UNIVERSITEIT TWENTE.

Final Project Thesis

Developing a Tool for Learning Concept Maps

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Part I

Introduction

Project Description

Over the centuries, knowledge has been fundamental to any learning process. Socrates already stated that knowledge is the only true virtue, and the tragedian Aeschylus regarded memory as the mother of all knowledge. Moreover, it was not only regarded as important by ancient thinkers, but is still regarded as such by modern scholars on education. Both the taxonomy of learning by Bloom, Engelhart, Furst, Hill, and Krathwohl (1956) as a revision of this taxonomy by Krathwohl (2002), as well as the three stages of skill acquisition by J. Anderson (1982), propose that all learning should start with memorising factual knowledge. Furthermore, von Glaserfield (2001), one of the main founders for critical constructivism, expresses a need for training students so that they permanently possess facts and are able to repeat them flawlessly whenever they are needed, while also understanding what is placed into their memory. Ericsson and Kintsch (1995) adds to this by stating that in order to perform complex tasks, people must maintain access to large amounts of information, and that solely encoding knowledge is not sufficient. Despite all of this, Karpicke (2012) argues that "[r]etrieval processes, the processes involved in using available cues to actively reconstruct knowledge, have received less attention" (p. 158), whereas basic research on learning and memory has emphasised that retrieval must be considered in any analysis of learning.

Traditionally, when students have to gain complex and meaningful knowledge – for example knowledge about a historical event or a chapter in a psychology textbook, they are asked to read the relevant chapter from a provided textbook. However, Mayer (2008) states that many students have difficulty gaining knowledge in this manner. He breaks reading for comprehension down into four separate skills, which are integrating, organising, elaborating, and monitoring. Integrating refers to relating a text to one's prior knowledge, for which evidence exists that rich background knowledge leads to better inferences about the text, and thereby to better comprehension. This need also has been stressed by Ausubel (1968), and forms different problems between individual readers having access to different background knowledge. After integration, the reader has to organise the text, so that the important ideas and the relationships among them are identified. This is mainly a problem for less experienced readers, possessing fewer strategies to quickly identify important parts and thereby spending too much time on reading unimportant information. While organising a text, the student also has to make necessary inferences while reading, or has to elaborate, which is quite difficult for readers when not prompted to do so. Finally, students have to monitor their comprehension, which refers to evaluating their understanding of the text and if necessary adjusting the reading strategy. This is again quite difficult for the average reader, however this can be trained.

While intergrating is something more dependent on the curriculum design, organising and elaborating can be facilitated by a technique called concept mapping, and monitoring by so-called flashcard systems. Furthermore, this research aims to develop a new tool combining these learning tools. In this chapter, concept mapping, flashcard systems, and the new learning tool called the flashmap will be explored on a practical level in order to establish their definitions together with a summary of arguments in favour or opposition of using them as tools for studying textual material, while also describing their current applications within education.

Concept mapping

A Concept map is a learning tool deviced by Joseph Novak in 1970's, based on constructivist theories of learning. It was originally intended for assessing the structure of student conceptions, before and after instruction, in order to map their prior knowledge and compare it to what they learned during the instruction. This expanded on the notions of Ausubel (1968), who stated that what the learner already knows is most important, and that this had to be ascertained before teaching. Although the use of concept maps as an assessment tool remains prevalent (Canas & Novak, 2012; Chung, O'Neil Jr., & Herl, 1999; Hwang, Wu, & Ke, 2011; Ruiz-Primo & Shavelson, 1996), over time, students began to use it as a tool to comprehend textual material by organising and elaborating on the included concepts (Canas & Novak, 2012; Eppler, 2006; Hwang et al., 2011; Karpicke & Blunt, 2011; Nesbit & Adesope, 2006).

Definition

One definition provided by Burdo and O'Dwyer (2015) states that "concept maps are hierarchical representations of knowledge. Construction of them involves linking concepts [...] through the use of linking phrases into propositional statements" (p. 335). The concepts are typically nouns or verbs with or without modifying adjectives or adverbs, and linking phrases specify the relationship between two concepts. Ruiz-Primo and Shavelson (1996) also mention these elements in their own definition, yet Canas and Novak (2012) and Eppler (2006) include a few extra features, such as the concepts being ordered in hierarchical fashion. They describe two different kinds of links, hierarchical links to indicate ranking between the concepts, and crosslinks to indicate relationships between concepts in different segments or domains of the concpt map. The latter would help to see how a concept in one domain of knowledge represented on the map is related to a concept in another part of the knowledge producer, enabling better connections to prior knowledge of the user. According to Eppler (2006), concept maps are always top-down and show systematic relationships among sub-concepts relating to one main concept, however Canas and Novak (2012) state that they can also be cyclical as long as the concepts still have a conceptual hierarchy. Finally, most of the above mentioned articles describe the links between concepts to be directed. In conclusion, the definition of concept maps used within this thesis will be:

> *A concept map refers to a directed graph, in which the nodes consist of concepts, and the edges of – either hierarchical or cross- – links labeled with linking phrases, forming several propositional statements about a knowledge domain.*

An example of a concept map is displayed in figure 1.

For this study, the more interesting aspects of concept maps are the use of concept mapping for elaborating, and of demonstrating meaningful relationships between concepts to learners. The first use of the concept map is known as generative use, and the second as supplantive (Smith & Ragan, 2005).

