

Learning and Knowledge Building with Social Software

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Abstract: The progress of the Internet in recent years has led to the emergence of so-called social software. This technology concedes users a more active role in creating Web content. This has important effects both on individual learning and collaborative knowledge building. In this paper we will present an integrative framework model to describe and explain learning and knowledge building with social software on the basis of systems theoretical and equilibration theoretical considerations. This model assumes that knowledge progress emerges from cognitive conflicts that result from incongruities between an individual's prior knowledge and the information which is contained in a shared digital artifact. This paper will provide empirical support for the model by applying it to Wikipedia articles and by examining knowledge-building processes using network analyses. Finally, this paper will present a review of a series of experimental studies.

Introduction

A fast development of the Internet could be witnessed in recent years. New tools and services, so-called *social software* technologies, such as weblogs, wikis, folksonomies, podcasts, file sharing, or virtual online worlds are changing their users' handling of data, information and knowledge (Kolbitsch & Maurer, 2006). Nowadays, users are actively involved in creating Web content. The distinction between producers and consumers of knowledge will not make sense any more. Content is linked beyond the limitations of single tools by using open interfaces. Desktop computers as individual repositories tend to be replaced by the Web (O'Reilly, 2005). This development has a strong impact on individual learning (Sigala, 2007). Individuals can participate in a collective advancement of knowledge and, in addition, they can benefit from an enormous amount of knowledge which is available globally.

In terms of constructivism, learning is intensified by what is offered through the World Wide Web: people participate in self-regulated learning in informal learning environments, as members of a *community of knowledge*. The world-wide availability of social software tools opens up a new dimension of knowledge processes: large numbers of users can work together on shared digital artifacts (Tapscott & Williams, 2006). This does not only lead to accumulation of knowledge (the knowledge of many individuals is brought together and is made available to others) but also to emergence, i.e. the creation of new knowledge (Johnson, 2002), a process that is being discussed using keywords like *wisdom of the crowds* (Arazy, Morgan, & Patterson, 2006; Surowiecki, 2005). But practice with many social software applications has shown that new knowledge will not emerge automatically due to large numbers of collaborating users. Web 2.0 environments will not necessarily lead to an optimal individual learning process, and it is not very frequent that new knowledge is in fact being developed within a social software community.

Accordingly, the question is under which circumstances these emergent phenomena do happen and social software tools can actually become promoters of knowledge advancement. In order to illustrate processes of knowledge progress and the conditions that facilitate it, we will present a framework model that describes and explains learning and knowledge-building processes with shared digital artifacts. This model is based on the systems-theoretical approach by Luhmann (1995) as well as on the model of equilibration by Piaget (1970). The following section will present the framework model, starting with a brief summary of the underlying theories followed by the description of our model. The *content analyses* section will discuss empirical evidence for the validity of this model, based on content analyses of Wikipedia articles. The *network analyses* section describes co-evolution of social systems (knowledge building) and cognitive systems (individual learning), referring to an example from Wikipedia as well. The *experimental studies* section will present findings from experiments under laboratory conditions. The article will conclude in a section that summarizes and discusses our considerations and findings.

Individual Learning and Collaborative Knowledge Building

Our framework model which we will present in this section is based on systemic and cognitive approaches to describe processes of collaborative knowledge production. Based on a systems-theoretical considerations, the model describes shared digital artifacts (developed with the help of social software tools) and their respective communities as social systems in terms of Luhmann (1984, 1986). In order to describe the processes that change such a social system and the cognitive systems of individual users, the model refers to Piaget's concept of

equilibration (Piaget, 1977a). Thus, the following paragraphs will first give a brief review of the approaches by Luhmann and Piaget before presenting an integrative framework model by Cress and Kimmerle (2007, 2008).

Systems Theoretical Considerations

Luhmann's theory distinguishes between "system" and "environment" (Luhmann, 2006): whatever does not belong to the system is part of its environment. A system consists of operations which create the difference between the system and the environment (Luhmann, 1984). The mode of operation of a social system is *communication*. Cognitive systems, however, operate via processes of consciousness and cognitive processes. Systems are autopoietic (Luhmann, 1984; cf. also Varela, Maturana, & Uribe, 1974). They are able to produce and reproduce themselves, hence guaranteeing their own existence (Luhmann, 1990). A system is not in a direct exchange with its respective environment, rather it is *operatively closed*. This operative closeness of systems excludes communication between autopoietic systems, since they operate in different modes. What we can still observe, however, is that a system is influenced by other systems and reacts to its environment.

Luhmann has dealt with this issue by stating that a system is both open and close, using the concept of structural coupling (Luhmann, 1992). *Structural coupling* is based on the structure of expectations that a system creates, which make it sensitive to *irritations* from the environment of that system (or from other systems respectively). Irritations from the environment will be transferred into the mode of operation that is inherent in that system. From the system's point of view, the environment will always be more complex and more chaotic than the system itself. The system will need to reduce this complexity by distinguishing between what belongs to the system and what does not.

