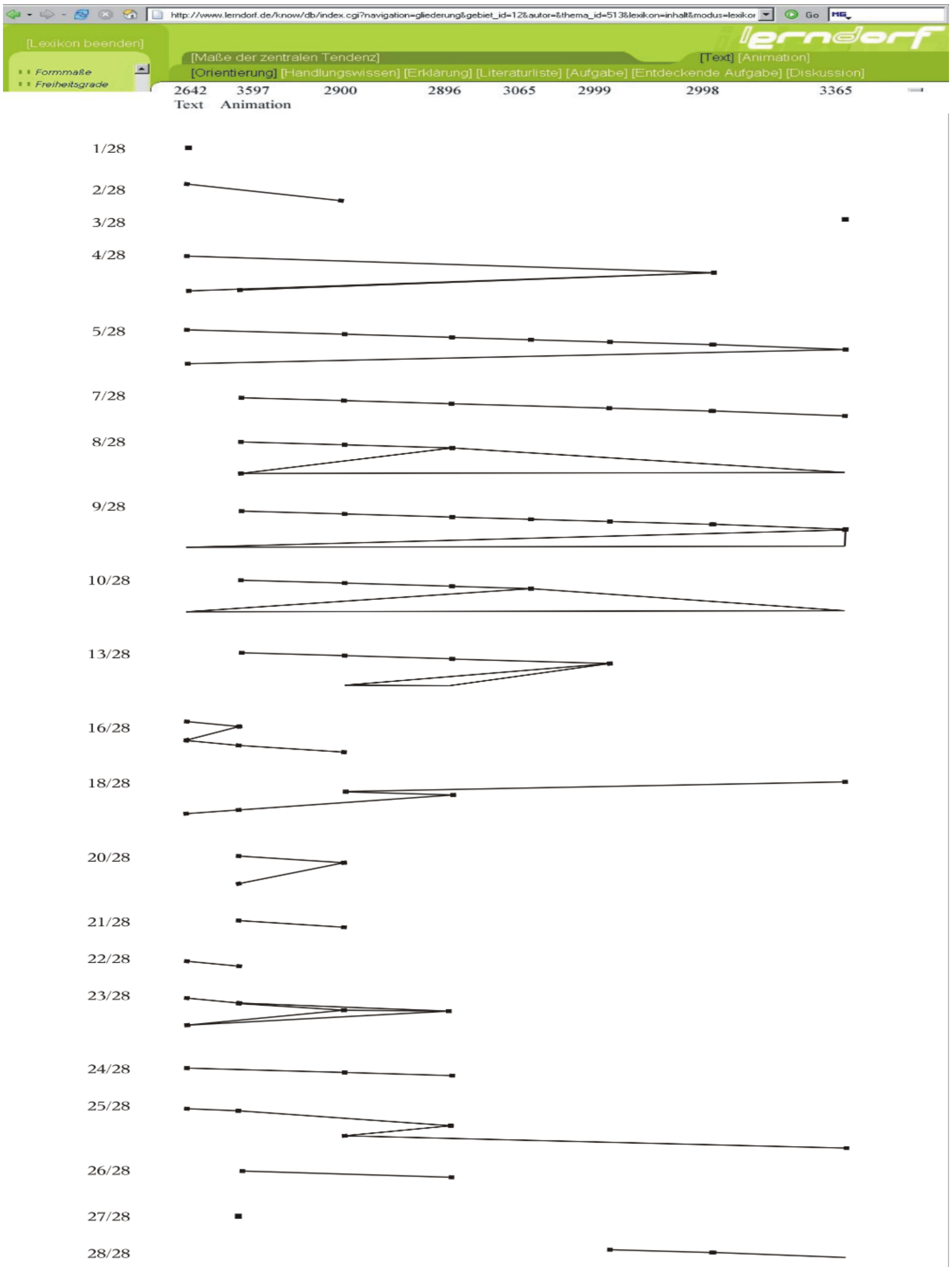
Sequence Analysis: Similar Sequences

In the following section, results of the analysis of navigational paths will be presented, which result from sequence analysis by means of optimal matching in combination with cluster analysis. The interpretation is based on the typical succession of the elements of the navigational path (as regards formal aspects like the layout of the learning environment) as well as on the didactical metadata (as regards content).

As a result of optimal matching analysis and cluster analysis, homogeneous groups of navigational paths are identified, which contain the following patterns (see Figure 3: Navigational patterns: Learning unit "measures of central tendency" (28 cluster solution)). The cluster typical navigational sequence are represented graphically in relation to the specific learning unit. The left column indicates the membership to a specific cluster of a 28 cluster solution. The right row illustrates the typical succession of knowledge units. Black dots symbolize visited knowledge units. A continued heterogeneous succession of knowledge units is symbolized by a triangle (see Figure 3, for example 10/28, 13/28). Several different behavioral patterns were identified:

- *Linear and non-linear navigational paths:* In regard to the graphical composition of the learning environment (layout, see Figure 1), linear navigational strategies can be distinguished from non-linear strategies: Linear strategies follow the layout of the learning environment (i.e. navigating from "left-to-right" or "top-down" in a navigational bar), whereas non-linear strategies diverge from layout and access specific knowledge units directly.
- *Focusing on specific knowledge units:* Clusters were identified, where navigation dominantly (and/or repeatedly) focuses on a specific knowledge unit.
- *Number of elements of cluster sequences:* the length of a sequence as the number of elements has a crucial impact on the particular calculation of the Levenshtein-

Figure 3. Extraction of navigational patterns: Learning unit "measures of central tendency" (28 cluster solution)



Distance and on the result of cluster analysis. Therefore a fundamental characteristic of each cluster is the typical length of sequence. Basically, clusters can be described by their number of sequence elements (one element, two elements, three and more elements).

