The Benefit of Errors

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Abstract

The cognitive load theory by Sweller (1988) describes the limitations of the working memory capacity. In his book 'Cognitive Load' (2011) Sweller described the many effects on workload. One of them is collective *working memory effect*, which refers to the phenomenon that individuals obtain higher learning outcomes when working collaboratively than when working alone. For this thesis, first a literature study was conducted concerning cognitive load. Thereupon, an experiment was designed to research the working memory effect in a computerized environment with a remote virtual student. This experiment is inspired by the research by Kirschner et al. (2009) on the effects of individual versus group learning with a transfer test-performance in the domain of biology. A pre-study was conducted to explore if the design was suitable. It is hypothesized that a group with a needy virtual student will outperform a group with a normal virtual student due to deeper processing of information by discussion, argumentation and reflection of the material. Measurement of cognitive load and performance was used to measure the efficiency of the tasks. The results of the pre-study are inconclusive, because no significant difference could be found between the groups. Therefore, recommendations for a full experiment are proposed. Results from a full experiment might be of further use in the artificial intelligence branch to help create software that can aid with the learning process of humans.

Keywords;
artificial intelligence, cognitive load, collaborative learning, computer aid

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1 Introduction

The aim of the artificial intelligence branch is on the one hand to develop intelligent machines and software, and on the other hand to simulate and study the human mind. Obviously, humans are quite efficient in learning, communication, comprehension of complex ideas, planning, logic, problem solving, etc. and thus considered intelligent (American Psychological Association, 1995; Gottfredson 1997). There exist cognitive architectures that step-by-step simulate human cognitive and perceptual operations, like the ACT-R and Soar. These models encode visual and auditory information, encode and retrieve memory, motor executive functions and even mental imagery manipulation (Anderson, 1995). For learning, information has to be processed in the working memory.

In educational psychology the term cognitive load was introduced to describe the load which is accompanied by the process of information in the working memory in order to aid with instructional design to achieve better learning results (Sweller 1998). This load is important because it concerns the complexity of a problem. It concerns the good and bad elements of how a problem can be presented and solved. 'Cognitive Load Theory' describes several effects on cognitive load from learning strategies to redundancy and element interactivity (Sweller et al. 2001). All these effects can be used to aid the learning process. By implementing and controlling all these effects in a computer program, it might give better and more individual aid for learners. One special effect on cognitive load, namely collaboration, forms the inspiration for a small experiment. Collaboration has proven to be beneficial for learning when dealing with complex problems (Olivera 2004; Kirschner 2009a, 2010). Tuning a computer to behave like a group could be helpful in education and simultaneously give better insight in how humans process information and how they deal with simple and complex problems.

A closely linked research by Kirschner et al. (2009) investigated the effects of individual versus group learning on efficiency of retention and transfer test-performance. It was hypothesized a group would construct higher quality cognitive schemata than individuals, due to more available processing capacity by sharing the high cognitive load imposed by complex learning tasks. Not being able to share the load, individuals would need all available processing capacity to remember the information leaving nothing left to work with the information. The results showed that individual students had experienced significantly more mental effort in the learning phase compared with the group members. However, individuals outperformed the group members on the retention test-performance. Group members did better on the transfer test-performance and experienced less mental effort and thus the hypothesis is confirmed.

The question arose whether the disadvantages of collaboration would be beneficial for the learning process. The research question of the thesis is as follows *Could a smart computer aid with the learning process of humans by making errors?* To answer this main question first a literature study was conducted on how the working memory of humans works, what cognitive load exactly is, and how cognitive load can be influenced.

Additionally, a small experiment was conducted on the effects of cognitive load on the simulation of human collaboration to see if this effect of cognitive load can be implemented in a computer to help humans learn. Because cognitive load and the learning process in collaboration is quite hard to control, a small set-up was required with previous tested material and a way to simulate collaboration while keeping track of the collaboration itself. So the experiment in this thesis uses the design of the research of Kirschner, yet in a different environment. Using a virtual student by means of chat, the imitation of collaboration was made remotely. The chat of the virtual student was scripted and the communication saved. Two groups were tested; one with a virtual student that helps properly and a second group where the virtual student was more needy. By collecting and comparing the score of the learning test and the end test, questionnaires and evaluation of the collaboration of the two groups, an answer may be provided whether or not collaboration with a needy student contribute to the learning process of humans.

The hypothesis is that test subjects in the second group will outperform the first group due to a more intensive learning process, expected by the extra explanation to the more needy virtual student. However, within the scope of this thesis, it was not possible to actually perform a scientifically sound experiment given the limitations of time and resources. This experiment is a pilot study into this unexplored field of deliberate errors in learning material and may be used as a pre-study for further research. This search for right questions, right measure methods and all the to be accounted for conditions, the right test set-up, getting test subjects and the testing itself has proven to be quite a challenge.

2 The Human Mind

To answer the main question *Could a smart computer benefit the learning process of humans by making errors?* firstly more information is needed on how humans learn: how do humans acquire, modify and regain knowledge, behavior and skills? Understanding how the human mind works, how it deals with incoming information, how it stores information and how it works with the information to get a desired outcome is important. Fortunately, this subject has been studied for years. It turns out there are several stages of information processing during learning and memory processing. In the next two sections the most influential models are discussed.

2.1 Memory Models

2.1.1 Modal Model

According to the model of memory from Atkinson and Shiffrin (1968), the Modal Model, there are three separated components that make up human memory.

The sensory memory This is where all the sensory information is registered from sight, sound, smell, taste to touch. It obtains sensory information, like audio or visual signals. The information lasts only a few millisecond, but it has a high capacity (Sperling 1960; Sams et al. 1993). If the brain is not able to deal with the incoming information, when identification fails for example, the information is lost, leaving the observer confused.

The short-term memory This receives and holds input for the sensory memory and long-term memory. It holds information for a short period of time, fifteen to twenty seconds and last up to minutes, but its capacity is limited, only seven ± two items at a time (Miller 1956). Features of the short-term memory are rehearsal and chunking. Rehearsal is the mentally repetition of information, so it can recursively re-enter into the short-term memory for another fifteen to twenty seconds (Atkinson and Shiffrin 1971). Rehearsal increases the efficiency of the encoding and storage processes, for if an item is recalled several times, the item will have a stronger connection in the long-term memory (Hebb 1949). The short-term memory does not concern the manipulation or organizing of the information (see next section) but it does make use of chunking. Chunking is the process of organizing information into groups, so the seven ± two items that can be held in the short-term memory may contain groups of items.

The long-term memory This is where information that need to be preserved is stored (permanent storage). The long-term memory lasts days to years and has a large capacity. Each time an item from the short-term memory is rehearsed, its strength in connection increases in the long-term memory (Hebb 1949). Most models divide the long-term memory in declarative memory and non-declarative (procedural) memory to make a distinction between knowledge that is conscious accessible, like decisions, and knowledge which is not, like motor skills. Components of the long-term memory are encoding of new information and retrieval of the stored information.

In order to solve a problem or perform a task, humans have to process the information. This processing requires organizing, combining, comparing and manipulating items of information. All this is done by the working memory.

2.1.2 Working Memory

Baddeley and Hitch (1974; 1992; 2000) adjust the short-term memory by adding the working memory to the Modal Model. They describe it as a short-term storage system in which cognitive operations like language, reasoning and learning are processed. Divided into four components, the theory becomes a multi-channel one. Central executive, visuo-spatial sketchpad, phonological loop and episodic buffer. See Figure 1. The central executive is a flexible system that controls and regulates cognitive processes -which gives us consciousness- and binds coherent information from different sources, coordinates slave systems, shifts between tasks or retrieval strategies and has control over selective attention and inhibition. It seems to be located in the frontal lobes of the brain. The phonological loop is concerned with sound and the repetition of sound. It is seemingly located in the left hemisphere and temporal lobe.