In addition, reduction of complexity is a prerequisite of emergence (Kofman & Senge, 1993). Emergence refers to systems with hierarchical structure in which features may occur at the higher level of the system which cannot be explained by features of the lower level of the system. These higher-level features are created by synergies between elements at the lower level of the system. Only holistic considerations make it possible to explain phenomena of emergence. This cannot be achieved by a reduction into partial systems or subsystems. Luhmann's theory is capable of describing computer-mediated construction and communication of knowledge. Shared digital artifacts (and their respective communities) may be understood as social systems that use written communication as their mode of operation. Communication is mediated, using shared digital artifacts, and the system is structurally coupled with the cognitive systems of its users.

Equilibration Theoretical Considerations

Luhmann is particularly interested in social systems. Other constructivist theoreticians, however, are more interested in psychological aspects. A constructivist approach that is highly relevant in order to understand processes of learning is that by Piaget. This approach explains how a cognitive system deals with "irritating" information from its environment. Piaget describes qualitative changes of cognitive schemas in the course of an individual's development (Piaget, 1977b). Cognitive schemas structure and simplify stimuli from the environment and help individuals to understand them. Thus, according to Piaget, knowledge is always a construction of one's environment, i.e. an interpretation of one's experience of the environment, with the help of cognitive schemas. Knowledge construction, then, is an increasingly more flexible application, adaptation, and modification of cognitive schemas. According to Piaget, the mechanism is as follows: an individual's experiences with the environment may lead to perturbation of this individual's cognitive balance ("equilibration") or, in other words, to a *cognitive conflict*. As a result, the individual's own cognitive schemas will no longer fit her or his experiences with the environment, requiring re-equilibration.

Here, Piaget distinguishes between two functions: assimilation and accommodation. *Assimilation* means active shaping of the environment by interpreting and explaining current experiences, giving them a place in existing schemas. *Accommodation* means adaptation to the environment in the form of qualitatively changing one's own cognitive schemas.

Integrative Model

In their framework model Cress and Kimmerle (2007, 2008) integrate the systemic and the constructivist approach. The authors have explained their model of knowledge building by referring to wikis as a prototype of a social software tool. They distinguish between two systems in terms of Luhmann: the social system (content of the wiki and the associated community) on the one hand, and the cognitive system of an individual on the other hand, meaning this person's declarative knowledge in semantic memory (Tulving, 1985). Since these two systems are both operatively closed, they cannot be transferred into each other. But they can both be developed further by means of structural coupling. This structural coupling is enabled by the exchange processes that occur between the cognitive system of the individual and the social system wiki. With respect to these exchange processes a distinction has to be made between externalization and internalization of knowledge.

In the course of externalization, a user will supplement or modify a wiki article on some topic by using his or her own knowledge. After that, this knowledge exists independently of the user in the form of information

in the wiki where it is accessible to anyone. This externalization process will not only bring about an increase of information in the social system wiki, it leads to the development of knowledge in the individual user's cognitive system as well. Externalization of somebody's own knowledge requires that a person deals in more depth with existing knowledge and considers it more thoroughly (Hayes & Flower, 1980), and this will lead to a re-alignment or improvement of cognitive schemas. Writing texts and working with them becomes a tool for individual knowledge acquisition (Tynjälä, Mason, & Lonka, 2001). The second process is internalization of information from the wiki. Pieces of information from the wiki are decoded and incorporated into existing internal knowledge structures. This will create new knowledge entities in that person's cognitive system, new associations between knowledge entities and new schemas.

The model by Cress and Kimmerle specifies the mechanisms of internalization and externalization. It expands Piaget's model by describing accommodation and assimilation not only from the perspective of an individual's cognitive system, but also from that of a social system. Users assimilate information from the artifact into their own cognitive schemas, and they accommodate by modifying their schemas induced by information from the wiki. An analogous process of assimilation may take place in the social system: users add pieces of information from their own knowledge, which will, however, not change the basic message and structure of the wiki, only add additional aspects. Accommodation is also possible in a wiki if users contribute their knowledge in such a way that the entire message is changed completely and, sometimes, new structures are being created. Accommodation tends to result in some qualitative modification of the artifact, whereas assimilation has to do with quantity, introducing new aspects or examples but no fundamental innovation.

As a consequence of the processes of internalization and externalization, both the social system wiki and the cognitive systems of the individuals involved will develop further. Both systems will mutually influence each other, and as a result of the difference between the two systems (in Luhmann's terminology: the boundary between the systems) new knowledge will be generated. What occurs is co-evolution of the two systems, which can be regarded as the result of structural coupling. The newly generated knowledge is emergent: it was previously neither part of the cognitive system nor of the social system, it can merely be explained by looking at both systems simultaneously (cf. also Holland, 1998).

Content Analyses

Citing various Wikipedia articles as examples, Cress and Kimmerle (2008) were able to demonstrate what these processes of assimilation and accommodation, as described above, can mean in practice for a shared digital artifact. For example, processes of equilibration could be observed in the English-language Wikipedia article on "AIDS origin". This subject is a matter of controversial discussion, which finds expression in a large number of modifications on the Wikipedia page. These consist both of assimilations and accommodations. An assimilation, for instance, is the following alteration which simply adds two items to the list of abbreviations [11, p. 116f]:

"In Russian it got the name SPID (Sindrom Priobretyonnoy Immunitetnoy Defitsitnosti)." (10 February 2007). "... and in Irish SEIF (Siondróm Easpa Imdhionachta Faighte)." (6 May 2007).

