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Exploring Hurdles to Transfer: Student Experiences of Applying Knowledge Across Disciplines

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This paper explores the ways students perceive the transfer of learned knowledge to new situations – often a surprisingly difficult prospect. The novel aspect compared to the traditional transfer studies is that the learning phase is not a part of the experiment itself. The intention was only to activate acquired knowledge relevant to the transfer target using a short primer immediately prior to the situation where the knowledge was to be applied. Eight volunteer students from either mathematics or computer science curricula were given a task of designing an adder circuit using logic gates: a new context in which to apply knowledge of binary arithmetic and Boolean algebra. The results of a phenomenographic classification of the views presented by the students in their post-experiment interviews are reported. The degree to which the students were conscious of the acquired knowledge they employed and how they applied it in a new context emerged as the differentiating factors.

Keywords: Transfer (Learning); Phenomenographic classification; Cross-discipline; Experiment

1. Introduction

A commonly heard complaint among teachers of advanced courses is the claim that many of their students have not learned the things they were supposed to learn on their basic courses, or that they have forgotten almost everything they learned [1]. Even if this often *seems* to be the case, the apparent lack or loss of skills may be explained, at least in part, by factors other than the ones proposed.

Memories certainly fade over time, sometimes within a couple of hours, as Jenkins's examples [1] indicate, but forgetfulness as the sole explanation prompts more questions than it really answers. In contrast, as Gick and Holyoak write [2], 'it is all too common for a student to fail to notice the relevance of knowledge acquired in one class to a problem encountered in another.' In one of their experiments, for instance, test subjects were presented a problem after having read a story that contained a solution to an analogous problem. In the experiment condition the subjects were given a hint to apply the story to the problem, resulting in as much as 92% of them presenting a solution analogous to the story, while only 20% did so in the control condition where the hint was not provided.

The underlying motivation for this paper is considering the possibility that failure to transfer previous knowledge to new situations is an important reason behind many difficulties in academic (and other) studies. Adopting the actor-oriented view of transfer endorsed by Lobato [3], we investigate students' perceptions of drawing on their past experiences to solve present problems. Bearing in mind that teacher's assistance is usually not sought until the time is at hand for the students to actually leverage their knowledge, and that the teacher often has had little to no control over what, and especially how, the students originally learned, we can say it would be a boon to better understand the factors helping and hindering transfer – a step towards potentially ameliorating significant difficulties on the path of many learners.

2. Theoretical framework

The act of learning something in one context, generalizing it, and applying it in other contexts is a complex phenomenon. Any discussion in that domain will require concepts of somewhat abstract nature. This study builds on the concepts of knowledge, understanding, and learning.

Knowledge as a concept is quite far-reaching, and nowadays, with artificial intelligence a major research field in computer science, its purview is not even limited to humans. Epistemologically, knowledge can be viewed from a highly philosophical side, or in a rather mechanical way as in modal logic [4]. The focus of this study is learning, and knowledge is treated as an object and a foundation of that process. To this end, we adopt a concept of knowledge that builds on the Piagetian theories of schemata, as described by Yilmaz [5]. Moreover, the concept of schema, defined as a mental structure for representing abstract concepts in one's mind, has practical implications that are of consequence for this study. Mainly these implications are related to the activation of existing schemata while learning, and having instructional materials and methods conforming to the learner's mental model [5]. While pinpointing the researchers' views of learning exactly on the continuum of epistemological spectrum between objectivism and constructivism [6] might be difficult, the author's conceptions are located closer to the constructivist end of this scale.

Knowing and understanding can be seen as objects rather than just processes. To gain knowledge or understanding, one needs to learn something new. Traditionally, learning has been seen as a change within a person, possibly as a response to external stimuli [7, 8]. The aforementioned constructivist view of knowledge can include this as the observable effect of the process of increasing connections within a person's schema. For a more contemporary view of learning in the context of transfer studies, Marton [9] presents various different definitions of learning across different views of psychological understandings of learning.

Knowing something does not necessarily mean that it is understood. Also, it is not entirely necessary to understand something to learn it, but only with learning by understanding, as opposed to learning by rote memorization, are the full benefits of education reapable [10]. Hiebert and Wearne have defined understanding from both general and mathematical points of view. Their generic definition is closely connected with the constructivist cognitive view and states that increased understanding is increased connections between ideas, facts, and procedures and their representations [11]. Perkins [10] has a somewhat more performance-centered definition of understanding, where an understood topic is something that can be mentally processed in a thought-demanding way, for example explained, generalized, or analogized. As discussed in this paper, the concept of understanding combines the two previous views: understanding is a range of states rather than simply present or absent; better understanding of a concept means more connections and perceived relations to other items of knowledge within the schema of that concept. Thus a well understood topic has good potential for transfer to different contexts.

