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CROWD IN, MAP OUT: CO-CREATIVE KNOWLEDGE BUILDING OF IGCSE MATH

Pia Niemelä, Tampere University of Technology, Finland
Jarkko Mylläri, University of Helsinki, Finland
Email: pia.s.niemela@gmail.com

Abstract. The present study focuses on the process of learning to learn by conceptualizing and modeling systems. The learning experiment synthesizes several simultaneous learning goals, the bottommost layer being concept mapping basics, the second layer deepening the knowledge of the selected domain area, in this case of math, and the third layer, even if most implicit, the primus motor of the whole study, i.e. testing students' preparedness for UML modelling. As a design-based research (DBR) the target is to study the possibilities of educational improvement, in this case getting a better general view of math by concept mapping. The study traces the experiences and results of the concept map experiment carried out among 8th and 9th graders (N=25) of the Hope International School of Cambodia. The experiment started out by familiarizing the students with mapping principles and the IGCSE math syllabus, after which each group got two syllabus areas to prepare a presentation, a teaching video and a concept map. The map could be on paper or in electronic form. In the final state, the maps were combined as one poster that could be understood as a collective presentation of the domain knowledge i.e. one sort of visualization of the wisdom of the whole class. During the preparation of the map, the syllabus areas were used as a means to reflect one's own math path.
The study asks: "How does concept mapping suit learning math?", "What are the meanings that the teacher and the students give to this learning experiment?" and "How could concept mapping help in enhancing skills needed in ICT?" The results encourage using concept mapping in learning math to get a better overview: new concepts were learnt, linkages strengthened, and the syllabus content and order of learning various areas were reviewed more thoroughly. All this helps in depicting the IGCSE exam requirements as a whole. Most students regarded concept mapping as a beneficial tool for organizing their knowledge. With concept mapping not only math, but also learning-to-learn competence was enhanced, which should have a positive transfer effect on learning other subjects as well. However, more effort should be put into learning the orthodox expression of concept mapping.

1 Introduction

The need to understand the process of conceptualizing and to improve students' general study skills by using the possibilities of modern co-editing technologies is one of the driving forces of this study. As a kick start of a new topic, putting additional emphasis on learning the main concepts is essential. Clarifying the concepts and establishing a subject-based vocabulary is a good approach in any learning environment, but it is vitally important in multicultural learning environments. At international schools, for example, inadequate language skills and missing the core concepts set remarkable obstacles for learning. Allowing language minorities to form groups and build their own sub-cultures within the classroom hinders taking the scientific concepts into use. Instead, students will develop their own and alternative expressions to talk about matters, whereas the target is to be fluent with academic, and more specifically scientific social language (Scott et al., 2007; Leach & Scott 2002).

Embracing essential concepts paves the way for the next phase of linking them together and to previous knowledge. Not only inadequate concept possession but also misconceptions in associations create obstacles for learning. Maps may be used to deepen the learning by creating clearer and denser connections. At the same time possible misunderstandings are exposed. Currently, assessing is mainly based on the test results and activity during lessons. This may be adequate in the case of measuring success in reaching smaller learning objectives. In contrast, a more detailed development of conceptual understanding and getting a bigger picture is less frequently examined, especially in subjects such as math, where superficial learning by having only in situ problem solving strategies is common at the expense of a wider perspective.

Concept maps as visual representations of the schema enable grasping a bigger picture of the content and in this study maps are meant to be digested at one glance. In addition, individual nodes should be visually appealing and to contain images, even videos. Co-creativity and negotiations within groups are fostered by using state-of-art tools such as Prezi and Google Docs in a co-editing mode. It is not the tools alone but combining them and developing a teaching practice of conceptual learning using these tools that fit the task of getting a holistic view of the topic, in this case the whole IGCSE syllabus of extended math. Conceptualization is an essential skill also in ICT modelling, e.g. to communicate the overall component and class structure of a system when a new artifact is being implemented. This study notes the value of conceptualization not only in learning to learn, but paving the way for UML diagrams used in describing the architecture of ICT systems.

2 Maps and Videos make Meanings

The biggest difference between expert and novice thinking is the consistency and density of the underlying concept schemes. Deeper learning implies linking atomic details to create bigger and robust constructs by consciously tying new knowledge to relevant concepts and previous propositions that the students already possess, Ausubel (1962) defines this as meaningful learning. The denser and more connected this mental construction is, the better and more versatile knowledge structure a student has. For example, problem solving is based on the consistency of the concept map and the quality of its links and associations (Trowbridge & Wandersee, 1989). “Generic models” i.e. bigger scheme entities that enable experts to intuit in new situations are highlighted by Nersessian (1995). Lacking these models leaves novices puzzled and progressing with trial and error. Bransford et. al (2000) and Reif (1995) recommend the use of different kinds of graphical presentations, hierarchical charts and concept maps in teaching so that students may order concepts and organize knowledge. A good practice to organize and memorize reading content is to draw semantic summaries as concept maps and hereby engage in higher cognitive functions (Novak, 1984).