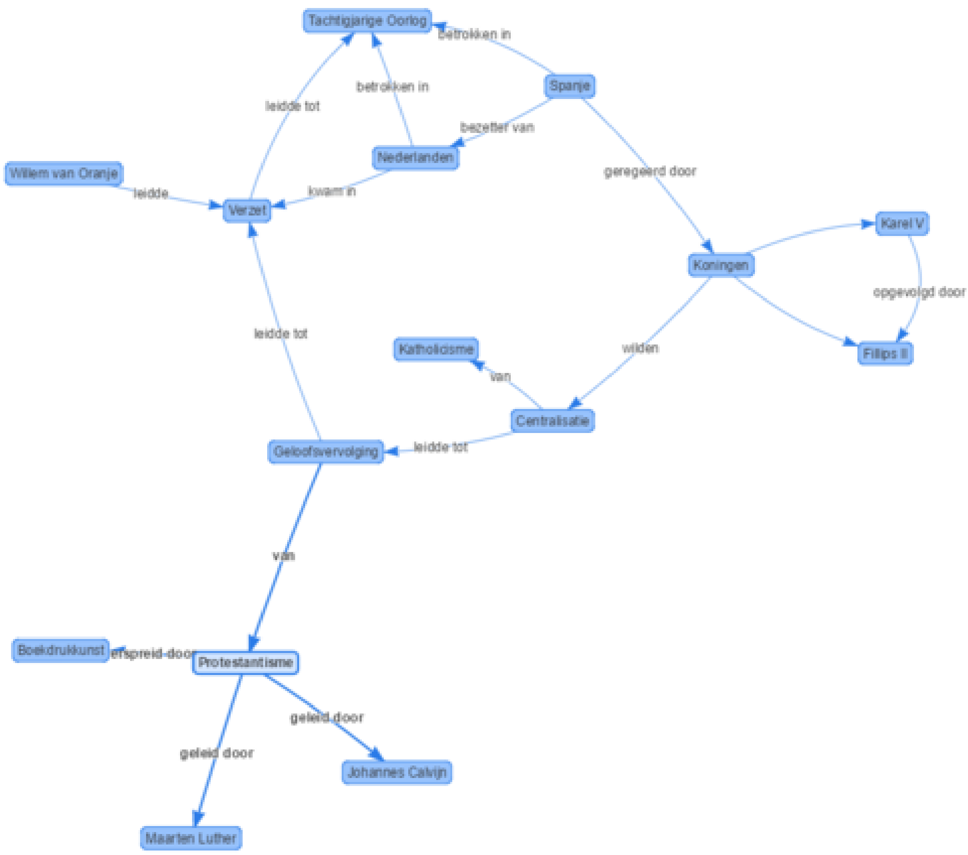


Figure 1: A fraction of the concept map used in this study

Effectiveness

Multiple studies, both qualitative and quantitative, have demonstrated that concept maps can promote meaningful learning (Canas & Novak, 2012; Hwang et al., 2011; Nesbit & Adesope, 2006; Subramaniam & Esprivalo Harrell, 2015). When comparing the concept mapping strategy with traditional teaching strategies (in a study conducted within the context of tertiary chemistry), Singh and Moono (2015) found that the concept map teaching strategy was more effective, however that it was most effective if both strategies were used in combination. One of the positives of the concept map is that it does not provide learning by means of disconnected facts, but rather as a cohesive narrative placing emphasis on the connections between the concepts. However, most studies state that merely studying a concept map (supplantive use) is not sufficient, and that the activity of constructing the concept map (generative use) is essential for using it as a learning tool. Canas and Novak (2012) even state that meaningful learning does not work by memorising a concept map, because the information is not integrated with other relevant knowledge. Furthermore, Nesbit and Adesope (2006) state that much of the benefits may be due to greater learner engagement rather than the properties of the concept map as an information medium. However, no studies were found testing these hypotheses, and yet Blankenship and Dansereau (2000) have found that expert generated concept maps are believed to help students form conceptual understanding. Still, this study did also indicate that greater maps (more than 20 nodes) used within textbooks lead to *map-shock*: "a type of cognitive overload that prevents students from effectively processing the concept map, thereby inhibiting their ability to learn from it" (Moore, North, Johri, & Paretti, 2015, p. 3). Finally, Eppler (2006) enlists some of the main advantages and disadvantages in comparison to other visualisation formats (mind maps, conceptual diagrams, and visual metaphors). In favour, students can gain information rapidly, because of the systematic, proven approach to provide an overview and the emphasis on relationships and connections among concepts. On the other hand, the technique of concept mapping is not easy to apply by novices and requires exstensive training, because without it they tend to turn out idiosyncratic. Furthermore, although better understandability is provided, the overall pattern does not necessarily assist memorability. Finally, the quality of concept maps can be assessed through evaluation rules, however this turns out to be quite a time consuming task for the tutors.

Applications of concept mapping

An article by De Simone (2007) states that despite the effectiveness of concept mapping, its use is not that widespread because students find it cognitively difficult, time consuming, or nonessential vis-à-vis task demands. The article then provides an overview of how concept maps are generally used in the classroom: as an external scratch pad to represent major ideas and their organisation, as a time-efficient tool for mental construction, and as a tool for exchange of diversifying ideas and gaining new insights, and provides benefits and limitations for each of these uses. When used as an external scratch pad, students map their ideas on paper by writing a main idea and linking it with other related concept through action words and arrows. Although most students find it helpful to offload information externally, additional to detecting and correcting gaps and inconsistencies in their knowledge, they still find the process of mapping to be time consuming. This is because they often have to make major revisions, requiring them to redraw the concept map multiple times. Therefore, a more time-efficient approach might be mental concept mapping, where they had to represent answers within the map to questions such as "what are the key ideas?" and "how are these ideas related?". This provided to be more efficient due to better mastery of the mapping strategies, and thereby more comfortable for the students. Finally, concept mapping enables students to draw relationships more freely, due to its flexibilities regarding layout and adding or removing concepts or relations. It also stimulated collaborative learning by enabling easier sharing and even co-construction. Nonetheless, of these strategies, the traditional strategy remains the most prevalent, since it is the best known use of concept mapping. Finally, as already stated before, Moore et al. (2015) state that multiple textbook publishers started including concept maps within their textbooks in order to provide an overview of the content.

Flashcard system

In contrast to concept maps, a flashcard system is not intended for meaningful knowledge encoding, but rather for the rehearsal of knowledge so that it keeps active and as such is prevented from being forgotten.

Definition

In the context of language learning, Nakata (2011) defines flashcard systems as learning tools in which "target items are presented outside meaning-focused tasks, and learners are asked to associate the L2 [foreign language] word form with its meaning, usually in the form of a first language translation, L2 synonym, or L2 definition" (p. 17). This form of learning is also referred to as a *paired-associate format*, which refers to learning by being presented by cues and the learner having to recall an associated counterpart. Besides vocabulary learning, it can also be used to memorise word definitions, or topographical information. In order to be more inclusive of other use cases, the following general definition is proposed:

> *A flashcard system refers to any system in which a learner is presented by cues and has to recall their counterparts from a paired-associate format.*

The most simple form of a flashcard system is a system where the learner has a stack of cards, with each containing a retrieval cue on one side and the correct associated response on the other side. A learning session then consists of going through the whole stack each day and trying to come up with correct answers. Efficiency can then be increased by repeating difficult cards more often, or skipping reviewing certain easy cards for multiple days. This way only on the pairs which are more needy of retrieval are focused on. Finally, the size of the stack of cards can be increased over multiple days in order to improve the spreading of cognitive load. Next to these paper flashcards, there is also a multitude of digital flashcard systems available (Hwang et al., 2011; Nakata, 2011; Edge, Fitchett, Whitney, & Landay, 2012), which allows for automating the rescheduling of flashcards, providing better access to more advanced algorithms for the rescheduling of flashcards.

Effectiveness

Flashcard systems have not been completely free from criticism by other researchers. Hulstijn (2001) for example describes flashcards as a relic of the old-fashioned behaviourist learning model, and McCullough (1955) states that the main emphasis of flashcards is memorisation, not comprehension. However, Zirkle and Ellis (2010) states that it is still important for teachers and students to understand and utilise memory in such a way that a store of knowledge is produced that remains flexibly retrievable in a variety of contexts over a period of time, even more so because even though it is deemed useless to learn without comprehension, students still should learn by heart many conventional facts (von Glaserfield, 2001). Flashcards have been found to be both a time efficient tool for learning large numbers of facts and an effective tool for these facts to be more resistant to decay in comparison to traditional teaching methods (Nakata, 2011). Their effectiveness also has been demonstrated accross studies in different contexts, for example that of language learning (Chien, 2015; Macquarrie, Tucker, Burns, & Hartman, 2002; McCullough, 1955; Nakata, 2011), word recognition (Joseph, Eveleigh, Konrad, Neef, & Volpe, 2012), psychology courses (Burgess & Murray, 2014; Golding, Wasarhaley, & Fletcher, 2012), and geography (Zirkle & Ellis, 2010). Therefore, many authors support pursuing research into flashcards and its effective application into classrooms.