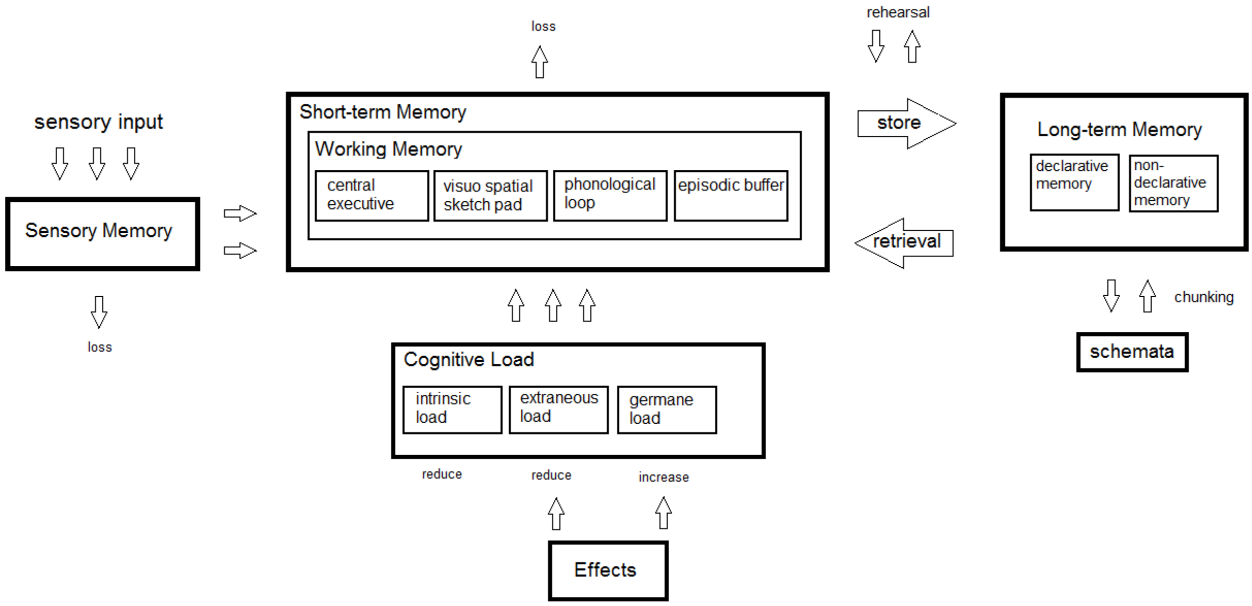

Figure 1: Overview (Based on overview by Mathew Mitchell (2007))

The visuo-spatial sketchpad is concerned with vision. It temporary stores spatial and visual information and can manipulate it. The location differs depending on the difficulty of the task; less intense tasks show activation in the occipital lobe, more complex tasks in the parietal lobe. Important to integrate information across domains is the episodic buffer (a slave system) which includes time sequencing.

Overall, most theories agree that, corresponding to modality, incoming information is processed briefly by the sensory systems. Certain parts of this information are passed onto the working memory/ Here, combined with information held in the long-term memory, it can be consciously processed. Some of this new combined information will be stored in the long-term memory, and thus learned, others will be discarded. The rehearsal and chunking described by Atkinson and Shiffrin apply here. Chunking and recall make the encoding and storage more efficient and rehearsal gradually makes the recall processes automated. And as Anderson states in 'a simple Theory of Complex Cognition' (1995); "The power of human cognition depends on the amount of knowledge encoded and the effective deployment of the encoded knowledge." If retrieval of knowledge is efficient, intelligent behavior may be observed.
Obviously there are limitations on how much humans can learn. The working memory has only a limited capacity and duration when dealing with novel information (Miller 1956; Cowan, 2001; Peterson & Peterson, 1959), whereas the capacity and duration seems unlimited when dealing with familiar information that is previously stored in the long-term memory (Chase & Simon 1973). When the capacity is exceeded, processing information fails and might stop altogether. Based on the limitation of the working memory, Sweller developed the cognitive load theory (Sweller, 1988).

2.2 Cognitive Load

2.2.1 Work load

During complex learning activity, information and interaction between working memory (that gets its input from the sensory memory and short- and long-term memory) and long-term memory has to be processed simultaneously. The working memory has to process the right kind of information and, together with the information from the long-term memory, it attempts to solve a problem. To get the right kind of information, first it has to be selected out of all incoming sensory information, passed through the short-term memory and it even may be manipulated before it becomes useful information. Broadbent described the human mind as an information processing system with limited capacity, where only a certain amount

of information can pass. He developed the filter model of selective attention where the filter is used to early select stimuli, basic initial properties. More complex stimuli passes the filter for further processing in the short-term memory, whereas unattended stimuli will be inhibited or discarded (Broadbent 1958). On the same subject, Kahneman developed a theory concerning multitasking. Humans can deal with several things at once, but not at the same time, for they have a limit to their attentional resources that they have to divide among several tasks using different modalities. Kahneman compared the human mind to a computer for not being able to exceed the limits of the processor. The mental effort depends on how demanding a task is. He suggested that the limit can be increased by study and practice. If a task becomes automated, there is room for a different task at the same time due to less mental effort. Other factors like arousal and anxiety influence the limit as well (Kahneman 1973).
Using selective attention and cognitive processing, the working memory attempts to solve a problem and this causes a certain amount of workload, because the working memory is limited with respect to its capacity. In line with Broadbent and Kahneman, John Sweller described the load concerning the processes of the working memory as cognitive load -the amount of mental effort a learner uses when processing information-. Cognitive load can be seen as a part of the working memory, and with learning and problem solving, selective attention and the limited capacity of cognitive processes are concerned. Cognitive load consist of the following three components (Sweller et al, 2011);

I Intrinsic load concerns the task complexity and learners prior knowledge. When intrinsic load is low, a problem is considered simple. If a problem is high in intrinsic cognitive load, it may be the case that a high amount of elements needs to be remembered, or that there is a high amount of essential elements that need to be processed simultaneously to make sense. Also, the degree in which the elements interact with each other (element interactivity) determines the intrinsic load (Ayres, 2006; Kalyuga et al. , 2003; Sweller and Chandler, 1994).
The difficulty of a task cannot be adjust by instruction, although it may be possible to divide the problem into sub-problems (sub-schemata) or to give a more simple problem so that some interacting elements are left out.

II Extraneous load are the instructional features that are not beneficial for learning and interfere with schema acquisition. It can be the way information is presented or the amount of unnecessary information. This load should be reduced as much as possible.

III Germane load are the instructional features that are beneficial for learning. The term can be described as germane resources, because it grasps the resources that are relevant to learning. Those resources are the way in which information is presented and steps required to solve problem. Germane load describes the factors that enhances learning like the effectiveness of schemata, organization of information, chunking and the use of techniques. Instructors should focus on the construction of schemata for problems (building on what learners already understand).

In educational psychology, cognitive load is designed to provide guidelines for instructions to help learners to optimize performance, considering the limitations of the working memory. The aim of instructional design is to reduce extraneous cognitive load -by redesigning instructional materials- and thus increasing the availability of the working memory of germane resources to intrinsic cognitive load (Sweller, et al. 2011; Copper, 1998). In cognitive psychology the focus lies on the load of executive control of the working memory when dealing with mental processes like memory, learning and problem-solving. They also conclude that complex activities have a higher amount of information and interactions that need to be processed simultaneously, which has a direct effect on the load of the working memory, but are more interested in the understanding of the underlying factors that reduce or increase the load like chunking information (Sweller, et al. , 1988; Miller 1956). In computer science, there is also a working memory with limiting factors like selecting relevant information, space and computing time. Overall, the computer memory is very similar to the cognitive load factors in the working memory of humans and thus the effects of cognitive load are worthy of attention for creating artificial intelligence.

In short, given a problem or a task, the problem or task itself has an amount of cognitive load that is intrinsic to itself. If the manner in which the problem or tasks is presented is functional for learning it is considered germane, when it is not beneficial for learning it is considered extraneous load. How is the load on the working memory when dealing with mental processes measured?

2.2.2 Measuring Cognitive Load

In order to measure cognitive load, it is necessary to keeping track of the problem difficulty, the subjects prior knowledge and used strategy. Most researchers tried to keep the intrinsic load constant and variate the extraneous load (Leppink et al., 2013). Methods used to measure cognitive load are performance measures like scores, time comparing and performance over time (following treatment). For example, Khawaja et al. used language complexity as a measure. They found that the lexical density of speech decreases with increased difficulty of a task (Khawaja et al., 2010). Or one can use subjective measuring, like self-reporting. Evidence of introspective measurement comes from a study from Ayres, which showed that error rates were highly correlated with subjective measures (Ayres, 2006). Also, psychophysiological measures can be used. The brain or heart rate are measured and learned performance is transferred into a second task. Antonenko and Niederhauser used EEG in combination with subjective measures and found reasonably good time resolutions for the tracking of changes in cognitive activity, as complex learning took place (Antonenko and Niederhauser, 2010). Halford et al. and Ayres showed that high element interactivity caused high working memory load with a secondary task and measured the reaction time (Halford, Maybery, and Bain, 1986; Ayres, 2001). Underwood et al., used eye tracking to see where and how long subjects focused on different combinations of text and pictures and concluded different levels of cognitive processing based on the eye fixation. Longer eye fixation indicates more cognitive processing (Underwood, Jebbert, and Roberts, 2004). These are just a few examples of the many ways researchers tried to measure cognitive load. Other physiological techniques like fMRI or PET showed no difference due to the low temporal resolution.

To continue, lets connect the learning and cognitive load. Figure 1, gives a neat overview on how cognitive load fits in the learning process of humans. In Baddeley's Model of Working Memory, the working memory consists of the central executive, phonological loop and visual-spatial sketchpad. Meaningful learning takes place when accurate schema are made in the long term memory.

Recalling that the central executive binds information, can shift between tasks or retrieval strategies, has control over selective attention and inhibition, the information goes by the central executive or directly back to the working memory. All depending on the high or low prior knowledge of the incoming information (intrinsic load). Cognitive load is closely linked to the working memory, because the extraneous, germane and intrinsic load determine the load on the working memory, in turn each of these parts can be influenced. More on these effects see section 2.4. With the information on how humans learn and what cognitive load is we proceed to the next step; how do humans solve problems?

