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Cognitive aspects of positive and negative
transfer learning

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1 Introduction

Transfer learning has been a problem for the cognitive psychologists for ages, because they are dealing with different learning situations and performance theories on how to achieve successful transfer. How to transfer knowledge that we had learned in school into our everyday life? Transfer learning is quite complex issue, therefore subjects' cognitive skills are considered to be factors for successful transfer learning. We can assume that people with better educational background will achieve better results in transfer learning tests, as Novick (1988) has shown in her study of analogical transfer. During the history of studying transfer learning, not much attention was paid on negative transfer learning, because the goal of the transfer is to ensure that it happens. Novick (1988) researched the negative and positive transfer of subjects, who were grouped into experts and novices. The problem solving was based on different solution patterns which shared either surface or structural features.

In the following section a short history overview of transfer learning is given, where Thorndike's and Piaget's theory are presented together with examples. Afterwards a positive and negative transfer, and analogical transfer in Novick's study are discussed more thoroughly. This part also contains the predictions on why and in which situation the negative transfer appears. In the last section Novick's experiment with experts and novices is presented, where presented with different solution and problem representations subjects provide interesting results.

2 Theory of Transfer Learning

The important issue in educational psychology is knowing how to transfer knowledge. In the real world children can transfer their knowledge, for example, about mathematics to a computer science, which is considered as transfer from one domain into a completely new domain. The aim of transfer learning is that people are able and know how to apply their previously learned knowledge in completely new situations for better and faster problem solving. Therefore transfer learning allows humans to learn and test previous knowledge across domains and it transverses boundaries.

In the following part we will present how psychologists see the study of transfer. Singley and Anderson (1989) stress the importance of transfer as a test for learning and performance theory where logic must be understood first and only then we have to know how transfer works[1]. They claim that the study of transfer research on how knowledge can be applied in a certain situation or can not be applied. According to them transfer can be considered as a fundamental educational question, especially the importance of designing curricula. For example, it determines how children learn things at school which they can apply directly to life and work. Transfer is also important in the world today where technology rapidly changes and people need to keep up with new technologies. One of the importance of transfer learning is not only to have knowledge but to know how to apply this knowledge to a task in specific situations, which Singley and Anderson (1989) call cognitive skill[1].

2.1 Short Historical Overview of Transfer

During the history there were several transfer theories, and in this part we will discuss some of the most important ones, for example Thorndike's theory, Piaget's theory and theory of gestalt psychologists.

First psychologist who studied transfer was Thorndike. Thorndike was one of the beginners who studied experimental psychology and spent many years observing animals, especially cats. The main point of his learning theory is that humans can learn through testing and failures. The stimulus which appears after this kind of behaviour has great importance to the future behaviour. According to his studies of animals, if a cat is locked in a some kind of puzzle box, it will somehow find way out of it1.

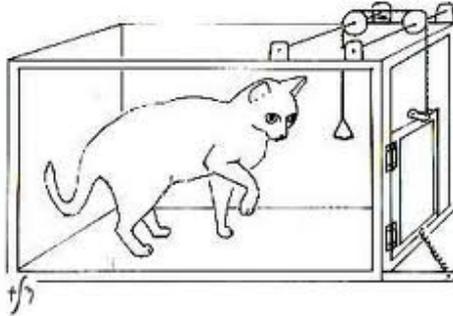


Figure 1: Shows Thorndike's puzzle-box¹

Thorndike's principles of this kind of behaviour as basis for learning were simple²:

1. Readiness - considers motivation to learn
2. Exercise or repeating - things that are the most often repeated are the best remembered, for example practising
3. Effect - considers emotional reaction of the person who learns, if learning succeed then the positive reaction is also motivation for learning next tasks, but if it is negative then the motivation decreases

Thorndike was, in his theory of learning, also dealing with transfer, where transfer brings into question the idea of exercising and repeating. The idea of transfer[1], also known as theory of identical elements where mental activities will improve others because they have common elements, for example knowledge of French improves the ability to learn Spanish, because many tasks that people learn in French can help to learn Spanish. Thorndike also did several exact tests with subjects presenting them with tasks that were closely related. Thorndike supposed that transfer is limited within function groups and if he makes changes in the input it will damage the function. He gave a group of subjects (trained in algebra) to solve customary and new algebraic problems to solve and the results were interesting. In the most cases changing the form of data did impede a performance, but one of the six problems was solved without impeding the performance and subjects' answers were