The researcher's view of transfer depends on their views of learning [9], thus the definition of learning is also of major importance for this study. In this paper it is based on the concepts of understanding and knowledge outlined above. The emphasis is on deeper understanding as a foundation of learning and we define the concept of learning as the process of increasing of connections within a schema of knowledge. Especially when dealing with higher education, students already have a vast array of past experiences to build on, both from formal education and their life as they have lived it. Thus, with regard to the situationist views [12], there is a significant context in which learning takes place. As Perkins and Salomon point out [13], something needs to be learned in the first place for a transfer to be possible. This process of accumulating understood knowledge by learning, abstracting it, and applying this abstraction in a different situation or problem is the focus of this study.

There are many different interpretations of transfer, see for example [9, 12, 14, 15]. Robins [16] considers several viewpoints to the concept by classifying transfer literature according to its approach to the subject: whether it emphasizes the similarity between tasks or the analysis of analogies between transfer contexts. Both these groups do recognize that there can be more than one possible levels to transfer mechanism, commonly referred to as surface level and deep (or structural) level. Perkins and Salomon [13] additionally introduce a temporal aspect to transfer, namely forward-reaching and backward-reaching types of transfer. Forward-reaching transfer refers to the process of abstracting concepts with future transfer contexts in mind, while backward-reaching transfer means finding abstractions within the current context in order to recognize connections to known abstractions from past experience. The latter is of primary interest for this study since it is expected in classrooms when a student needs to abstract the key characteristic of a problem and reach backward into their experience for a potential match for this characteristic [13]. These types of transfer problems are instrumental when assessing a student's understanding of a topic [10, 17].

In addition to the situationist view of transfer [12], a number of developments have arisen from attempts to analyze learning and transfer in a more practical setting than the straightforward behaviorist experiment [18]. One such attempt is the actor-oriented study of transfer [3], which focuses on the learner's conception of the transfer situation. From the similarity viewpoint, actor-orientation means taking interest in what similarity relations the learner constructs and how learner's prior knowledge and experience affect the current activity, as opposed to the orbserver's predetermined understanding of the transfer situation [3].

Since the phenomenographic methods take the same second-order approach to the matter of interest [19], they are well suited for the actor-oriented study of transfer in general and backward-reaching transfer in particular. Another important viewpoint that diverges from the traditional school of transfer studies is presented by Marton [9], downplaying the doctrine of similarity and promoting variation as a source for finding the common structures between transfer contexts. Thus constructing robust mental schemata requires the learner to observe the effects of changes in the conditions of the studied topic, enabling the increasing of connections among the learner's schemata and producing knowledge more amenable to transfer and future learning. In other words, understanding provides potential to transfer knowledge.

3. Method

This study joins the phenomenographic research tradition by seeking to extract *categories of description* [19] from the students' accounts of their use of previous knowledge in solving a problem. These methods for data analysis are described on a more practical level by Kinnunen and Simon [20]. The qualitative interview process is reported following the guidelines presented by Myers and Newman [21].

When planning this study, we originally set out to investigate the perception commonly voiced by teachers that many university students do not understand, or are not able to apply, the knowledge they were taught earlier in their curricula. We interpreted this phenomenon as a failure to transfer learned knowledge and wished to examine a few actions a teacher might take, just prior to the situation where the previous knowledge is needed, in order to facilitate transfer. Thus the setting of our experiment differs at least in three points from studies based on the classical idea of transfer [7, 22], which Marton [9] describes to be the discerning of a general principle from experiences in situation A and subsequently applying that principle in situation B. First, we made no attempt to control the situation(s) A, where the subjects are supposed to learn, in sufficient generality, the knowledge they later apply (or fail to apply) in situation B. On one hand, this is due to a facet of the practical problem which motivated our study: the teacher observing the failure to transfer often has no control over the original learning situations and thus could not have been 'teaching for transfer' [13]. On the other hand, we acknowledge Marton's criticism [9] of the assumption that test subjects should be able to extract a general principle from a learning situation without variation; we suspect that we could not have

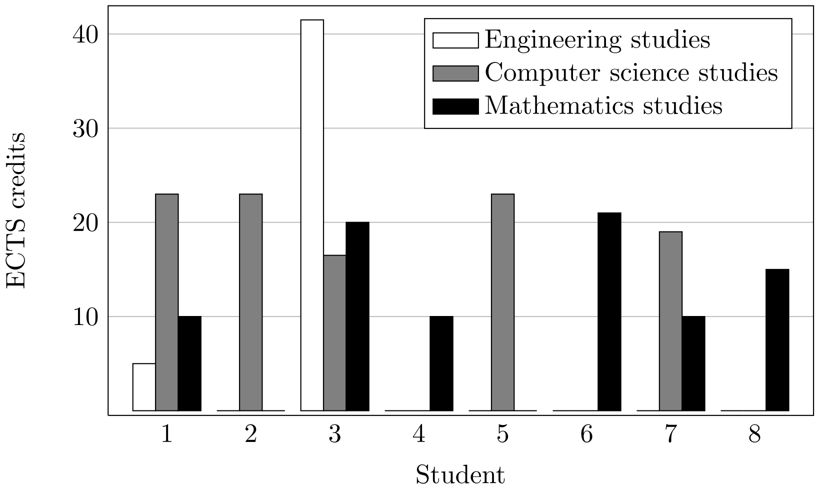

Figure 1. The amount of participants' studies in courses relevant to the tasks of the experiment, grouped according to the field of study.

provided a rich enough learning experience within the limited time available for this experiment. Second, since we wished to explore some teaching actions that might facilitate transfer, our experiment contained a *primer* component immediately before situation B, in which the subjects could review their understanding and refresh their memory about the topics that we had considered useful for solving the problem in situation B. The subjects' actions during the primer also gave us an opportunity to assess their fluency in the topics covered. Third, we adopt the actor-oriented view of transfer endorsed by Lobato [3], focusing on the students' perceptions of similarity between subject matters instead of the connections presumed by the researchers. Consequently, our primary sources of data were the post-assignment interviews of the students.

