New Perspectives in Science Education
International Conference NEW PERSPECTIVES in SCIENCE EDUCATION
5th Edition

# Students' understanding of scientific inquiry
# A formative concept map study

**Christine Buchegger[1], Erika Keller[2], Suzanne Kapelari[3]**
[1, 2, 3] AECC Biology, University of Vienna (Austria
[1]christinebuchegger@gmx.at, [2]erika.keller@univie.ac.a, [3]suzanne.kapelari@univie.ac.at

## Abstract
*A main objective in science education is to foster students' development of a profound understanding of Nature of Science (NOS) und Nature of Science Inquiry (NOSI). Both are regarded important to become scientifically literate.*
*One goal of this student–scientist partnership project is to enhance students' development of understanding and knowledge on NOS/NOSI.*
*The "Sparkling Science" project – "Pollen and Respirable Dust – Mutual Allergy Triggers?" and the follow up project "Pollen & Respirable Dust 2" – provide suitable environments for students to learn about research processes in an authentic inquiry setting. A formative concept map study is carried out, to understand, how high-school students' participation in this research process influences their understanding of and their views on inquiry processes. In the course of the two projects, concept maps (c-maps) are employed before and during the introduction workshop as well as after having completed the workshops/the summer internship. The final c-maps are created in a think aloud process by the students. In this paper we present the methodology for the formative c-map setting, developed in a pre study, as well as preliminary outcomes and implications for the main study.*

## 1. Introduction
"Sparkling Science" is a program funded by the Austrian Federal Ministry of Science, Research and Economy (BMWFW) to involve young people in science. From 2012 until 2014, within this program, the project "*Pollen and Respirable Dust – Mutual Allergy Triggers?*" took place. In 2015 the follow up project "*Pollen & Respirable Dust 2*" has started und will be finished in 2016.
Three high schools (*project 1*: BRG Kepler, HBLW ECOLE; *project 2*: BRG Kepler, BG/BRG Seebacher,) and two universities (University of Graz, University of Vienna) cooperate in these projects. Three science research areas **–** Microbiology, Analytical Chemistry and Botany – are involved. The students participate in all the disciplines according to a three-step model presented by Keller in 2015 [4]. The intention is, that the whole class takes part in an introduction workshop, where the students get to know the principles of laboratory work and the inquiry tools of each area first. Secondly interested students can participate three-day advanced courses voluntarily. Finally those who want to deepen their research skills are invited to apply for an one-month internship in one of those areas they have already attended.
Our educational research within the two projects is focused to the analysis of the development of students' understanding of NOSI due to their involvement in the project.
Outcomes from the *project 1* will be presented here as these results inform the main study, based on the data of *project 2*, which is currently in progress.
The focus of this preliminary study lies on the development of an analysis methodology for the c-map setting, that can then be employed in the main study.

## 2. Theoretical Background
The concepts "Nature of Science (NOS)" and "Nature of Scientific Inquiry (NOSI)" both include the principles and basics of scientific knowledge acquisition: scientific thinking and working practices, science standards etc. [7]. NOSI focuses on aspects, related to the procedure of the inquiry process in particular [9] .
The inquiry process can be represented by the following dimensions "Exploration and Discovery", "Testing Ideas" (the central issue of the inquiry process, with its subdivisions "Gathering ideas" and "Interpreting ideas"), "Benefits and outcomes" and "Community analysis and feedback" [3]. According

to this scheme all dimensions can mutually influence each other and there is no predetermination of a particular sequence of steps [3]. In order to get an insight in the actual state of students' understanding of NOSI, c-maps that are defined as graphical tools for organizing and representing knowledge, can be used [6]. They are organized in concepts and connecting lines between two concepts. Such a link is called proposition. Lines are labeled with symbols (e.g. + or =) or words to specify the relationship between the concepts [6]. According to Kinchin [5], three basic map structures, "spoke", "chain" and "net" may be identified in c-maps (see Figure 1.).