At the same time, however, processes of accommodation could also be observed. An example is the case of a controversial theory which was introduced into the article. 'This theory assumes that research on substances for polio vaccination was initially accountable for transmitting the AIDS virus to humans. One sentence in the article: "[The viruses] most likely got into humans via the hunting and eating of the original primate species" was changed as follows to leave more room for other explanations: "Possible ways for this virus to have originally infected humans include the hunting and eating of the original primate species" (3 March 2006). Afterwards, the whole approach of the explanation is modified: "A more controversial theory known as the OPV AIDS hypothesis suggests that the AIDS epidemic was inadvertently started in the late 1950s in the Belgian Congo by Hilary Koprowski's research into a polio vaccine" (28 November 2006). Reference is made, once again, to a theory that had already previously (20 February 2006) been described as follows:

"One currently controversial possibility for the origin of HIV/AIDS was discussed in a 1992 Rolling Stone magazine article by freelance journalist Tom Curtis. He put forward the theory that AIDS was inadvertently caused in the late 1950's in the Belgian Congo by Hilary Koprowski's research into a polio vaccine. Although subsequently retracted due to libel issues surrounding its claims, the Rolling Stone article encouraged another freelance journalist, Edward Hooper, to travel to Africa for 7 years of research into this subject. Hooper's research resulted in his publishing a 1999 book, The River, in which he alleged that an experimental oral polio vaccine prepared using chimpanzee kidney tissue was the route through which SIV mutated into HIV and started the human AIDS epidemic, some time between 1957 to 1959."

Here, various stages of accommodation can be observed, in which a new idea is presented, then qualified to some extent, and finally integrated into the text in such a way that it supplements other theories. Further examples of assimilation and accommodation processes in Wikipedia can be found in Cress and Kimmerle (2008).

It is, however, not only interesting to look at modifications of the shared digital artifact, it is also important to look at the corresponding changes in the cognitive systems of users. One technique to study this co-

evolution of cognitive and social systems – using Wikipedia articles as well – will be described in the following section.

Network Analyses of Wikipedia

Network analyses (Wassermann & Faust, 1994) were able to demonstrate that changes of the content orientation of related Wikipedia articles were accompanied by similar changes in the orientation of the users who were involved (Harrer, Moskaliuk, Kimmerle, & Cress, 2008). The development of this co-evolution was illustrated on the basis of the article on “schizophrenia” in the German-language version of Wikipedia. This topic is particularly appropriate for initiating socio-cognitive conflicts and, consequently, equilibration efforts, since different approaches exist to explain what causes schizophrenia, which are the subject of controversial discussion. One approach deals with biological and genetic aspects, another one with social causes of schizophrenia, and the so-called diathesis-stress model combines these two explanations. There is also a psycho-analytical model of explanation, which is, however, less accepted.

To examine the co-evolution of cognitive and social systems, it was studied how the Wikipedia page on schizophrenia (and articles linked to this page) changed in the course of time. At the same time a closer look was taken on the development of the views of participating authors. In order to analyze developments of the artifact, all articles that were linked to the schizophrenia page were rated by experts to which explanation model (biological/genetic, social, or psycho-analytical) they belonged. These articles and the links between them were treated as the artifact network that was of interest here. In the visualization, the size of a page is an expression of the number of links that refer to that page. Visualization of the development of wiki pages and their links provides a representation of the development of the social system. In order to analyze the authors of these wiki articles, attention was paid to the topics of their articles and revisions in the course of time.

With respect to the shared digital artifact, the network analyses were able to show clear-cut effects. Comparing, for example, the artifact networks in 2007 and 2008 (as on 1 January respectively) revealed significant changes. In 2007 the social and the biological cluster were still obviously separated (see Figure 1). The social cluster, as it appears on the top of Figure 1 (“s-cluster”), includes pages on “Paul Watzlawick”, “Metakommunikation“ (*meta communication*), or “Doppelbindungstheorie“ (*double-bind theory*). The biological cluster, further down on the right hand side (“b-cluster” in Figure 1), includes topics such as “Temporallappen“ (*temporal lobe*), “Amygdala”, and “Nervensystem“ (*nervous system*). The psycho-analytical cluster (“p-cluster” in Figure 1), is represented by pages on “Psychoanalyse“ (*psychoanalysis*), “Sigmund Freud”, and “Über-Ich“ (*super-ego*).