2.3 Learning and Solving Problems

Whether it may be a new skill or an addition, different behavior, new or additional knowledge or more values, obtaining knowledge demands the ability to gather, comprehend and use information. With the ability to process information, problems can be solved. They can be solved by cognitive thinking which uses several steps; information gathering, analyzing, planning, solving, checking and evaluating (Newell and Simon, 1972). One can learn through education, personal development, training and play. Essentially vision and auditory signals are most important for learning. Most skills are learned unconsciously, like learning to speak, whereas other skills require discipline and hard conscious work (Jensen, 1998).

Psychology mostly looks at problem solving to reach a goal state or desire from a start condition through cognitive processes. Opposite to behaviorists, who look at learning as a response acquisition by conditioning by reward and penalty (Skinner, by Bjork 2013), educational psychology is more interested in how learning takes place. The learning theory they describe is a conceptual framework based on prior experience, environment, cognitive and emotions. They want to know how understanding is acquired or changed by looking at how information is absorbed, processed and retained during learning (Thorndike 1932). Neuropsychology takes a closer look at the structure and function of the specific brain regions related to learning. Constructivists hold learning as knowledge acquisition, in which the learner builds upon what he already knows and understands. On the other hand, humanism focuses on the intrapersonal and interpersonal learning, while the instructional theory is concerned with explicit guidance and aim to prescribes how to better help (Bower and Hilgard, 1981). More interesting with regard to this thesis is the view of the computer scientist. As stated before, a computer is very similar to a human mind, with its own working memory, storing place and limitations. To execute a task, a computer needs its procedural knowledge, the execution of sub-tasks, to get to the declarative knowledge stored in the long-term memory. So by using sub-tasks, declarative knowledge is retrieved to the working memory and here it may be refined or manipulate to finally execute the main task, doing so by using algorithms, heuristics, root cause analysis, and so forth (Laird and Rosenbloom, 1996).

Once material is learned, it may be used in new situations. When a novel problem, in a similar context, can be solved using learned material it is called near transfer. When the novel problem is presented in a different context it is called far transfer. If prior learning supports problem solving it is called positive transfer, if prior learning interferes with novel problem solving it is called negative transfer (Perkins and Salomon 1994). Novice learners have many strategies to handle a problem. When given a goal, they intuitively make use of Means-End strategy, working from an initial state towards a goal state with use of sub-goals. Working backwards, the only steps that are taken are the one that reduce the difference between a given problem state and the goal state. Without a goal this method does not work (Sweller 1988). Other methods like searching for proof, method of focal objects, morphological analysis, root cause analysis, fault tree analysis, reduction, and trial-and-error can be used. (Mayer 1992; Schooler et al 1993). Experts are usually good at organizing the needed information and have a high level of automation so tasks can be performed without concentration. They use forward-working sequences and choose appropriate steps leading to the goal because they recognize each sub-problem. Experts have the memory of problem state configurations and so called schemata (see below) which in turn consist of elements (see next section). Novice learners, unlike experts, do not possess the appropriate schemata or the ability to recognize the sub-problems (Sweller 1988). The brain systems have to temporarily store and manipulate necessary information for complex cognitive tasks like learning, reasoning or language comprehension. A problem or a task consists of several elements of information, all those elements have to be processed, or rather learned, in order to be able to be combined into useful information. There are several obstacles that occur before a problem is solved. The situation has to be clear with a clear goal and no irrelevant or misleading information (extraneous load). A problem becomes harder if multiple goals are targeted. Also people tend to make assumptions and work in a mental set where heuristics can be helpful. However, this may also lead to tunnel vision (Mayer 1992). Depending on the difficulty of a problem, some elements of that problem can be learned one element at the time. Other elements have to be processed simultaneously because they are more complex and the understanding of it depends on other elements. The levels of intrinsic and extraneous cognitive load are determined by element interactivity. High interactivity due to simultaneous processing relates to high intrinsic load and similar, high unnecessary element interactivity relates to high extraneous cognitive load (Sweller 2011). After learning, interacting elements can be integrated into a schema.
Schemata consist of multiple interacting elements that are incorporated into a single element with a specific function. Now one element, instead of several interacting elements is to be processed. Once it is learned how these elements interact, the interaction can be ignored and processed unconsciously when the schema is used, because it becomes a single element itself. Several schemata can interact and so new schemata can be constructed (Sweller et al. , 2011). Therefore, load can be reduced. When a schema is constructed one might speak of meaningful learning and if a schema is used often enough it can even become automated which lead to obtaining skills (Sweller et al. 1998).
Recalling the working memory as a theoretical framework, it describes the structures and processes used for temporarily storing and manipulation information. To understand a problem, the information concerning that problem, all of the (interacting) elements, have to be processed in the working memory. Given a complex problem, information is difficult to understand when there are more interacting elements than the working memory is able to process (Sweller et al. , 2011). If too much information is given, a problem may become more difficult due to the redundancy, whereas given the right instructions a problem can become less difficult. Combining the working memory, cognitive load and problem solving, a learner has to use the limited working memory efficiently to solve a problem. After the assignment of certain cognitive load to intrinsic load, the remaining working memory capacity is used to deal with

extraneous and germane load. Intrinsic load cannot be changed, but germane and extraneous load are connected. Reduction of extraneous load and a increase in germane load often collide -more effective instructions- or the reduction of extraneous or germane load causes a shift in distribution of the capacity. If less capacity is needed for extraneous load this may lead to more capacity for germane load. Likewise the use of schemata will reduce intrinsic load, which in turn freeing working memory capacity. For learning to occur, the total load must not be exceeded, because learning might fail to occur. Rather than shift the distribution of the load, freeing working memory capacity will allow learners to acquire more advanced schemata.

2.4 Cognitive Load and AI

Artificial intelligence has two goals. First, to create smart computers that can do the work of humans. Second, to use computers to simulate human mind as to find out how humans work and to help them to be better in their work. For this thesis, the focus lies on how humans learn and how computers could aid humans with learning. With the understanding of how the working memory of humans work, what cognitive load is exactly and how it can be influenced, we arrive at the question how this can be used by a computer to help humans learn. Several computational models were developed that simulate cognitive processes for the sake of gaining more insight on the complex brain systems involved in learning, memory and problem solving. Best known are ACT-R, Soar, CLARION and EPIC. (Anderson J.R., 1995; Laird, Newell and Rosenbloom, 1996; Sun R. 2006; Kieras and Meyer 1997). Anderson (1995) developed the Adaptive Control of Thought-Rational (ACT-R) theory. ACT-R involves with procedural knowledge and declarative knowledge. The procedural knowledge are the simple encoding of transformation, the production rules. Declarative knowledge consist of the simple encoding of objects; chunks, like storage in the long-term memory. Laird and Newell (1996) Soar's cognitive architecture uses symbolic systems for the representation of the procedural, declarative and episodic knowledge. When solving a problem, the system searches within a problem space for the goal state and by means-end, only takes a step if this brings it closer to the goal state. Each step is decision based by taking all the pieces of knowledge bearing the problem to Soar's working memory. The architecture CLARION by Ron Sun (2006) makes a distinction between implicit and explicit processes and tries to capture the interaction between the two. Executive-Process/Interactive Control (EPIC) focus on the perceptual and motor capabilities. All models have a computational implementation and produces a step-by-step simulation of human behavior (i.e. visual and auditory encoding, motor programming and execution, encoding and retrieval of memory and so forth). Each step consist of predictions of latencies and accuracies. The models are tested by comparing the results to behavioral experimental data.
Recalling that the human working memory is limited, but schema acquisition and automation of knowledge ensure humans can learn properly and efficient. Computers also use schemata as they have a network of information that is hierarchically classified, but also need to connect concepts that are not hierarchically linked (Shaffer Doube and Tuovinen, 2003). If a computer wants to solve a problem, the intrinsic load may stand for its resources and the complexity of the problem itself. The germane load are all the available algorithms and extraneous load the obstacles to overcome, like getting the relevant information. As with human, if there is a way to manipulate the load, a problem may be easier to solve because the needed information becomes easier to access, more strategies may be available or the problem can be broken down into components. To aid humans with learning, computers could try to manipulate the load.