Concept maps represent a person's understanding in a hierarchical way, so that more general concepts are more to the top or center in the map, whereas subconcepts are lower or peripheral. However, the mapping syntax in this study regarding layout, linking (arcs) or concepts (nodes) is allowed to be loose in order to keep it as inclusive as possible. Moreover, no distinction between map types is made, and syntactically loose mindmaps are recognized alongside stricter concept maps, the orthodox use of which requires commutativity between the visual and verbal representations. According to concept map rules, nodes (concepts) must be connected with an arc (the verb), which then constructs a sentence: a subject - a predicate - an object. Hence, maps may be read, which Åhlberg (2002, 2005) states especially beneficial regarding learning. In general, elaboration with different representations supports learning.

The utility of multiple representations is not new, but has been pronounced in different theories, e.g. dual-coding by Paivio (1991), where imagens and logogens, in other words images and language, are handled differently in memory. Processing words is sequential, whereas images can be handled also simultaneously and in parallel, hence the processing speed of imagens overcomes logogens. Mandler (2014) has proved that memorizing images is easier, especially if the order of the items is not important, whereas remembering in sequence is advantageous in the verbal case. As exact sciences that consist of hierarchical concepts and relations, STEM subjects are especially fit for concept mapping.

In physics, Kurki-Suonio and Kurki-Suonio (2000) have presented a directed quantity map as the natural order of introducing quantities illustrated in Figure 1, where distance *s* is the first quantity, the change of distance as the function of time is the consecutive concept of velocity *v*, and finally the change of velocity as the function of time represented as acceleration *a*.

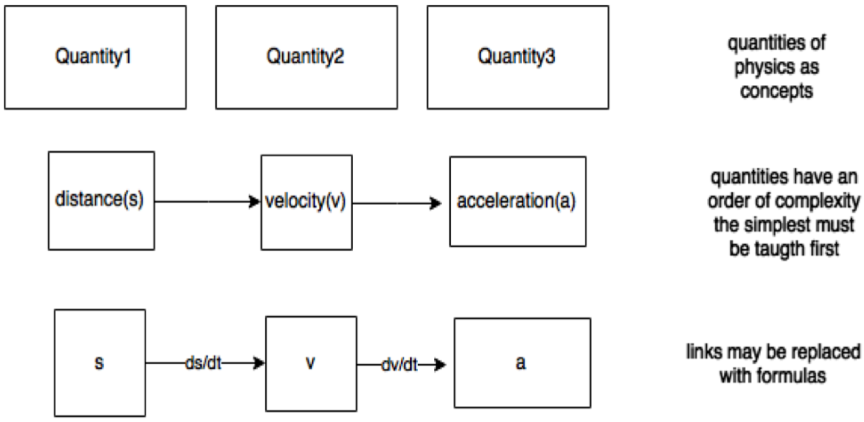

Figure 1. The directed quantity map dictating the order of teaching in physics.

The seven basic quantities of natural sciences include length (distance), mass, time, electric current, temperature, mass, and light intensity. Other quantities are derived from these by combining or elaborating the seven basic quantities. The linking verbs of the map may even be replaced with mathematical equations. The final directed graph is a representation of all the physics quantities and their relations (the fundamental laws of physics) and gives a sensible order of introducing new quantities.

In math, albeit a definite set of 7 base quantities does not exist, a path of developing numeric/algebraic thinking is well justified: e.g. in the number domain transferring from positive integers to negative, from which to rational and then irrational numbers by first calculating with four basic operations (add, subtract, divide, multiply) and then gradually expanding to more complex operations of powers and logarithms. In parallel, a paradigm shift of switching from numbers to letters and solving unknowns in functions is accomplished. Abstracting algebra is followed by a similar epistemology in geometry, emerging from 1D points and lines, through 2D shapes of triangles, squares, and circles to 3D shapes of pyramids, cubes and spheres, and their transformations.

The IGCSE math syllabus summarizes 11 subdomains of Number, Algebra, Functions, Geometry, Transformations and Vectors, Mensuration, Co-ordinate Geometry, Trigonometry, Sets, Probability, and Statistics (IGCSE syllabus, 2016). Instead of considering math as a trick collection of solving various problems we made an attempt of handling it as an academic subject that would benefit from a variety of elaboration mechanisms such as concept maps and preparing narratives in the form of digital stories. In this study, we would like to not only broaden the students' view regarding math as a subject, but also diversify the methods of learning it.