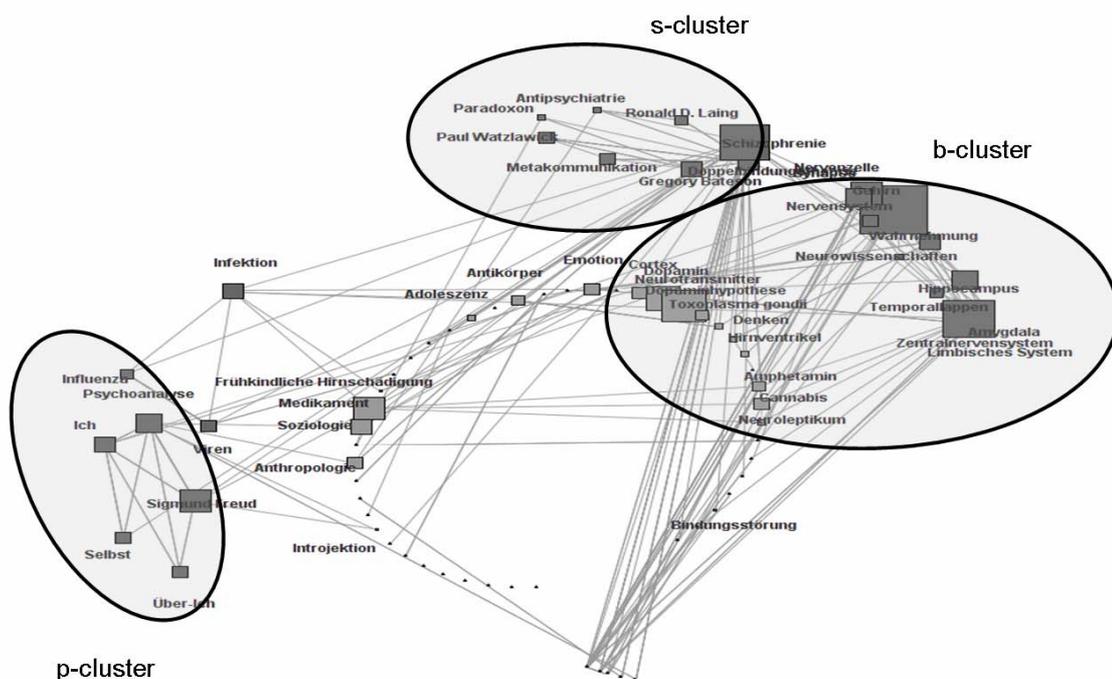


Figure 1. Artifact network 2007.

But with respect to the year 2008, the right hand side of Figure 2 contains a large common cluster which consists of both the articles on social and biological causes (“merged b+s-cluster”). The psycho-analytical cluster (“p-cluster”) still stands on its own and is barely linked to the rest.

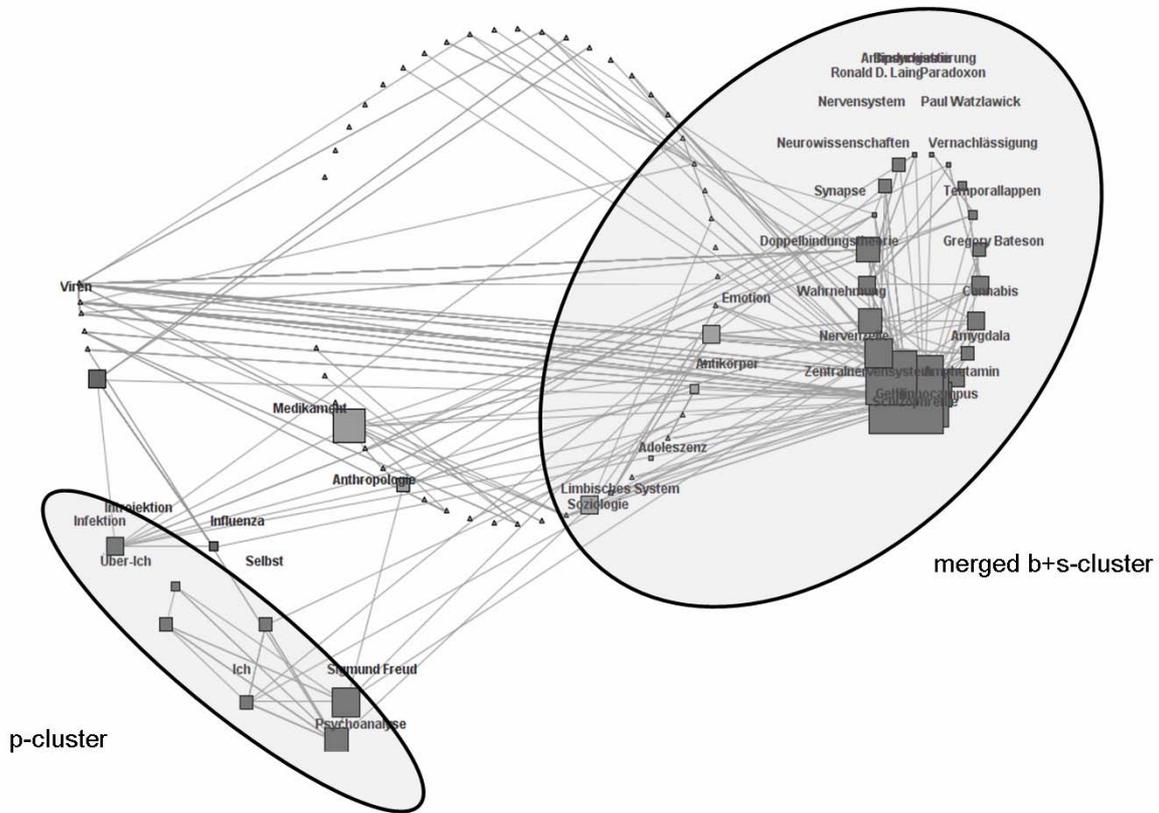


Figure 2. Artifact network 2008.

This is in line with a general tendency in literature on schizophrenia: the diathesis-stress model (which supposes that there are both biological and social causes) has become the major explanation, whereas the psycho-analytical approach tends to be regarded as an outsider position.