In his book "Cognitive Load Theory" (Sweller et al. 2011) Sweller discusses several effects of manipulating cognitive load. These effects are suggestions to lower cognitive load. However these effects were only found with high-complexity tasks (Sweller & Chandler 1994; Sweller 2004).
The *Goal-Free Effect* refers to reducing cognitive load when a task with a specific goal is replacement with a non-specific goal. Solving all sub-problems of a problem is less intensive compared with solving a specific problem that needs the sub-problems. The *Worked Example Effect* makes use of a step-by-step solution. Learners are given a problem-solving schema they have to follow. This keeps the intrinsic working memory load at a low level. Related to this is the *Problem Completion Effect* where learners get worked examples but with missing elements. This makes the learning more active, although it may only have effect on far transfer. Gradually decreasing the level of instruction is called the *Guidance Fading Effect*. Here the transition from less to more expert learners is made. The *Coherence Effect* disturbs

learning when too much information is extraneous. The *Split-Attention Effect* occurs when temporal or spatial separated sources of information cannot be understood without mentally integrating. When two streams of relevant information are placed near each other, either temporal, spatial or both, integrating it into one piece of information (a diagram for example), the capacity of the working memory will be increased because less information needs to be remembered or compared. If two streams of information are unintelligible in isolation the *Modality Effect* occurs. The information has to be combined in order to make sense wholly. Using audio-visual input rather than visual reduces the load on the visual channel. Connected to the *Modality Effect* is the *Transient Information Effect*. It describes the loss of learning when information disappears before a learner adequately process it and links it with new information when dealing with complex information. The *Redundancy Effect* refers to the process of nonessential information, either not relevant to the information needed to solve a problem or the redundant information is meaningful on its own but not for the problem. The *Expertise Reversal Effect* occurs when the level of knowledge of a learner negatively affects all cognitive load. Redundant information will lead to more extraneous cognitive load for experts, whereas novice learners need the information that was extraneous for experts. The *Multimedia Effect* showed that people learn better when both words and graphics are present, as long as the graphics are not too obvious. With the *Imagination Effect* one makes a mental reproduction of a procedure or concept for better learning results. Likewise with the *Self-Explanation Effect*, if one can clearly explain what a concept is, surely one has learned it. The *Element Interactivity Effect* refers to the level of interactivity between essential elements of information, this determines the intrinsic cognitive load. This may be manipulated by changing the nature of a task. *Collective Working Memory Effect* is a new cognitive load theory effect referring to the phenomenon that individuals obtain higher learning outcomes when working collaborative than when learning alone. Debatable are the invested resources which might be inefficient. Students might become more actively engaged in learning process with collaboration, but the opposite has also been observed.

The easiest way to reduce overall workload is by some small adjustments, like changing strategies by avoiding means-end approach and use goal-free approach (Miller, 2006;Sweller, 1988,1999). Means-end approach to solving simple problems needs more inputs and computations than a goal-free approach (Sweller 1988). Physically integrate multiple sources of information (split-attention effect), by this the extraneous load is reduced because learners do not have to mentally integrate the information but can comprehend it in one go (Sweller 1999). As well, reduction of redundancy and repetitive information is very effective (redundancy effect). Finally the combined use of auditory and visual information has proven to increase the capacity of the working memory (modality effect and transient information). Spoken information has to be processed and integrated in order to understand it, this demands a great effort of the working memory (information held in one sentence may need to be integrated in to another sentence to understand the whole). To keep information alive in the working memory, one needs to rehearse it mentally. If information can be written down, remembering is more easily achieved. Access to this permanent written record had the advantage that written information is easily being transformed into spoken information and transient information may overload working memory more than permanent information (Sweller et al. 2011). Although there are studies that showed that visual instructions are superior to audio-visual (reverse modality effect) (Tabbers et al. 2004) this may be explained by the transient information effect (with written material the learner can focus on complex sections) (Tabbers et al. 2004; Merriënboer 2009). As a side note, decreasing intrinsic cognitive load can be done through a sequence of different processing like pre-training, focusing on sub-goals, separating procedural and conceptual processes, all of these examples are basically reducing element interactivity (Sweller 1999).

3 Experiment

The effects on cognitive load can be used to aid the learning process of humans. When implemented in an educational computer program, the effects may be controlled and adjusted for individual learners to give better guidance in the learning process. With the insight into how humans process information, what cognitive load exactly is and how it can be influenced try to implement one of the effects in an educational environment. There exist digital tutor programs that help humans study (Goettl, 1998). Furthermore, several studies suggest that peer tutoring is just as effectieve,if not more, as an expert tutor (Topping, 2005). By simulating a human mind, the *collaboration effect* on cognitive load can explore the effects on the working memory. *Collective Working Memory Effect* as described by Sweller, has proven to be beneficial for learning when dealing with complex problems (Olivera 2004; Kirschner 2009a, 2010). There have been negative reports of collaboration, however Kirschner et al. (2009a) have identified possible causes of the negative outcomes of the Collective Working Memory Effect; Learning and individual outcomes are often not measured, only the process of the collaboration. There are few randomized controlled experiments and goals are often poorly defined. The research by Kirschner et al. (2009a), proved the benefits of collaboration in the learning process by testing 70 high-school students in the domain of biology, heredity. By considering groups as information processing systems, Kirschner et al. argued that a group has expanded processing capacity because the task can be subdivided in all working memories, sharing the intrinsic cognitive load. Sharing and coordinating information might come with a cost because it requires working memory resources, the transaction costs (Kirschner et al 2009b). If the transition cost are less than the cost of processing the large number of (interacting) elements, there is an advantage to divide the load. For the experiment, they divided the students into two groups, the collaborative groups consisting of three members, all with one third of the total amount of information, and the individuals. After the test, based on combining performance with mental effort measures, the students who learned individually were more efficient learners in retention tasks, whereas students who learned in groups outperformed the individuals on transfer tasks. The sharing of cognitive load imposes the decreasing of needed capacity and thus leaves more room for the construction of higher quality schemata in their long-term memory. Individual students processed the elements at a more superficial level; better retention of surface information. They had also experienced significantly more mental effort in the learning phase compared with the group members. So while collaboration comes with a cost, time used by arguing about simple decisions (like who is going to write something down), miscommunication, explaining and hearing different point of views, off-topic discussions and so forth, they do not stand in the way of the benefits of collaborative learning.

To stretch this even further, what if some of the disadvantages of collaboration would be beneficial for the learning process. If a computer could behave like a group, this could be helpful in education and simultaneously give better insight in how humans process information and how they deal with simple and complex problems. Little research has been done on the topic of simulating human errors and learning transfer. The goal of the research is to see whether the penalties found in former research of collaborative learning are just as important for the transfer of learning skills as benefits of collaboration are. This brings us back to the research question of the thesis; *could a smart computer aid with the learning process of humans by making errors?*

3.1 Subjects

Fifteen subjects (nine males, six females) with a minimal knowledge of biology (no more that three years of biology in high school), participated in the experiment. Their mean age was 22,9 years (range 19-30 years). All were Dutch students and no compensation for participation was provided.

3.2 Apparatus

The experiment took place in a private room with a Windows computer. Google Chat was used for the remote collaboration and to keep track of the chat log. Text and mostly multiple choice questions were provided in a Google sheet.

3.3 Material

Femke Kirschner provided the material for this study (many thanks) as used in former research on collective working memory effect (Kirschner et al. 2009b, 2010). The material was in the biology domain, covering heredity; the genotypic and phenotypic transmission of biological traits from parents to offspring. The material was delimited and it was easy to change the complexity. The material was slightly adjusted to make it more suitable for higher level students; a shorter introduction, more formal layout and less pictures (see Appendix B and C). An instruction was given to explain the goal of the test (remote collaboration) and to help establish the collaboration. Two sets were made by making a selection of the material provided by Kirschner. One set for learning, which was broken down into several sub-tasks, either text based or a problem-solving task. The difficulty of the tasks increased slowly. For every task, feedback with the right answer was provided. In two questions, different pieces of information were provided to the test subject and the virtual student script to stimulate collaboration. The learning material has the same principle as the end task so transfer could be measured. The second set, the test set, consisted of two problem-solving tasks with many interacting elements and no feedback. A subjective questionnaire was also provided, to indicate the difficulty of every task by rating a nine-point cognitive load rating scale, with 1 no trouble at all and 9 not being able to get to a solution (also provided by Kirschner et al.), see Appendix D. A distraction task was given between the learning and test; the 2048 game by Gabriele Cirulli. Further, a list with relevant terminology was available to keep the focus on the learning process of heritage and not learning terms (also provided by Kirschner et al.) see Appendix A. A script was made for the communication between test subject and the virtual student. To reduce the change that subject would use the virtual student as an information tool instead of collaborating with it, the conversation was quite natural and the virtual student was set to take initiative. See Appendix E for a selection of one of the conversations.

3.4 Conditions

In condition 1, the virtual group member aided the subject in all possible ways. Information which was to be shared was conducted so immediately. Given solutions were correct and complete. In condition 2, the virtual group member deliberately made mistakes so to simulate a needy student. It tried to challenge them to explicitly explain what they just learned and asked for extra information. Information which was to be shared was only given when asked for or when the participant was stuck. See Appendix E, Figure. 11 for the differences in scripts. For example, the answer from the virtual student to question 4 was found in the glossary. For question 6 there was an extra check if the subject's reasoning was correct. For question 8, the virtual student deliberately gave the right answer, but with the wrong reasoning to see if the subjects would go with the virtual student or remark the mistake.

