Tracing knowledge co-evolution in a realistic course setting: A wiki-based field experiment

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Abstract

The co-evolution model of collaborative knowledge building by Cress & Kimmerle (2008) assumes that cognitive and social processes interact when users build knowledge with shared digital artifacts. While these assumptions have been tested in various lab experiments, a test under natural field conditions in educational settings has not been conducted. Here, we present a field experiment where we triggered knowledge co-evolution in an accommodation and an assimilation condition, and measured effects on student knowledge building outside the laboratory in the context of two university courses. Therefore, 48 students received different kinds of prompts that triggered external accommodation and assimilation while writing a wiki text. Knowledge building was measured with a content analysis of the students’ texts and comments (externalization), and with concept maps and association tests (internalization). The findings reveal that (a) different modes of externalization (accommodation and assimilation) could be triggered with prompts, (b) across both conditions, this externalization co-occurred with internalization (student learning), and (c) there is some evidence that external assimilation and accommodation had differential effects on internal assimilation and accommodation. Thus, the field experiment supports the assumptions of the co-evolution model in a realistic course setting. On a more general note, the study provides an example of how wikis can be used successfully for collaborative knowledge building within educational contexts.

Keywords: cooperative/collaborative learning; distributed learning environments; interactive learning environments; teaching/learning strategies
1. Introduction

Social media, such as wikis, weblogs or social networking tools have been widely used to support learning in educational settings (Bennett, Bishop, Dalgarno, Waycott & Kennedy, 2012; Alexander, 2006; Dron, 2007; Bonderup Dohn, 2009; Kang & Glassmann, 2011). In particular, there is great potential to employ social media for collaborative knowledge building (Scardamalia & Bereiter, 1994), a form of learning that stresses the active, social and constructive character of learning (Larusson & Alterman, 2009; Cacciamani, Cesareni, Martini, Ferrini & Fujita, 2012). Specifically, wikis have been popular means to apply novel teaching methods in classrooms (e.g., Barry, 2012; Biasutti, 2011; Everett, 2011; Heafner & Friedman, 2008; Ioannou, 2011; Larusson, & Alterman, 2009; Naismith, Lee & Pilkington, 2011; Pifarré & Kleine Staarman, 2011; Wheeler, Yeomans & Wheeler, 2008), albeit with mixed success (Cole, 2009).

To describe social and cognitive processes that take place during collaborative knowledge building with shared digital artifacts such as wikis, Cress & Kimmerle (2008; see also Kimmerle, Cress & Held, 2010) suggested a co-evolution model. The basic assumption of the co-evolution model is that individual cognitive structures co-evolve with the information that is documented in a shared digital artifact. The cognitive structures are modified as a result of internalization of knowledge (by processing information from the shared artifact), and the information that is documented in the shared artifact is modified through externalization of knowledge (from the cognitive system). While in knowledge building research significant theoretical (e.g., Stahl, 2002) and methodological (e.g., Suthers, Dwyer, Medina & Vatrapu, 2010; Suthers & Medina, 2011) progress has been made in looking at artifact-mediated collaborative learning processes in the field of educational practice, the co-evolution model offers a distinct contribution in that it looks at how cognitive and social processes mutually influence each other.
The co-evolution model has been developed based on exploratory evidence from the online-encyclopedia Wikipedia (Cress & Kimmerle, 2008; Kimmerle, Moskaliuk, Bientzle, Thiel, & Cress, 2012), and has since provided the basis for a number of experiments under laboratory conditions (e.g., Kimmerle, Moskaliuk & Cress, 2011; Ley, Schweiger & Seitlinger, 2011; Moskaliuk, Kimmerle & Cress, 2009, 2012). However, to investigate the interplay of cognitive and social processes, a setting is needed that allows collaborative growth and development of knowledge to emerge naturally from a social, artifact-mediated interaction. Therefore, the aim of this paper was to investigate knowledge co-evolution in a realistic course setting in an educational context. In such a setting and in the context of students’ typical learning activities, would it be possible to trigger external accommodation and assimilation (in the wiki)? And, if so, what would be the effect on the internalization that would take place (in the cognitive systems of the individuals)?

To answer these questions, we designed a rigorous field experiment and compared an accommodation and an assimilation condition. We gave learners the opportunity to interact with each other over a two week period in a relatively unconstrained manner. The experiment was part of two university courses where dyads of students had to accomplish a collaborative wiki writing task during two weeks allowing us to trace co-evolution in a realistic field setting. We expected that students in the accommodation condition would show more external accommodation than students in the assimilation condition, and vice versa. Following the assumptions of the co-evolution model, this should also have an impact on the internalization of knowledge: different forms of externalization should co-occur with different forms of internalization.

The paper is organized as follows. We briefly introduce the co-evolution model and present findings from previous studies. We then highlight challenges for measuring external and internal accommodation and assimilation, especially in a realistic educational setting in the field, and suggest approaches to tackle these challenges. Afterwards, we present the
2. The co-evolution model of knowledge building

2.1. Basic assumptions of the co-evolution model

Following a constructivist tradition, the co-evolution model suggested by Cress & Kimmerle (2008) posits learning as an active construction of knowledge. The co-evolution model builds on Luhmann’s system theory of social systems (1995), and views individual learning and collaborative knowledge building (e.g., Scardamalia & Bereiter, 1994) as two interrelated processes: When people construct knowledge through shared digital artifacts, individual learning processes mutually influence each other (see also Kafai, 2005; Scardamalia & Bereiter, 1994). One main assumption of the co-evolution model is that knowledge documented in the artifact co-evolves with knowledge in the cognitive systems of the individual contributors.