To provide the students with more opportunities for co-creation, this concept map intervention was enhanced with digital stories that in the context of education may be called pedagogical digital stories (Vivitsou et al., 2014). By negotiating over the manuscript, shooting and editing videos, the problem area will become more self-experienced, authentic and meaningful, which is an essential cornerstone of a more active and student-centered instructional set-up. Elaborating the theme as well as evaluating and selecting the best clips, enhance the progress to higher levels of Bloom's taxonomy of analysis, evaluation and creation. Climbing up the Bloom's taxonomy is considered a valid way of intensifying learning, for higher cognitive functions are involved.

3 Method

The teaching experiment was realized in the Hope International School of Cambodia with classes Year 8 (N=19) and Year 9 (N=6). The attempt was to familiarize students with the math syllabus and its concepts and ultimately construct an overview of the whole content. As DBR research the ultimate goal is to iteratively improve this learning artifact to provide meaningful modifications in math praxis, especially as regards creating an overview. The experiment included:

1. Scaffolded 'Functions' concept map, concept mapping principles explained
2. Taboo game with syllabus concepts
3. Syllabus read-through: sketchy mindmaps with and without the syllabus paper as a pair work
4. Presentations, one syllabus area per a group (Number, Mensuration, Probability, Algebra, Geometry)
5. Claymations of the same syllabus area
6. Scaffolded 'Trigonometry' concept map (<= the phase where Year 9 joined in)
7. The final concept maps of the current and next syllabus areas, electronic or paper
8. Reflection of one's own math path using syllabus area list
9. Poster
10. Survey

The IGCSE syllabus was split into 11 separate areas and the first area handled was 'Functions'. The exercise was included as a part of the test of the graphical solving. In the mapping exercise a student had to identify the main concepts based on the given text and build a map using these concepts. The teacher showed an example of constructing a map that is understood here as an expert skeleton map. The text was written to cover a short bullet list style of the actual syllabus, for in its entire conciseness it did not explain things clearly enough for the students to be capable of understanding the basic idea. Quite a few things in the syllabus were new to the students. To get the basic idea and gain more confidence in constructing concept maps the students went through the map instructions in teacher-directed style after getting their tests back. To give an example, the teacher showed how she would construct the map. After digesting the first bite the whole syllabus elephant was to be eaten. The first joyful practice of getting a grasp of syllabus concepts was playing the "Taboo" game. The player is not allowed to use the concept or its components while he is explaining it to his group by using different words. Symptomatically, the group of Korean girls struggled with the very basics, such as "subtract".

Next it was time to run through the whole syllabus, one colored paper per each syllabus area was filled with syllabus content and after that these papers were grouped so that closest relatives, such as Geometry and Coordinate Geometry, stood together. Each group selected one area for presentation, most of the presentations were PowerPoints (3) and one Prezi. The presentations were videoed and evaluated by other students. After the presentations the topic was further elaborated with Claymation, one of the groups selected Legos. The duration of the whole video was meant to be short, the recommendation was 30 seconds. Being able to squeeze up the essential is one of the key skills in modelling. However, the instruction aimed at creating as short clips as possible to make sharing and merging them easy. The ultimate goal in the beginning was to add videos to the final Prezi concept map of 11 different syllabus areas.

Another example, in this case Trigonometry, was shown and the topic was revised in general, when groups started to move back to concept mapping. In this phase Year 9 had completed their last topic, Trigonometry, and joined in. The remaining syllabus areas were distributed among groups. The students were advised to make the maps as presentable as possible i.e. visually appealing with lots of graphics and symmetricity, if that was easy to achieve. With the help of the syllabus, each student traversed his or her own math path from the very beginning and tried to recall the best learning experiences as well as strong and weak math areas. In the final phase, these individual concept maps were merged as one poster, and the survey was filled out.

In the following chapter, we focus on the analysis of data such as concept maps and digital stories that were produced during the process. In addition, also the qualitative data of surveys was used as a qualifier of how the process of getting the overview succeeded. In maps, we are interested in the terms applied; whether scientific or alternative concepts and how hierarchical and related the concepts were. It was supposed that the videos highlight the main concepts and demonstrate the mathematical rules and lemmas by oral means. The learning process that appears between the first and the last concept map as well as the meanings that the students give to the experiments are explicated.

4 Results

4.1 Sketches Scratch the Surface

In this learning experiment, a number of conceptualization exercises with various presentations and mapping techniques were used. The first syllabus read-through and resulting mindmaps demonstrated well-balanced but simplistic representations that exposed the common stereotypes connected with each domain, such as trees, dices and impertinent decorations (flowers). In visualizations, the students easily resorted to stereotypic hints, albeit in the later phase representations began to get more authentic (e.g. Algebra: Superman & Ironman), detailed and nuanced. However, knowing more also tempts the students to show off their skills causing the problem of excessive verbosity. In view of the poster, this was a problem, since only two of the final maps could be considered visually presentable and concise enough to be transferred to the poster. With the remaining maps, iteration rounds were necessary to simplify the end result.