Design features

Nakata (2011) also describes general design features of flashcard software, which are seperated in terms of creation and editing of flashcards, and learning of flashcards. Examples are whether learners are able to create their own flashcards or flashcard sets, whether learners merely have to recall an answer or have to produce an answer, how big a learning session is and how repetitions are scheduled. Partly, these features are also applicable on paper flashcards. The features will be further elaborated later on page INSERT REFERENCE TO DESIGN CHAPTER, but for now it is sufficient to state that at the time of writing there are no commonly accepted guidelines for how flaschard software should be designed. This mainly is due to the fact that not a lot of research is conducted on specific design-features, research reviewing mostly the same program, and there being discrepancies in the way they are designed, and further research is needed in order to establish these guidelines.

Application of flashcards

Multiple sources describe an increase in the use of flashcards in education: Kornell and Bjork (2008) states that "perhaps no memorisation technique is more widely used than flashcards" (p. 125), and more recently textbooks have also started making them available (Burgess & Murray, 2014; Golding et al., 2012). Two reasons for the popularity of flashcards are provided by Golding et al. (2012): students can generate flashcards for themselves, they feel that they are 'doing' something when they study. Most of the studies found is based around flashcard usage in language courses (Nakata, 2011; Joseph et al., 2012; Chien, 2015), but there also exists a study by Golding et al. (2012) describing that 70% of general psychology students used flashcards for at least one exam.

Chien (2015) and Nakata (2011) describe that multimedia and digital flashcards are used widely within vocabulary learning, because they can be easily programmed to keep track of performance and better control the sequency, which is cumbersome if done manually. Furthermore, students might be more motivated using digital flashcards because of the enhanced presentation of materials due to their multimedia capabilities. However, Golding et al. (2012) still found the majority of students using written flashcards. These findings surprised Burgess and Murray (2014), since many students have their smart phones with them most of the time – 75% of students report using smartphones during breaks, meetings etc, 55% while waiting, and 45% for school related uses – and phones are more portable than large stacks of traditional flashcards. However, when he pursued the study by providing students with either written or digital flashcards, students used the digital flashcards less frequently than the traditional flashcards, even when the students had to make their own flashcards. Reasons students provided were technical issues such as battery consumption, simply forgetting about it, using entertainment apps instead of studying, and preference for traditional flashcards.

Comparison of the two tools

In summary, most studies describe concept mapping as a tool for meaningful encoding, whereas flashcards are described as a tool for rote memorisation, and therefore imply that the former approach leads to more comprehension than the latter. A recent study by Karpicke and Blunt (2011) researched this hypothesis by having participants study a science text with four different learning conditions and prompting them afterwards with verbatim and inference questions and metacognitive predictions. Within the first condition, students only had to read the text and then answer the quesions. The second group studied the text in four consecutive study periods. Students within the third group studied the text in one initial study period and then created a concept map after being instructed in concept mapping. The final group studied the text in an initial study period and then had to recall as much as they could on a free recall test, and repeated this strategy. The time spent on concept mapping and recalling was equal. When analysing the results, it was found that the retrieval practice group performed highest on both the verbatim and the inference questions, whereas the repeated study and concept mapping groups performed about equally well and the study once group performed the worst. Interestingly enough, the retrieval practice group judged their own learning the lowest, and the repeated study group the highest. The same effect of concept mapping and retrieval practice was found again in a second reproduction study, and also in another study by Burdo and O'Dwyer (2015). It is theorised that during elaboration, subjects attain detailed representations of encoded knowledge by linking concepts together in meaningful ways, but that during retrieval, subjects use retrieval cues to reconstruct meaning en thereby already organise the content in a meaningful way. Karpicke and Blunt (2011) conclude that these insights could pave the way for the design of new educational activities with retrieval practices in mind.

Flashmap system

The object of this study is therefore to create such an activity, and intends to combine both the visual overview of concept maps with the retrieval mechanism of flashcard systems by means of a new digital tool, which from this point onwards will be referred to as the Flashmap system. It will present incomplete parts of a concept map, in which the student has to fill in the missing parts of propositions represented by that map. These parts will consecutively be repeated according to algorithms already used by digital flashcard systems. The flashmap system might have the potential to bridge the gap between the two systems, and therefore make meaningful and effective rote memorisation possible, for it should make the relations between the concepts explicit to the student, thereby increasing the organisation of the knowledge and reducing the segregation of facts. Hereby, this tool might facilitate the needs stressed by both Karpicke (2012) and Zirkle and Ellis (2010) of more meaningful retrieval. Furthermore, by having the students memorise the concept map and graduately expanding on it, the generally experienced map shock occuring with expert-generated concept maps might also be mitigated (see also Tzeng, 2010).

The following two chapters within the introduction will elaborate further on the needs for memorisation and the cognitive theories underlying concept mapping and flaschard systems, after which the design and development of the flashmap will be described in part II.

Context

As can be read in the previous chapter, the aim of this study is to develop and evaluate a tool designed for the purpose of meaningful memorisation. However, why is it actually important to memorise? This question has historically been debated since the days of the early Greek philosophers, and still remains relevant today. Therefore, it seems important to briefly reflect on this question before delving into the effectivity and specifications of the tool itself. This chapter does not aim to answer this age-old question, but rather tries to provide both some philosophical and historical context, for better understanding of the relevance of a better memorisation tool, and what is generally considered to be better. Furthermore, it will relate these questions more specifically to the tools investigated within this study.

Five educational philosophies

Curriculum theorisers have proposed many different systems of categories (Marsh & Willis, 1999), of which the aim is to investigate which goals people involved with education have, and which aspects they therefore regard as being important. Apps (1973) differentiates between the five philosophies of education, being *Perennialism*, *Essentialism*, *Progressivism*, *Reconstructionalism*, and *Existentionalist education*, which have also (at least partly) been acknowledged by other authors (Brameld, 1971; Ozmon & Johnson, 1967; Yilmaz, Altinkurt, & Cokluk, 2011; Howick, 1971). Furthermore, Yilmaz et al. (2011) have found these categories to be sufficiently valid and reliable upon measuring their prevalence among teachers. In this chapter, these categories will be discussed further individually in order to provide philosophical context towards the function of knowledge.

Perennialism

According to perennialism, there is no alterior motive for obtaining knowledge, but rather that it is a purpose on itself. This is along philosophy of Socrates, who concluded that knowledge is the only virtue. He concluded this based on that wisdom is the same as knowledge (Meno, 2000), that wisdom is one of the five cardinal virtues, and that all other virtues (e.g. justice) are merely derived from the virtue of wisdom.