Internalization and externalization, then, build the basis for the co-evolution of knowledge. Externalization is the activity by which people communicate their knowledge; that is, they introduce some information that corresponds to what they know into the shared digital artifact. Internalization is a cognitive activity by which people process information from the shared artifact, and as a result integrate some new pieces of information into their own cognitive structures; that is, they learn. Applying Piaget’s (1977, cf. Miller, 2010) ideas to the co-evolution model has led to its second main assumption: According to Piaget, individual learning is triggered by a cognitive conflict that results from a incongruity of information encountered in the external world and the prior knowledge of a person. To resolve the cognitive conflict, individuals may either assimilate new information to any prior knowledge, or they may modify some existing knowledge to accommodate new insights. The co-evolution model assumes that this distinction of cognitive processes (i.e., during experimental setup, methods and operationalizations, and report the findings separately for externalization and internalization processes. We then draw conclusions on the co-evolution model and our methodology, and discuss pedagogical implications of our work.
internalization) can similarly be observed in the process of externalization: External assimilation occurs when information is introduced into an artifact (e.g., a wiki article) that does not change the organization of the artifact, its structure and general line of argumentation. External accommodation takes place when the organization of the artifact is changed to accommodate the newly introduced information, for example, by integrating information which modifies, improves or corrects the argumentation (see also Majchrzak, Wagner, & Yates, 2006).

The co-evolution model assumes that accommodation and assimilation both occur within the cognitive system, as well as in the artifact that is collaboratively created by users of the social software. Similar arguments have been made by Fu (2008) who assumes that artifacts created in the use of social software can lead to changes in cognitive schemas.

2.2. Field evidence of the co-evolution model

The development of the co-evolution model was based on exploratory field evidence (Cress & Kimmerle, 2008; Kimmerle, Moskaliuk, Harrer & Cress, 2010; Kimmerle et al., 2012). Cress & Kimmerle (2008) analyzed external assimilation and accommodation within two articles of the online-encyclopedia Wikipedia. They compared different versions of the text to illustrate the development of a text from a first idea that was brought in, reformulated and finally integrated in the text. Methods based on social network analysis (e.g., Wassermann & Faust, 1994) were also used to examine the mutual development of cognitive and social systems. In another exploratory study, Kimmerle et al. (2010) analyzed a set of Wikipedia articles and described the development of the artifact network. They found a similar development of the authors’ clustering (derived from a content analysis of the articles they were working on) and the clustering of the network (measured by the link-structure of the network), and interpreted their findings as indicators for the mutual development of the cognitive system of the authors and the artifact network. Because the study was based on an
analysis of modifications of ‘real’ Wikipedia articles, a limitation of these findings is that no
direct measure of internalized knowledge could be employed.

2.3. Laboratory studies building on the co-evolution model

The limitation of directly measuring internalized knowledge has been overcome in
several empirical investigations under laboratory conditions to understand the mechanisms of
coevolution. Moskaliuk et al. (2009), Kimmerle et al. (2011), and Moskaliuk et al. (2012)
focused on the incongruity between prior knowledge and information presented in a wiki as
trigger for internalization and externalization and manipulated different aspects of the
incongruity. In these studies, participants had to work with a wiki, and were instructed to
introduce their own prior knowledge and improve the text. In the first study, to examine
externalization, information available in a wiki was manipulated and the prior knowledge of
the participants was held constant (Moskaliuk et al., 2009). The results confirmed that a
medium level of incongruity (compared to low and high levels of incongruity) between own
prior knowledge and information available in a wiki leads to individual learning and
collaborative knowledge building. To examine internalization, information available in a wiki
was held constant and the prior knowledge of the participants was manipulated in a second
study (Kimmerle et al., 2011). The results showed that a medium incongruity between prior
knowledge and information in the wiki triggered external accommodation. Two further
studies focused on the redundancy and the polarity of prior knowledge and information in a
wiki as two aspects of incongruity (Moskaliuk et al., 2012). The redundancy supports
participants to find connecting points between prior knowledge and information available in
the wiki, and leads to an integration of the different arguments in the text. This resulted in
more external accommodation. The polarity activates people to add their own contradicting
arguments in order to reach a balanced text. This also resulted in more external
accommodation.
In these laboratory experiments, the authors found that incongruence would trigger different modes of externalization (accommodation and assimilation), and that different modes of externalization would result in different modes of internalization. This finding is also backed by a study of Ley et al. (2011), who found preliminary evidence that incongruence of the information in the artifact and the knowledge of a participant leads to internal accommodation and assimilation, and that these processes can be detected by different knowledge measures. In their study, cognitive conflict was triggered by different exercises that matched or did not match what participants had encountered in the wiki, thereby triggering participants to assimilate or accommodate. When later asked to externalize their knowledge (by drawing concept maps and performing an association test), the externalized structures were different in the assimilation and the accommodation conditions.

So far, these experimental studies have mainly focused on individual aspects of internalization and externalization. To investigate the interplay of cognitive and social processes, however, a setting is needed that allows natural collaborative interaction and long-term knowledge building. Such a situation can hardly be achieved within the laboratory, and a more realistic setting is needed. In the study described in this paper, it was our aim to investigate knowledge co-evolution in such a realistic field setting.

The questions we were posing at the outset of our study were: If users collaboratively work on a digital artifact in a realistic field setting, can we trace knowledge co-evolution in the artifact and the cognitive structures? More specifically, can we evoke external accommodation and assimilation? Will we find evidence that externalization leads to internalization of knowledge? And finally, does external assimilation of knowledge in the wiki co-occur with internal assimilation, and external accommodation with internal accommodation? These questions also have implications for educational practice. If it is possible to trigger different cognitive processes, this would offer ways to achieve specific learning effects according to educational objectives.
2.4 Triggering co-evolution

With regard to practical relevance in educational contexts, the co-evolution model suggests that different modes of externalization (accommodation versus assimilation) will trigger different modes of internalization. Hence, the question arising at this point is how to trigger different types of externalization in a field setting. While under laboratory conditions different extent and modes of externalization were triggered by strictly controlling the information that was given to the participants (see e.g., Kimmerle et al., 2011; Ley et al., 2011; Moskaliuk et al., 2009, 2012), this is not possible in the field. To evoke different modes of externalization (accommodation and assimilation) we thus decided to use accommodation and assimilation prompts. Prompts are short requests that ask leaners to process learning materials with specific strategies (Renkl, 2005), and they are commonly used to guide learning in a pedagogical context. Research has shown that prompting for certain processing strategies has an impact on internal learning: For example, prompting self-explanation leads to higher learning outcomes (Atkinson, Renkl & Merrill, 2003; Schworm & Renkl, 2007).