- ***One-element-sequences.*** A significant number of identical sequences of each cluster are sequences with only one element (one-element-sequences) within a specific learning unit. Although these paths do not represent a sequence in a classical meaning ("succession of at least 2 elements"), these sequences are part of a parent navigational path concerning the navigation between learning units (macro-navigation). In this case for example one-element-sequences are part of the strategy "overview". For analyzing navigational paths within the learning units, these one-element-sequences are excluded from further analysis.
- ***Two-element-sequences.*** Two - element - sequences are composed of one starting element "orientation" and one additional element. This strategy can be described as a strategy of "selective" or "targeted consulting".
- ***Three-and-more-element-sequences.*** Navigational sequences consisting of three and more elements can be described as strategies of "exploration and examination".

In addition to these formal strategies, the following strategies regarded as general didactical patterns are identified as homogeneous clusters: example-focused strategies (orientation – example – et al.); assignment-focused strategies (orientation – assignment – er al., see Figure 3, 4/28); explanation-focused strategies (orientation – explanation – et al., see Figure 3, 23/28).

To outline the potential of optimal matching analysis, even more detailed navigational strategies were identified as homogeneous clusters: This potential can be demonstrated using the example of "left-to-right" navigational strategies. This strategy varies in several aspects, which are identified as specific homogeneous clusters: "left-to-right" navigation:

- *without* skipping of elements and without continued navigation within the learning unit,
- *without* skipping of elements and with continued navigation within the learning unit (see Figure 3, 9/28),
- *with* returning to the starting point within the learning unit (see Figure 3, 5/28),
- *without* returning to the starting point within the learning unit,
- *with* skipping of elements but without continued navigation within the learning unit (see Figure 3, 7/28),
- *with* skipping of elements and with continued navigation within the learning unit.

Additionally to this "left-to-right" navigation and its variations, which are oriented at a linear navigational strategy, there are manifold strategies with non-linear, direct access to knowledge units. The efficiency of optimal matching to identify detailed and homogeneous groups of similar sequences become especially apparent concerning differentiated cluster solutions for these navigational patterns. To sum up, the following patterns are grouped in the different clusters.

- "orientation" - "action" - "explanation" as a 3-element sequence.
- "orientation" - "action" - "explanation" with continued navigation in terms of
  - "resource" and other heterogeneous successions of knowledge units,

- "example" without continued navigation as a 4-element sequence,
- "example" with continued navigation, i.e. in terms of "action" or "test (multiple choice)"
- "test" with continued navigation, i.e. in terms of "explanation" or "action"

Besides these cluster solutions, which can be interpreted from a formal or a content-related point of view, there are several clusters where a strategy is not that obvious and therefore can not be related directly to a theory-based pattern. This is especially true for long sequences (more than 5 elements). Further research is required to analyze these specific navigational paths.

CONCLUSION

The described methodological approach of sequence analysis (optimal matching) in combination with cluster analysis is a new and highly productive approach to analyze navigational paths in on-line learning environments. Considering the temporality of acting in hypertextual learning environments, this methodology enables the inductive identification of patterns, structures and regularities within navigational paths of users.

But in contrast to the identification and documentation of "design-patterns", the described results refer to the empirical analysis of "learning-patterns" as clustered behavioral patterns of users in the context of a specific hypertextual environment (which is based on the didactical ontoly of Web-Didaktik, see Meder, 2006).

One overall aim of analyzing "learning-patterns" from a didactic-pedagogical perspective is to facilitate "didactical diversity" (Flechsig, 1996) concerning different ways of interacting with learning environments as well as processes of acquisition. The importance of this "didactical diversity" is emphasized by the heterogeneousness of empirical navigational paths: There is no single "golden" navigational path, which is appropriate to all learners. Furthermore, the same hypertextual environment is used in very different ways: Several formal and content-related "learning-patterns" were described as learning strategies, which were identified as homogeneous groups of similar navigational paths. Nevertheless the learning environment represents a space of possibilities concerning navigation. But it is extremely difficult to infer empirical usage processes from structure alone: a space of possibilities is neither a perceived not a realized space. On the other hand, the described methodology documents empirical usage patterns, which can be compared to intended usage patterns. In this perspective, the usage of "behavioral patterns" can be analyzed in order to evaluate a "design-pattern" (in the sense of Alexander) as "best-practice" or as a "proven solutions" to a recurrent problem – especially in the field of e-learning, where it is extremely difficult to keep an eye on learning processes.

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ENDNOTES

1 It is important to note that Koper refers to the term "design patterns" in a different way than Alexander. Following the concept of Alexander, "design patterns" are hardly – if anything - to be recognised automatically.

2 http://www.lerndorf.de, (10.06.2006).