The perennialists are mainly based on either the general philosophy of idealism or of realism. The most notable idealist perennialist are the scholastics, who focused on teaching the great classical and religious works in order to better understand their supreme being. Realist perennialists believe the classic works still have much implications today, and therefore should be taught to the next generation.

Methods generally practiced by are considered to be rather traditional, example of these are memorisation, reading, writing, drill, and recitation. It is also the only philosophy which has many of its followers believing that education should be directed towards the intellectually gifted, and that other students should only receive vocational education.

Perennialism has been the leading philosophy in academics before the enlightenment. In the classical era, Greek students had to memorise and recite famous poetry, such as the Iliad and Odyssey by Homer, because these were believed to "provide great moral lessons and taught them what it meant to be a Greek" (Renshaw, 2008, p.139). This academic tradition was then perpetuated throughout the middle ages by the scholastics, who used the rationalism of the Greek philosophers to defend christian doctrine – most notably in the *Summa Theologica* by Thomas Aquinas. Scholastic instruction consisted of four elements: *lectio*, the reading of an authoritative text; *mediatio*, a reflection on the text; *quaestio*, questions from students about the text; and *disputationes*, a discussion about controversial *quaestiones*. With the coming of the enlightenment, academics made a transistion from using classical idealism as a source of truth and instead used experimentalism as a source of learning about the material world and verifying truth claims, and humanism as a means to a better understanding of the human endeavour. Nonetheless, perennialism remained a prominent philosophy in education until the industrial revolution in the 19th century, and still has a place in modern society in the form of for example the Great Book program proposed by Hutchins, albeit in a far lesser degree than before the enlightenment.

Essentialism

Essentialism is generally seen as a child philosophy of perennialism, and is more goal oriented than its parent. Its purpose is to pass on knowledge to new generations in order for them to be able to function in society, and focuses on subject matter. It is also a very teacher oriented approach to education.

This philosophy also is based on both idealism and realism, whereas the idealists think the content comes from history, language and the classics, and the realists think it comes from the physical world, including mathematics and the natural sciences.

Just like perennialism, essentialist teaching methods are rather traditional, and include returning to the three R's, reading, lectures, memorisation, repetition, audio-visual materials, and examinations.

The earliest form recognisable as essentialist is the factory model of education (Stokes, 2013), which was a means to deliver education to the general public for the benefit of the whole society. This model was improved upon by introducing aspects of behaviourism with the introduction of reinforcement and repetition in order to shape the behaviour the teacher wanted. Furthermore, it introduced the audio-lingual method, where the whole class as a group chanted correct answers or key phrases. Furthermore, because of the importance of high-quality instruction, cognitivism contributed towards a better understanding of how to present materials more effectively. Essentialism still remains a popular philosophy in the form of people wanting to go 'back to basics' or wanting more order in the classroom.

Progressivism

Progressivism goes one step further than essentialists by teaching new students not only to function in society, but to go beyond and improve society. This is rather involved for it has its base in opposing authorianism instead of conforming to it.

It also has its root philosophy in experimentalism, where truth is not constant such as in idealism or realism, but rather is constantly in transition to a better understanding. Therefore, a progressivist curriculum focuses itself not on teaching already existing knowledge, but rather on the methods existing to discover knowledge, such as the scientific method. This, however, does not mean that knowledge has become irrelevant. Students still have to be brought up to date with the newest developments in their field of interest, and thereby there is still some knowledge transfer necessary. The only difference is that this knowledge is never taught to be final, and the focus still lies within the transition and the still unknown parts.

Progressivists generally use more generative methods for instruction, such as enquiry learning, the scientific method and problem solving skills.

Starting from the philosophy of pragmatism of Peirce and James, progressivism became a serious contender for perennialism and essentialism in the 1920's, opposing their extreme authoritarian positions. As an educational practice, they grew larger with cognitivism and constructionism, where enquiry learning developed further and proved to be a more meaningful way of education. Yet, this approach was also criticised by the traditionalists, because it lacked rote learning and therefore could not be controlled, and was deemed highly inefficient for the students had to invent the wheel over and over again. However, progressivists argued that discovering truth is a very important part of learning, for it makes it meaningful and independent of an authoritarian truth. This idea of knowledge transmission also sprouted the idea of constructivism, a movement very close to progressivism.

Reconstructivism

There are many similarities between progressivism and reconstructivism, such as both subscribing to experimentalism, moral and epistemological relativism, and the goal of improving society instead of conforming to society. Yet, reconstructivists differ from progressivists in the sense that they are more concerned with the ends than the means. Their goal is not to teach problem solving, but rather problem solving itself, and that society should be repaired. This emphasises the idea that the current society is broken, and focuses on social problems such as inequalities.

One might conclude that reconstructivism is thereby not different from the traditional perennialism and essentialism, because these philosophies also focus on the ends rather than the means. However, these philosophies still assume that the truth is absolute, unchanging, and provided by previous generations, whereas reconstructivism is still rooted in experimentalism and as such states that the truth has to be discovered using the scientific method.

Reconstructivism stems from critical pedagogy, which is again based on postmodernism, antiracism, feminism, and queer theories. Critical pedagogy was also applied in other countries with problems of social injustice and poverty, such as the Philippines and South-Africa during the apartheid. Reconstructivism was then created by Theodore Brameld, who advocated for using it in the US for avoiding fascism and fighting the still prevalent institutionalised racism.

Existentionalism

Out of all described educational philosophies, existentionalism differentiates itself the most. Its core direction is towards individual self-fulfillment, and views education as an instrument for encouraging individual choice and autonomy. Not only does it oppose current authority, but it even goes far enough to state that there should be no authority, and that nobody should decide what students are supposed to learn. It also states that what a person is capable of knowing and experiencing is more important than what he knows.

The main method of existentionalism is to put students into situations where they have to make meaningful choices, and to let them confront them alone in order to overcome personal

Educational Philosophy	Perennialism	Essentialism	Progressivism	Reconstructivism	Existentialism
Function of knowledge	As a purpose on itself	In order to function in society	In order to improve society	In order to change society	In order to discover oneself
Purpose of education	Preserving knowledge	Supplying knowledge	Supplying tools for discovering knowledge	Supplying tools for discovering inequalities	Encouraging maximum individual choice and autonomy
Philosophies	Classical idealism, realism	Idealism, realism	Experimentalism	Experimentalism	Existentialism
Subject matter	Classical literature	Three R's	Scientific method	Social problems	Personal reflection
Methodology	Memorisation, reading, writing, drill, recitation	Reading, lectures, memorisation, repetition, audiovisual materials, examinations	Problem solving	Problem solving	Subjecting students to crises
Authority	Ancient works	Teacher	Science	Socialists	Student

Table 1: A comparative summary on the five educational philosophies (Apps, 1973)

crises so he develops selfreliance and overcomes despair. These are completely different from the methods used by other philosophies, since they do not rely on values preexistent to actions and thereby merely waiting to be discovered.