2.5 Measuring external and internal accommodation and assimilation

External accommodation and assimilation can be measured by analyzing the textual ‘output’ of the co-evolution process in the shared artifact; that is, modifications of the wiki text. Measures of external accommodation and assimilation that have been employed in the past include content analytical approaches that result in an accommodation index, and a measure of word count that is interpreted as assimilation index (Moskaliuk et al., 2009, 2012; Kimmerle et al., 2011). Content analytical measures are applicable also in a field setting. In contrast, using word count as a metric would require that the total time of wiki editing can be held constant for all participants; this, however does not seem possible in a field context where collaborative wiki writing is a long-term activity over several weeks.

While internalization of knowledge can be measured by knowledge gain (i.e., learning), distinguishing internal assimilation and accommodation seems more challenging.
Research on co-evolution used traditional knowledge tests to measure the increase in factual knowledge (e.g., Moskaliuk et al., 2012), or factual and conceptual knowledge (e.g., Kimmerle et al., 2011; Moskaliuk et al., 2009). Such tests, however, are only possible if the knowledge that the participants ought to acquire during the co-evolution phase can strictly be controlled.

For the field experiment, we therefore needed alternative measures of internalization. Specifically, to distinguish internal accommodation and assimilation, measures of internalization should also allow us to differentiate modifications in knowledge structures that resulted from the two modes of internalization. To measure the extent of internalization, and to distinguish modifications in knowledge structures that are due to accommodation and assimilation, in their experiment in the laboratory, Ley et al. (2011) used concept maps (e.g., Novak, 1972, 1998; Ruiz-Primo, 2000; Ruiz-Primo and Shavelson, 1996), and word association tests (e.g., Meyer, 2007, Jonassen, Beissner & Yacci, 1993). These measurements are basically also applicable in settings where the prior knowledge of the participants as well as the information which they process during the experiment cannot be controlled.

2.5.1 Measuring the extent of internalization and distinguishing different modes of internalization with concept maps

Concept maps are assumed to be visual representations of explicit cognitive structures in a certain topic of interest (e.g., Ruiz-Primo, 2000). Concept maps consist of nodes and links, where nodes represent ‘concepts’, and links represent ‘relations’ between these concepts. Two concepts linked by a relation correspond to one proposition, for example, “Wikipedia is an encyclopedia”. The count of concepts in the concept map is a simple measure for the amount of concepts the learner knows in the domain. An increase in the number of concepts of the concept map therefore may serve as an indicator for the extent of internalization.
According to Hay (2007, see also Hay, Kehoe, Miquel, Hatzipanagos, Kinchin, Keevil et al., 2008), the more nodes in a concept map that are linked through meaningful links, the better a person’s understanding of the topic of interest. Hence, an increase in the number of interconnected links in a concept map may also serve as an indicator for internalization.

Besides measuring the extent of internalization, studies suggest that concept maps also measure structural knowledge that is not accessible by conventional test (Ifenthaler, Masduki & Seel, 2009; Markham, Mintzes & Jones, 1994; Wallace & Mintzes, 1990). In line with preliminary findings by Ley et al. (2011), we thus assume that concept maps allow a distinction between internal accommodation and assimilation.

According to the assumptions of the co-evolution model, internal assimilation means quantitative changes in the cognitive structure. When measuring internalization with concept maps, as found by Ley et al. (2011), we would therefore expect the number of concepts to increase to a larger extent in an assimilation condition than in an accommodation condition. In contrast, internal accommodation means that there are qualitative changes to the cognitive structure. In the concept map, internal accommodation should become visible through structural changes of concept maps: an increase in the number of links should be more pronounced in the accommodation condition as compared to the assimilation condition.

2.5.2 Measuring different modes of internalization with an association test

The word association test (e.g., Jonassen et al., 1993; Meyer, 2007) is a second method that is applicable in a field setting, which has previously been used to distinguish internal accommodation and assimilation (e.g., Ley et al., 2011). This test elicits implicit knowledge about concepts underlying verbal representations (DeDeyne & Storms, 2008). Subjects are presented with stimulus words and asked to write down all associations coming to their mind.

By counting the number of associations, the test informs about the strength of representation of concepts in memory represented by the stimulus words (Weldon & Coyote, 1996; Ley & Seitlinger, 2010). This view is based on the conception of retrieval from memory
as a spreading activation mechanism (Anderson, Bothell, Byrne, Douglass, Lebiere, & Qin, 2004; Collins, & Loftus, 1975): The better a concept has been learned, the stronger is its base activation in memory, and the more activation it passes to associated concepts. Hence, the number of associations per stimulus serves as a measure of associative strength of a stimulus. In other words, the strength of association (as measured by the number of associations produced for a stimulus) does not indicate how much has been internalized but how well a certain concept has been internalized. Ley et al. (2011) found an interaction effect for the mean number of associations per stimulus: Persons in the assimilation condition showed an increase in the number of associations while no such increase was observed in the accommodation condition. This may be explained by the fact that assimilative processing of information (i.e., integrating new knowledge into existing structures) reinforces the strength of association in existing structures while accommodative processing modifies existing cognitive structures.

Another way to look at structural changes of students’ associative knowledge structures with a word association test is observing the co-occurrences between associations. Co-occurrences of associations mean that different stimuli produce the same responses. For example, if the stimuli “house” and “building” produce the same associations (e.g., “living”, “room”), then associations are said to “co-occur” across the two stimuli, and these two stimuli are assumed to be semantically related. Ley et al. (2011) found a tendency for a structural effect in distinguishing internal assimilation and accommodation based on co-occurrences (measured as the density of the overall network of co-occurrences). This preliminary finding of different processing modes (accommodation and assimilation) leading to different effects with regard to co-occurrences of associations can be explained with the distinction between relational processing and item-specific processing of information (Mulligan, 2012). While in assimilation, relational processing may be dominant which focusses on features shared by items; in accommodation, we assume to find item-specific processing which focusses on
differences between items and features unique to an item. Processing that focusses on features shared by items should lead to an increased number of co-occurrences, while processing that focusses on features unique to items should not. Because of these assumptions, internal assimilation should become visible in an increase of co-occurrences of associations.