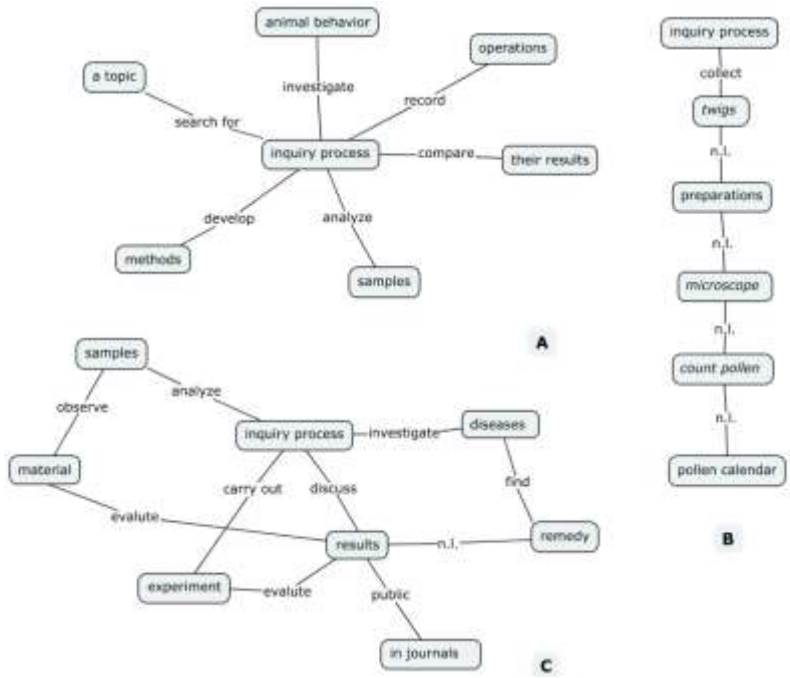


Figure1. Examples of basic-map structures taken from students' c-maps: A: spoke B: chain C: net; l.n.means that the line wasn't labeled.

## 3. Methods and Tools used

### 3.1 Formative c-map setting

In both projects an "open" c-map tool was employed [2]. No guidelines were prescribed regarding the number and kind of concepts or lines.
In project 1, before the introduction workshop started, all students ($n_1$=18, $n_2$=23, $n_3$=26) were invited to generate c-maps individually ($n_1$=11, $n_2$=0, $n_3$=8). The focus question for the first c-map was: *"What do scientists do in their research?"* During the introduction workshop the students were asked to amplify or to modfiy their first c-maps according to the experiences they had already gained (second c-map) or if there was no first c-map, to create one ($n_1$=18, $n_2$=23, $n_3$=26).
After having completed the advanced courses each participating student, generated a third c-map ($n_1$= 8, $n_2$=22, $n_3$=0). This time, in order to get a better understanding of the students' knowledge of NOSI, , students were asked to elaborate the c-maps in a think-aloud process [10]. The focus question for this c-map was reworded according to the students' experiences: *"Thinking concretely on your research experience, can you describe what you did/what the scientists did to carry out the research ?"*. Each c-map was coded and thus can be assigned to individual students. In this case, after the one-month internships no further c-maps were created.

### 3.2 Analysis of the c-maps

C-maps were analyzed, in a quantitative and qualitative way. Therefore c-maps of students (n=5), for those complete data sets (three c-maps and think-aloud protocol) could be determined, were chosen.

To analyze this data the softwares *MaNET 1.10.2, CmapTools 6.01.01* and *f4transkript 3.0.3* were used. The Software *MaNET 1.10.2* supported a quantitative analysis based on Bonatos' graph theory [1]. Following indices were employed to evalute the data: (1) the number of used concepts (2) the total number of possible propositions and (3) the number of actual existing propositions related to the total number (*link density (ld)*).
For qualitative assessment the structures of the c-maps were analyzed following Kinchins' scheme [5]. For the classification of the propositions, used by students, we refered to the four dimensions of a research process, published by the Universitiy of California, Museum of Paleontology [3].
In this case, the think-aloud protocols of the third c-maps, were used to eliminate difficulties of understanding during the classifcation of propositions. A Qualitative Content Analysis (QIA) for the protocols according to Mayring [8] was not carried out in this preliminary study.

## 4. Results

In the preliminary study the analysis of the c-maps (all in all 15 maps) was carried out as follows:

### 4.1 Structure and propositions

The three basic map structures (see 2.) were founded within the anlyzed c-maps. Especially type A ("spoke") and C ("net") as well as a combination of them (see Figure 2.) was observed frequently.

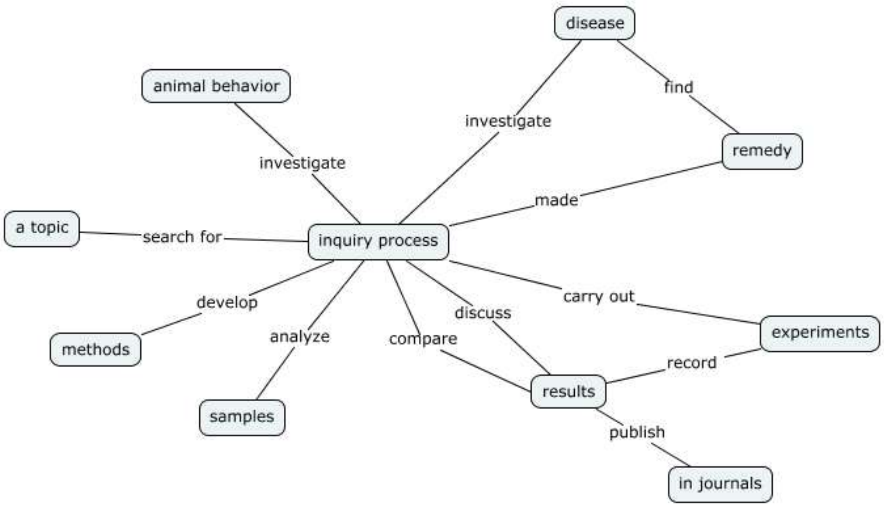


Figure 2. An Example of a combination of type A nd C found in this study.

