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In the study presented here, we address the issue of how to investigate future primary school teachers' responses to more or less expected children's answers and questions. We observe future primary teachers exposed to contingent situations mediated by an educational tool called Concept Cartoons, and analyse their responses with respect to mathematics subject knowledge. The Concept Cartoons presented in this article deal with addition of natural numbers.

Keywords: Concept Cartoons, teachers' knowledge, mathematics subject knowledge, knowledge quartet, contingency.

INTRODUCTION

The study presented here is a part of a three-year project focusing on opportunities to influence professional competences of future primary teachers through experienced *inquiry based mathematics education*. We realize a set of university mathematics courses for future primary teachers in which they can experience inquiry based education as students, and analyse its impact on their content knowledge. An integral part of the project consists of repeated diagnosis of mathematics subject knowledge of project participants. We generally observed inquiry based education from the perspective of the *knowledge quartet*, and realized that this kind of education is extremely rich in *contingent* (unpredictable) situations. As far as contingent situations are unpredictable, and it is difficult to simulate them systematically, we decided to imitate such situations by an educational tool called *Concept Cartoons*. We use this tool as one of the diagnostic tools in our project.

In this particular study we observe future primary teachers exposed to contingent situations mediated by Concept Cartoons, and analyse their responses. Our research question is: What aspects of future teachers' mathematics subject knowledge can we investigate using Concept Cartoons?

THEORETICAL BACKGROUND OF THE RESEARCH

Teachers and their knowledge

Describing and analysing teacher work is a very attractive field of recent international research in mathematics education. Starting with Shulman's widely accepted concepts of *subject matter content knowledge* (SMK) and *pedagogical content knowledge* (PCK) (Shulman, 1986), researchers try to analyse different kinds of teachers' knowledge, its content, relations, and obstacles in their formation.

An extensive research on mathematics subject knowledge of future primary teachers has been conducted by a group around Rowland. Their research resulted in the identification of aspects of the behaviour that seems to be significant as information about one's SMK or PCK in mathematics. They introduced 20 categories which were subsequently grouped into four broad dimensions: foundation, transformation, connection, and contingency – the so-called *knowledge quartet* (Rowland, Huckstep, & Thwaites, 2005; Rowland, Turner, & Thwaites, 2013, 2014). Knowledge quartet and its subsequent categories can now be used as a tool for conceptualizing the ways in which teachers' knowledge comes into play in the classroom.

As for the particular dimensions, *foundation* refers to teacher's theoretical background and beliefs, *transformation* concerns knowledge-in-action with central focus on representations (analogies, examples, explanations, etc.), *connection* refers to ways the teacher achieves coherence within and between lessons. The last dimension, *contingency*, involves aspects dealing with unpredictable (contingent) events in the classroom. It concerns teachers' responses to events that were not anticipated in the planning. The dimension of contingency consists of five subcategories: *responding to students' ideas* (RSI), *deviation from lesson agenda*, *teacher insight*, *use of opportunities*, and *responding to the (un)availability of tools and resources* (Rowland et al., 2014).

In our study, we shall investigate responses related to the RSI code:

> This code includes the ability to make cogent, reasoned, and well-informed responses to unanticipated ideas or suggestions from students. These teachers' responses are to students' contributions to the (mathematical) development of the lesson. These contributions are typically oral, but could be written. Our analysis of the data available to us identifies three sub-types of triggers in this category: 1) student's response to a question from the teacher; 2) student's spontaneous response to an activity or discussion; 3) student's incorrect answer – to a question or as a contribution to a discussion. ('Knowledge Quartet', 2012)

In addition to knowledge quartet we also observe future teachers' knowledge from procedural and conceptual perspectives. Hiebert and Lefevre (1986) characterized conceptual knowledge as a connected network of facts and propositions, and procedural knowledge as a structured set of mathematical symbols and conventions for their use, rules, algorithms and procedures. This construct was attacked by some researchers for inconsistency, and reconceptualised several times. We find the most suitable the reconceptualization given by Baroody, Feil, and Johnson (2007, p. 123):

> *Procedural knowledge* consists of mental actions or manipulations, including rules, strategies, and algorithms, for completing a task.
>
> *Conceptual knowledge* is knowledge about facts, generalizations, and principles.

Concept Cartoons

In our research we make use of an educational (and in this study diagnostic) tool called *Concept Cartoons* (CCs). CCs were developed in 1991 by Keogh and Naylor as a tool for learning and teaching science (Keogh & Naylor, 1993); lately they have been created also for other school subjects, for example, mathematics (Dabell, Keogh, & Naylor, 2008). Each CC is a cartoon-style picture showing a group of children in a bubble-dialogue based on an everyday situation, the children presenting different viewpoints on the situation (Figure 1). The alternatives displayed in bubbles may be based on real events, on classroom scenarios, on common conceptions and misconceptions, or might be prepared intentionally.