3. Hypotheses

To sum up from the previous sections, we propose the following hypotheses with regard to knowledge co-evolution in our field experiment:

_Hypothesis 1:_ Different types of prompts should trigger different types of externalization. Participants who receive accommodation prompts should show more external accommodation in a wiki than participants who receive assimilation prompts and vice versa.

_Hypothesis 2:_ Writing in a wiki (externalization) should lead to a general increase of knowledge (internalization), regardless of whether the dyads received accommodation or assimilation prompts. This should become visible in an increased number of concepts and links in concept maps.

_Hypothesis 3:_ Different modes of externalization should come along with different modes of internalization. Participants who receive accommodation prompts should show more internal accommodation than participants who receive assimilation prompts and vice versa. This should become visible in interaction effects both in the number of concepts and links in concept maps, and in the number of associations and co-occurrences in word association tests.

4. Method

4.1 Design

A 2x2 field experiment with the between-subjects factor _experimental condition_ (accommodation vs. assimilation) and the within-subjects factor _time_ (pre-test: t1; post-test: t2) was designed to research knowledge co-evolution in a realistic course setting. The experiment was conducted as part of two regular university courses on similar topics running
in parallel, one in Austria and one in Germany. The students were paired up in dyads and randomly assigned to two experimental conditions, the assimilation condition and the accommodation condition. As dependent variables we measured external accommodation and assimilation with content analytical methods, and internal accommodation and assimilation with concept maps and a word-association test (both administered as pre- and post-tests).

4.2 Participants and dyads

48 graduate students of Psychology participated in the study as part of their courses, 24 from Austria (20 females), and 24 from Germany (22 females). Collaboratively writing the wiki article was required for the students to successfully complete the course, however, for ethical reasons the quality of the article was later not taken into account for the students’ grades. For the purpose of the collaborative writing task, 24 dyads were randomly created which always consisted of one student from Germany and one student from Austria. In order to maintain the field character of the study and ensure a maximum of ecological validity, the students were not told that they were participating in an experiment. For this reason, no additional demographic data (e.g., age, experience with social media etc.) was collected before the experiment. After the experimental phase, the students were de-briefed and told that they could withdraw their data from the experiment without any harm to their final course grades. None of the students withdrew from the experiment and none withdrew their data.

4.3 Wiki-software

For the course, we used the wiki-software MediaWiki 1.16.2 and created individual user accounts for all participants of the two seminars. The wiki served as a learning management system throughout the whole seminar where the lecturers uploaded their materials, entered dates, and so forth. A discussion section was available at the bottom of each wiki article where the students were asked to comment and discuss the changes they made in the wiki to facilitate collaboration.
To make sure that users became familiar with the functionalities provided, such as editing text, inserting links, using the discussion section and so forth, a wiki tutorial was created and presented to the users in the first session of the course. Students also had to complete two homework assignments prior to the experimental phase to ensure that they were confident in using the wiki.

For the experimental phase, we created dedicated wiki pages in two identical ‘wiki spaces’, one for the assimilation and one for the accommodation condition, which were not accessible for participants from the other experimental condition. Participants were not made aware of the existence of these two spaces, and their login credentials prevented them from viewing the pages created in the other condition.

4.4 Topics and sub-concepts of wiki articles

To rule out easy opportunities for copy-and-pasting information from other online sources (e.g., Wikipedia), we designed the collaborative wiki editing task to be an essay style in the style of popular science (1000 to 1500 words approximately), rather than a purely fact-based article. The students were invited to discuss pros and cons and provide their opinion on the topic assigned to them. This was to evoke the development of news ideas and the active construction of knowledge.

Specifically, each dyad was asked to write an essay on certain aspects of collaborative knowledge creation, the topic of both seminars. In order to make sure that the assigned topics were comparable but not the same, we defined five sub-concepts, namely learning, knowledge representation, knowledge exchange, learning community, and web 2.0. Then, we defined 12 different titles for essays focusing on these sub-concepts, for example “Future trends of collaborative knowledge creation with social media”, or “The evolution of knowledge in groups”. For each title, a few sentences were given to provoke thought and introduce the topic, mentioning the five sub-concepts. Students were explicitly told to focus their essay on the topics mentioned in these sentences; that is, to the five sub-concepts provided to them.
4.5 Prompts for accommodation and assimilation

The experimental manipulation was realized with different types of prompts provided by the tutor of the course: assimilation prompts and accommodation prompts. Assimilation prompts were designed to trigger external assimilation; that is, quantitative changes in the content of the wiki articles without substantially affecting the article structure. Accommodation prompts were designed to trigger external accommodation; that is, qualitative changes and modifications of the article structure. Assimilation prompts were only given in the assimilation group, accommodation prompts only in the accommodation group.

The students were instructed to follow the comments (i.e., prompts) of the tutor.

While the participants were made to believe that these prompts were related to the contents of their articles, the prompts were pre-fabricated, carefully designed both with regard to content and wording, and selected randomly in the course of the experiment. Table 1 gives examples of accommodation and assimilation prompts. Assimilation and accommodation prompts were derived from theoretical considerations on knowledge co-evolution as described in Kimmerle, Moskaliuk & Cress (2009), Cress and Kimmerle (2008), and based on work regarding the concepts of accommodation and assimilation by Piaget (1977), Lawson (1979), and Block (1982). From the theory, we derived six types of activities that indicate assimilation: amendments for more elaborate descriptions, extensions to better explain the problem, adding examples, adding arguments, adding an explanatory section, and adding explanatory materials (tables, figures, links etc.). Nine types of activities were derived that indicate accommodation: editing the article structure, aligning different viewpoints, improving the argumentation, weighting the arguments/points of view, improving the flow of reading, improving comprehensibility, improving the edits, and adding a conclusion.
Table 1 goes approximately here

Each dyad received three experimental prompts during the experimental phase. Because the participants of one dyad could see the tutor’s comments for the other eleven dyads in their own experimental group, different prompts had to be designed for each intervention, resulting in 36 accommodation prompts and 36 assimilation prompts. In order not to make the intervention too obvious, we gave one general motivating prompt (neither accommodation nor assimilation) at the beginning of the experimental phase (e.g., “Well done, collaboration from the first minute! Now keep the pace, and build on your collaboration!”).