3.1 *Participants*

Volunteer subjects for this study were sought via public announcement on appropriate mailing lists, and the authors also recruited from their departments' lectures and exercise sessions. All eight students to express an interest in participating were accepted. The phase of their studies ranged from first year in the university to working on their second master's-level degree. The students, all enrolled at the University of Oulu, were equally divided between mathematics and computer science according to what they presently studied, but some had either minor studies in the other subject or vocational studies in a closely related field. Furthermore, it turned out in the interviews that one participant accepted as a mathematics student was actually a statistics major, but had minor studies in mathematics. Part of the computer science students were focusing on information systems and others leaned more towards software engineering. The participants' studies from the courses (in ECTS credits) deemed relevant to the experiment by the authors is presented in Figure 1.

Strict confidentiality was maintained throughout the study. This was communicated clearly to each participant: their identity will be known to the researchers only, and the results of the study shall be reported in such a manner that no individual can be recognized from the accounts without prior knowledge of their actions during the experiment sessions. In this paper, the participating students are referred to by a number from 1 to 8. To minimize the risk of exposing the identities of the small number of participants, we do not disclose information on the genders of the students beyond the fact that both genders were represented in the study. To this end, we also use the genderneutral pronoun 'they' in this text when referring to any one of the participants.

3.2 *Experiment Structure*

During a single week, a total of eight experiment sessions were conducted, one for each student. Both authors were present in all the sessions. Their duration ranged from one and a half to two hours, depending on how long the subjects spent on working with the tasks. After introductions, the sessions contained a primer task, followed by the main task and an interview. The parts are all explained in more detail below.

3.2.1 The Introduction

The sessions began with a five minute introduction, wherein the participant was explained the nature and schedule of the session and permission was obtained to record the entire session on video for later analysis. The time constraints were given loosely, with the implication that the students should take their time when working on the assigned tasks.

3.2.2 The Primer

The intention of the primer was to set the student's mind to the task ahead, and recalling or revising the topics from the student's curriculum that we had considered relevant to the task. This part took 0–30 minutes, depending on its specific type. Each participant did one primer, which was selected on the spot by the experimenters based on their assessment of the subject's competence, so that any given primer was done by one mathematics and by one computer science student. The general idea was to present the primers that offered more support for solving the main task to those students that appeared less equipped to tackle it, so that the discussion about their problem solving process in the interview would be more fruitful. Considered from most to least demanding with regard to the difficulty of the actual task, the primers were:

(1) (No primer)
(2) Reflecting on previous knowledge
(3) Revision exercise
(4) Teacher-led revision

In order to affect their approach to the main task as little as possible, two students had no primer component in their session and instead were given the main task directly after the introduction without any further preparation. The *revision exercise* consisted of short and simple tasks, going over those topics from the curricula that we had considered relevant to the main task when designing the experiment. The students were advised to skip the exercises concerning topics with which they were unfamiliar. *Teacher-led revision* went over the same exercises, but the teacher took an active role in the discussion, prompting and guiding the student towards the solution when necessary. Finally, the students who did *reflecting on previous knowledge*, produced a free-form presentation, a mind map or a short text supported with discussion, about their understanding of the key concepts of the same topics covered in the revision exercise. The topics visited in reflecting and both revision primers were binary arithmetic, Boolean algebra, and the SELECT statement of SQL[1].

3.2.3 The Task

The main portion of time, about 40–90 minutes, students spent working on the main task. The task was designed with the intention to place it in a context new to all par-

[1]Structured Query Language: a data retrieval and manipulation language used with relational databases

ticipants while providing the students opportunities to utilize their understanding of (at least) binary arithmetic, Boolean algebra, databases, and computer architectures. These topics are all parallel to, applicable in, or a foundation for, the target topic of logic circuits. Like the students, these topics came from two different curricula: mathematics and computer science. The authors consider the task challenging but solvable for students with either background, while being very unlikely to be solved in the allotted time by a person with no background in any of the mentioned topics.

The setting of the task, logic circuits, was presented to the students in the form of a two-page assignment (see Appendix A), which introduced the concepts of logic gates (AND, OR, NOT), how current can be interpreted as numbers and truth values, and how circuits can be composed out of logic gates. An implementation of the 'exclusive or' operation (XOR) using the aforementioned gates was provided as an example. The actual task that the students were requested to undertake was to design, utilizing the presented logic gates, a circuit for calculating the sum of two nonnegative two-bit integers.