The mindmap of JDYC group as an example of the collage type mindmap is quite consistently organized and justified. Some groups dedicated one paper to Math main concept, but here Math is missing and instead syllabus areas construct it as a whole according to IGCSE’s definition. In the collage mindmaps arcs are implicit “consists of” links. To improve the inner logic of the JDYC map, Mensuration and Geometry could be swapped to get Geometry nearer to other geometric topics of Co-ordinate Geometry and Trigonometry, after which Mensuration and Algebra could also be swapped.

Regarding other groups, the SJEY set Transformations and Trigonometry close to each other, whereas DJ CHART Geometry and Coordinate Geometry, which is justified also based on naming. In many maps Algebra and Functions were positioned close to each other, as well as Sets, Statistics and Probability as one group. The Number domain was central almost in all the maps and it was used synonymously with the main concept of Math. The dominant position of Numbers demonstrates the number-centricity of mathematical understanding: students still lean heavily on the arithmetic calculation taught in the primary school. Counting with numbers is “real math”, whereas algebra with variables (letters) is “artificial math”.

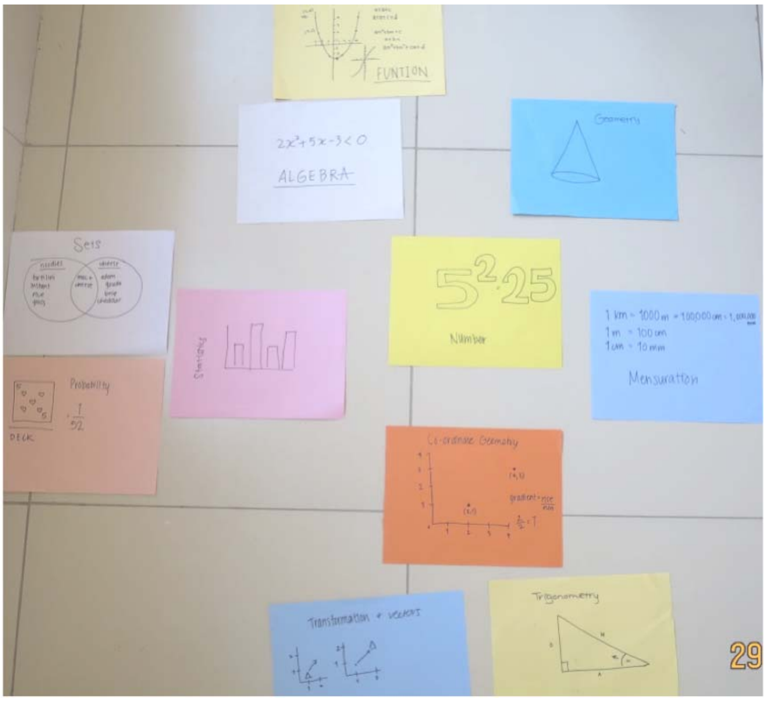

Figure 2. Math syllabus as a collage map (group: JDYC).

After drawing initial sketches with the syllabus paper readily at hand, the next task was to draw maps by heart that is considered reflecting students' mental models more faithfully. These maps started to include also emotions, such as math is "fun", "hard", "love" or "confusion" as in Figure 3.