4.6 Procedure

In the first session of the course when the students received a wiki tutorial, they were asked to sign a consent that log data from the wiki (edits, contents) could be collected. The experimental phase started after a few regular course lessons, where the students were instructed in the use of the wiki software and could acquire some knowledge on the topic. Before the dyads started working on their wiki articles, we trained the students in drawing concept maps, and measured students’ knowledge at t1 with an association test and a concept map (pre-test).

First, the association test was carried out. As stimulus words, we used the five sub-concepts they should also use in their wiki articles (learning, knowledge representation, knowledge exchange, learning community, and web 2.0). Stimuli were read out loud to the participants, and they were asked to write down all associations coming to their mind. The response time was confined to 30 seconds, and the inter-stimulus interval was 3 seconds.
For completing the concept maps, in a group setting, students received A3 sheets of paper where the overall topic of their wiki article (knowledge creation), and the five sub-topics which they should use in their wiki article (learning, knowledge representation, knowledge exchange, learning community, and web 2.0) were printed. They were asked to draw a concept map (on the empty side of the sheet) on the topic of their article thereby including the five sub-concepts. They were given 10 minutes to draw the concept map. The first two minutes should be spent on thinking about how the map should look like.

Then, the participants were randomly assigned to dyads and experimental conditions (assimilation or accommodation) and they received the instruction for the collaborative writing task. We instructed all participants that for successfully completing the task it was necessary to work continuously on the article, to make substantial edits at least seven times per participant during the two week period, and to follow the comments of the tutor. The participants were asked to post a comment on each edit of the wiki article in the discussion section and to briefly describe to their dyad partners what they had modified. These comments allowed us to get a better understanding of the type of edits that were applied and their rationale, and to track the progress of the articles more easily. Moreover, these comments served as an additional dependent variable for externalization (see Section 4.7). The explicitly described topics on which the dyads had to write their articles, further instructions on how to write the article, and the link to the wiki page where they should write their text were e-mailed to them on the following day.

During the two-week experimental phase, the students worked from home on their articles in the two separate wiki spaces. No course sessions took place during the experimental phase. In the first lesson after the two weeks of working on the wiki (t2), we again measured knowledge with the association test and the concept map, applying the same procedure as at t1 (post-test).

4.7 Dependent variables measuring different modes of externalization
To measure different modes of externalization, we analyzed the edits of the wiki articles as logged by the wiki, and the comments of the participants in the discussion sections which they were asked to make for each edit. We expected more accommodation activities in the accommodation condition than in the assimilation condition, and more assimilation activities in the assimilation condition than in the accommodation condition. These effects should become visible both in the actual edits and in the comments of the participants.

We analyzed the wiki edits based on the categories of actions described in Section 4.5 and based on definitions of accommodation and assimilation by Kimmerle et al. (2009), Cress & Kimmerle (2008), Block (1982), Lawson (1979), and Piaget (1977), and categorized each edit as ‘assimilation’, ‘accommodation’, or ‘neither assimilation nor accommodation’. For example, if a person had inserted an additional link for a topic in the wiki article, this activity was categorized as assimilation activity; if a person had moved text from one position to another in the article, this was categorized as accommodation activity. For the classification, a content analytic approach consisting on the two sub-steps paraphrasing and categorization was applied. In the step of paraphrasing, the core content of a sentence was described in its most concise form. In the categorization phase, the activity was categorized as either assimilation, accommodation, or neither assimilation nor accommodation. For example, the paraphrase ‘inserted some examples’ was classified as assimilation activity; the paraphrase ‘re-arranged paragraphs’ was classified as accommodation activity.

Because the proportion of edits and comments that were classified as neither accommodation nor assimilation was negligible (0.04% of the edits and also 0.04% of the comments), the ‘neither assimilation nor accommodation’ categories were excluded from further analyses. The result of the content analysis was a classification of edits and comments into either accommodation or assimilation.

4.8 Dependent variables measuring internalization
Four measures were used to measure internalization, two based on data from the concept maps and two on data from the association tests. Unlike the externalization metrics which were only looked at per dyad, internalization metrics were available for each participant.

Concept maps were produced by the participants at t1 and t2. For each concept map we counted the number of concepts and the number of links in the pre- and post-test which then served as within-subject variables in the statistical analyses.

Also word association tests were available for individuals for t1 and t2, revealing two further within-subjects factors. The first dependent variable from the association test was the mean number of associations per stimulus (five stimuli had been presented). The second variable from the association test was the number of co-occurrences (i.e., the number of responses that were given to more than one stimulus in the word association test).

4.9 Operational hypotheses

For the extent of externalization (H1), we proposed the following operational hypotheses:

- **H1a**: The ratio of accommodation edits to assimilation edits is higher in the accommodation condition than in the assimilation condition.

- **H1b**: The ratio of accommodation comments to assimilation comments is higher in the accommodation condition than in the assimilation condition.

For the extent of internalization (H2), we proposed the following operational hypotheses:

- **H2a**: The number of concepts in the concept maps is higher at t2 in both conditions than at t1.

- **H2b**: The number of links in the concept maps is higher at t2 in both conditions than at t1.
For the distinction of internal accommodation and assimilation (H3), we proposed the following operational hypotheses:

- **H3a:** The number of concepts in the concept maps shows an interaction effect over time: In the assimilation condition, at t2, the number of concepts is higher than in the accommodation condition.

- **H3b:** The number of links between concepts in the concept maps shows an interaction effect over time: At t2, the number of links is higher in the accommodation condition than in the assimilation condition.

- **H3c:** The mean number of associations in the association test shows an interaction effect over time: At t2, the number of associations is higher in the assimilation condition than in the accommodation condition.

- **H3d:** The number of co-occurrences in the association test shows an interaction effect over time: At t2, the number of co-occurrences is higher in the assimilation condition than at t1.

