

# Comparing Expert and Novice Concept Map Construction Through a Talk-Aloud Protocol

Beat A. Schwendimann<sup>(✉)</sup>

École Polytechnique Fédérale de Lausanne (EPFL),

Lausanne, Switzerland

beat.schwendimann@gmail.com

**Abstract.** Concept map analysis usually focuses only on the final product. This case study used a talk aloud protocol to study the concept map construction processes of novices and experts. Three biology experts and three novices (9th/10th grade high school students) constructed a concept map from a given list of concepts. Findings suggest that final concept maps of high performing students cannot be distinguished from expert-generated maps. However, analysis of oral elaborations during the construction process revealed that experts often used the same link labels as novices but associated more complex knowledge with the label. Some final propositions would be considered incorrect without an oral explanation. Findings suggest extending concept map evaluation by complementing the final product with an analysis of intermediate stages and accompanying elaborations. Additionally, this study highlights that each expert created a different map and that there is no single best expert map.

**Keywords:** Concept map construction · Case study · Expert-novice comparison · Talk-aloud protocol · Science education · Biology education

## 1 Introduction

Concept maps can reveal learners' knowledge organization by showing connections, clusters of concepts, hierarchical levels, and cross-links between concepts from different levels [1]. Connections between concepts can be seen as an indicator for more integrated knowledge [2, 3]. Concept maps can be a helpful metacognitive tool to visualize the interaction between prior and new conceptual understanding of learners.

However, concept map analysis often uses only the final product without taking the construction process into account. The ability to construct a concept map illustrates two important properties of understanding: Representation and organization of concepts [4]. As a representation, concept maps include not all but selected aspects of the represented world. Experts and novices differ in how they structure and connect concepts [5, 6] and in their abilities to distinguish salient surface features from structurally important features of a representation [7]. Experts can better decide how a certain external representation allows them to illustrate, communicate, and analyze a certain principle and create new forms of representations, if required. Developing expertise in a domain includes learning how to detect important elements and organize information.

This case study investigates how experts and novices differ in their concept map construction using a talk-aloud protocol to distinguish two modes of reasoning, *constraint-based* and *model-based* reasoning [8]. *Constraint-based* reasoning refers to the cognitive process of finding values for a set of variables that will satisfy a given set of constraints. When utilizing this kind of reasoning, learners focus primarily on the constraints, one at a time. The second mode is *model-based reasoning*. Using this holistic approach, learners try to address all or most constraints at the same time to create a global model of the whole scenario.

This study aims to answer the research questions:

1. How do novices and experts differ in their concept map construction processes?
2. How do novices of different academic performance levels differ in their concept map construction?
3. How does verbal reasoning (talk aloud) align with concept map construction?

## 2 Methods

### 2.1 Procedure

Prior to the concept mapping task, each participant was interviewed about their familiarity with concept mapping in general, their self-assessment of their evolution biology knowledge, and their experience with concept mapping software. Each participant received initial training in basic concept mapping techniques and the software ‘Inspiration’ by a researcher. The training phase included the presentation of a sample concept map and a step-by-step concept map construction protocol. The participants were instructed to (1) group related concepts, (2) link concepts with arrows, (3) label each link, (4) add cross-links, and (5) revise the whole map.

All participants were instructed to talk aloud to describe their actions and reasoning while constructing their concept map. The think-aloud technique has been found to reveal thought processes in a variety of tasks [9], for example concept map construction [10], multiple-choice test taking [11], performance assessment [12], and problem solving [13]. Ericsson suggests that verbalization is a direct encoding of heeded thoughts that reflects their structure [9]. Verbalizing one’s inner dialogue does not need translation and does not require a significant amount of additional processing; therefore, talking aloud does not slow down task performance – as long as connections between concepts can be recalled from memory. When connections between concepts need to be newly generated, it leads to measurably slower verbalization. Because of their greater existing content knowledge, experts might need to generate fewer new propositions (connections between concepts) when constructing concept maps in their area of expertise than novices. Experts might therefore show more fluent and faster construction of concept maps.

Each participant was instructed to construct a concept map from a given list of eighteen concepts (see Table 1). These concepts were identified as core elements in the US national educational standards for cell biology, genetics, and evolution. Concepts from all three different areas (DNA, cell, and evolution) were chosen and provided in a

randomly arranged list (without the grouping shown in Table 1). The forced-choice design constrained participants to use only the provided concepts but allowed them to generate their own links and labels. The important concept ‘mutation’ was deliberately omitted from the list to investigate if participants would introduce the concept on their own as a link label. [14] highlighted the importance of iteratively revising concept maps. Therefore, participants received no time limit and were allowed to revise their concept map until satisfied with the final product.