Existentionalism has seen the least progress in comparison to the aforementioned philosophies, both because of its relative novelty and its radical difference in methodology. It is also the philosophy which is most difficult to implement in current schools. One could even argue that existentialists are opposed to institutionalised education, since it revolves around self discovery and has a very anti-authoritarian viewpoint in the sense that no one should have the authority on deciding what students have to learn. One might argue that democratic schools are a form of an existentionalist curriculum, since here the students get to vote on the content they get to learn, and this school teaches democracy not from theory, but by experience. However, it is not a full realisation, for students do not learn by overcoming personal crises. Another form could be the Dutch *Iederwijs*, a school where students are placed together in a learn-friendly environment and are allowed to do whatever they please. However, this *laissez-faire* method of education still does not challenge the students in any way, which still would be part of existentionalism.

Discussion of the five educational philosophies

Table 1 shows a comparitive summary on all aforementioned philosophies, giving an indication on the growing perspective on knowledge and learning methodology throughout history. In general the older philosophies, perennialism and essentialism, are labeled as the traditional philosophies, whereas the other three, progressivism, reconstructivism, and existentionalism, are often labeled as the modern philosophies. These two groups have the most apparent clashes: traditionalists place most trust in the current authorities where the modernists oppose them; traditionalists emphasise rote memorisation where modernists emphasise enquiry; and traditionalists want students to conform to society where modernists want students to change it.

Comparing these two general paradigms with the tools investigated within this thesis, the drill and practice used by the flashcards is most advocated for by the traditionalists, whereas the constructionist concept mapping technique fits mostly to the enquiry practice of the modernists. Flashcards are used by perennialists to memorise data such as dates and reproduction questions, and even more so by essentialists for drilling facts such as multiplication tables and spelling. Concept maps however would be used to shift the attention towards the meaning behind the surface concepts: progressivists use them to discover the ever expanding scientific body of knowledge, reconstructivists for demonstrating historical causality behind social inequalities and how these could be countered, and existentialists to let students map out their own experience and knowledge. However, this preference is not absolute, perennialists could for example also use concept mapping in order to let students figure out the arguments of Socrates in a philosophy assignment (an argument map), and a modernist could still use flashcards for drilling vocabulary.

It is important to consider the five educational philosophies when attempting to succesfully develop the new learning tool flashmaps which combines the flashcards and concept maps. For example, one might ask themselves the questions ‘what are the benefits of concept map visualisation of flashcards for essentialists’ or ‘why would an existentialist want to memorise the concept map’, but also more practical questions such as ‘should the concept map be provided to or constructed by the students’ or ‘in which order shoud the student traverse through the map’. These are questions which have to be addressed during the design and development of the new tool.

Cognitive theories

This chapter aims to explain the effectivity and inner workings of both concept mapping and flashcard systems by elaborating on the physiology of the relevant parts of the brain, and the relevant cognitive theories. It is important however that these theories mainly focus on a certain type of learning only. According to Squire (1987), there are multiple varieties of memory, which can mainly be categorised into declarative and nondeclarative knowledge, sometimes also referred to as respectively explicit and implicit knowledge J. Anderson (2015). Declarative knowledge also refers to memories that can be explicitly recalled, entailing facts such as definitions, paired associations etc., but also the events where these facts were acquired. Nondeclarative memory involves every memory which can be demonstrated in action, but not in conscious recall per se. Subcategories of these memories are procedural skills, priming, conditioning, and nonassociative memories. Because of the nature of this study, the cognitive theories discussed below are mainly focused on declarative knowledge, although most theories also are relevant to nondeclarative memory in some degree.

Furthermore, Smith and Ragan (2005) describes declarative knowledge as one of Gagné's types of learning outcomes, and relates declarative knowledge to Bloom's levels of recall and understanding, meaning that declarative knowledge does not only encompass rote memorisation of facts, but also understanding the meaning behind this fact. This is also in line with the essay written by von Glaserfield (2001) on radical constructivism, in which it is stated that whatever it is that students are to place into memory they should also understand. Another category of learning outcomes applicable to this context is that of intellectual skills, mainly that of concepts. These, according to Smith and Ragan (2005), help the learners simplify the world and can make them into more efficient thinkers. From a cognitive perspective however, there is not a great difference in dealing with declarative knowledge or concepts, because both relate to explicitly recallable memories and thereby can both be considered as being explicit (Squire, 1987).

Storage and retrieval

Although the whole brain is involved in storing memories, the most prominent areas facilitating the process of memorising are the frontal lobes, medial septum and the hippocampus (J. Anderson, 2015) (see figure 2). The prefrontal regions are responsible for the creation and retrieval of memories, whereas the hippocampal and surrounding areas are responsible for permanent storage of these memories. Because of this dynamic, Atkinson and Shiffrin (1968) conceived a modal theory of memory, displayed in figure 3. In this model, information is perceived as sensory input, and is then shortly stored in the sensory memory. If the perceiver has paid enough attention to the input, it is then transfered (or encoded) into short-term memory. When the input is strong enough, that is, rehearsed often enough within short term memory, it can be more permanently stored in long-term memory. If not, the input fades away from memory and is forgotten. When

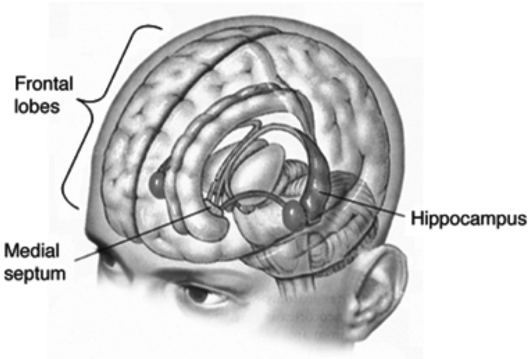


Figure 2: The brain areas mainly involved in storing and retrieving declarative knowledge (White, 2003)

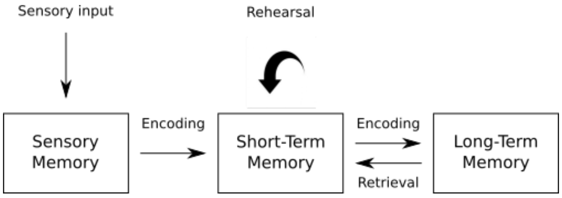


Figure 3: The modal model of memory proposed by Atkinson and Shiffrin (1968)

a memory exists in long-term memory, it has to be retrieved into short-term memory in order to be remembered and used.

This model was heavily influenced by developments in electrical engineering and computer sciences, and can be thought of as functioning like a complex computer, where data is written on a hard drive (the long-term memory), and can be used by first retrieving it into working memory (or short-term memory) and later be transferred to the hard drive again. However, the way the brain works is different from a computer in the sense that a brain has to put effort into memorising data, and that a brain forgets data over time. Therefore, instead of merely inputting the data, learning requires a more rigid approach.