²Source: http://en.wikipedia.org/wiki/Principles_of_learning(20. June 2012)

about 50 percent correct. This experiment provided a small support of his theory of identical elements, but strong support for positive transfer in the algebraic function group. Thorndike's tests and observed transfer could not be explained by common stimulus-response elements alone, so his theory was often criticised. The theory has one problem, his theory of identical elements denies the existence of transfer absolutely and transfer is possible only in that cases where the same responses for the same stimuli were required. It is impossible to assume that two situations are truly identical, Thorndike's theory was closely related only to physical world and not to abstract mental representations.

Another Psychologist who studied Transfer within his theory of cognitive development was Piaget. According to him, children pass through four stages on their way to cognitive maturity[5]:

1. The sensorimotor stage (between birth and age of 2) - for example, sucking of objects in the mouth and caching them, object permanence-children are conscious that objects exist even they can not see them, developing mental images-children can imagine how object is moving, and they are conscious of themselves in a mirror and understand what mirror is
2. Preoperational stage (between age of 2 and 7) - for example children are concrete and they do not understand metaphors, children are egocentric and they do not understand emotional needs of other person, they are conscious of the principle of conservation - the quantity of things is the same no matter of the shape, then animism - children believe that objects are alive
3. Concrete operational stage (between age of 7 and 11) - children are less impulsive and gullible/naive, they are not egocentric any more, they understand the principle of conservation - if they put a water in a bigger glass, that the quantity stays the same
4. Formal operational stage (from adolescence into adulthood) - people develop ability of abstract thinking and reasoning

Piaget defined stages by specific modes of thought and his theory was criticised, because if child is in one particular stage, his all reasoning is caused by characteristics of that stage. Piaget's position was that knowledge is abstract and that some knowledge structures apply broadly[1]. He had opinion that abstract thinking can not be taught or trained and also that children

can not be pushed through the development. Other researchers, as Seigler (1986), Katz and Beilin (1976), Miller (1976), Kinsbourne (1978) and others had shown that in one particular stage children may not do well on some versions of tasks, therefore Piaget's domain-independent, abstract knowledge has been exaggerated in his theory[1].

Judd, etc. (1908) showed in his study that transfer depends on the kind of tasks representations subjects have, the importance of representation could not be ignored[1]. Two groups of young boys needed to throw darts at an underwater target, one group had theory instructions, other not, the group with theory instructions solved tasks better and more quickly than the other group. In his study Judd has shown that understanding basics helps to generate new problem solutions.

Gestalt psychologists like Wertheimer, Koffka and Kantona (1940) studied *senseless learning* (learned by associations), and *meaningful learning* where is present the real understanding[1]. They showed that *senseless learning* shows little or no transfer and that *meaningful learning* shows quite a bit of transfer. The principle of gestalt psychologists theory was that it is important to look at the whole rather than the sum of tasks³. Gagné, as an educational psychologist was bringing the study of transfer with the more complex classroom tasks under special conditions using new "programmed instructions" technology. His goal was to improve designing curricula with a stress on learning and transferring⁴.

³More about their experiments [1]

⁴More about "programmed instructions"[1]

3 Positive and negative transfer in the study of Novick (1988)

As has already been mentioned, transfer appears when learning in one context impacts performance in another context. The goal of education is to learn in one context, for example classroom, and apply the knowledge into another ultimate context of application, for example to a job. The main problem is if this does not happen then education has failed. Psychologists always assume that transfer will happen, and in that case we are talking about positive transfer, but studies have also shown that transfer can fail. In this case we are talking about the negative transfer. Negative transfer occurs when knowledge in one context impedes performance in another context, for example a related language learning can cause a positive transfer as well as negative (because of the vocabulary or phonetic barrier).