In contrast to the primers, where teacher's help was readily offered, the students were left to their own devices in solving the task. They were advised to think aloud as much as they felt comfortable doing, but the experimenters avoided confirming or denying the claims or questions they presented, except when a clarification about the assignment or its introduction was requested. For example, we were very careful not to suggest what the inputs and outputs of the circuit should be, letting the subjects choose their own approach to the problem.

The students were allowed to work on the problem as long as they felt they could make progress. In all cases we reserved at least half an hour at the end of the session for the interview. Since the maximum total time scheduled for the session was two hours, those students who did shorter primers – or no primer at all – had a little more time available for the problem. While some subjects had to stop before they expressed a desire to do so, most of them finished or decided to stop working before they were asked to do so. However, none of them appeared to have been interrupted at an important phase of their problem-solving process.

3.3 *Interviews*

Each test session concluded with a half-hour interview which, like the entire experiment, was recorded on video for later analysis. This allowed the interviewers to focus their full attention on the interviewee's reactions and answers, and conducting the interview in general. Additionally, all written records made by the students during the sessions were collected and used in the analysis when applicable. The interview was semi-structured, meaning that the interviewers had a list of topics and questions prepared in advance, but they were ready to follow any interesting ideas that might arise during the discussion. Conversation on each topic was pursued until a mutual understanding of the interviewee's opinions was reached. The guidelines used in the planning and reporting of the interviews can be found in [21].

The authors of this study, who both teach in the University of Oulu, performed all the interviews together. Neither had previous experience in conducting interviews, and both noticed improvement in their abilities in this role towards the later sessions. The authors have several years of teaching experience and are well established in their roles as teachers. Many of the interviewees were known beforehand to at least one of the interviewers, and one was known to both. Two students were not previously known to either of the interviewers, because their studies were still in such an early stage that they had not yet taken courses that the interviewers teach.

A teacher-student setting was inherent in the structure of the experiment sessions with the primer component. However, as artificial situations, these were certainly removed from usual classroom settings. The distinction becomes further pronounced by the lack of existing teacher-student relation between the interviewee and at least one of the interviewers. The recording of the sessions did not appear to be a cause of anxiety or inhibition, and the students seemed to pay no attention to the camera. The researchers tried to keep the conversation as casual as possible within the limits of the planned experiment structure, which was not too rigid in itself. Attempt was made to abolish possible perceived conflicts of interest between the parties present and establish a common goal by stressing to the students that the experiments may ultimately help teachers better plan their teaching and courses – the same ones the students will probably attend in the future.

Researchers attempted to influence the answers as little as possible by avoiding suggestive queries and generally posing open-ended questions. The intent was to evoke as much thinking and discussion as possible, enabling the students to present their own ideas freely. Interviewers were alert to explore interesting or unexpected avenues that might arise during conversations. When delving deeper into the topic at hand, interviewers used the mirroring technique and tried to employ the language used by the students.

Interviewees appeared unreserved to the researchers: they talked about their ideas, strengths, shortcomings, and backgrounds quite openly. The students' accounts of their problem solving processes often left a lot to be desired; the interviewers were unable to extract much information about this topic without (or even with) very specific questions. We think this is mostly due to the students' low metacognitive skills that are not exercised much in the current curricula. In any case, one must bear in mind that in all interactions, the parties act as interpreters whenever they receive a message of form a reply. Due to the chosen method of analysis, these interpretations are exactly what we are after. There remains of course the possible distortion of the interviewees' ideas because of the role they play with respect to the roles of the interviewers, but, like it was pointed above, this did not appear to be a serious problem in this study.

3.4 *Analysis of data*

Although our experiments were artificial, our outlook on the transfer phenomenon is actor-oriented [3], meaning that we are interested in the way students are conscious of transferring their skills and how they perceive connections between the task we presented and their prior knowledge. As the focus is on the perceptions of the students, the interviews were the main source of data in this study, and phenomenography [19] became a natural choice for the analysis method.

Instead of an ideal view of the studied topic, phenomenography seeks to understand how people experience the situations of interest. This can be called a second-order approach, whereas the first-order approach, which is the one taken in phenomenology, would refer to the way a researcher understands the situations [20]. The roots of phenomenography lie in education research, especially in endeavors to understand how different learners interpret the same text in qualitatively different ways. A phenomenographer is concerned with discovering the variation in students' understandings of the topic in question and classifying the variations into categories of description [19]. In addition, relationships between categories and their types are of interest as well [20, 23].

In this study, the interviews were analyzed by viewing the video recordings and transcribing the parts that were deemed to be potentially relevant. The analysis process was three-staged, as described in [20], but with a slightly different scopes for the stages. In the initial stage, both researchers reviewed some of the interviews separately, providing their own opinions on what issues the main focus should lie in the following phases. The views were then compared, contrasted, and combined into a working plan for further analysis. During the second stage, following the previously decided guidelines but remaining on the lookout for new ideas, both researchers viewed all interviews together, collecting potential clues from the recordings as to what categories could be distinguished from the students' accounts of their problem-solving process, the associations they made and the skills they consciously employed. In the third stage, the collected interview data was iteratively reviewed, seeking confirmation and refining the categories that emerged during the earlier stages. The results of this study have thus arisen from discussions based on the observations that the two researchers have made of the interview data.