Karpicke (2012) describes two seperate learning practices based on the modal model of memory, namely encoding and retrieval practices, where encoding practices are focused on meaningful encoding or construction of knowledge, and retrieval practiced are more focused on the reconstruction and rehearsal of knowledge. He states that both practices are essential to enhancing learning. Flashcards are a famous retrieval practice, which emphasises drilling the same facts over and over again by means of pairs by association, whereas concept maps are known to be an encoding practice where the student has to connect diverse concepts within one topic by meaningful relations.

The following sections will elaborate on cognitive effects with regard to both encoding and retrieval practices, and relating them with their relevance to the effectiveness of concept mapping and flashcard systems respectively.

Cognitive effects with regard to encoding practices

The first step of memorisation always is encoding, because (logically speaking) it first has to be processed and encoded in either Short-Term or Long-Term Memory in order to be retrieved or used later on. After all, one cannot retrieve a memory which is not already there. It therefore is important to first acknowledge by which means knowledge is encoded, and in what kind of structure it is then stored.

Early metaphors for the brain

For centuries, a lot of metaphors describing memory characterised the brain as a room where a person could store physical things, such as a library filled with books or a storehouse with items (Roediger, 1980). The fact that this metaphor seems intuitive and is easy to understand, it is one of the most popular metaphors, and is still prevalent today. It is for example explicitly used in many popular depictions of memory, such as in the film Inside Out (2015), where memories are stored as physical balls. There even exists a widely-used memorisation technique called the *loci method*, which lets students envision a house where they have to store memories physically in the room. They can then later retrieve the memories by walking through the house and walking along the places they stored the memories at (J. Anderson, 2015).

Yet, there are certain flaws with this model. Firstly, with regards to retrieval practices, it depicts memories as static objects which only have to be stored there and consequently being remembered forever (although inside out already addressed this partly by showing the decay theory of memory by the balls being thrown away when never used, and illustrated strong flashbulb memories as being 'core memories' stored seperately), misleading students, teachers and scientists into focusing more on encoding practices than on retrieval practices (Karpicke, 2012). Furthermore, it treats memories as existing as separate objects, which does not correspond with how memories are encoded in the brain. As a matter of fact, already in the 19th century, Cajal discovered that memories were patterns of electricity through neurons by means of synapses (Bliss & Collingridge, 1993). This enabled another spatial metaphor, namely that of a switchboard, where the synapses were represented by electrical wires (Roediger, 1980). Later on, when the field of computer science begun to emerge, this metaphor transformed to that of a computer, enabling the conception of the modal model of memory. This is already a more useful metaphor than the physical space metaphor, since it is more biologically accurate, and it emphasises the need of communication between certain nodes (encoding and retrieval between the different memory systems).

However, the metaphor of a computer still has its flaws. A computer stores information on certain independent addresses in the form of binary data, and thereby implies that one can store data for later use without any need for comprehension of the data, and that the data can be formatted in any way the user would like to. Yet, the brain is differently structured, which has consequences for succesfull encoding.

The brain as an associative network

Unlike a computer, the brain is not organised with bits with physical addresses, but rather structured as an associative network. This entails the data being stored and retrieved by means of associated peers. In the brain, the neurons function as the nodes, and the synapses function as the edges. When information is encoded, new neurons are marked, and these are connected to other relevant, already marked neurons in the network. When something then has to be retrieved from memory, neurons signal relevant neighbouring neurons in order to activate the relevant parts of the brain. More generally speaking, when stimulated with a retrieval cue, the brain can then use neural pathways to find a corresponding item in the brain. These networks are sometimes referred to as *semantic networks*, and the implication for retrieval as *spreading activation* (J. Anderson, 2015). This effect has also been found on a cognitive level, for example

Kintsch, Welsch, Schmalhofer, and Zimny (1990) has found that material is often not literally encoded, but rather as a set of abstract meaning units representing certain associations between concepts.

Elaborative processing

Because information is retrieved in the brain via related nodes and edges in the semantic network, strong neural pathways facilitate the retrieval process. One way of creating these pathways is elaborative processing (Karpicke, 2012; J. Anderson, 2015), which focuses on meaningful processing of the content. Craik and Lockhart (1972) conducted an experiment where students were to freely recall from a list of words, where the students had to train the words by one of the following techniques: answering questions about structural details (e.g. is it in capital letters); about phonemical details (e.g. the word rhyming on another word); whether the word fits into a certain category; and whether the word fits in a certain sentence. They found that students had higher retrieval rates in ascending order of these techniques. Furthermore, research conducted by Nelson (1979) presented students with paired associates that where either semantic or phonetic (in this case rhymes), and students showed a significantly higher recall of semantic associates. Both of these studies demonstrate the importance of meaningful processing for retention.

Implications for concept mapping

Reflecting on the previously described theory of associated networks, it appears that a semantic network is very similar in structure to concept maps, and thereby the maps provide an accurate representation of the way information is retrieved from the brain. For example, Canas and Novak (2012) states that "the widespread use of concept maps is based on the notion that a concept map is a reflection of the builder's cognitive structure and thus portrays his or her understanding of the domain depicted in the map" (p. 1). Nesbit and Adesope (2006) speculate that because of this, more and better retrieval cues are created when learning from or generating a concept map. Furthermore, a concept map displays the relations between certain concepts, and thereby focuses more on the meaning behind the content, rather than just the content itself.

Cognitive effects with regard to retrieval practices

According to Karpicke (2012), a lot of educational practices have placed an emphasis on finding optimal ways to encode knowledge and experiences, but that retrieval practices have received less attention. Nevertheless, basic research has indicated that retrieval is still important to consider in any analysis of learning. This is mainly due to the fact that information is not stored exactly and indefinitely, but rather that memories are forgotten over time. Two theories have been proposed and debated over explaining why forgetting occurs, namely by interference of other redundant memories and by decay of existing memories.

Interference and Decay

The theory of interference being responsible for forgetting has been demonstrated by an experiment by J. Anderson (1974). The participants were asked to memorise sentences in the form *A <person> is in the <location>*, where sometimes multiple persons where associated with only one location, and some locations with only one person. They found that if a sentence contained locations or persons with multiple associations this had an impact on the recognition time for that sentence, and even more so if both the location and the person had multiple associations.