3.1 Analogical Transfer

Analogical transfer is a new approach to problem solving. How to solve a problem by analogy? A subject is told about the similar problem whose solution is known and he needs to map that solution to the current problem. Many studies have shown that subjects had difficulties to notice similarities between problems and draw analogous solution (Reed, Ernst, and Banerji, 1974; Hayes and Simon, 1997; Kotovsky, Hayes and Simon, 1985)[1]. For example, studies of Gick and Holyoak (1980, 1983) where the subjects were presented with Duncker's⁵ (1945) classic radiation problem[1]. Subjects were first introduced to a similar story about an analogous military problem and its solution⁶, as shown in the following figure2.

⁵Duncker's (1945) candle problem: "Subjects have a box of nails, a book of matches, and a hammer to attach a candle to the wall so that it will burn properly. The solution is to nail the box to the wall and to put the candle inside of or on top of the box. Experimental subjects learned candle-box as one of nine paired associates before attempting to solve the problem. Candlebox did not cue the desired solution unless subjects were told that one of the paired associates would help them solve the problem." [2]

⁶"In this story a general wants to capture an enemy fortress. Outward from the fortress are many roads, each of which is mined in such a way that the passing of any large force will cause an explosion. This precludes a full-scale direct attack. General's plan is to divide his army, send a small group down each road and converge on the fortress." [1]

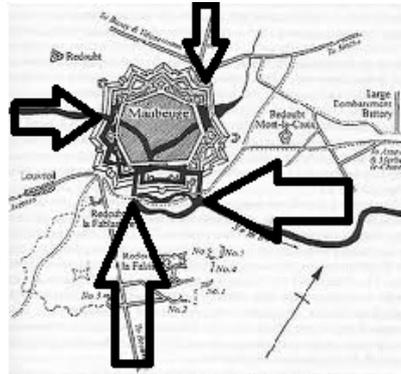


Figure 2: Shows Duncker's military problem ⁷

Afterwards subjects were faced with a new problem story - with a patient who has an inoperable stomach tumour⁸, as shown in the following figure3.

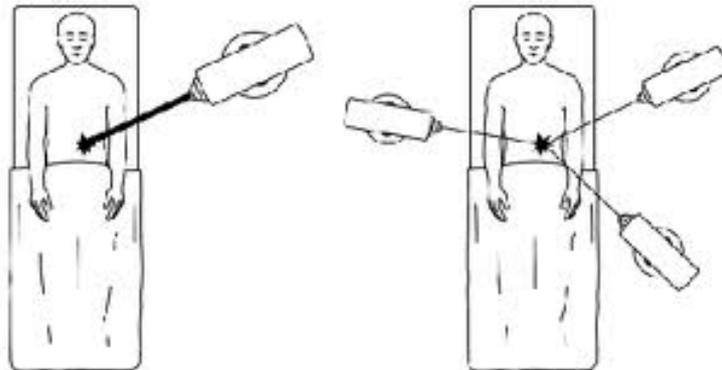


Figure 3: Shows Duncker's tumor problem ⁹

We can see that the strategy to solve both problems is similar and based on principle "divide and conquer". Subjects should do following steps: divide the force, attack from different sides and converge on the target[1]. The results were poor, after reading fortress problem story, only about 30 percent of subjects could solve the radiation problem, Gick and Holyoak (1983)

⁸"Suppose you are a doctor faced with a patient who has an inoperable stomach tumor. You have at your disposal rays that can destroy human tissue when directed with sufficient intensity. How can you use these rays to destroy the tumor without destroying the surrounding healthy tissue? (adapted from Gick and Holyoak, 1983 in [1])"

concluded that difficulties appear either in the initial noticing that problems are similar or in the mapping. That the mapping process is a big problem in analogical transfer have shown also other studies have also shown (Reed, Ernst, and Banerji, 1974; Hayes and Simon, 1997; Kotovsky, Hayes and Simon, 1985)[3][4].

Novick (1988) is dealing with a transfer problem using the principles of analogical transfer considering the importance of expertise. According to her the main processes involved in analogical transfer are problem representation, search/retrieval, mapping, and procedure adaptation[2]. She believes that for understanding analogical transfer it is very important to consider the different problem representations of experts and non-experts and also different results.

3.2 Transfer failure

Duncker (1945) says that before they start working on a problem, subject first construct a representation of it[2]. This representation and problem solving depend on subjects expertise in the problem domain. For example, subject who is not good in mathematics doesn't provide as good representations as subject who is an expert in mathematics with more abstract representations. Novick (1988) stresses the importance of understanding transfer failures. she believes that subjects should search for related problems in their memories where information about similar problems is stored[2]. However, this requires a lot of time and effort, because without that the transfer is not possible.