Particularly interesting in this context is the fact that an analogous development as in the Wikipedia articles has also occurred with respect to the authors who contributed to these articles. It could be shown that various users who originally had been involved in articles on either biological or social aspects seemed to have adopted a more integrative viewpoint in the course of time (Harrer et al., 2008). But with Wikipedia authors who had mainly been involved in psycho-analytical pages no such development could be observed.

So here, the question is how such co-evolution between cognitive and social systems is induced. One feature which is regarded as an important starting point of internalization and externalization processes and – in this way – of individual and collective learning was examined in a series of laboratory experiments, which will be presented in the following section.

Series of Experimental Studies

The mainspring of this co-evolution, according to the model by Cress and Kimmerle, is incongruity between the information contained in the shared digital artifact and the previously existing knowledge of somebody who reads that information. This will lead to a cognitive conflict of that user to which this individual will react with equilibration in terms of Piaget. The model uses an analogy to the work of Berlyne (1960) and Hunt (1965) assuming that there is a relationship between this incongruity and the extent of knowledge development which may be visualized as an inverted U-shape: low incongruity will not lead to perturbation of the cognitive balance, users will not experience a cognitive conflict, adaptation is not required. In the case of very high incongruity it will be difficult to link new information with existing knowledge; this will prevent accommodation or assimilation as well. Medium incongruity, however, is ideal to support the construction of new knowledge.

In order to allow empirical investigation of this model, an experimental paradigm was created. To operationalize the model, it was necessary to find a knowledge domain in which it is possible to distribute

various knowledge items systematically between different people and the shared digital artifact. Again, schizophrenia and the question what causes this disorder was selected as a suitable knowledge domain. In order to create experimental material, extracts were made from textbooks on clinical psychology, presenting four arguments of about the same length on social explanations of the disease, four arguments on biological explanations and two arguments on the diathesis-stress model. Each of these ten arguments was complete in itself. This was the information base for a newly created digital artifact (wiki article on causes of schizophrenia) accompanied by what purported to be “newsletter articles” that were presented to participants, which they could then use as their own “previous knowledge” when working on the artifact.

Each of the three experiments was conducted in groups with five to ten participants. Going through the experiment took about two hours. Mobile computers were used for presenting two questionnaires (at the beginning and end of the experiment), for the instructions, and for a short tutorial which introduced the handling of the wiki. Participants were first provided with information contained in the newsletters; each of these covered one item of information (the substance of these newsletters contained the same information as the corresponding wiki entries, but the newsletters had been enriched with additional information). Then, participants had access to the wiki, which contained a varying number of information items, depending on the experimental condition. Participants were instructed to work on the wiki for 50 minutes. After that, the following dependent variables were measured:

- Internal assimilation: Factual knowledge about the arguments on the causes of schizophrenia (knowledge test with 15 multiple choice items).
- Internal accommodation: Conceptual knowledge about the role played jointly by diathesis and stress in causing schizophrenia. This conceptual knowledge was operationalized by using an open question on causes of schizophrenia, measuring the extent to which arguments were combined in the sense of a diathesis-stress model. Participants’ answers were rated by two experts to distinguish between different levels of conceptual knowledge. An answer which contained a simple explanation (biological or social respectively) was rated with one point. Two points were assigned when participants named both biological and social causes. They received three points if they pointed out to some kind of interaction or correlation between different social and biological factors. And participants received four points if they referred to a model that postulates that external stress (social) can uncover an inherent (biological) vulnerability.
- External assimilation: For measuring external processes we made log-file analyses to compare the initial version of the wiki page to the last version at the end of the experiment. External assimilation was measured by counting the number of words inserted into the digital artifact.
- External accommodation: For measuring external accommodation we counted the number of the phrases which participants either used to refer to interaction between social and biological causes of schizophrenia or which they used to connect arguments (e.g., “on the one hand ... on the other hand”, “in contrast”, “however”) in the digital artifact.

Three studies examined the hypothesis of an inverted U-shape relationship between information in the shared digital artifact and knowledge of individuals on the one hand and knowledge progress on the other, comparing processes of externalization and internalization.

Incongruity was operationalized in these studies as the difference between knowledge entities in the cognitive system and information entities in the social system. There are two possible experimental implementations: keeping constant the amount of knowledge available in the cognitive system and manipulating the amount of information in the social system or keeping constant the amount of available information in the social system and manipulating the amount of knowledge in the cognitive system. The former option was implemented in Study #1, the latter in Studies #2 and #3. Thus, in the sense of the model, Study #1 primarily varied the option for externalization and Studies #2 and #3 the options for internalization.

Study #1

Study #1 examined three experimental conditions with different degrees of incongruity between knowledge in the cognitive systems and information in the social system, keeping knowledge in the cognitive systems constant. In all three experimental conditions, all of the ten arguments were available for the participants as their own “prior knowledge”. Variation in the experimental conditions concerned the extent of information that were presented in the digital artifact: the ten arguments were used to build four different versions of the wiki page on the causes of schizophrenia, distinguishing three experimental conditions. The wiki page in the low-incongruity condition contained all the arguments; it might be described as a complete entry. Taking into account potential qualitative differences between the two positions, the medium-incongruity condition in the experiment was based on two versions of the wiki page: one version contained the four biological arguments and the other version the four social arguments. Both of these might be labeled as one-sided content. The wiki page on the causes of schizophrenia in the high-incongruity condition did not contain any content (see Figure 3).