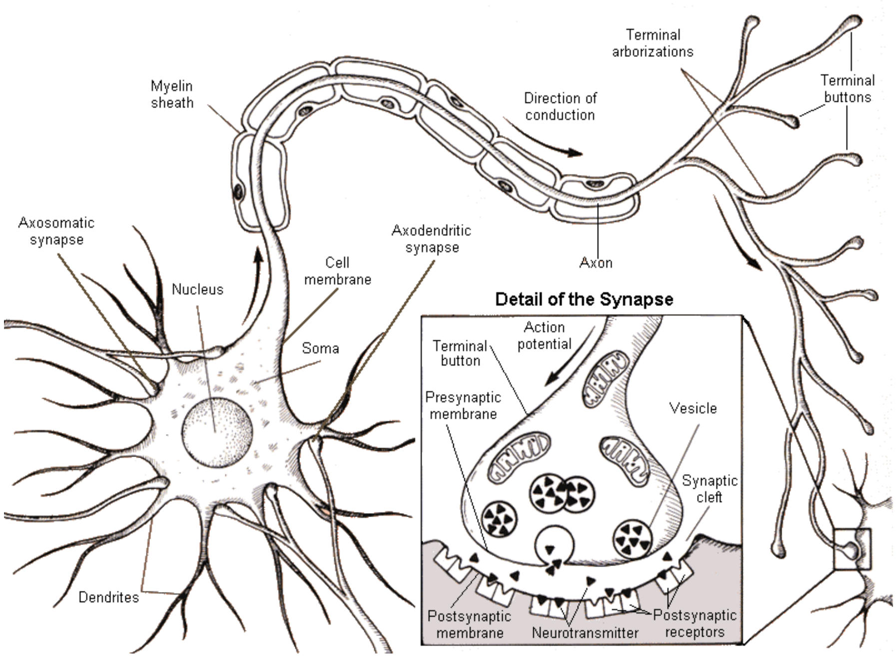


Figure 4: A schematic image of a neuron with a closeup of a synapse (Matsaridis, 2013)

The explanation for this phenomenon is that since memories are retrieved by means of spreading activation and only limited activation can spread from one source (J. Anderson, 2015), the activity has to be divided over different branches in the semantic network, increasing the retrieval difficulty of the correct node. The increase in difficulty is also related to as the *fan effect*.

The effect of decaying memories takes place in the connections between neurons, and therefore it is important to first examine how neurons communicate signals. Figure 4 displays a schematic representation of a neuron in which it can be seen how the soma (cell body) is connected via an axon to the dendritic tree of other cells. The neuron can transmit stimuli by creating an action potential in the nucleus, transmitting this signal through the axon to the terminal button in the connected telodendrion (in the image refered to as the terminal aborization). There, neurotransmitters are released from vesicles, and after they have crossed the synaptic cleft there is a certain chance of being received by postsynaptic receptors. When this is the case, the nucleus of the receiving cell is triggered via the connected dendrite to also create an action potential, where the whole process is repeated (Bliss & Collingridge, 1993). The strength of a certain connection between neurons is therefore dependent on the action potential generated by a nucleus, the amount of telodendria over which the action potential has to be distributed (hence the aforementioned fan effect), the amount of neurotransmitters in the terminal button, and the amount of postsynaptic receptors in the dendrite of the next neuron.

One widely studied effect with regard to the increase and decrease of action potential and strength of memory traces is called long-term potentiation (LTP) (J. Anderson, 2015; Bliss & Collingridge, 1993; Pavlik & Anderson, 2005; White, 2003). Whenever a neurotransmitter is received by by a receptor, not only is the next nucleus activated to release its action potential, but also more receptors are activated, so that the postsynaptic membrane is able to receive more neurotransmitters at the next activation. Furthermore, another process is activated altering the dna in the neuron, causing it to create proteins for more stable increased sensitivity towards stimuli. It is also speculated that there might be a retrograde effect, causing presynaptci modifications such as the creation of more neurotransmitted in the presenaptic vessicles (Bliss & Collingridge, 1993). This all results in an increased sensitivity in the postsynaptic neuron towards action potential in the presynaptic neuron, which then again increases the stength of this particular memory trace. Over time, if a specific neural pathway is not used, the effects of LTP decrease again, causing its strength to decrease and thereby causing decay. This also is a predictor for the *testing effect*, the effect of retrieval strengthening memory more than extra opportunities for further encoding, even when the retrieval is only carried out internally without any outward response (Edge et al., 2012).

Although both the effect of interference and decay have been proposed as separate theories and have been debated, they are still mutually inclusive, and J. Anderson (2015) therefore conludes that forgetting results both from decay and from interference.

Power laws of forgetting and learning

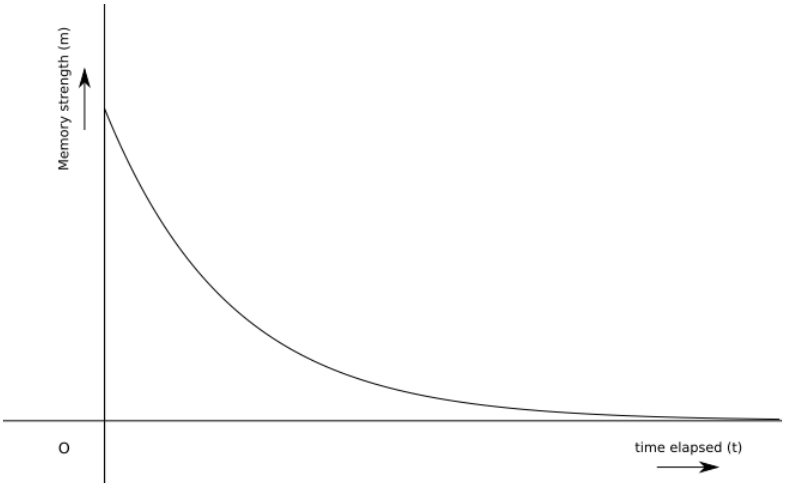
Now that the relevant theories for learning and forgetting have been discussed, it is important to investigate with which rate people learn and forget. Already in 1885, Ebbinghaus discovered the power law of learning, referred to as the inversal exponential nature of forgetting (Edge et al., 2012; Pavlik & Anderson, 2005). The implication of this model is that memory not only systematically deteriorates with delay, but also that this loss is negatively accelerated, meaning that the rate of change gets smaller with increasing delay (J. Anderson, 2015). Wickelgren (1974) already proposed the formula $m = \lambda(1 + \beta t)^{-\psi}$, where m is memory strength (the probability of recognition), t is time, λ is the state of long-term memory at $t = 0$, ψ is the rate of forgetting, and β is the scaling parameter (see figure 5a). This formula has also found to be accurate by Wixted and Carpenter (2007). Finally, the effect has been directly related to LTP in the rat hippocampus by stimulating neural pathways directly with electrical signals (Raymond & Redman, 2006).

A similar effect has been found for the effectiveness of repetition: Newell and Rosenbloom (1981) have proposed a power law of learning, stating that a learning curve is inversal exponential (see also R. Anderson (2001) and Wixted and Ebessen (1991)). Murre and Chessa (2011) propose $P = p(t) = 1 - e^{-\mu_i t}$ as a function describing this power law, where P or p is the probability of recognition after t iterations and μ is the learning rate of student i (see figure 5b). The power law describes the effect that repetitions have a positive effect on retrieval probability, however that it diminishes with more repetitions. Again, this effect has also been demonstrated in the context of LTP in rat hippocampi (Barnes, 1979). The stronger memory trace from a higher repetition rate does not only result in a higher recall probability, but also in a more gradual retention curve, allowing memories to persist longer.