3.5 Procedure

Randomly divided into one of the groups, participants first got a short introduction on the goal of the test and the procedures (collaboration, learning and solving problems by working from memory). In the learning phase, the heritage material was divided into sub elements. After reading a small amount of information about each sub element, subjects had to answer a question, while communicating with the virtual student about this sub element. Also subjects were instructed to solve the problems from memory. After each question that had to be answered, feedback was provided with the correct solution. Right after the feedback was provided, a subjective questionnaire was to be filled in on how difficult the participants experienced the previous questions. After the test phase, a distraction task was given for five minutes and after wards, each participant made the end task individually so the transfer of learning could be tested. No feedback was provided in the phase, but they also had to fill in the questionnaires. Finally, an evaluation was to be filled in on how they thought the collaboration went and on their own effort.

3.6 Measurements

The *cognitive load measurement* was gained from a 9-point cognitive load rating scale (Paas, 1992) that participants had to fill in after every test task. The *performance measurement* was solely based on the test tasks because the aim of the learning tasks with the collaboration was that the participant learned as much as possible. For every correct answer one point, some questions consisted of multiple answers and thus one point for every correct sub answer. The *efficiency measurement* was calculated by test scores and additional mental effort investment in the task by the following formula based on the work of Paas and Van Merriënboer (1993). High efficiency indicates high test-performance and low mental effort rating. Low efficiency relatively correlates with low test-performance and relatively high mental effort rating. $E = \frac{(P-R)}{2}$. The efficiency is calculated by getting the performance scores (P) minus the effort rating (R). To be able to compare the performance scores and the effort rating their z-scores have to be calculated. The z-score is calculated by $z = \frac{x-\mu}{\sigma}$ with x is the raw score, μ is the average of the population and σ the standard deviation, calculated by $\sqrt{\sum(score - average)^2}$.

3.7 Results

Figure 2 gives an overview of the mental effort during the test phase for both groups. Table 1 shows the means and standard deviations for the test phase. The mean of condition I was 5,84 on the mental effort scale rating from 1 to 9. For group II this was 5. Figure 3 gives the results of the performance on the test phase for both groups in percentage correct. The average score for group I was 60.6%, for group II this was 67,6%. The mental effort and the performance combined with the raw data forms the efficiency measure, displayed per question in Figure 4. The questions are sorted in increasing difficulty. The evaluation results are shown in Figure 5 and 6. The rating scale range was 0 to 5.

Table 1

Means (M) and standard deviations (SD) in test phase of performance and mental effort for condition I and condition II.

	I		**II**	
	M	SD	M	SD
Performance	1,33	1,47	1,47	1,19
Effort	5,84	2,35	5	2,04

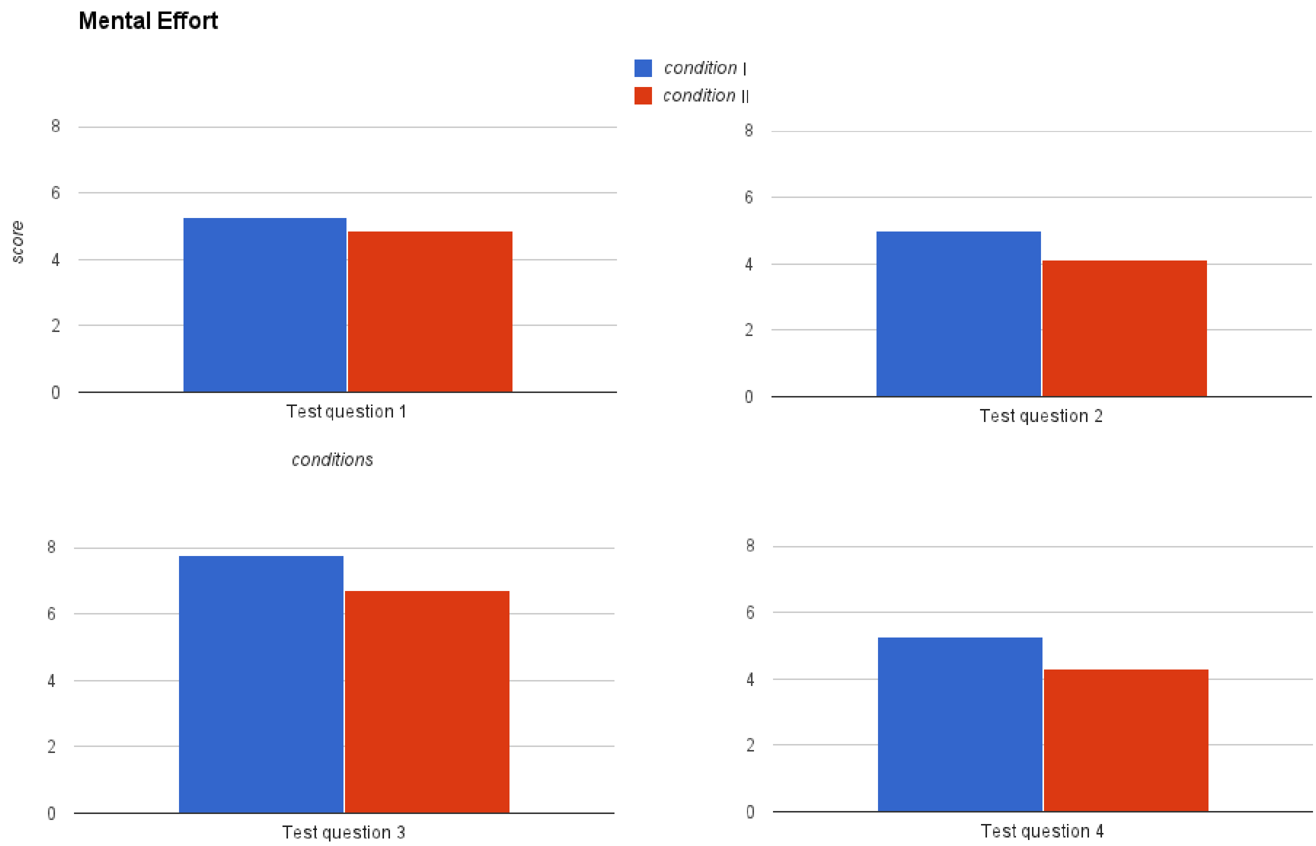

Figure 2: Mental effort per test question

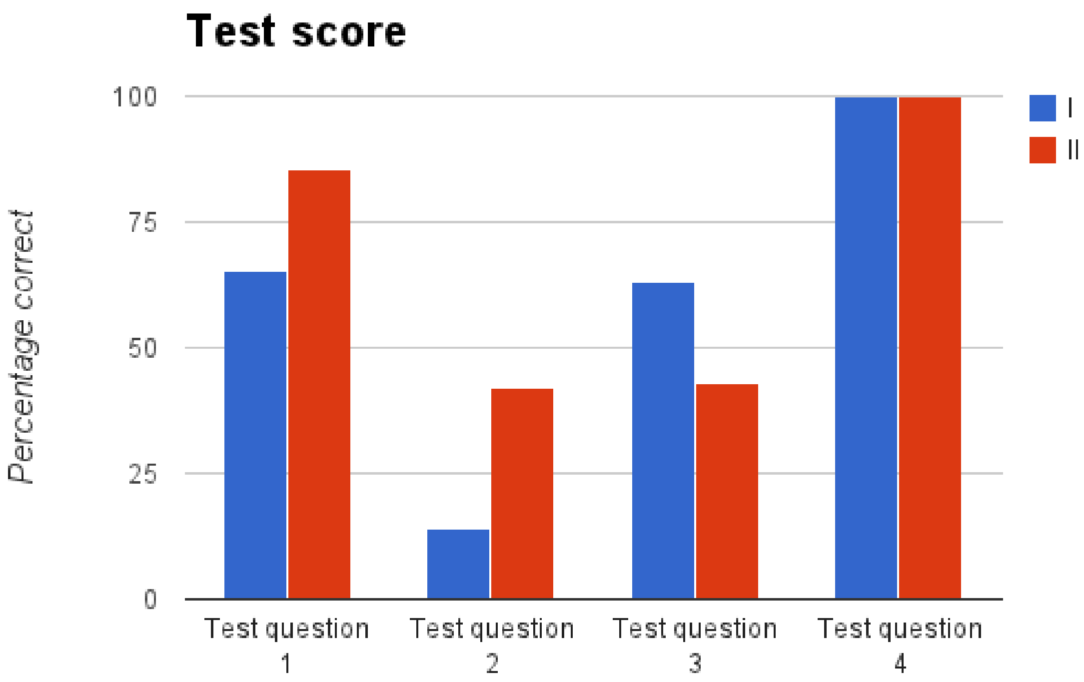

Figure 3: Score test phase

3.8 Discussion

In this thesis it was hypothesized that a group with a needy virtual student would outperform a group with a normal virtual student due to deeper processing of information by discussion, argumentation and reflection of the material. The outcome of the experiment neither supported nor refuted the hypothesis. The data was inconclusive because there is no significant distinction between the groups.
The average of mental effort during the learning phase was 3,75 for condition I and 4 for condition II which suggests that group I found the learning phase slightly less difficult than group II. However the difference is minimal. Learning scores could not be compared, because in both conditions the aim was to let subjects learn as much as possible. The second group experienced a little less mental effort during the test phase (see Figure 2) compared with the first group. However, the difference between the means of the two conditions is only 0,48 (see table 2). This 9,3% on the 1 to 9 point scale is not enough to support the hypothesis. Additionally, the difference in mean of the test scores was a mere 7%. Furthermore, using the z-scores to compare the mental effort and performance (Figure 4), the efficiency shows how close the results of the two groups lie together. Although group II scores a little higher on efficiency, which indicates high test-performance and low mental effort rating, no conclusion could be drawn concerning the hypothesis.