4. Results

Analysis of the interviews revealed different ways that the students experienced the use of acquired knowledge in solving the target task. We have divided them into the following three distinct categories:

nonconscious associations: Student does not explicitly indicate associations between past experience and current situation.

unactionable associations: Student indicates connections to past experiences, but fails to apply them successfully in current context.

actionable associations: Student indicates connections to past experiences and successfully draws on it while solving the current problem.

The factors distinguishing the students' accounts of their experience are, on one hand, the amount and accuracy to which they could describe the connections between the target task and their previous knowledge, and, on the other hand, the confidence and skill they demonstrated when describing how they applied that knowledge to solve the problem. In some cases we observed the student apparently following a determinate course in their problem-solving process but being unable to explain the process during the interview later.

The first group, nonconscious associations, could be described from the student's perspective with the sentiment: 'How am I supposed to solve this?' The students exhibiting views of this type could not point out any connections between the task and their past experience. Whatever skills they applied in working with the task apparently functioned below the conscious level. Their approach to the problem usually lacked direction, often being just combining the components with trial and error.

> Often, when you start to work on a difficult problem, you have no idea what to do. You just get going and trust it'll work out. (Student 1)

> I saw it right away that combining the gates – nothing will come out of it for me. If I had figured out that addition [algorithm] was involved, I could've at least checked out how it works. (Student 1)

> This [solution] isn't in any way rigorous and demonstrable, more like the result of trial and error. (Student 4)

The Second group, unactionable associations, could be summarized as the feeling of 'I know what this is about, but I can't do it!' The students in this group were able to describe what areas of their knowledge they considered or utilized when working on the problem. They usually attributed their difficulties to poor recollection of the key topics, or lack of proper understanding of them in the first place. Lack of experience or skill in applying abstract knowledge was also mentioned. Sometimes the student made a connection to an area of knowledge they were highly proficient in, but ran into problems because the relation of it to the target task was remote or their expertise was difficult to apply in the current context for some other reason.

> I think of these as sequences [of digits]; should I consider them as numbers? [...] There's no way this'll become a correct solution. [laughs heartily] No way! (Student 3)

> If memory serves, I did this coursework [similar to the task] with a guy who did all these [coursework assignments]. The truth is revealed! (Student 3)

> [Answer to the question if adding one-bit integers would have been easier:] Well, then it would have been just that [points at a part of the solution attempt]. Or actually, no. No? I mean yes. No. I don't know. Maybe. (Student 7)

> I did understand what was required, but I just cannot do it. (Student 7)

Cases where the student associated the problem to something that didn't aid in solving it can be accounted as special cases of this second group. One student attributed this to past experiences in a related field, but in such a way that the associated experience did not help solve the problem but rather blocked all alternative approaches from their mind:

> During the 90's I was working in a company that manufactured radio transmitters [...] This [solving] didn't exactly gel as it should have. [...] In real-time systems you cannot disassemble the sequence [of input pulses] just like that. (Student 3)

In one case the student associated the entire problem domain to bad learning experiences, which caused them to abort the attempt to solve the problem very soon. In this case the associations were made to contexts that could have aided in solving the problem, but the experiences from those contexts were highly discouraging:

> I remember doing these [problems] in Computer architectures [course]. They were always wrong. [...] This reminded me of all those mathematics lessons where I stare at the problem, totally lost. [...] and then the teacher always said that the answer is now obvious and I couldn't see it for the life of me. (Student 7)

Students in the third group, actionable associations, described their perception of the problem along the lines of 'I can solve this using X.' Like the previous group, they were able to describe the knowledge they considered when analyzing the problem and were usually fairly confident that their selected approach would yield good results – and rightfully so: their understanding of the relevant topics was sufficient to produce a working adder in most cases. Even if the solution was not completed, they could describe a workable general idea for finishing the task.

> It's basically the exclusive or which does it. [...] I Wonder if I should check with the truth tables that it works before starting to use it. Oh, well. Let's try it like this. (Student 5)

> ... it [binary arithmetic] was probably during the first year. But I think that it's easy. (Student 5)

> Well, these gate thingies were familiar to me even before [seeing them at] school, but maybe I understand them better after the course. (Student 2)

The accounts given by the students of their transfer experiences fall into the categories presented above as follows: Students 1 and 4, when prompted during the interviews, could not relate the task of the experiment to their past experiences, hence their perceptions belong to the category of nonconscious associations. Students 3 and 7 made the associations, but for one reason or another their attempts at a solution did not significantly benefit from this. Thus their experiences belong to the category of unactionable associations. Students 2, 5, 6, and 8 attributed their progress towards a solution, at least in part, to their prior knowledge of concepts related to the problem, so their accounts belong to the category of actionable associations.