3.3 Positive vs. Negative Transfer

In this section will be observed subjects or problem solvers, according to Novick (1988), "Which problem solvers are likely to show what type of transfer (positive vs. negative) in what type of situations and for what reason"[2]. First prediction of transfer behaviour of experts and novices is: "...if source and target problems share surface and structural features, spontaneous positive transfer should be observed regardless of expertise" [2]. Second prediction is that "more spontaneous transfer is predicted for experts than for novices if the source and target have only abstract, structural features in common"[2]. Third prediction is considering negative transfer and "situations where the source and target share only surface features" [2]. Spontaneous negative transfer is here more often for novices than for experts.

3.3.1 Experiments of Novick (1988)

Novick (1988) tested the mentioned positive transfer predictions in Experiment 1 and 3 and negative transfer prediction in Experiments 2 and 3. She uses procedures to solve problems which is here more important than success or failure. Positive transfer happens when the source problem is analogous to the target problem and when the solution procedure is used correctly[2]. Negative transfer happens when the source and target problem are not analogous but its procedure is used[2].

In the following section we will show which problem and solution procedures were given to subject to solve the target problem, see table 1.

Remote analogue problem	Distractor problem	Target problem
<p>"Mr. and Mrs. Renshaw were planning to arrange vegetable plants in their garden. They agreed on the total number of plants but not on how many of each kind to get. Mr. Renshaw wanted to have a few kinds of vegetables and ten of each kind. Mrs. Renshaw wanted more different kinds of vegetables, so she suggested having only four of each kind. They agreed to have five of each vegetable, but there was room for two more plants, although then there wouldn't be the same number of each kind of vegetable. So they decided to buy six of each vegetable what was a good idea. Given this information, what was the fewest number of vegetable plants the Renshaws could have in their garden?"(adapted from [2])</p>	<p>"Two assistant deans were planning how to seat the recipients on the auditorium stage. They couldn't figure out how many award recipients to put in each row. The first assistant dean wanted to put nine people in each row, but with that plan there would be one person left over. So the second assistant dean suggested seating the award recipients in column of six, but even then there would be one person left over. Their next idea was to put four people in each row, but then three people would be left over. The dean told them to put five people in each row and no people were left over. Given that there were at least 20 but fewer than 120 award recipients, how many people did the assistant deans have to seat?" (adapted from [2])</p>	<p>"Members of a High School Band were practising for a parade. First they tried marching in rows of twelve, but Andrew was left by himself and he wasn't very pleased. The director told the band members to march in columns of eight. But Andrew was still left to march alone. Even when the band marched in rows of three, Andrew was left out. Finally, Andrew told that they should march in rows of five in order to have all the rows filled and he was right. Given that there were at least 45 musicians on the field but fewer than 200 musicians, how many students were there in High School Band?"(adapted from [2])</p>
	Solution procedure	

<p>"Mr. and Mrs. agreed on the number of plant to buy, 10, 4 and 5 must all go evenly into that number, whatever it is. The first thing to do is to find the smallest number that is divisible by those 3 numbers, which is 20. So the original number of plants they were thinking of buying could be any multiple of 20 (that is 20, or 40, or 60 or 80, etc.). But then they wanted to buy 2 additional plants, so that the total number must be 2 more then the multiples of 20 (that is, 22 or 42, or 62 or 82, etc.). This means that 10,4 and 5 will no longer go evenly into the total number of plants. Finally, they agreed to buy 6 of each vegetable, so that the total number must be evenly divisible by 6 and the smallest total number of plants that is evenly divisible by 6 is 42, which is correct answer."(adapted from [2])</p>	<p>"In the first arrangement, each row has 9 recipients in it, but one person was left over. In the second arrangement, each column has 6 recipients in it. Since this is the same as the first arrangement, there must have been $9 \times 6 = 54$ recipients in the regular part of the seating arrangement. To get the total number of recipients you just need to add 1 to this number to account for the one extra person who was left over. So the answer is 55. Note that it is between 20 and 120 and that 55 divided by 4 (rows of 4) leaves a remainder of 3. Finally, as suggested in the problem, 55 is evenly divisible by 5."(adapted from [2])</p>	<p>Here the procedure is similar to the procedure in the remote analogue problem using LCM - lowest common multiple (see [2])</p>
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Table 1: Describes problems and their solution procedures in Experiments 1, 2 and 3