In Figure 5 the evaluation of the digital student is displayed. What stands out is that the first group was more positive about the collaboration compared with the second group. In the evaluation of the subjects on their own contribution (see Figure 6) the first group is less positive about their own contribution. This likely indicates that the second group was more involved in the collaboration, because the rating of the contribution of the virtual student was less positive compared with the first group. Additionally the evaluation of their own contribution was more positive. This demonstrates the distinction between the two conditions. A needy student is less likely to explain too much, let alone explain substantial connections. A needy student additionally needs more time and is less reliable. On top of that, when collaborating with a needy student, one has to explain, motivate and help more.

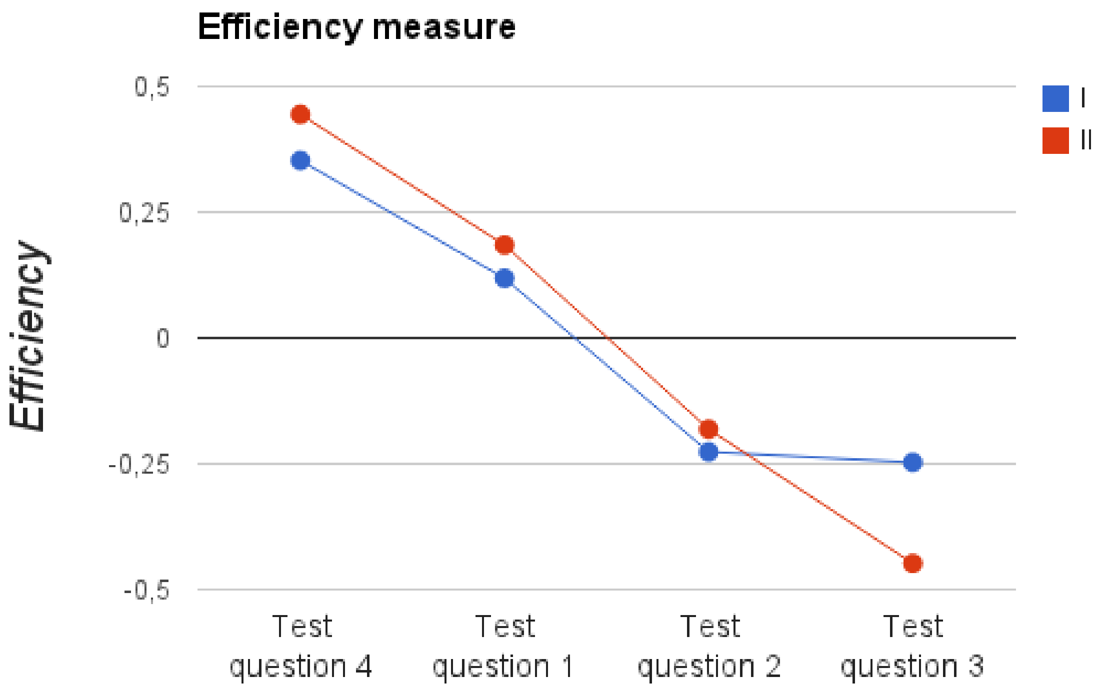

Figure 4: Efficiency measure comparing both conditions

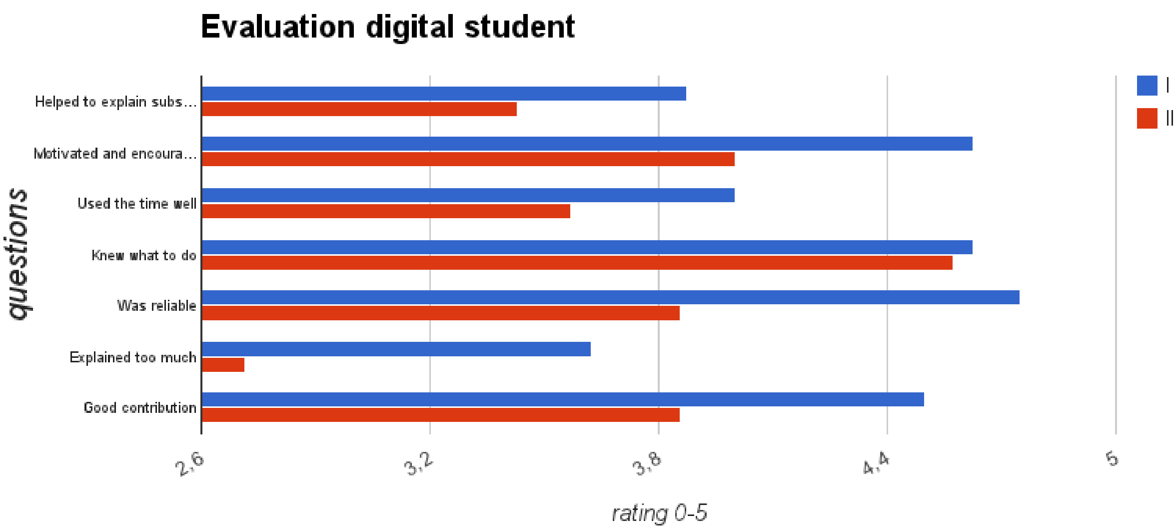

Figure 5: Results evaluation digital student

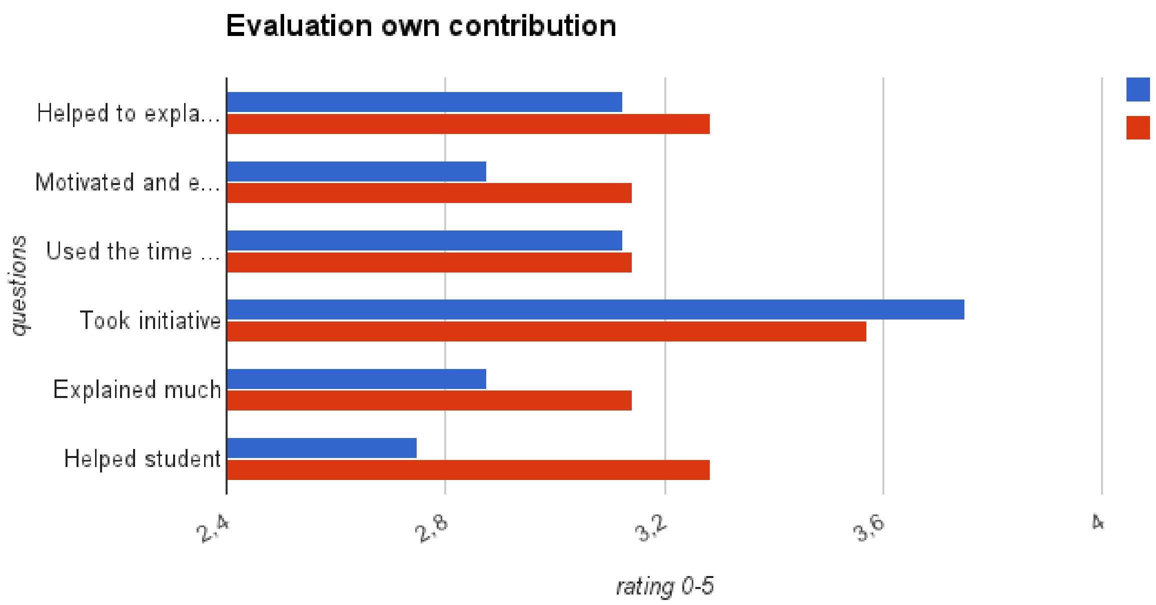

Figure 6: Results evaluation own contribution

Recommendations

Subjects More test subjects are needed to be able to find whether there is a difference between the conditions or not.

Material It would be a good idea to change the set-up of the learning phase, this way the performance scores could be included in the results. This means that a lot more information could be obtained from the experiment. Perhaps this would give a better understanding of which points the virtual student was helping with. To accomplish this, the script and questions have to be changed in a way that the subject has to answer first for certain questions so that the virtual student agree with the answers of the subject. The script could also be more natural; the fourth question of Figure 5 indicates that the needy student knew what to do. It is true that in the current script the virtual student knew the correct answers, whereas a real student would not. It was also unclear that the virtual student sometimes had additional information which was the case for learning question 7. Additional, more question have to be added in both phases to be able to keep better track of the learning process.