CCs are used mainly in the classroom to support teaching and learning by generating discussion, stimulating investigation, and promoting learners' involvement and motivation, i.e., as a tool oriented mainly on pupils (Naylor & Keogh, 2012). In the study presented here, we aspire to use CCs innovatively for investigating future primary teachers' content knowledge.

In view of the fact that each CC offers a situation not invented by the teacher, and children's various responses on this situation, a suitably chosen CC can provide the teacher an educational model of a contingent situation. In the context of the RSI code, each CC is an artificial reality that partially imitates triggers of the 1st type (it shows children's responses to a question, but the question was not asked directly by the teacher, and sometimes the question is not explicitly expressed in the cartoon), and with an appropriate choice of the content of bubbles it can partially imitate triggers of the 2nd type (children in the picture can response to other children's answers; this case would serve Peter's bubble in Figure 1 changed to "Kevin, you are not right, they scored more."), and entirely imitate triggers of the 3rd type (some answers in bubbles are incorrect).

As the RSI code admits not only oral but also written contributions from children (see the characteristics of RSI above), we place CCs on worksheets, and let the respondents react to them in written form.

DESIGN OF THE STUDY

Participants

Participants of the research are two groups of master students of primary teacher training from our Faculty of Education. This master's degree training lasts 5 years, and covers all the primary curriculum subjects. We involved 29 students of the 2nd year, and 35 students of the 3rd year. The 2nd year students

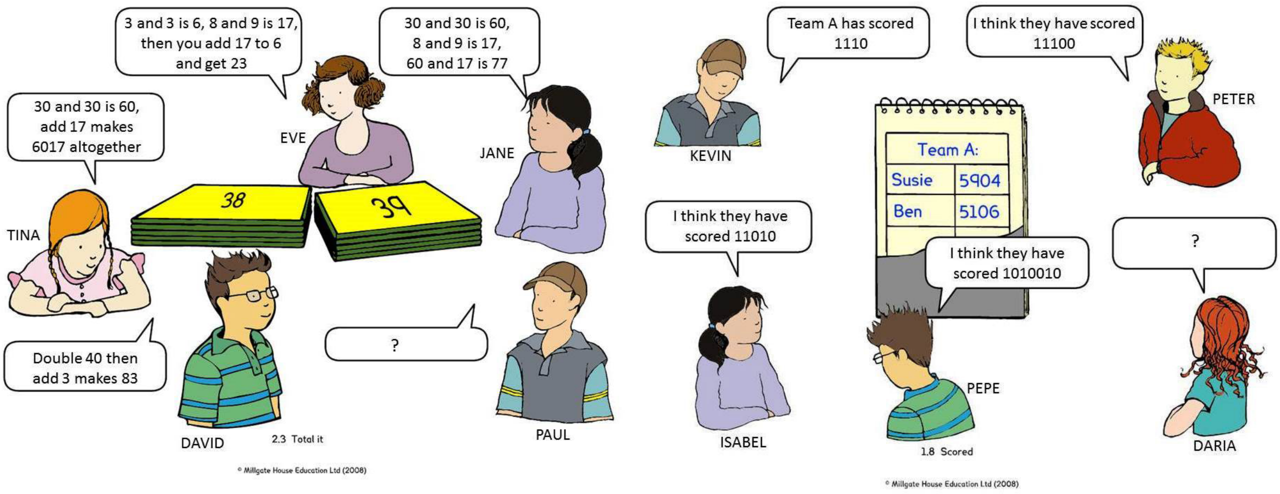

Figure 1: Two examples of Concept Cartoons; taken from (Dabell et al., 2008), slightly modified

have recently completed the "Natural numbers" part of Arithmetic courses, but have not attended any Didactics yet. The 3rd year students have recently completed the "Natural numbers" part of Didactics of mathematics courses.

Course of the study

In the data collection stage of the research we gave each respondent a worksheet consisting of four CCs on addition and subtraction of natural numbers (two of them are in Figure 1), with four common questions:

1) Which child do you strongly agree with?

2) Which child do you strongly disagree with?

3) Decide which ideas are right and which are wrong. Give reasons for your decision.

4) Try to discover the cause of the mistakes, and advise the children how to correct them.

Respondents were asked to fill in the worksheet individually. For all respondents it was the first occasion to work with CCs.

We processed this output qualitatively, using grounded theory methods (Strauss, 1987): we started with open coding, then grouped the codes according to similarities and internal relation into categories, and marked codes with plus or minus sign to denote positive or negative aspects (good or poor knowledge, correct or incorrect recognition, etc.). Then we several times reinspected all the output, looked for new fragments and new contexts, rearranged existing fragments and codes, and debugged the coding process as well as the process of sorting codes into categories.