5. Results

We first report results on the externalization measures (number of edits and comments in the wiki (Hypothesis H1), then we turn to the internalization measures (Hypotheses H2 and H3).

5.1 Externalization

All statistical analyses with regard to externalization were calculated per dyad (i.e., per wiki article), and not per participant, as the contributions of single persons were not independent of the contributions of their dyad partners.

To measure different modes of externalization, we looked at the number of assimilation and accommodation edits that the participants had made in the wiki, and at the number of assimilation and accommodation comments that the participants had provided in
the discussion section of the wiki (see Section 4.7). Table 2 gives an overview of the mean absolute numbers of accommodation and assimilation edits and comments in the wiki.

<table>
<thead>
<tr>
<th>Table 2 goes approximately here</th>
</tr>
</thead>
</table>

Because there was high variability within experimental conditions in the overall number of edits and comments, we calculated an externalization index for each dyad to compare the modes of externalization in the two groups. For wiki edits the externalization index was calculated as the ratio of accommodation edits to assimilation edits. This ratio is higher than 1 if more accommodation than assimilation activities took place, and lower than 1 if more assimilation activities than accommodation took place. In the same way, a ratio of accommodation comments to assimilation comments was calculated.

Then, two t-tests with the independent variable condition and the dependent variables externalization index for edits and externalization index for comments were computed. As expected, in the accommodation condition the ratio of accommodation to assimilation edits ($M = 1.48, SD = 0.567$) was higher than in the assimilation condition ($M = 0.46, SD = 0.203$, with $t(22) = 5.889, p < .01$) and also the ratio of accommodation comments was higher in the accommodation condition ($M = 1.20, SD = 0.481$) than in the assimilation condition ($M = 0.42, SD = 0.203$, with $t(22) = 4.848, p < .01$). Therefore, we can conclude that by means of different prompts (accommodation vs. assimilation) the mode of externalization was changed. These findings support Hypothesis 1a (main effect for accommodation and assimilation edits) and 1b (main effect for accommodation and assimilation comments). From the absolute numbers of edits and comments in Table 2, one can observe that prompting was especially...
effective in increasing the accommodation edits and comments, while in the case of assimilation, only moderate increases were observed.

To compare the two measures (wiki edits and comments), we also correlated the two ratios for wiki edits and comments. We found a highly positive rank correlation (Spearman’s $\rho = .91, p < .01$) of the ratio of accommodation edits and the ratio of accommodation comments. This means that the analysis of wiki edits and the content analysis of comments in the wiki lead to similar results. Not only is this finding an indicator for the reliability of the content analyses but it is also of practical relevance as the analysis of comments is much more economic than the analysis of edits in the wiki.

5.2 Internalization

For the hypotheses on internalization (H2 and H3), a 2x2 Analysis of Variance (ANOVA) was applied with one between-subjects factor experimental condition (accommodation vs. assimilation) and one within-subjects factor time (pre-test: t1, post-test: t2). As dependent variables, several measures of internal assimilation and accommodation were used (number of nodes and links in the concept maps and mean number of associations and co-occurrences in the association test). With this design, testing for the main effect of time allows us to detect changes in the dependent variables over time independent of the condition. We interpret these as showing learning effects in the groups as a result of the learning activities in the course as proposed by H2. Testing for an interaction effect of time and experimental condition allows us to detect differential effects of the assimilation and accommodation prompts on the dependent measures. This allows us to test whether the mode of internalization differed in the two groups as a result of the prompts (hypothesis H3).

Prerequisites for the ANOVA (normal distribution, homogeneity of variances) were fulfilled, except for the number of associations and the number of co-occurrences in the association test. These were not distributed normally but conformed more to an exponential distribution. Hence, a non-parametric alternative to the ANOVA, the Adjusted Rank
Transform (ART) test was applied that has been proposed by several researchers in such situations (Leys & Schumann, 2010; Sawilowsky, 1990; Wobbrock, Findlater, Gergle, & Higgins, 2011). The ART test has been shown in simulation studies to have greater power than the ANOVA and to be as robust in 2x2 designs with cell sizes greater five (Sawilowsky, 1990). The ART test transforms the data into ranks, and then allows for testing interaction effects in a 2x2 design after subtracting the main effects from the interaction effect. This adjustment has been found to improve the robustness of the rank transformation as the presence of main effects confounds the interaction effects. We used ARTool 1.5.1 (Wobbrock et al. 2011) to calculate the adjusted rank transformations. The adjusted ranks were then used in a standard ANOVA, comparing the obtained values to the critical values in the F-distribution.

5.2.1 Concept maps

As a measure for distinguishing different modes of internalization, the number of concepts and the number of links in the concept maps of the two experimental groups at t1 and t2 were considered (see Section 4.8).

Two one-way ANOVAs with the independent variable condition and repeated measures of the two dependent variables number of concepts and number of links were computed. The descriptive statistics are reported in Table 3.

| Table 3 goes approximately here |

As expected, the concept maps of the participants in both conditions contained more nodes at t2 ($M = 19.79$, $SD = 8.343$) than at t1 ($M = 15.97$, $SD = 5.587$) with $F(1,31) = 21.004$, $p < .01$. We found a tendency for a significant main effect for condition ($F(1,31) = 3.175$, $p < .10$), and no significant interaction ($F(1,31) = 0.784$, $p = .383$). This outcome
supports Hypothesis 2a (main effect for time of measurement) but does not support Hypothesis 3a (interaction effect for time and condition).

Similarly, as expected the concept maps of the participants in both conditions contained more links at t2 ($M = 22.06, SD = 8.116$) than at t1 ($M = 17.00, SD = 5.651$) with $F(1,31) = 27.952, p < .01$. We found no significant main effect for condition ($F(1,31) = 1.641, p = .210$), and no significant interaction ($F(1,31) = 0.004, p = .951$). This outcome supports Hypothesis 2b (main effect for time of measurement) but does not support Hypothesis 3b (interaction effect for time and condition).

The findings imply that internalization took place in both experimental groups: the number of nodes and number of links increased. No differences between the two experimental groups at t2 (interaction effects) were found with these two concept map measures; that is, internal assimilation and accommodation could not be distinguished on the basis of the concept map data.