First experiment included 64 Stanford University student and they were assigned to one of two conditions, remote analogue or baseline. In the expert group were 8 male and 8 female subjects in each conditions. In the novice group there were 7 male and 9 female subjects in each conditions. These conditions were defined in terms of the relation between four problems presented at the beginning of the session and the target problem presented later.

In the first phase of this experiment subjects received the four problems and their solution procedures. This phase is considered as a pretest phase.

After this phase subjects were told that they would begin with the real experiment-target problem.

Results: in the baseline condition, 6.3% both groups used the lowest common multiple (LCM) procedure to solve the problem. In the remote analogue

condition 6.3% of novices used LCM procedure because they were not affected by the analogue problem. Expert group showed strong positive transfer, they use of LCM was about 56.3% in the remote analogue condition[2].

Second experiment was designed to test the negative transfer, with performance of subjects who received a distractor problem and performance of subjects who did not. Subjects were 41 students of University of California, 12 of which were randomly assigned to the distractor condition, and 9 experts and 8 novices were assigned to the baseline condition. Subjects participated in one of two conditions: distractor or baseline. In baseline condition all four problems were unrelated to the target problem and in the distractor condition, the first, third and fourth problems were unrelated to the target problem, while the second problem was superficially similar to the target problem[2].

Results showed that negative transfer was indicated by strong use of the incorrect row/column multiplication procedure in the distractor condition than in the baseline condition. Therefore the distractor condition showed strong negative transfer as for the novices (92%) as experts (83%)[2].

Third experiment was designed to test the negative transfer, so it was assumed that negative transfer should be stronger for the novices than for the experts if they receive the distractor and remote analogue problem. Subjects were 71 Stanford University students and they were assigned to two conditions. In each condition there were 6 male and 6 female subjects for experts and high novices, and for the low novices there were 7 female and 4 or 5 male subjects in each condition. There were used distractor and remote analogue conditions and subjects were given three problems. The procedure was the same as in the previous experiments[2].

Results showed that the first hypothesis that experts would show more positive transfer than the novices and less negative transfer than the novices, was confirmed. The importance of this study was that problem should be included in theories of analogical transfer and subjects expertise can be included as experimental design[2].

4 Conclusion

We saw that during history the transfer learning was in the focus of psychology several times. Each psychologist has had different approach and different interest in it. Thorndike researched cats and applied his theory of learning through testing and failures to humans. He showed the importance of future transfer success comparing it to the after behaviour stimulus. If the stimulus from the previous task was positive then it determinates further behaviour of problem solving. Unfortunately, his theory can not be applied completely to humans, because he did not consider that cognition and transfer knowledge are related. People do not want food after completing a task successfully, they want to understand how one particular problem can be solved in different ways and how they can accomplish this.

Piaget was more concentrated on the cognitive development of a child through four stages. What he did not consider is that with those phases actually he limits child's development, but his position that knowledge is abstract was right. According to this fact, people can apply some knowledge structures broadly, which means that transfer learning in these times was considered as the abstract way of thinking of each child and this skill can be trained. Today we can say that education has big influence on child competences and transfer learning. Educational psychologists do research how to improve learning through transfer learning and it will be a big discussion in coming years.

Positive transfer depends on many factors, such as the representation of similar solution patterns, the expertise of subjects, different types of features, etc. The study of Novick (1988) showed that for the analogical transfer it is important to include problem solving expertise and to assess expertise of subjects. It has been shown that dealing with different problem similarity has a lot of influence for transfer what Novick (1988) showed in her study.

In this paper both positive and negative transfer in different studies is discussed. Transfer learning allows learning and testing across domains and goes out of boundaries in our everyday lives. People should know how to use their potential and apply knowledge in different domain giving transfer learning place in decision making and problem solving. It is necessary also to observe the negative transfer which is often omitted in recent studies, because studying negative transfer can be useful to understand transfer learning better.

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