Note that this classification, while not based on the students' success in solving the task *per se*, is nevertheless a good indicator of it: the nonconscious associations group fared poorly in general, the students who indicated actionable associations usually solved the problem or came very close, and the performance of the unactionable associations group was somewhere in the middle. Our choice of categories differentiates the students' experiences of the target task based on how they used their acquired knowledge in solving it. A strong contributing factor to our choice was the prevalence of this topic in the interviews, which in turn is mostly due to us structuring the experiments around the task of designing an adder circuit.

5. Discussion and Conclusions

It appears that the students who could better explain afterwards what knowledge they used when working with the problem produced more promising attempts at a solution. For example, none of the students whose accounts belong to the nonconscious associations group managed to complete a solution, while most of those who experienced actionable associations solved the problem or at least got very close. There would seem to be a connection between how well one can describe one's ideas and how well one can apply them. This might be explained by well-formed schemata being easier to apply in practice [24].

From the three resulting categories of student views, the first, nonconscious associations, arguably has connections to surface learning by rote memorization, as described by Perkins [10], or to reliance on low-road transfer only [13]. If the student is unaware of their current mental schema of knowledge, it is difficult or impossible to produce observable elaborations of their schemata in a way that indicates connections between the past experiences and current problem context [10, 11].

While the first step required for transferring skills to a new situation is seeing a possible connection, the success also depends critically on one's proficiency in the skill to be applied. This manifested with the students whose views we classified into the unactionable associations group. A characterizing feature for these views was confidence in subject matter X or Y being involved in a solution, whose specifics eluded the student. That being said, the creative aspect involved in solving any problem, and certainly one as challenging as ours, should not be forgotten when interpreting the results.

5.1 *Primers and the Task*

It was mentioned earlier that our experiment differed from traditional transfer experiments by not having a situation A, where test subjects would be taught something whose possible transfer would later be observed in situation B. However, our experiments contained a primer component at the corresponding point in time, so one may ask what the difference is. The purpose of the primers was not to teach something new but to refresh or activate existing knowledge – the intention was to give the subjects a clue about potentially useful tools in the main task. The main task portion, on the other hand, is no different from the classical situation B, except that we do not use it quantitatively to measure the success of transfer; its presence is warranted as a basis for discussion with the test subjects about their use of acquired knowledge. Why this change from the traditional formula? The origin of the change lies in the practical situations from teacher's work that motivated us: a desire to help students better build on their previous knowledge when studying new topics. Furthermore, in the actor-oriented viewpoint on transfer [3], we cannot presume to know what skills or knowledge the subject draws on when asked to tackle the target problem. Indeed, this is an important issue in studies like ours. The primers were designed around the topics that we, the experimenters, had considered useful in solving the target problem. We expected that even mentioning those topics right before the task would be a strong suggestion to apply them, provided that the subject was proficient enough in them to do so. The primers varied in the intensity that they required the subjects to direct at these topics, from none to solving problems using the skills in question.

The question about the primers that would interest a teacher is whether they have any effect on the students. Of course the types of primers we used are not the only ones possible, nor are they necessarily among the better ones. We chose a few primers suitable for solitary work that we thought would have variable effect on guiding the students' work. The subjects who did the primers usually began their efforts for a solution by attempting to apply the visited topics to the problem. However, in some cases it seemed that the topic of the primer and the subject's prior knowledge were distant enough for the primer to possibly hinder their problem-solving process.

The reason we chose designing an adder circuit as our target task lies in the students that participated in the experiment. We wanted to use the same task for everyone and to see how people from related but separate backgrounds deal with the situation. Thus the task had to be reasonable for students with either mathematics or computer science background. The absolute minimum knowledge we considered necessary for tackling the task was familiarity with basic logical connectives, the binary number system, and, of course, integer addition. These were all among the topics covered in the revision exercises, but the reflecting primer did not mention the addition algorithm. This set of intended minimum requirements derives from our own understanding of a straightforward solution to the task, namely using logic gates to implement the familiar addition algorithm in base 2.

Many students had notable difficulties with carrying out addition in base 2, and some confessed to having forgotten or never having calculated sums in any base apart from 10. While the students who did the reflecting primer may have had one less clue than those who did the exercises, they were perhaps freer to come up with their own approaches to the problem. As things stand, we consider performing the addition algorithm in a base other than 10 a part of the new context for the base 10 addition in case it was unfamiliar. This may make the task more challenging to some students, but it cannot be avoided, even in principle, since the students' proficiency in the skills they choose to apply will invariably vary.

5.2 *Practical Implications*

The categories of description can help teachers identify the types of learning problems that their students encounter and adjust teaching accordingly. We observed the primer potentially bridging the gap between the past experiences and the problem at hand. For example the problem assignment contained the XOR gate as an example, which additionally served as a reminder of a useful component:

> 'I don't think I would've used XOR if it wasn't given as an example. Then I wouldn't have gotten anywhere with this.' (Student 1)

Highlighting the connections between the topic at hand and past experiences is an important and all too often neglected part of teachers' day-to-day work.