5.2.2 Association test

As a second measure for distinguishing different modes of internalization, the number of associations per stimulus in the association test and the number of co-occurrences for the five stimuli in the two experimental groups at t1 and t2 were considered (see Section 4.8; for descriptive statistics see Table 4).

| Table 4 goes approximately here |
| ================================== |

For the dependent variable number of associations, the ART test revealed no main effect for time ($F(1,42) = 1.942, p = .171$), no main effect for condition ($F(1,42) = .681, p = .414$), and no interaction ($F(1,42) = 2.107, p = .154$). Thus, Hypothesis 3c is not supported
by the outcomes: While descriptively the interaction was in the expected direction (the
number of associations increased more for the assimilation group than for the accommodation
group), the difference did not reach significance. This may be due to the fact that implicit
measures (like the association test) are usually prone to greater variability in the answers,
thereby decreasing their reliability.

As proposed in Hypothesis 3d, for the number of co-occurrences, the ART test
revealed a significant interaction \( (F(1,42) = 6.045, p < .05) \). While, as expected, no main
effect of condition \( (F(1,42) = 0.127, p = .732) \) could be observed, a main effect for time
\( (F(1,42) = 4.998, p < .05) \) became significant which however must not be interpreted due to
the disordinal interaction. That is, as expected, participants in the assimilation condition
showed higher numbers of co-occurrences at t2 than at t1 while participants in the
accommodation condition did not show higher numbers of co-occurrences at t2 (see Figure 1).
The statistical data based on co-occurrences of associations support the hypothesis that
different modes of externalization co-occur with different modes of internalization.

6. Discussion and conclusion

In the introduction of this article, we have argued that a field study in a realistic course
setting is needed to analyze collaborative knowledge building. While recent progress has been
made on analyzing knowledge building on the artifact level in such contexts (e.g., Suthers et
al., 2010), a similar progress needs to be made on the cognitive level to understand artifact-
mediated learning. In the present paper, we have contributed to this perspective by suggesting
instruments for tracking internalization in a realistic course setting.

The question at the outset of this paper was: When users collaboratively work on a
digital artifact in a realistic course setting, can we trace knowledge co-evolution in the artifact
and the cognitive system? We conclude that our field experiment provides evidence for co-evolution processes in such settings. Moreover, our study has surfaced theoretical, methodological, and pedagogical insights which we will discuss subsequently.

From a theoretical perspective, our findings are in line with the assumptions of the co-evolution model and indicate the model’s practical relevance. With regard to externalization, the findings reveal that we were able to trigger external accommodation and assimilation with different types of prompts (Hypotheses 1a and 1b). Moreover, we found that externalization of knowledge is accompanied by a corresponding process of internalization of knowledge as measured with concept maps, both in terms of the number of concepts (Hypothesis 2a) and the number of links (Hypothesis 2b). We found that students increased their knowledge as a result of the knowledge building task. Mixed results were obtained for the question if different modes of externalization would come along with different modes of internalization. While Ley et al. (2011) found differences between an assimilation and accommodation condition in several concept map measures in a lab study, we were not able to distinguish different modes of internalization with concept maps in the present field study (Hypotheses 3a and 3b).

However, a significant interaction in the expected direction was found with the word association test (Hypothesis 3d): After the experimental treatment, the dyads in the assimilation condition showed more co-occurrences in the association test. This corresponds to the close to significant interaction of density of the association structures in the Ley et al. (2011) study. And while the test did not reach statistical significance, as found by Ley et al. (2011), descriptively, group differences at t2 in the number of associations were higher in the assimilation condition than in the accommodation condition (Hypothesis 3c).

It shall be highlighted that detecting these differences is a major challenge in field settings as there is much less control over the learning situation and processes, and many intervening variables can potentially influence the results. For example, the learners in these
two weeks had a number of other commitments and thus the individual motivation and effort they put into the course differed to a great extent.

The methods we have chosen to distinguish different aspects of cognitive processing (concept maps and association tests) have shown mixed results, and it will be necessary to better understand the exact role of these aspects in knowledge building in the future. Specifically, it will be necessary to examine whether or not structural aspects of concept maps are useful for distinguishing different modes of internalization, as suggested by Ley et al. (2011). Further, the concept map method should be refined in order to allow for more detailed analyses of quantitative (assimilation) and qualitative (accommodation) changes in cognitive structures as a result of a co-evolution process. For instance, the instructions of the concept maps should allow for comparisons of the actual content of the concept maps in the pre- and post-tests, as well as comparisons between individuals to see if their knowledge in the post-test phases has converged through co-evolution. Also, the reliability and validity of the number of associations and the number of co-occurrences for distinguishing internal accommodation and assimilation need to be further explored. Recent progress on the cognitive foundations of categorization in social learning may help to construct theoretically valid instruments (Fu & Dong, 2012; Ley & Seitlinger, 2013).

Our study has two important methodological implications. First, we could show that different types of prompts can trigger different modes of externalization; that is, different ways of how participants collaboratively edit wikis. Previous studies (e.g., Ley et al., 2011; Moskaliuk et al., 2009, 2012) carefully manipulated prior knowledge and information in the wiki to create a cognitive conflict and to trigger assimilation and accommodation. As this is not possible in a realistic learning setting, our study suggests that using assimilation and accommodation prompts is a practicable way to trigger external accommodation and assimilation. Second, we found strong evidence that comments of participants about their own
wiki edits reliably reflected the nature of their wiki edits, so that cumbersome manual
analyses of log files may not be needed.

From a pedagogical perspective, an exciting possibility implied by our study is that
teachers and tutors may be able to use instructional prompts as a way to trigger cognitive
conflict that can be productive for learning. More specifically and depending on the
instructional objectives, different prompts that activate different ways of how learners edit
contents, would lead to different cognitive processing strategies.