Conditions It is necessary to have a control group to be able to conclude that in this digital environment group collaboration is beneficial. The control group would consist of individual students that have to learn and make the test on their own.

Measurements The time spent on each question during the learning phase was not considered, because the discussion during the collaboration varied too much among subjects. For the test phase, it was easy to keep track on the time. Unfortunately, the evaluation was included in the recorded time and that caused to much variation in end time among subjects. Furthermore, in this experiment, there was hardly any time between the learning and test phase. This was the case because it was not possible to ask participant to invest more than an hour of their time in participating in the experiment. For a full experiment, other research has to be done to determine much time would suffice. Considering the results of the test scores (see Figure 3), either the difficulty level of questions has to be adjusted or the intelligence level of the subjects. Because there is no information in a perfect score, like was achieved in question 4 by all the subjects.

It would be quite interesting to expend this experiment for further research. Variation in intervals between the learning and testing phase is desirable for better tuning to the optimal learning to transfer of learning setting. Different control groups could be used, like students that perform the test on their own without a chat. Two students that collaborate through a chat without computer help or even two students that collaborate in real life. If possible the amount of unity of the virtual student could be changed. It would be interesting to see if a larger group would work the same way as a smaller one. Also the degree in how much help is given by the computer could be varied.
Using another type of measurement could also be considered in further research. Even though this setting is quite convenient because it only takes two computers and a quiet room, beside the possibility that it could be transferred to a digital learning environment with a digital tutor as the collaboration partner, it is quite unrealistic to ask students to work tasks from memory.

4 Conclusion

The main question of this thesis - *Could a smart computer aid with the learning process of humans by making errors?*- could not be answered based on the results of the pre-study. However, in the literature study, positive findings from other studies were found on the effect of collaboration. Therefore indicating a positive answer. The literature study has given more insight on how the workload concerning the process of learning could be affected. The several effects of manipulating cognitive load give an overview of the many ways to reduce the load. One of these effects - the collective working memory effect - was further explored. The information given on cognitive architectures that are able to simulate behavior of humans, enabled the exploration of the possibilities to use a computer to simulate collaboration and act as a tutor. Such a smart virtual AI tutor could aid with education and improve the learning process. Based on a study of Kirschner et al. (2009b) the experiment was designed to research the effect of digital collaboration. The pre-study was conducted to explore if collaborative behavior could be implemented in a computer. The results of the pre-study were inconclusive, because no significant difference could be found between the groups. However, the distinction between the conditions, based on the evaluations, indicated that collaboration was indeed established. In conclusion, a full experiment has to be done with the designed and recommendations as proposed in this thesis to give a decisive answer if a virtual AI tutor could aid with the learning process of humans.

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A Glossary

<table>
<tr><th>Begrip</th><th>Omschrijving</th></tr>
<tr><td>Gen</td><td>Een deel van een chromosoom dat de informatie bevat voor één erfelijke eigenschap (bijv: haarvorm)</td></tr>
<tr><td>Genotype</td><td>De informatie voor de erfelijke eigenschappen van een individu (bijv: Gg, GG of gg)</td></tr>
<tr><td>Fenotype</td><td>De waarneembare eigenschappen van een individu (bijv: krullen of stijl haar)</td></tr>
<tr><td>Homozygoot</td><td>Het genenpaar voor een eigenschap bestaat uit twee gelijke genen (bijv: GG of gg)</td></tr>
<tr><td>Heterozygoot</td><td>Het genenpaar voor een eigenschap bestaat uit twee ongelijke genen (bijv: Gg)</td></tr>
<tr><td>Dominant</td><td>Het gen (bijv: G) dat altijd tot uiting komt in het fenotype</td></tr>
<tr><td>Recessief</td><td>Het gen (bijv: g) dat alleen tot uiting komt in het fenotype als er geen dominant gen aanwezig is</td></tr>
<tr><td>Kruisingschema</td><td><table><tr><td>V
M</td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td></tr></table></td></tr>
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Figure 7: Glossary

B Learning questions

Opdracht 1
Genotype
Erfelijke eigenschappen worden doorgegeven van ouders op hun nakomelingen. Elke erfelijke eigenschap noemen we een gen. Voor elke erfelijke eigenschap krijg je één gen van je vader en één gen van je moeder. Zo'n genenpaar wordt het genotype van iemand genoemd.

Een eigenschap kan worden doorgegeven:
a) Van planten op dieren
b) Van ouders op nakomelingen
c) Van soort op soort
d) Van cel naar cel

Opdracht 2
Fenotype
Hoe iemand eruit komt te zien op basis van zijn/haar genotype (genenpaar) wordt iemands fenotype genoemd. Als de twee genen hetzelfde vertellen over de eigenschap, dan zal het lichaam de eigenschap van dat gen laten zien.

Het uiterlijk van een organisme noemt men:
a) Erfelijkheid
b) Gen
c) Genotype
d) Fenotype

Opdracht 3
Dominant en recessief
Welk van de genotype zich uit hangt af van welke van de twee genen domineert over het andere. Het dominante gen is sterker en is dus het gen dat bepaalt welke eigenschap zichtbaar zal zijn. Een dominant gen wordt aangegeven met een hoofdletter en een recessief gen met een kleine letter.

Welke genotypen kan een organisme hebben die een dominante eigenschap laat zien:
a) AA en Aa
b) AA en aa
c) Aa en aa
d) Alleen AA

Opdracht 4
Homozygoot, Hetrozygoot
Genen kunnen identiek zijn (bijv., 'GG' zoals de vader of 'gg' zoals de moeder), dan heet het individu homozygoot. Als de twee identieke genen dominant zijn (bijv., GG), dan is het individu homozygoot dominant. Als de twee identieke genen recessief zijn (bijv., gg), dan is het individu homozygoot recessief. Als de beide genen voor een eigenschap verschillend zijn (bijv., als de nakomelingen de genen 'Gg' hebben), heet dat heterozygoot. Alleen het dominante gen komt tot uiting in het fenotype.

Van 2 organismen is er 1 homozygoot en 1 heterozygoot. De juiste genotypen die hierbij horen zijn:
a) AA en aa
b) AA en Aa
c) Aa en Aa
d) aA en aa

Opdracht 5
Kruisingsschema
Een kruisingsschema is een tabel waarin je kan berekenen welke eigenschappen de nakomelingen van een kruising zullen hebben. Hiermee kun je de kans op bepaalde eigenschappen berekenen. In een kruis-

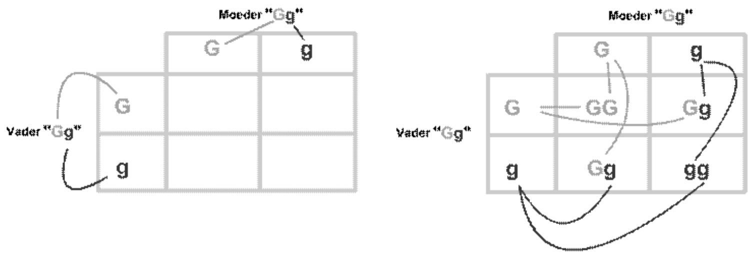


Figure 8: Kruisingsschema

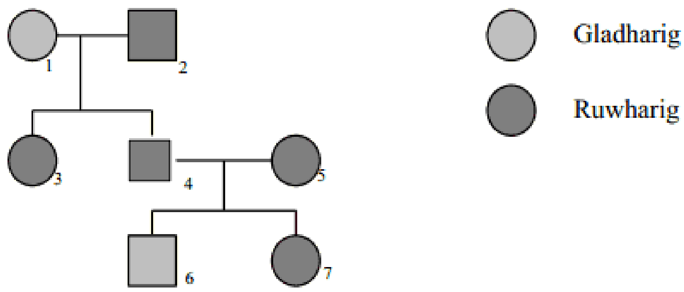


Figure 9: Stamboom

ingsschema verdeel je de eigenschappen van de ouders over de verschillende cellen van het schema. Die van de moeder in de bovenste rij en die van de vader in de linker kolom.

Bij een kruising tussen een organisme met genotype RR en een organisme met genotype Rr zullen de nakomelingen de volgende genotypen hebben:
a) RR en rr
b) RR en Rr
c) RR, Rr en rr
d) Alleen RR

Opdracht 6
Generaties
Voor het beschrijven van familierelaties worden de volgende termen gebruikt: Het ouderpaar krijgt de term 'F0', de nakomelingen van het ouderpaar krijgen de term 'F1', dit is de eerste generatie, de nakomelingen van de nakomelingen vormen de tweede generatie en noem je 'F2', de nakomelingen van de nakomelingen van de nakomelingen noemen we dus 'F3', en zo kan je door blijven gaan. De ouders van de F0, noemen we F-1.
GEGEVEN
In een stamboom zie je in één keer alle fenotypen van een familie. In een stamboom worden mannetjes weergegeven door een vierkant en vrouwtjes door een rondje. Bij honden komen ruwharige en gladharige dieren voor. In de afbeelding is een stamboom van honden weergegeven.