As relevant for our study appeared the following code categories:

A) respondent's spontaneous response (the very first opinion) on ideas in bubbles

B) respondent's subsequent response on ideas in bubbles

- recognition of right and wrong answers

- recognition of procedures used by children, identification of the causes of mistakes

C) the way how the CC was composed, i.e. the nature of the CC

We distinguish between A and B categories, because in relation to contingency we consider as important an immediate response to the content of bubbles. We assume that such immediate response can be triggered by worksheet questions 1 and 2, while subsequent response is rather a matter of questions 3 and 4. More precisely, thought processes caused by questions 1 and 2 are different from those caused by questions 3 and 4 – respondents do not need to go into a deeper analysis while looking for a child with whom they strongly (dis)agree. Therefore, aspects related to A codes are mainly triggered by questions 1 and 2, aspects related to B codes are mainly triggered by questions 3 and 4.

In the next stage of the analysis we examined relationships between codes and between categories, from the perspective of the content of particular bubbles as well as from the perspective of particular respondents.

FINDINGS

The initial finding we made during the coding process was that participants' responses are substantially affected by the nature of the individual CC (i.e., by aspects hidden under the C codes). The effect is clearly seen when comparing the two CCs from Figure 1 – both of them show a situation that need to be transformed to mathematics, mistakes displayed in bubbles are standard, and each bubble contains no more than one type of mistake. But their other features differ, for example:

Figure 1a

- the arithmetic task is not explicitly stated, it needs to be revealed from the picture
- each bubble describes the procedure of calculation, and the result

Figure 1b

- the arithmetic task is outlined, numbers to sum are aligned below each other
- each bubble shows only the result of calculation

Thus, with the first CC respondents can comment results and procedures described in bubbles, and look for errors in procedures leading to incorrect results (and also in procedures leading to correct results). While with the second CC respondents can comment only results; it simplifies decision at a bubble with a correct result, but complicates decision at a bubble with an incorrect result: the procedures hidden behind the incorrect result are not described, and respondents have to make an attempt to discover them.

In the first CC, majority of the 2nd year respondents failed to decode the David's procedure, many of them even mentioned David as the child with whom they strongly disagree:

P28	Where did David take the 40?
P11	I strongly disagree with David. David – I do not understand how he came to the 40.

But the David's procedure is very inventive, with only a small mistake in the final. The bigger compliment goes to these respondents who praised David for his procedure, and advised him the right ending:

P31	David has a good tactic, but he mistook a sign, instead of adding there should be subtracting. David, you do not have those 2 x 40, you have less, so you must subtract.

On the contrary, the 3rd year respondents managed the David's issue without hesitation. Here the PCK acquired in Didactics courses comes into play – these respondents already attended Didactics on natural numbers where they learned how to utilize various counting procedures in the classroom.

Some 2nd year respondents had also difficulties with the Eve's procedure; they were not able to discover why she started with 3 + 3:

P22	Eve counted wrong from the start.
P20	Eve makes a sum of random.
P31	Eve does not watch orders, she is short of tens.
P27	Eve counted tens incorrectly; she took 3 + 3 instead of 30 + 30.
P12	Eve has a problem with counting of tens. Eve, we decompose 38 to 30 and 8, not to 3 and 8.
P33	Eve handled incorrectly the numbers; she did not take them as wholes, but separately. She did not realize that 39 is 30 and 9, and made 3 and 9 of it. Eve, you messed ones and tens, 39 must be expressed as 30 and 9.

To clarify the situation we should mention that counting tens separately during mental addition is not a standard procedure in our schools. On the other hand, the respondents recently attended Arithmetic courses on decimal numeral system, so that the excerpts above point to inflexible thinking of their authors.

In the second CC, respondents often succeeded in finding the procedure hidden behind the results, some of them suggested really credible rationale for why the mistake happened:

P14	Kevin completely eliminated the column with zeros.
P27	Kevin, if you count 0 + 0, you must enter the final 0 to the calculation.
P14	Peter probably thought that 0 is not a number, and added 1 to the next sum.
P37	Peter forgot to add 1 to the tens place, and added it later to the hundreds.

But there appeared also rationales that do not look likely:

P13	Peter swapped 0 and 1.

The tendency not to seek the procedure but only compare the bubble and the correct result, which is noticeable on the last line of the transcript above, appeared even stronger in some 3rd year students' outputs:

A03	Peter wrote the third '1' to the wrong place.
A10	Peter is coming to accuracy, but his result is 90 more. Peter, recount it again, your result is 90 more than the correct result. Pepe has 2 more zeros in his result. Pepe, your result is too high compared to the computed numbers. Recount again the example, and remove some numbers.