Moreover, studying knowledge co-evolution in lab settings has inherent limitations
that caution against generalizations to educational practice: In a lab setting, learners know
they are taking part in an experiment and hence they may exhibit behaviors they would not
normally show. Also, the occurrence of collaborative knowledge building depends on socio-
emotional processes that are not directly related to the task, as highlighted in a review by
Kreijns, Kirschner & Jochems (2003). Specifically, the authors mention the importance of
developing trust and a sense of belonging. The social dynamics of these processes are difficult
to reinstate in a lab setting. From informal observations of our experiment, we have clear
indications that socio-emotional processes have played a significant role in how students
approached the tasks. For example, in one of the groups there was a clear tendency to attribute
behavior of the other group to generally low motivation. While these processes should be
considered more systematically in future work, we content that with the present study we
were successful in creating a realistic social situation and therefore assume high external
validity.

Finally, our findings imply that the application of wikis in educational contexts
definitely can lead to substantial learning effects. Thus, our study constitutes a strong case
that exemplifies how wikis can be successfully applied for collaborative knowledge building
in an educational setting in higher education, when they are systematically integrated in a
course context, and accompanied by active scaffolding.
References


Ifenthaler, D., Masduki, I., & Seel, N. M. (2009). The mystery of cognitive structure and how we can detect it: tracking the development of cognitive structures over time. *Instructional Science, 39*(1), 41–61.


List of tables

Table 1: Examples for assimilation and accommodation prompts that were used during the experiment (translated from German).

Table 2: Mean absolute frequency of edits and comments in the accommodation and assimilation conditions. Means are computed across dyads/articles. Standard deviations are given in brackets.

Table 3: Mean and standard deviation (in brackets) of nodes and links in the concept maps of the accommodation and assimilation conditions at t1 and t2.

Table 4: Mean and standard deviation (in brackets) of numbers of associations per stimulus and of number of co-occurrences, and standard deviation (in brackets) of responses of the accommodation and assimilation conditions at t1 and t2.
Table 1: Examples for assimilation and accommodation prompts that were used during the experiment (translated from German).

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Examples for prompts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation</td>
<td><em>The statements should be supported with further arguments.</em></td>
</tr>
<tr>
<td></td>
<td><em>At some points in the article, more elaborate explications should be given.</em></td>
</tr>
<tr>
<td></td>
<td><em>Some illustrative examples would improve the article.</em></td>
</tr>
<tr>
<td>Accommodation</td>
<td><em>The structure of the article should be reworked.</em></td>
</tr>
<tr>
<td></td>
<td><em>Different points of view should be combined better.</em></td>
</tr>
<tr>
<td></td>
<td><em>The line of argument should be improved in order to make the common thread more visible.</em></td>
</tr>
</tbody>
</table>
Table 2: Mean absolute frequency of edits and comments in the accommodation and assimilation conditions. Means are computed across dyads/articles. Standard deviations are given in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Edits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean absolute</td>
<td>Mean absolute</td>
</tr>
<tr>
<td></td>
<td>frequency of</td>
<td>frequency of</td>
</tr>
<tr>
<td></td>
<td>assimilation</td>
<td>accommodation</td>
</tr>
<tr>
<td></td>
<td>edits</td>
<td>edits</td>
</tr>
<tr>
<td><strong>Assimilation</strong></td>
<td>13.67</td>
<td>6.58</td>
</tr>
<tr>
<td>condition (n=12)</td>
<td>(3.651)</td>
<td>(3.895)</td>
</tr>
<tr>
<td><strong>Accommodation</strong></td>
<td>11.42</td>
<td>16.42</td>
</tr>
<tr>
<td>condition (n=12)</td>
<td>(3.232)</td>
<td>(6.721)</td>
</tr>
<tr>
<td><strong>Total (n=24)</strong></td>
<td>12.54</td>
<td>11.50</td>
</tr>
<tr>
<td></td>
<td>(3.563)</td>
<td>(7.354)</td>
</tr>
</tbody>
</table>
Table 3: Mean and standard deviation (in brackets) of nodes and links in the concept maps of the accommodation and assimilation conditions at t1 and t2.

<table>
<thead>
<tr>
<th></th>
<th>Mean n(nodes)</th>
<th>Mean n(links)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t1</td>
<td>t2</td>
</tr>
<tr>
<td><strong>Assimilation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>condition (n=17)</td>
<td>17.71</td>
<td>22.24</td>
</tr>
<tr>
<td><strong>Accommodation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>condition (n=16)</td>
<td>14.13</td>
<td>17.19</td>
</tr>
<tr>
<td></td>
<td>(3.879)</td>
<td>(5.540)</td>
</tr>
<tr>
<td><strong>Total (N=33)</strong></td>
<td>15.97</td>
<td>19.79</td>
</tr>
<tr>
<td></td>
<td>(5.587)</td>
<td>(8.343)</td>
</tr>
</tbody>
</table>
Table 4: Mean and standard deviation (in brackets) of numbers of associations per stimulus and of number of co-occurrences, and standard deviation (in brackets) of responses of the accommodation and assimilation conditions at t1 and t2.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean n(associations) t1</th>
<th>Mean n(associations) t2</th>
<th>Mean n(co-occurrences) t1</th>
<th>Mean n(co-occurrences) t2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation condition</td>
<td>5.32 (1.310)</td>
<td>5.33 (1.575)</td>
<td>2.14 (3.013)</td>
<td>3.23 (2.810)</td>
</tr>
<tr>
<td>Accommodation condition</td>
<td>5.21 (1.160)</td>
<td>4.80 (1.365)</td>
<td>2.27 (1.907)</td>
<td>2.32 (2.169)</td>
</tr>
<tr>
<td>Total (N=44)</td>
<td>5.26 (1.224)</td>
<td>5.06 (1.481)</td>
<td>2.20 (2.493)</td>
<td>2.77 (2.523)</td>
</tr>
</tbody>
</table>
List of figures

Figure 1: Boxplot of the number of co-occurrences at t1 and t2 in the accommodation and assimilation conditions.
Figure 1: Boxplot of the number of co-occurrences at t1 and t2 in the accommodation and assimilation conditions.
Highlights

- knowledge co-evolution was traced in a field setting
- external accommodation and assimilation can be triggered with prompts
- externalization of knowledge co-occurs with internalization of knowledge
- collaborative wiki editing can lead to substantial learning effects