So the emphasis in this experiment was on manipulating processes of externalization. 61 university students participated in this study. 43 of them were women, 17 men (and 1 person with undisclosed gender). The participants' mean age was 24.64 years ($SD=10.58$). They were distributed at random between the experimental conditions (Moskaliuk, Kimmerle, & Cress, 2008).

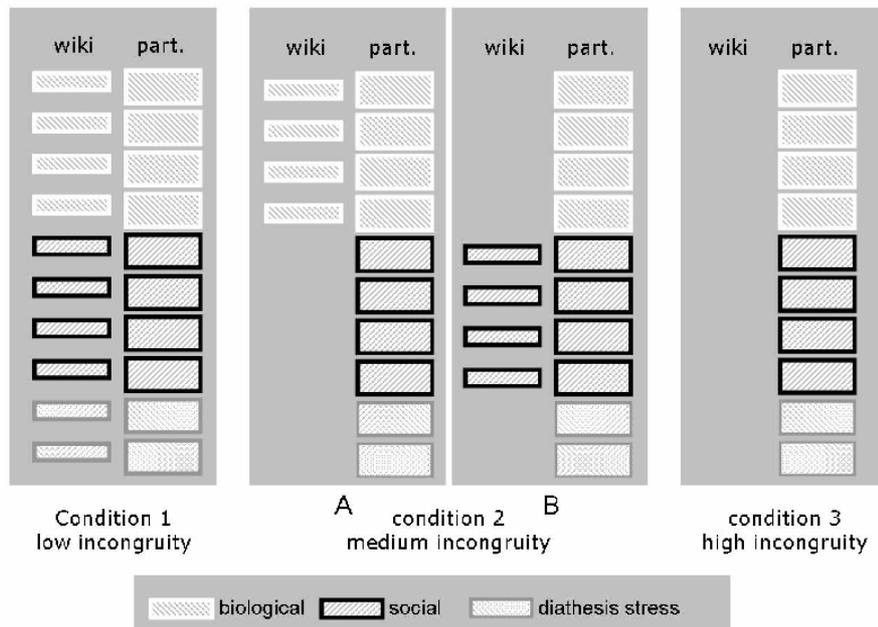


Figure 3. Distribution of information provided in the artifact and availability to participants in three experimental conditions of Study #1 (condition 2A and 2B are logically equivalent).

It was expected that medium incongruity will be most conducive to all four processes: in the medium-incongruity condition more external assimilation (Hypothesis 1), more internal assimilation (Hypothesis 2), more external accommodation (Hypothesis 3), and more internal accommodation (Hypothesis 4) were expected.

Statistical analyses of the data revealed the following results:

External assimilation. As expected (Hypothesis 1), in the medium-incongruity condition participants contributed significantly more words than in the low-incongruity condition: $M_{med}=210.00$ ($SD=124.98$) vs. $M_{low}=78.78$ ($SD=64.17$), $t(38)=4.03$, $p<.01$. But there was no difference between high and medium incongruity: $M_{med}=210.00$ ($SD=124.98$) vs. $M_{high}=268.70$ ($SD=99.35$), $t(40)=-1.67$, $p>.05$.

Internal assimilation. As expected (Hypothesis 2), the factual knowledge in the medium-incongruity condition was higher than in the low-incongruity condition: $M_{med}=15.50$ ($SD=2.30$) vs. $M_{low}=13.78$ ($SD=2.82$), $t(38)=2.13$, $p=.02$. Factual knowledge in the medium-incongruity condition was also higher than in the high-incongruity condition: $M_{med}=15.50$ ($SD=2.30$) vs. $M_{high}=14.24$ ($SD=1.92$), $t(41)=1.95$, $p=.03$.

External accommodation. As expected (Hypothesis 3), we found significantly more external accommodation in the medium-incongruity condition than in the low-incongruity condition: $M_{med}=3.29$ ($SD=2.70$) vs. $M_{low}=1.78$ ($SD=1.70$), $t(37)=2.04$, $p=.02$. And there was also more external accommodation in the medium-incongruity condition than in the high-incongruity condition: $M_{med}=3.29$ ($SD=2.70$) vs. $M_{high}=2.05$ ($SD=0.94$), $t(39)=1.93$, $p=.03$.

Internal accommodation. As expected (Hypothesis 4), the conceptual knowledge in the medium-incongruity condition was higher than in the low-incongruity condition: $M_{med}=3.04$ ($SD=1.13$) vs. $M_{low}=2.29$ ($SD=1.16$), $t(37)=2.03$, $p=.02$. Conceptual knowledge in the medium-incongruity condition was also higher than in the high-incongruity condition: $M_{med}=3.04$ ($SD=1.13$) vs. $M_{high}=2.43$ ($SD=1.03$), $t(41)=1.87$, $p=.03$.

Study #2

The second experiment was, so to speak, a mirror-inverted replica of the previous one. While in the experimental conditions of the previous study participants' prior knowledge was kept constant and the shared digital artifact differed in the information it contained, the artifact in the second experiment contained the same information in all conditions, and variation concerned the knowledge of the participants.