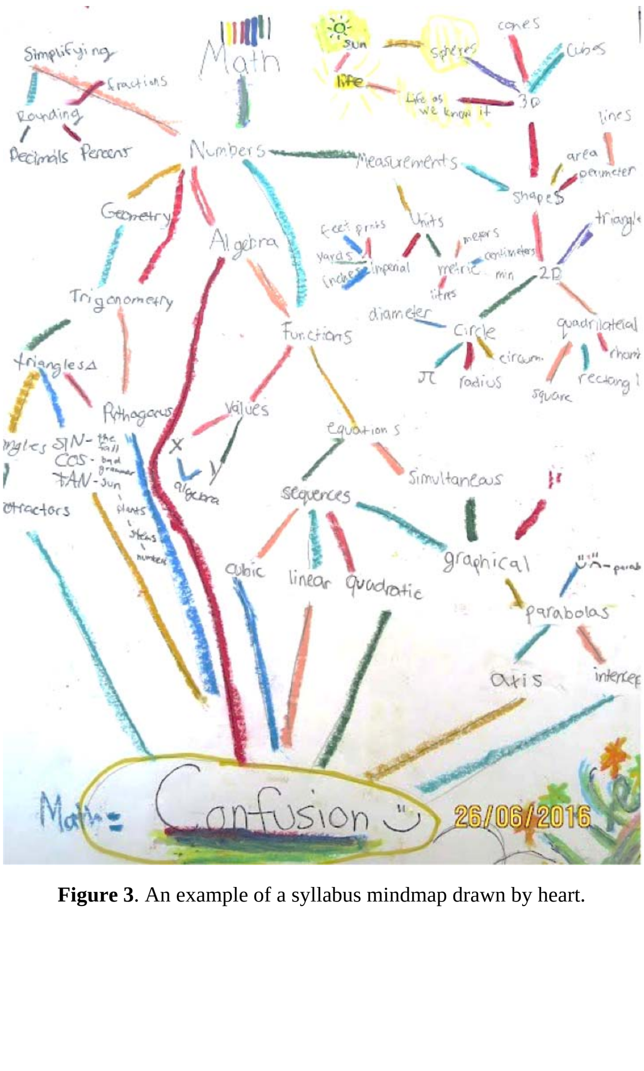

Figure 3. An example of a syllabus mindmap drawn by heart.

This map also manifests the increase in hierarchy levels, whereas most maps are still as flat as a Math central node and its direct children. The maps in Figure 4 exemplify this shallowness. In addition to the flat hierarchy, also inconsistencies in constructing the map indicate that conceptualization skills are still in their infancy. On the left, the syllabus areas of Numbers, Functions and Trigonometry are missing, but their subtopics are presented as the first level nodes. On the right, the map contains “Graph” as a child node, even if such a domain does not exist and the Graph node was found in other maps, too. This might reflect the division of the math mental model into numeric and graphical sections, but another sound and more probable rationale is the proximity of the last topic of Graphical Solving, which had been covered just before starting this learning experiment.

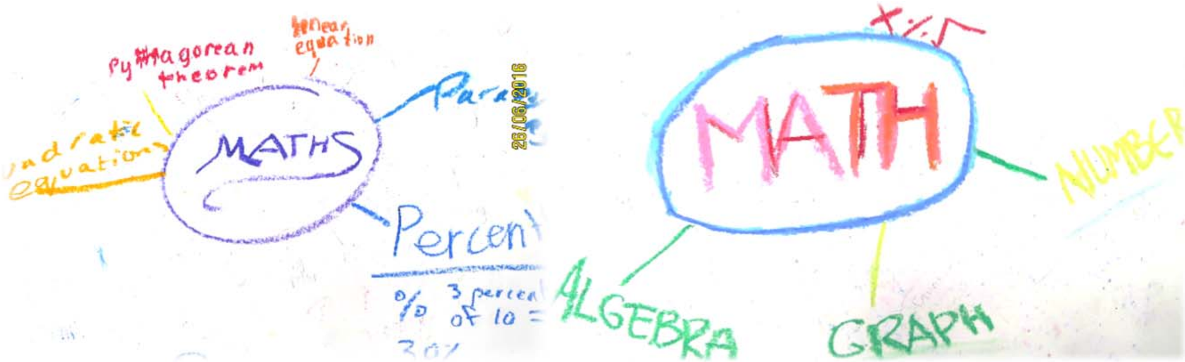

Figure 4. Mental model maps without hierarchy or consistency, Graph domain discovered right.

4.2 *Rolling in the Deep*

Gradually, the maps started to become more accurate and deeper in a hierarchy and more deliberately laid out, which demonstrates the development of conceptualization skills. The ultimate goal of this learning experiment was to get the syllabus poster constructed and for that purpose the individual domain maps should be as visual and concise as possible. An appropriate instruction could be the quotation claimed to be Einstein’s, “Things should be made as simple as possible, but no simpler”; the accordingly constructed maps of Mensuration and Geometry in Figure 5.