1. Welk van de genen, gladharig of ruwharig, is dominant en welk is recessief? 2. Wat is het genotype voor haarvorm van hond nummer 4, 5 en 6 (gebruik hoofdletter 'H' voor het dominante gen en kleine lekker 'h' voor het recessieve gen)?
Opdracht 7
Gegevens:
Bij mensen is het gen voor groene ogen (G) dominant over het gen voor blauwe ogen (g)
Moeder Sandra heeft groene ogen
De moeder van Sandra is homozygoot voor oogkleur

De vader van Sandra heeft groene ogen
De vader van Sandra is homozygoot voor oogkleur
Vader Wim heeft blauwe ogen
Lucy, één van de kinderen van moeder Sandra en vader Wim, trouwt met Piet.
De vader van Piet heeft blauwe ogen

Wat kunnen de Genotypen (genenpaar) voor oogkleur van de kinderen van Piet en Lucy zijn en in welke verhoudingen komen die voor?

Opdracht 8
Bij mensen is het gen voor rode haren (H) dominant over het gen voor blonde haren (h)

Kim heeft een genotype dat voor 50% in haar generatie van broertjes en zusjes voorkomt
Jasper is met Kim getrouwd en heeft rood haar
De moeder van Kim, Wilma, heeft een genotype dat voor 50% in haar generatie van broertjes en zusjes voorkomt
De vader van Kim, Ton, is heterozygoot voor haarkleur
De moeder van Wilma heeft rood haar
De moeder van Wilma is heterozygoot voor haarkleur
De vader van Wilma is heterozygoot voor haarkleur

Wat kunnen de Fenotypen (uiterlijk) voor haarkleur van de kinderen van Jasper en Kim zijn en in welke verhoudingen komen die voor?

C Test

Vraag 1
Het X chromosoom
Vrouwelijke geslachtschromosomen bestaan uit XX. Mannelijke geslachtschromosomen bestaan uit XY. X chromosomen bevatten genen, Y chromosomen niet. De genen die op de X chromosoom liggen noemen we X-chromosomaal. In kruisingsschema's geef je een dominant gen aan met XˆA en en recessief X-chromosomaal gen met Xˆa. Een vrouw kan homozygoot (XˆAXˆA) zijn of heterozygoot(XˆAXˆa of XˆaX ˆa) Een man kan als genotype XˆAY of XˆaY hebben.

GEGEVEN
Bij bananenvliegjes wordt de oogkleur onder andere bepaald door een X-chromosomaal gen
Het gen voor rode oogkleur (A) is dominant over het gen voor witte oogkleur (a)
Een vrouwtje met witte ogen wordt gekruist met een mannetje met rode ogen
Een vrouwelijke nakomeling, Els, paart met een mannelijke nakomeling, Piet.

VRAGEN
1. Wat zijn de genotypen voor oogkleur van Els en Piet?
2. Wat kunnen de genotypen voor oogkleur van de nakomelingen van Piet en Els zijn?

Vraag 2
GEGEVEN
De nakomelingen van cavia vrouwtje Carla en cavia mannetje Peter hebben voor 75% rechte oren.
Cavia mannetje Hans heeft in ieder geval 1 recessief gen.
Het gen voor rechte oorvorm (H) is dominant over het gen voor gekrulde oorvorm (h).
Cavia vrouwtje Willy heeft rechte oren.
Cavia mannetje Hans is homozygoot voor oorvorm.
De vader van cavia vrouwtje Willy had in ieder geval 1 recessief gen.
De moeder van cavia vrouwtje Willy heeft genotype Hh voor oorvorm.
De vader van cavia vrouwtje Willy was homozygoot voor oorvorm.
Één van de nakomelingen van cavia vrouwtje Willy en cavia mannetje Hans, cavia vrouwtje Carla krijgt kinderen met cavia mannetje Peter.

VRAGEN
1. Wat kunnen de genotypen en fenotypen van Carla zijn en in welke verhouding komen ze voor?
2. Wat is het genotype en fenotype van Peter?

D Examples from the experiment

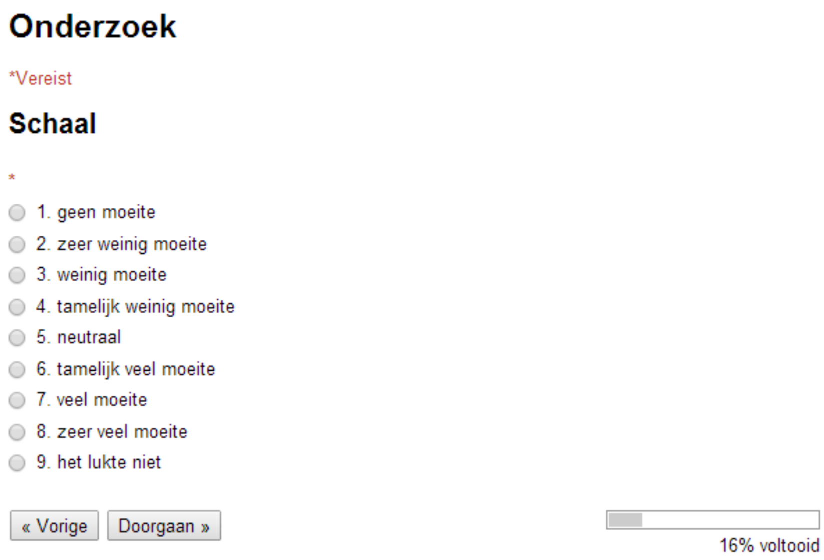


Figure 10: Subjective questionnaire

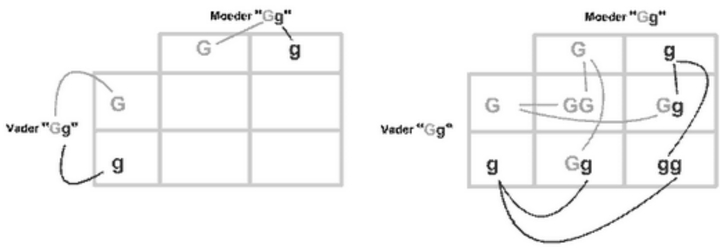
Onderzoek

*Vereist

Opdracht 5: Kruisingsschema

Een kruisingsschema is een tabel waarin je kan berekenen welke eigenschappen de nakomelingen van een kruising zullen hebben. Hiermee kun je de kans op bepaalde eigenschappen berekenen. In een kruisingsschema verdeel je de eigenschappen van de ouders over de verschillende cellen van het schema. Die van de moeder in de bovenste rij en die van de vader in de linker kolom.

Kruisingsschema



Bij een kruising tussen een organisme met genotype RR en een organisme met genotype Rr zullen de nakomelingen de volgende genotypen hebben: *

- RR en rr
- RR en Rr
- RR, Rr en rr
- Alleen RR

« Vorige | Doorgaan »

52% voltooid

Figure 11: Example question learning phase

E Script examples

	I	II
4	*Homnozygoot is zelfde en hetrozygoot niet dus AA en Aa.*	*Hoe zit het dat met aa? Komt die nooit tot uiting?*
6	*Dat dacht ik ook!*	*Kun je je redenatie geven? Waarom kan 5 niet AA zijn?*
7	*Ik zie dat ik nog aanvullende informatie heb; Vader Wim heeft blauwe ogen*	*Pft, waarom mochten we geen pen en papier gebruiken?*
8	*Om de fenotypen te bepalen moeten we weten wat de ouders voor genen hebben. Gezien de grootouders heterozygoot zijn (Hh) en 50% overdraagt, geldt voor Wilma ook Hh en voor Kim dus ook Hh. Dan blijft Jasper over. Ik heb geen informatie over Jasper, jij wel? Weet jij of homozygoot of heterozygoot is?*	*Om de fenotypen te bepalen moeten we weten wat de ouders voor genen hebben. Gezien de grootouders 50% overdragen, geldt voor Wilma ook HH en voor Kim's dus ook HH. Dan blijft Jasper over. Heb jij informatie over Jasper? Of hij homozygoot of heterozygoot is.*

Figure 12: Script

ja, dus RR en Rr?

Deelnemer 2
Ja, had ik ook!

Deelnemer 1
Oké, volgende vraag!
Welk gen dominant is kan je zien door hoe vaak die voorkomt in de stamboom?

Deelnemer 2
Het lijkt mij ook dat een grotere kans op een fenotype een domiant gen aanduidt.

Deelnemer 1
ja, dus dan gaan we voor ruwharig

Deelnemer 2
Ja
Yeah!

Deelnemer 1
Hoera, we hebben het goed

Deelnemer 2
Pft, dat zijn veel opties

Deelnemer 1
Inderdaad
Hond 4 heeft Aa denk ik, omdat diens moeder en vader een ander fenotype hebben?
Of kan je dat zo niet zeggen?

Figure 13: Conversation example