In all three experimental conditions, all of the arguments were presented in the digital artifact. Here, the artifact only provided the four social and the four biological arguments. Participants were not provided with the arguments on the diathesis-stress model because we wanted to examine whether they were able to find out these arguments on their own (this was considered a more valid test for the construction of conceptual

knowledge). Variation in the experimental conditions concerned the extent of information that was available to participants as their own “prior knowledge” when working on the digital artifact (see Figure 4).

In condition 1 (low incongruity), the participants knew all eight arguments, in condition 3 (high incongruity) they had no prior knowledge at all. In the “medium incongruity” condition, the participants only knew the arguments of one position on causes of schizophrenia, i.e. either the four social arguments (condition 2A) or the four biological arguments (condition 2B).

In all conditions, participants had instant access to the wiki and were able to work with it while reading the newsletters. This study was carried out with 77 participants. 45 of these were women, 32 men. Their mean age was 23.55 years ($SD=3.59$). The participants were randomly assigned to one of the three experimental conditions.

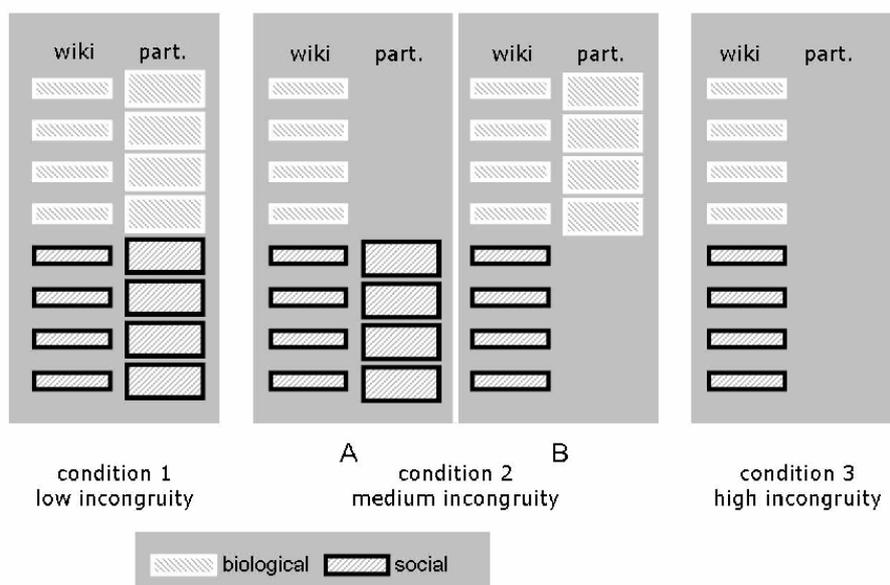


Figure 4. Distribution of information provided in the artifact and availability to participants in three experimental conditions (condition 2A and 2B are logically equivalent) in Studies #2 and #3.

The varying extent of information that was available through the newsletters provided a variable for the extent of possible internalization in the experiment. The potential for externalization was kept at a constantly low level, as the artifact contained all the relevant information. The theoretical considerations and corresponding research questions, as presented above, led to the following hypotheses:

People with little previous knowledge will find it difficult to externalize anything at all, so the lowest external assimilation was expected in condition 3 (Hypothesis 1). As the groups differ in their prior knowledge, a corresponding difference of factual knowledge was expected, which could also serve as a treatment check. It was assumed, in other words, that differences of prior knowledge continue to exist because of the lack of opportunities to externalize one’s own knowledge (Hypothesis 2). The theoretical model predicted that the perceived conflict between information in the artifact and the participants’ own prior knowledge was highest at medium incongruity. This should lead to more accommodation (Hypothesis 3) in the digital artifact and more distinct conceptual knowledge, as a result of internal accommodation (Hypothesis 4).

Statistical analyses of the data revealed the following results:

External assimilation. As assumed (Hypothesis 1) we found more external assimilation in the medium-incongruity condition than in the high-incongruity condition: $M_{med}=64.33$ ($SD=59.65$) vs. $M_{high}=11.71$ ($SD=26.09$), $t(49)=3.79$, $p<.01$. And we found more external assimilation in the low-incongruity condition than in the high-incongruity condition: $M_{low}=64.28$ ($SD=58.80$) vs. $M_{high}=11.71$ ($SD=26.09$), $t(44)=3.79$, $p<.01$.

Internal assimilation. As assumed (Hypothesis 2) we found more internal assimilation in the low-incongruity condition than in the medium-incongruity condition: $M_{low}=13.88$ ($SD=2.38$) vs. $M_{med}=12.57$ ($SD=2.67$), $t(52)=1.87$, $p=.03$. But we could not find more internal assimilation in the medium-incongruity condition than in the high-incongruity condition: $M_{high}=11.82$ ($SD=3.17$) vs. $M_{med}=12.57$ ($SD=2.67$), $t(50)=0.92$, $p=.18$.

External accommodation. As assumed (Hypothesis 3) we found more external accommodation in the medium-incongruity condition than in the low-incongruity condition. The data tended to support this hypothesis; this is, however, only a marginal effect: $M_{med}=1.57$ ($SD=1.89$) vs. $M_{low}=0.96$ ($SD=0.89$), $t(53)=1.48$, $p=.07$. And we found more external accommodation in the medium-incongruity condition than in the high-incongruity condition: $M_{med}=1.57$ ($SD=1.89$) vs. $M_{high}=0.29$ ($SD=0.46$), $t(49)=3.04$, $p<.01$.