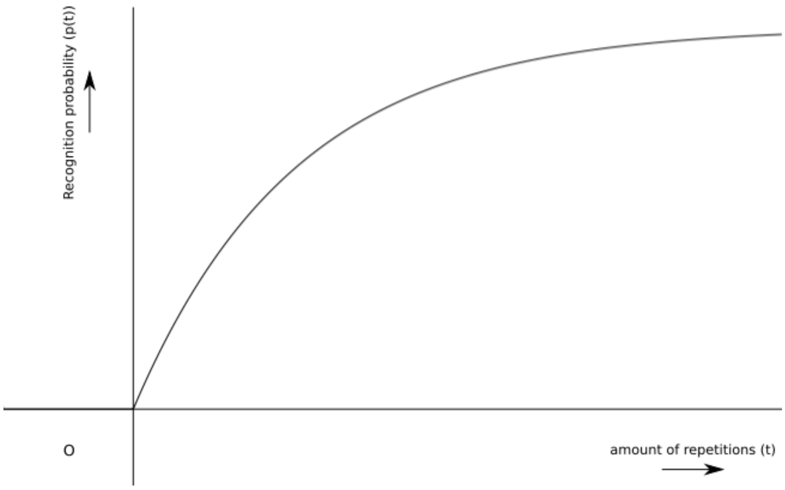
Spacing effect

The spacing effect is a well known effect occuring within paired-associate learning, and demonstrates that repeated items are better remembered when both occurences are separated by other events or items than when they are presented in immediate succession (Verkoeijen & Delaney, 2008; Logan, Castel, Haber, & Viehman, 2012; Siegel & Kahana, 2014; Xue et al., 2011; Karpicke & Blunt, 2011), which is demonstrated with diverse populations (Verkoeijen & Delaney, 2008; Logan et al., 2012), under various learning conditions (Verkoeijen & Delaney, 2008; Logan et al., 2012), and in both explicit and implicit memory tasks (Verkoeijen & Delaney, 2008). Items in immediate succession are called massed items, and items in separated succession are called spaced items.

One can test the spacing effect either by using pure lists or mixed lists. When using pure



(a) The power law of forgetting, with m as the probability of recognition and t as the time passed since learning



(b) The power law of forgetting, with p(t) as the probability of recognition and t as the iterations of learning

Figure 5: The power laws

lists, one compares the effect of learning a list containing only massed items with a list containing only spaced items, and using mixed lists one measures the effect of learning both massed items and spaced items in one list, comparing their individual retentions. Verkoeijen and Delaney (2008) states that the vast majority of studies are conducted using mixed lists and found that spaced items where consistenly better recalled than massed items, yet studies using pure lists are relatively rare and have produced contradictory outcomes. They conducted a study providing participants first with an all-massed list, then letting them write down as many words as they could remember, and repeat an identical procedure for an all-spaced list with a 2 minute break inbetween. They conducted this experiment with short-lagged spaced items (with 1-4 items in between) and long-lagged spaced items (with 4-13), and found only a spacing effect in the latter experiment. However, Wahlheim, Maddox, and Jacoby (2014) adds to this that repetition is only increases when a student detects the repetition of an item, and therefore the lag should not be too long.

Two theories have been presented explaining this phenomenon, namely the contextual variability theory and the study-phase retrieval theory (Siegel & Kahana, 2014). The first theory entails that because context is not static but continuous, and that therefore spaced items are studied in a greater variety of contexts and as such are easier to recall in yet other contexts than massed items due to the so-called encoding-specificity principle (J. Anderson, 2015). This principle entails that the probability of recalling an item depends on the similarity of the context during the encoding. The study-phase retrieval theory entails that additional retrieval cues for the repetition of an item are generated by earlier occurences and their associated contexts being associated with the repeated item. These theories are not mutually exclusive (Siegel & Kahana, 2014).

Inspired by the power laws of learning and forgetting, Karpicke and Bauernschmidt (2011) conducted an experiment to test the effect of constant or varying lags between items have a significant effect on learning. They tested this by conducting a similar experiment to Verkoeijen and Delaney (2008), however in this experiment they only tested pure lists with three different lag intervals to test for an absolute spacing effect, and for each lag interval category they tested for an expanding lag condition (where the lag would increase for the repetition of each next item), an equal lag condition (where the lag would remain constant) and a contracting lag condition (where the lag would decrease for the repetition of each next item) in order to test for a relative spacing effect. From their findings they confirmed the effect of absolute spacing, namely that longer gaps between items do have an effect on long-term retention, yet they did not find a relative spacing effect. However, this has not been tested for spacing for longer intervals, such as intervals spanning multiple days or weeks.

Implications for the flashcard system

It can be concluded that the flashcard system derives its effects mainly from the testing effect by having students actively retrieve information instead of simply encoding it, and from the spacing effect by students going through the items interspersally instead of by immediate succession. The key question however is how often a single card has to be repeated. Herein one has to balance *overlearning* – the student repeating an item too often resulting only in diminished learning effects because of the power law of learning, and also only on the short term (Rohrer, Taylor, Pashler, Wixted, & Cepeda, 2005) – because its inefficiency, and forgetting items in between intervals, since then the spacing effect does not apply anymore. In order to solve this problem, most modern digital flashcard systems apply a system called *adaptive spaced-repetition learning* (e.g. the Pimsleur system, the Leitner system, Supermemo, and Anki (Edge et al., 2012). In this system, exponentially expanding intervals are used, not because of a relative spacing effect

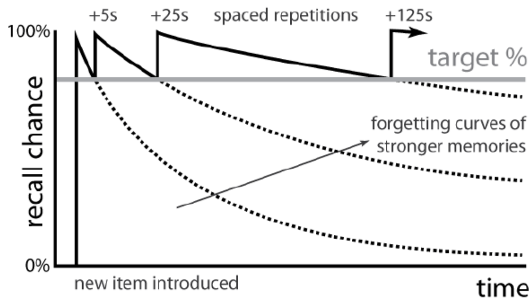


Figure 6: Adaptive spaced-repetition learning (taken from Edge et al. (2012))

which does not exist according to the previously mentioned literature, but rather to increase the average (absolute) spacing with each new repetition. This creates a stronger memory trace every time, but also takes into account the further decreasing risk of forgetting because of the slower declining retention curve (see figure 6).

Conclusion

Overall, this chapter has discussed several cognitive theories related to the storage and retrieval of explicit (or declarative) knowledge in and from the hippocampus. Related to encoding practices, it has now been established that the brain works as an associative or semantic network, and that meaningful or elaborative processing is important for the later retrieval of memories. This seems to fit with the structure and process of concept mapping, although more research is needed in this area. Furthermore, the theories of interference and decay have been discussed in order to explain forgetting of memories, together with Long-Term Potentiation and its effects on the rate of forgetting and learning. In addition, articles were discussed demonstrating that spaced rehearsal is more effective than massed rehearsal. This has finally led to the conclusion that adaptive spaced-repetition learning is an effective method to expand absolute spacing, which entails that items are repeated with exponentially increasing intervals.

Part II

Design

Part III

Research

Part IV

Recommendations

Epilogue

Part V

Appendices

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