Another thing to note is that the connections made to previous knowledge that the students rely on in a given situation may often differ from the connections that their teacher would make: presenting the teacher's associations as hints may actually hinder the student's problem-solving process. One example of this in our study was the assumption on our part that the students might associate parts of our problem with SQL. According to the experiments, this was not the case: none of the students who had studied SQL previously made this connection. We do not consider this a problem with the experiment, but rather an indication that in practical teaching work a connection between logical operators and SQL should be emphasized more explicitly. As can be seen from this example, the actor-oriented view of transfer can indicate connections within the curriculum that the students have missed or the teacher has incorrectly assumed to be evident to the students, thus providing a chance to increase understanding by increasing connections between topics learned [10]. This should be considered encouragement towards more student-centered teaching situations.

5.3 *Validity and Future Work*

It could be argued that using a primer in preparation for the transfer is no different from what is called the 'situation A' in the classical transfer experiment culture [9]. While it is true that both the classical setting and our primer deal with the same content matter, the primer is not aimed at teaching something new, but instead reminding the subject of their existing mental schema. In our case, only one of the primers, namely reflecting on previous knowledge, adhered to this ideal completely. Other primers may have involved some learning, perhaps through new ways of looking at the subject matter, depending on the subject's schema at that point.

More conclusions could have been drawn if more detailed information on the students' existing learning experiences was available, especially concerning the unactionable associations category, where the problem often seemed to be insufficient proficiency in the topic to be applied. One possible cause for shallow learning results is lack of variance in learning experiences [9]. Exploring these experiences could give more insight and improve the resulting categorization by giving reasons why others find their associations actionable and others do not.

We analyzed the data cooperatively in order to benefit from distributing the workload and receiving feedback as early as possible. During the initial analysis process, the data was partly divided 'vertically' [20, 25], and during later stages, the entire material was analyzed 'horizontally' by both authors. It was surmised that this would yield the best possible coverage of the data as well as most variation in our views and ideas. The views were discussed until a consensus was reached.

Selecting different primers for different students may have equipped some students to express their experiences better than they could have with a uniform primer. However, this is unlikely to have reduced the observed variation in the students' accounts, affecting only their distribution into categories. To foster fruitful discussions about the solution process, the more supportive primers were assigned to those students that the experimenters considered to need them the most. Another factor that might hide variation is that the task of explicating one's problem-solving process requires a meta-level skill which is not extensively practiced within the students' curricula. Not much could be done about this within the scope of this study.

Since the experiment we conducted belongs to the fields of mathematics and computer science education, we can only draw conclusions pertaining to those fields. Due to the cumulative nature of knowledge in both mathematics and computer science, the observed phenomena are especially prominent in these disciplines. Since the basis of this study is in the general theories of learning and knowledge [e.g. 7, 9, 13] these results could be more generally applicable, but the generality of the results needs supporting evidence from other disciplines.

Considering the limitations within the design and implementation of this study, it appears that a better understanding about the students' perceptions of applying their knowledge could be obtained through a more longitudinal approach. Such a study could include the students' initial learning situations, yielding more control and an opportunity to provide sufficient variation in learning experiences regarding the salient topics. Eschewing the use of multiple types of primers in favor of just a single one (or none) would reduce the effect of researchers' subjective judgement on the test situations.

There exist plenty of other possibilities for future work within the topics discussed in this paper. The effects of different primers could be studied, possibly using statistical or other methods in more authentic situations. Having studied the students' conceptions of the associations they make between topics, it would be natural to supplement the picture by interviewing teachers about their opinions on the conundrum presented in the introduction: Do their students appear to learn and carry skills well from one course to another? What do the teachers think the possible problems are, and what the underlying reasons may be? On a different note, our interest was piqued by some students apparently following a fairly certain course when solving the adder problem but being mysteriously unable to explain their approach satisfactorily during the interview afterwards.

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References

[1] Jenkins L. Permission to forget: And nine other root causes of america's frustration with education. Asq Press. 2004.
[2] Gick ML, Holyoak KJ. Analogical problem solving. Cognitive psychology. 1980;12(3):306–355.
[3] Lobato J. How design experiments can inform a rethinking of transfer and vice versa. Educational Researcher. 2003;32(1):17–20.
[4] Fagin R, Halpern JY, Moses Y, Vardi MY. Reasoning about knowledge. Vol. 4. MIT press Cambridge. 1995.
[5] Yilmaz K. The cognitive perspective on learning: its theoretical underpinnings and implications for classroom practices. The Clearing House: A Journal of Educational Strategies, Issues and Ideas. 2011;84(5):204–212.
[6] Jonassen DH. Objectivism versus constructivism: Do we need a new philosophical paradigm? Educational technology research and development. 1991;39(3):5–14.
[7] Thorndike EL. Educational psychology: The psychology of learning. Vol. 2. Teachers College, Columbia University. 1913.
[8] Weick KE. The nontraditional quality of organizational learning. Organization science. 1991; 2(1):116–124.
[9] Marton F. Sameness and difference in transfer. The Journal of the Learning Sciences. 2006; 15(4):499–535.
[10] Perkins DN. Teaching for understanding. American Educator. 1993;17:28–35.
[11] Hiebert J, Wearne D. Instruction, understanding, and skill in multidigit addition and subtraction. Cognition and instruction. 1996;14(3):251–283.
[12] Lave J. Cognition in practice: Mind, mathematics and culture in everyday life. Cambridge University Press. 1988.
[13] Perkins DN, Salomon G. Teaching for transfer. Educational Leadership. 1988;46(1):22–32.