Internal accommodation. Hypothesis 4 assumed that we would find more internal accommodation in the medium-incongruity condition than in the low-incongruity condition. The data did not support this hypothesis: $M_{low}=1.12$ ($SD=0.38$) vs. $M_{med}=1.07$ ($SD=0.37$), $t(53)=0.38$, $p=.35$. And we did not find more internal accommodation in the medium-incongruity condition than in the high-incongruity condition: $M_{high}=1.05$ ($SD=0.58$) vs. $M_{med}=1.07$ ($SD=0.37$), $t(50)=0.16$, $p=.44$.

This means that some of the expected effects could not be detected or were only of marginal significance. The results concerning Hypothesis 2 would indicate that the difference of knowledge of those users who participated in the study may have been too small. For that reason, a period of learning was introduced in the following study. Prior to working on the wiki, participants were asked to consider the content of the newsletter.

Study #3

This experiment corresponded to Study #2, except that an additional learning phase preceded the rest in order to obtain more significant differences of the participants' prior knowledge. The learning phase differed depending on the number of newsletters which a participant had received. In condition 1, participants had 20 minutes to consider the newsletters, in condition 2 this was 10 minutes, and in condition 3 no such learning phase was necessary because participants were meant not to acquire any prior knowledge. So, this condition is exactly the same as the high-incongruity condition in Study #2. In order to conduct the experiment efficiently, we simply re-used the data for this condition from Study #2 (i.e. did not invite any new participants for this condition). This study was carried out with 72 participants. 55 of these were women, 17 men. Their mean age was 22.06 years ($SD=3.48$).

Statistical analyses of the data revealed the following results:

Internal assimilation. As assumed (Hypothesis 1) we found more external assimilation in the medium-incongruity condition than in the high-incongruity condition: $M_{med}=84.00$ ($SD=64.92$) vs. $M_{high}=11.71$ ($SD=26.09$), $t(44)=4.78$, $p<.01$. And we found more external assimilation in the low-incongruity condition than in the high-incongruity condition: $M_{low}=89.00$ ($SD=63.38$) vs. $M_{high}=11.71$ ($SD=26.09$), $t(43)=5.21$, $p<.01$.

Internal assimilation. As assumed (Hypothesis 2) we found more internal assimilation in the low-incongruity condition than in the medium-incongruity condition: $M_{low}=14.72$ ($SD=2.01$) vs. $M_{med}=13.68$ ($SD=2.34$), $t(48)=1.69$, $p=.05$. And we could also find more internal assimilation in the medium-incongruity condition than in the high-incongruity condition: $M_{high}=11.82$ ($SD=3.17$) vs. $M_{med}=13.68$ ($SD=2.34$), $t(45)=2.31$, $p=.01$.

External accommodation. As assumed (Hypothesis 3) we found more external accommodation in the medium-incongruity condition than in the low-incongruity condition, yielding a more clear-cut effect than in Study #2: $M_{med}=2.04$ ($SD=1.79$) vs. $M_{low}=0.58$ ($SD=0.93$), $t(44)=4.36$, $p<.01$. And we found more external accommodation in the medium-incongruity condition than in the high-incongruity condition: $M_{med}=2.04$ ($SD=1.79$) vs. $M_{high}=0.29$ ($SD=0.46$), $t(49)=3.04$, $p<.01$.

Internal accommodation. Hypothesis 4 assumed that we would find more internal accommodation in the medium-incongruity condition than in the low-incongruity condition. The data tended to support this hypothesis; this is, however, only a marginal effect: $M_{low}=1.20$ ($SD=0.65$) vs. $M_{med}=1.48$ ($SD=0.82$), $t(48)=1.34$, $p=.09$. And we could also find more internal accommodation in the medium-incongruity condition than in the high-incongruity condition: $M_{high}=1.05$ ($SD=0.58$) vs. $M_{med}=1.48$ ($SD=0.82$), $t(45)=2.07$, $p=.02$.

In this study, the result that more learning time leads to more factual knowledge (Hypothesis 2) may be interpreted as a successful treatment check. What is relevant from the point of view of verifying theoretical predictions is the advantage of medium incongruity for processes of internal and external accommodation. This cannot be explained with the length of learning time, but only with incongruity between the information contained in the shared digital artifact and the participants' own knowledge.

Discussion

This article provides a survey of studies on a framework model of learning and knowledge building with shared digital artifacts. On the basis of Luhmann's systems theory the model describes processes of individual learning and collaborative knowledge building by identifying shared digital artifacts and the respective communities behind these artifacts as "social systems", and by examining the interaction between such a social system and the cognitive systems of individuals. The model refers to Piaget's theory of equilibration to illustrate cognitive development and applies the concept of assimilation and accommodation processes to the social system as well.

The article highlighted assimilation and accommodation processes in a shared digital artifact by citing real examples from the Online Encyclopedia *Wikipedia*. Co-evolution of cognitive systems and the social system was visualized by means of social network analysis. The model considers incongruity between the information in the digital artifact and people's previously existing knowledge as an important factor of people's willingness to participate in knowledge-building processes and, thus, to contribute to the development of cognitive and social systems. Experimental studies have indeed shown that this incongruity is a significant

factor of collaborative knowledge building. Future research in this field should aim at identifying further influencing factors of collaborative knowledge building with social software.

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