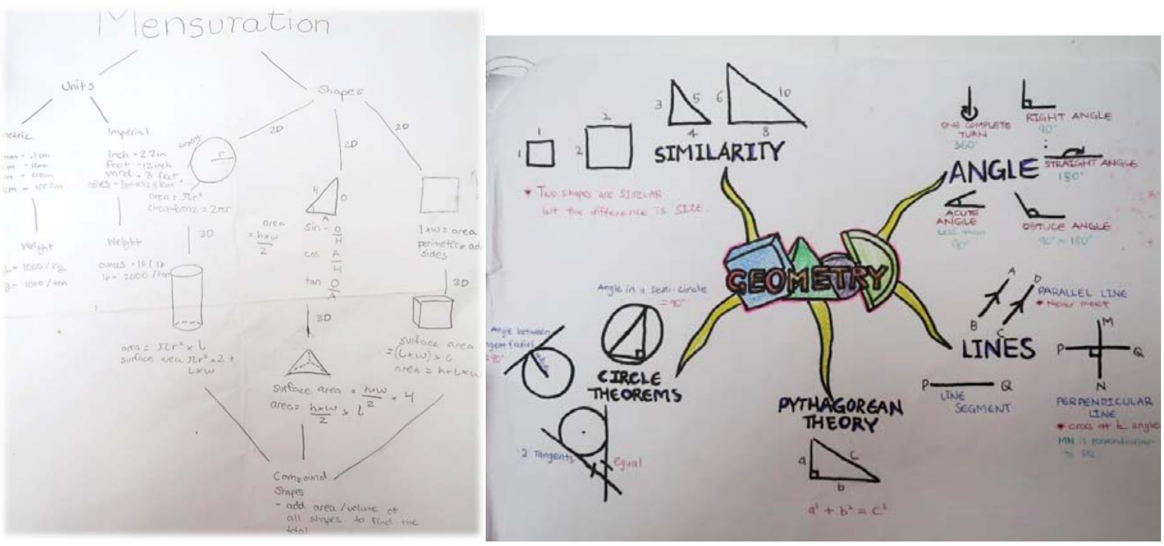

Figure 5. Examples of visually apt maps (groups: DJ CHART, Single Ladies) ready to be transferred to the poster.

Some groups got the conciseness requirement quickly as in Figure 5, whereas the Algebra map in Figure 6 demonstrated the ‘knowing more’ verbosity. Actually, as a test response the map would be an excellent answer, however, simplicity-wise it is too detailed and verbose. Further elaborations should be made with the mindset of designing a logo bearing in mind that symmetry and less text are valid means to increase harmony.

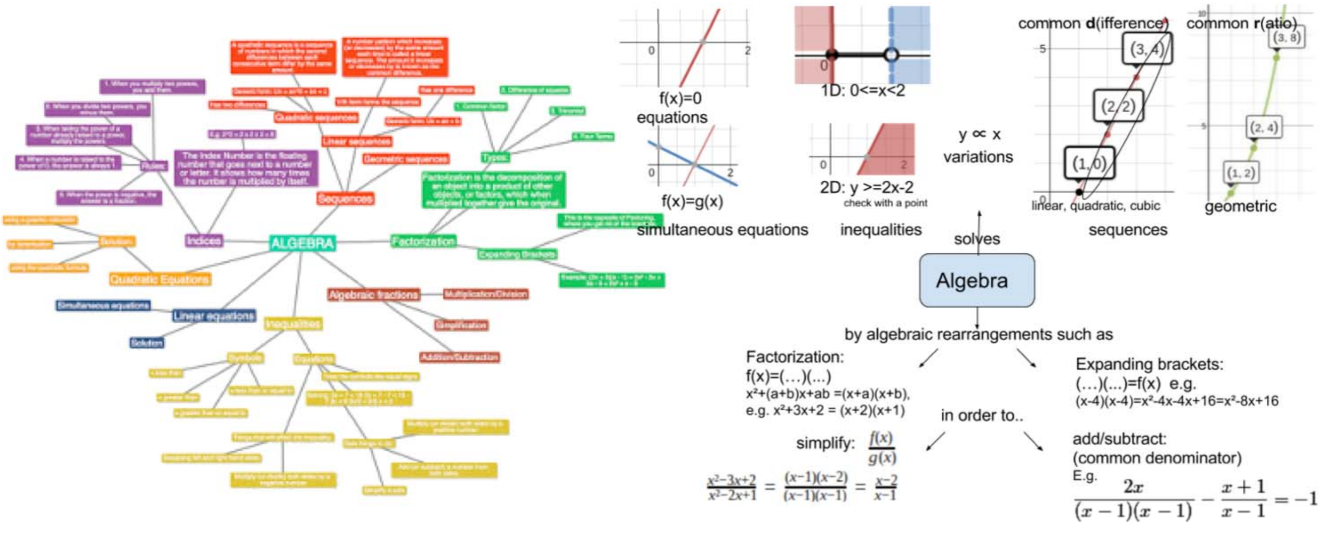

Figure 6. Squeezing and visualizing Algebra (group: SJEY).

Verbosity was reduced by iterating the map with the teacher, who gave visual hints; the next Algebra map drawn with the Google Drawings was then ready for the poster, the final version in Figure 6, on the right.

4.3 Claymation keeps Edutained

Claymation was obviously more fun for the students than mind mapping. The groups prepared videos with slow motion technique by merging images together. As a starter, a couple of claymation YouTube videos were watched. The examples contained only visual means played by clay characters, no audio and no text, which left some groups puzzled. In this way expression takes quite an abstract shape. Only one of the four videos (Geometry) was visual only and implementing syllabus subtopics as a fluent part of it proved almost insurmountable. Instead the edutainment values of the Algebra video with a clear background story were undisputable; the more bizarre its narrative, the more easily it will be remembered (see the screen capture of two heroic problem solvers in Figure 7).