Following table shows the different types of propositions found in these c-maps:

| Type | Definition |
| --- | --- |
| label<br>(1) 1st concept ——— 2nd concept | Proposition with a labeled line. |
| label related to the focus question<br>(2) 1st concept ——— 2nd concept | Proposition with a labeled line.<br>The line represents the connection to the next process step. But the label is associated with the focus question. |
| (3) 1st concept ——— 2nd concept | Proposition with an unlabeled line. |
| (4) 1stconcept ——— 2nd concept + label | Proposition with an unlabeled line;<br>one concept (here the second) presents a combination of concept and label. |

Table 1. Types of propositions found in the study.

## 4.2 Classification of propositions

During the classification of the propositions into the four dimensions of the research process (see 2.), it was realized that two further categories were needed to describe the maps completely :(1) "Students' views on the process" and (2) "Images of scientists". Table 2. shows the definitions and examples of the categories applied in the study:

| Deductive categories | Definition | Example |
|---|---|---|
| (1) Exploration & Discovery | Including steps before and while forming a hypothesis, e.g. asking questions, exploring the literature, making observations etc. | *search for*<br>*inquiry process* — *a topic* |
| (2a) Testing Ideas: Gathering data | All steps from forming a hypothesis to evaluating the data | *carry out*<br>*inquiry process* — *experiments* |
| (2b) Testing Ideas: Interpreting data | Finding explanations | *conclude*<br>*inquiry process* — *from results* |
| (3) Benefits & outcomes | The mutal influence of the process of science and the society, e.g. developing technology, dealing with everyday problems | *develop*<br>*inquiry process* — *remedies* |
| (4) Community analysis & feedback | The scientific community helps to ensure sciences' accuracy by giving feedback and peer review, discussing with colleagues, writing publications etc. | *publish*<br>*results* — *in journals* |
| **Inductive Categories** | **Definition** | **Example** |
| (1) Students' view on the process | Description of students' experiences and feelings in the students-scientists-partnership | =<br>*failures* — *part of scientists' every day live* |
| (2) Images of scientists | Description of scientists' personality and motivation, regarding their work | *needs*<br>*inquiry process* — *good will* |

Table 2. Deductive and inductive categories to classify the propositions.

## 4.3 Quantitative analysis and comparison of categories

Comparing the initial c-maps (1st) with the final one (3nd), a trend of an increasing average number (n) of used concepts ($n_{1st}$= 12,6; $n_{3nd}$=19) and a declining average *link density* ($ld_{1st}$= 0,21; $ld_{3nd}$=0,16) from the frist to the third map, could be observed.
Comparing the c-maps within the five cases a trend of a category-reduction from to first to the third c-map could be observed (see Table 3).

| Category | n (1st c-map) | n (3rd c-map) |
|---|---|---|
| Exploration & Discovery | 2 | 1 |
| Testing Ideas | 5 | 5 |
| Benefits & outcomes | 2 | 2 |
| Community analysis & feedback | 5 | 0 |
| Images of Scientists | 2 | 1 |
| Students' view on the process | 0 | 2 |

Table 3. Categories used within the students' c-maps: n= number of students who used the category.

Whereas in the first and second c-maps all categories, especially "Testing ideas" and "Community analysis and feedback", with the exception of "Students' views on the process" could be observed, in the final c-map, exepted from "Testing ideas", the categories were less frequently represented or remained the same. "Students' view on the process" manifested themselves only in the third c-map.

## 5. Discussion

### 5.1 Structure and propositions

The structural analysis shows that students use all three morphological types of c-maps according to Kinchin [5]. Especially "spoke" and "net" as well as a combination of them were found frequently. The structure "spoke" together with unlabeled connecting lines (Type 3, Table 1.) indicated, that the students mixed up concept- and mind-maps.
The four types of propositions (Table 1) will be usefull in the main study to classify connected concepts. Additionally the think-aloud protocol will be analyzed via QIA [8], in order to get a more profound picture of the students' views and knowledge of the inquiry processes.

### 5.2 Classification of propositions

The four dimensions of the research process model [3] provide useful deductive categories. Apart form these dimensions personal motivation, curiosity and joy of discovery, among others, are described as possible starting points into the inquiry process. According to this, the inductive category "Images of scientists" is useful, because scientists personalities and motivations have definitely an influence on their work [3].

## 6. Outlook

It is important to mention, the results of this preliminary study can only show trends due to the small sample of five students. Nevertheless the tested methodology proved largely to be suitable for the purpose of the main study. However in the following aspects the methodology has to be refined or further developed:
1. The think-aloud protocol should be analyzed with the QIA [8], to avoid missunderstandings and to get a better understanding of the students' knowledge of NOSI.
2. Directly after the development of the final c-map, after having completed the workshops/the summer internship, the students will be shown their previous c-maps and they will be asked to compare them and to comment, what has changed in their perception of the inquiry process in the course of the project.

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