Among 2nd year respondents we found two who confused terms 'number' and 'digit' in their explanations. Further analysis of their responses showed that the problem might not be only terminological:

P24	Tina is right. If I add 17 to a digit 60, I get 6017. But if I count up, I would get 77.
P18	Tina and Jane are right, they followed the instructions exactly. David's bubble should be corrected: 2 x 40 = 80, add 3 makes 803.

These statements can be signals of deep misunderstanding of the concept of number. To be sure, we would need further data from these respondents.

During the analysis of completed worksheets it became apparent that in some responses to the first CC it is possible to distinguish between procedural and conceptual knowledge. This fact was especially evident for the following two respondents; both are 2nd year students, with average performance in Arithmetic. The first respondent answered the questions as follows:

P33	ad 2)	I strongly disagree with David.
	ad 3)	David is wrong. He confused it all.
	ad 4)	Instead of subtracting 3 from 40 · 2 = 80, he added it. He needs to have the whole counting explained again.

In the beginning, David is the only child in reply to a question with whom the respondent strongly disagree. Then we can see that the respondent knows the procedure that David used; she even says where the mistake is and what the correct version of this part of procedure is. Yet in the end she states that David needs to learn the whole procedure again. This respondent probably got her knowledge by rote learning. She does not understand the procedure as a sequence of individual steps, but as one indivisible whole. She knows the procedure very well; she is even able to compare her calculation with David's, and find the mistake. But she is not able to divide the procedure into individual steps, and repair just the wrong one. In her kind of understanding the only way how to repair the procedure is to learn it again as a whole. Summarized, in this task the respondent displayed no conceptual knowledge, and only superficial procedural knowledge.

With this respondent we can also clearly illustrate the difference between SMK and PCK: she knows how to count the example for herself (an indicator of SMK) but is not able to help the child (an indicator of a lack of PCK).

The second respondent wrote:

P37	ad 2)	I strongly disagree with David and Tina.
	ad 3)	Eve is wrong.
	ad 4)	Eve, you can calculate this way, but you have to write the second number under

the first, digits lined up in columns.
David, you must not round the numbers. If you round, you have to sum the numbers, and subtract their difference from the result.

This respondent has her knowledge too closely tied to the context in which it was learned (e.g., counting of numbers that are written below each other), so that the knowledge cannot generalize to other situations. As Hiebert and Lefevre (1986, p. 8) note, also this kind of knowledge used to be obtained by rote learning. Again, this respondent shows no conceptual knowledge, and superficial procedural knowledge. As in the previous case, the respondent displays SMK but no PCK.

CONCLUSIONS

In this study we introduced an educational tool called Concept Cartoons (CCs), and used it innovatively for investigating future primary teachers' mathematics content knowledge. For this purpose we prepared a set of CCs on an essential topic "addition and subtraction of natural numbers". These CCs imitate contingent situations, and we may observe future teachers' responses to more or less expected children's ideas.

As the results show, CCs are a very flexible tool, and we may investigate various aspects of knowledge with them. If the CC contains bubbles showing both procedures and results, then we might be able to distinguish clearly between procedural and conceptual knowledge, and between SMK and PCK (David & P33, Eve & David & P37). This kind of CCs also reveals when respondents have troubles to decode a simple procedure containing a mistake (David's and Eve's cases). The incorrect procedures presented by children might be ambiguous at first glance, and some respondents could display inappropriate spontaneous reactions – disagree strongly with an idea they do not understand (David & P11), or wrongfully blame the child to count randomly (Eve & P20). Moreover, the description of an incorrect procedure in the bubble can influence some respondents to incorporate the mistake into their own responses (David & P18, Tina & P24).

The CC containing bubbles with results only can serve as a useful supplement to the previous type. Respondents can display good transformation knowledge when looking for examples of procedures that could fit to incorrect results in bubbles (Kevin & P27, Peter & P14). On the contrary, some respondents can show a lack of PCK by just comparing the incorrect result in the bubble with the correct result, and giving the child advice without looking for the procedure hidden behind the mistake (Peter & P13, Peter & Pepe & A10).

The analysis of the data obtained during the research led us to the need to investigate deeper the question how different kinds of knowledge can be displayed through the mediation of CCs. This is the direction we will continue our research. We found out that further systematic triangulation from different perspectives (responses to CCs, Arithmetic tests, interviews) is necessary for the creation of a grounded theory.

We appreciate the advantage that CCs offer in comparison to other diagnostic tools such as videos or classroom scenarios: the possibility to prepare the content of the bubbles intentionally, on a chosen purpose. We expect that this feature shall allow us to investigate teachers' knowledge more deeply through presenting bubbles with alternatives that are able to reveal important aspects of teachers' knowledge but sometimes might remain unspoken in a real classroom.

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