Figure 7. Superman, Ironman and the Mystery of ‘x’ Missing Flowers.

The Probability video was more faithful to the given syllabus area and its subtopics and could be considered as a full revision of the area, thus profitable learning-wise. Fibonacci team picked up the exclusive but captivating theme of the golden ratio found in many visually appealing objects in nature. With clay, instead of fully internalizing and elaborating the syllabus domains, the students started to concentrate more on the visual appearance of their product and impressing their peers. Moreover, clay is quite slow as a material, which made some students move to Legos instead. In facilitating digital storytelling, Penttilä et al. (2014) argue that using a storyboard and closed instructions will catalyze the process; as an adjustment based on the outcome we would also recommend to have, if not a storyboard, at least fairly clear narrative as a starting point.

4.4 Math Path of Nested Spirals, Numeric and Graphical

The last reflective exercise, which was executed during the elaborations of the final maps, consisted of presenting the students' own math paths from the beginning of their school to the prevailing moment.

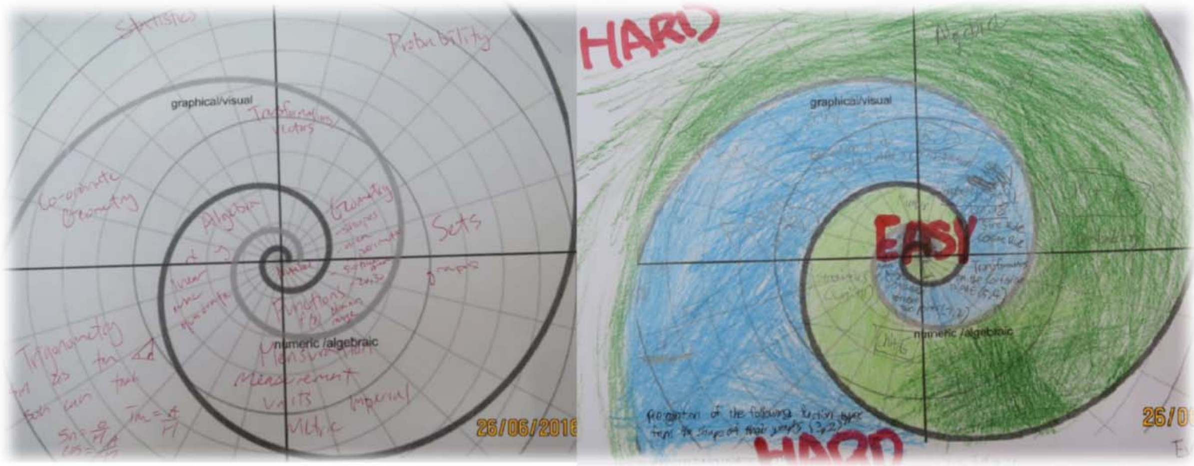

Figure 8. Spiral learning of IGCSE math.

The path was divided into two parts of numeric/algebraic and graphical/visual in order to give the students more structure for reflection. In Figure 8 on the left division is well justified, in the numeric path Number, Algebra, Mensuration, Sets, Probability and Statistics, in graphical Functions Geometry, Transformations, Co-ordinate Geometry and Trigonometry. Geometry starts in the primary school, however, the start of the graphical path with Functions is delayed till the beginning of formal operations that will take place in the middle school (Piaget & Duckworth, 1970). The order of Figure 8 is quite fit quickly reviewed, i.e. Number domain trains the concrete operations, where amounts and basic operations of adding and subtracting are natural starting points. Iterative additions may be streamlined as multiplication and division as its inverse are introduced. Dividing integers yields fractions. In addition to expanding Numbers, different Mensurations support the phase of concrete operations: geometric shapes and their lengths are measured and scaled from millis to kilos, time and money calculations are included. The algebraic paradigm shift of introducing functions and variables is made in the dawn of formal operations after the phase of concrete operations; functions begin to be visualized and solved by graphical means, hence in Figure 8 Algebra and Mensuration are to be swapped. The threshold of moving from arithmetic operations to algebraic is remarkable and often not without hardships. The threshold concepts of functions and variables are to be learnt properly in order to gracefully progress.

Alongside the subject knowledge, the math path exercise may be used to identify the bottlenecks of learning and shaping the student’s math-id. This implies that there should also be enough time for reflecting the results, which we unfortunately did not have. In addition to instructed chronology, some students made the journey from Easy to Hard. This direction was not intended but interesting to take, exposing that Numbers and Statistics are considered Easy, Algebra and Functions Hard.