[14] Anderson JR, Reder LM, Simon HA. Situated learning and education. Educational researcher. 1996;25(4):5–11.
[15] Anderson JR, Reder LM, Simon HA. Rejoinder: Situative versus cognitive perspectives: Form versus substance. Educational Researcher. 1997;26(1):18–21.
[16] Robins A. Transfer in cognition. Connection science. 1996;8(2):185–204.
[17] Hiebert J, Wearne D. Instruction and cognitive change in mathematics. Educational Psychologist. 1988;23(2):105–117.
[18] Evans J. Building bridges: reflections on the problem of transfer of learning in mathematics. Educational Studies in Mathematics. 1999;39(1):23–44.
[19] Marton F. Phenomenography — describing conceptions of the world around us. Instructional Science. 1981;10:177–200. Available from: http://dx.doi.org/10.1007/BF00132516.
[20] Kinnunen P, Simon B. Phenomenography and grounded theory as research methods in computing education research field. Computer Science Education. 2012;22(2):199–218.
[21] Myers MD, Newman M. The qualitative interview in IS research: Examining the craft. Information and organization. 2007;17(1):2–26.
[22] Judd CH. The relation of special training to general intelligence. Educational review. 1908; 36(28-42).
[23] Booth S. On phenomenography, learning and teaching. Higher education research & development. 1997;16(2):135–158.
[24] Chinnappan M. Schemas and mental models in geometry problem solving. Educational Studies in Mathematics. 1998;36(3):201–217.
[25] Kinnunen P, McCartney R, Murphy L, Thomas L. Through the eyes of instructors: a phenomenographic investigation of student success. In: Proceedings of the third international workshop on computing education research. ACM. 2007. p. 61–72.

Appendix A. Assignment (translated from Finnish)

A.1 *Introduction*

One can easily distinguish between two fundamental states in electrical systems: the presence or absence of electrical current within a given conductor. In connection to logical systems, it is natural to interpret these two states as the truth values *true* and *false*. On the other hand, to represent an integer in binary (base-2) form, only two digits are required: 0 and 1. The binary digits are usually referred to as *bits*. One can, of course, choose the interpretation of electrical states arbitrarily, but let us agree for now to employ the correspondence presented in Table A1.

Table A1. Interpretation of states

	truth value	digit
current	*true*	1
no current	*false*	0

By combining *logic gates* that correspond to logical operations, one can construct electrical circuits to evaluate logical propositions in the sense that when the inputs of the circuit express the truth values of the variables in the proposition, the circuit's output represents the truth value of the entire proposition. A few logic gates corresponding to familiar logical operators are presented in Figure A1. The inputs of these gates are in the bottom ('in 1' and 'in 2', or 'in') and outputs ('out') on top. For instance, the output of the OR gate is *true* if at least one of its inputs is *true*; otherwise the output is *false*.

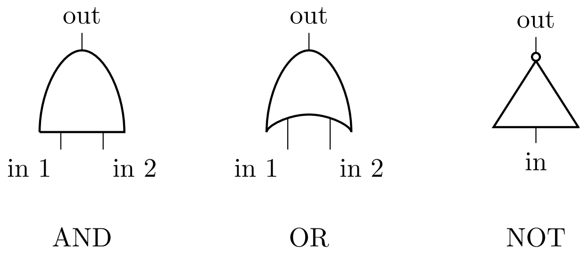

Figure A1. Available logic gates

A.2 *Example*

The usual symbol for the *exclusive or* (also known as XOR) gate is presented in Figure A2. It outputs *true* when exactly one of its inputs is *true*; otherwise the output is *false*. The the XOR gate can be replaced with an equivalent combination of other gates. One

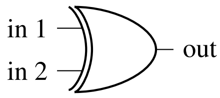

Figure A2. The XOR gate

possible way to implement the functionality of the XOR gate is presented in Figure A3. In this diagram, a dot at the point where conductor lines meet indicates a connection (fork), while the absence of a dot at an intersection of lines means that the conductors are not connected at that point (crossing).

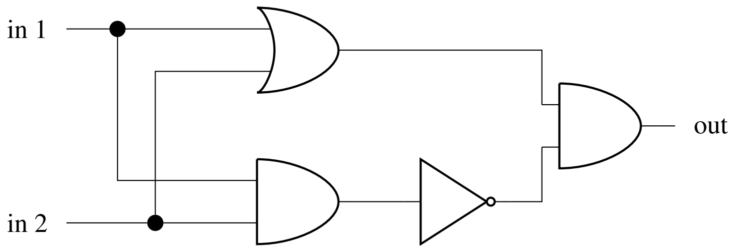

Figure A3. The XOR gate implemented using AND, OR, and NOT gates

A.3 *Task*

Design a circuit that calculates the sum of two nonnegative two-bit integers.

You have an unlimited supply of conductors and logic gates presented in Figure A1 (AND, OR, NOT) at your disposal.