4.5 Peaked in the Poster

Year 8 and Year 9 cooperated in preparing the poster. Together we painted the background and produced the syllabus area transparencies. When they were put in their places, the chronological order was abandoned due to lack of space. Relevant and irrelevant decorations were added, e.g. Escher’s graphic to illustrate transformations (translate-reflect-rotate-scale), Figure 9 the top and right middle edge.

Figure 9. The syllabus poster.

Completing the poster was running amok against the time and circumstances, but we were capable of finalizing it a day before the semester end. The participants were proud of the eduart achieved together; especially the input of Year 9 girls was crucial at this point and they also desired their effort to be recognized. The maps and other material were gathered and saved for further analysis and the students filled out the survey. One of the few negative comments was, “It can get repetitive and it’s not really that fun”. However, most of the students regarded concept mapping as a beneficial tool for organizing their knowledge, for example, “It is a creative way of showing how everything in math is related and how it all mixes”, “It was helpful because it was visual and it laid out the information nicely”, and “It helps me to organize the thoughts and ideas relating to the topic.”

5 Summary

How does concept mapping suit learning math? Based on the survey feedback concept mapping suits well also teaching mathematics, especially getting a better overview when revising. In general, study skills are worth investing in: information will cease and things tend to be easily forgotten, but study skills remain. Metacognitive skills refer to a student's awareness of his means of learning and allow him to plan good strategies for learning, which implies that a student possesses strategies to choose from, such as concept mapping. However, learning to learn should be a cross-curricular goal involving the entire academic field, not only math that is by nature rather exercise-based, practical and succinct in text, hence not the most obvious choice for mapping.

What are the meanings that the teacher and the students give to this learning experiment? The students were not acquainted with concept mapping beforehand, which caused some extra work in beginning, but familiarized themselves with the process quickly. If mapping is a new thing, it is good to spend some time to justify and motivate the experiment: the more positive the attitude, the better the student learns. As a motivational speech, the teacher revised her own education history in which concept mapping has had a significant role. The compact and visual expression of a concept map and consistency in constructing the knowledge resonated with her learning style and speeded up learning remarkably.

Similarly, the students in the present experiment viewed concept mapping very positively, acknowledging the value of the visual tool for organizing and associating things. Only three comments (3/25) could be interpreted mildly negative, speaking in favor of exercises as superior means over mapping, such as “For me doing problems in the book might help more” and “I think that solving many problems is the best way learn math - that solving many problems helps you to get familiar with the methods you are using.” Indeed, concept mapping would complement, not substitute, exercises as the main means to learn.

As a reflective exercise 'My math path' was also promising, “It helped me review everything I know about math and go through the syllabus and organize what I need to know”. The path may be used to improve the students' math self-concept and enable them to identify their own strengths and weaknesses; knowing one’s weak spots reveals where to put more effort. As a consequence of all these elaborations one student granted, “I feel like becoming a better mathematician”.

How could concept mapping help in enhancing skills needed in ICT? An ICT architect needs to model e.g. the components, behavior and interactions of a system. In industry, the de facto standard is unified modelling language (UML) analogical to concept mapping. However, UML is more restrictive. Two concepts must be connected with a specific link, whether inheritance, dependency, aggregation, containment, association or realization. The link type is indicated by selecting a proper arrow.

In this experiment, the mapping style was free, ranging from groupings with no lines to lines with and without describing verbs. With mindmaps degrees of freedom are numerous regarding connections and layout, which leads to the wide variety in an outcome. Mindmapping is creative, sometimes even comparable to the visual arts, but the creativity should be sacrificed in favor of knowledge building clarity, especially if the data is to be reused and refined further. Strict rules give freedom in follow-up and choosing between various visualization tools. In this experiment, the students’ conceptualization skills developed towards more hierarchical and fine-grained structures, in which phase new rules may be brought into play. In this phase, introducing UML basics in ICT lessons would be beneficial. For example, cardinality and attributes provide the new options of focusing.

In general, the better defined and more exact the data is, the easier it is to convert it from one form to another. Usability of well-defined data may be exemplified with the difference of HTML and XHTML, where the validness and well formedness of XHTML enables tools such as schemas, validators and transformations. Moreover, propositions constructed as a triplet form (known as a turtle form in RDF) of a subject, a predicate and an object grants semantic web tools such as RDF visualizations. Visualizations are useful not only for teachers desiring more detailed methods of reviewing how their students think but also for the students themselves tracking their process of the knowledge building.

In this experiment, the students voted for a paper poster - doing with hands is the new black. The DBR research obliges reflective modifications to the learning artifact based on the feedback. In further research, we would realize the syllabus map in digital form and combine it with exercises, for instance, as links to exam papers from the map. The map should also merge all the project outcomes such as videos and presentations. Stored maps may complement traditional evaluation methods and be further elaborated as digital portfolios or digital learning journals that focus on the assessment of broader skills or competencies (National Education Association, 2012).

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