**Table 1.** List of given concepts (organized by areas)

<b>DNA</b>	Chromosomes, chromatids, crossing over, random segregation of chromosomes
<b>Cell</b>	Cell division, random fusion of gametes, clones, diploid, haploid, mitosis, meiosis, body cells, sex cells (gametes), sperm cells, egg cells (ovum)
<b>Evolution</b>	Evolution, genetic variability, natural selection

**Data Sources.** Three different kinds of data were collected:

- Concept maps can be drawn by hand or by using specialized computer software. Royer’s comparison between these two methods indicated significantly more complex concept maps when generated using concept mapping software [15]. This study used the concept mapping tool ‘Inspiration’ [16].
- Screen recording software [17] was used to capture the concept map construction process. To describe the concept map construction process, two screenshots of intermediate stages and the final product were captured.
- Voice recorders captured the talk aloud utterances of the participants during the concept map construction process.

## 2.2 Participants

This case study included three adult domain experts (two postdoctoral biology researchers and one experienced biology teacher) and three 9th and 10th grade students from a public high school. Following purposive sampling, the experts were selected to represent two different forms of expertise (research and teaching) while the students represented the range of general academic performance levels (high, middle, and low). The students received extra credit from their teacher for their voluntary participation. All three high school students attended the same biology class. Prior to participating in the study, each student completed a week-long session on cell biology and genetics that included all concepts provided for the concept mapping activity. All three students were familiar with concept mapping techniques but none of the students used the software ‘Inspiration’ before.

### 3 Results

The result section describes the concept map construction and critique tasks by the three experts and the three novices.

#### 3.1 Experts

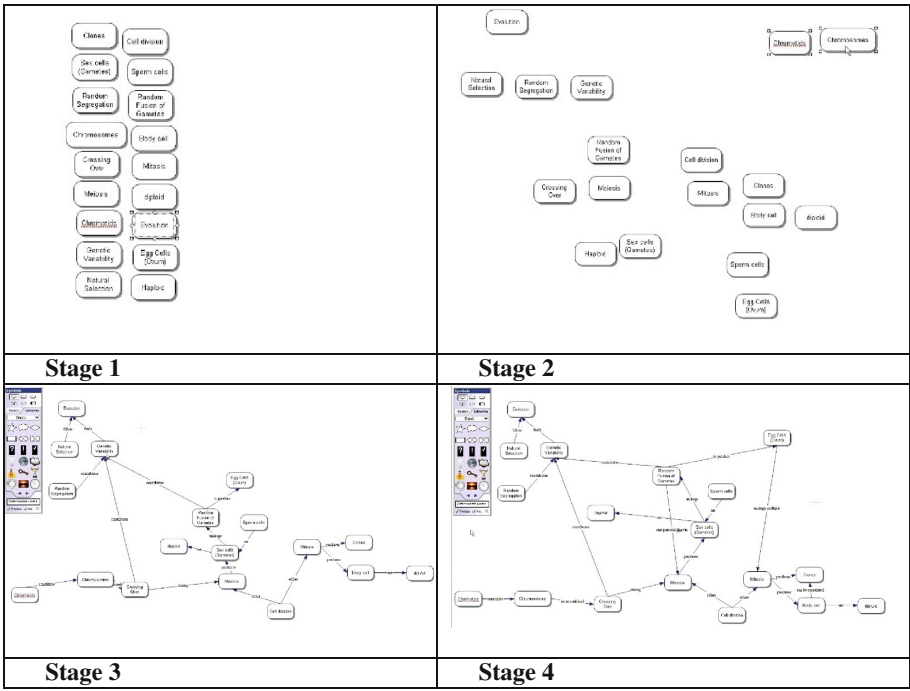
**Biology Expert A.** Expert A was a postdoctoral fellow in biophysical sciences at a major U.S. research university. A had no prior experience with concept mapping or the ‘Inspiration’ software, but frequently used flow charts in professional presentations. Expert A quickly understood the principles of concept mapping and the handling of the Inspiration software after the training session.

Concept map construction task: Expert A began the concept map by dividing the provided concepts into two groups: cell division/meiosis/mitosis/clones and body cells/sex cells/sperm cells/crossing over/random fusion of gametes (see Table 2, stage 2). Expert A placed the most comprehensive concept ‘evolution’ on top, ‘cell division’ at the bottom and then grouped related terms around them. In a second arrangement phase, A divided the concepts into the groups ‘meiosis’ and ‘mitosis’. Only after arranging and clustering all concepts, A began linking them. Expert A said “I am thinking hierarchically, but the connectors are not going to be very hierarchical because sometimes a concept is the subject and sometimes an object”, while pointing at a horizontal chain of concepts (see stage 3). At the end of the systematic construction activity, which took only 15 min, expert A started adding cross-links. This led to the final concept map (see stage 4), which partially followed the ‘circle of life’-model: Random fusion of gametes → fertilized ovum → mitosis → meiosis → new gametes. Expert A did not create a connection between egg cells and sex cells because of A’s interpretation of egg cells as being already fertilized. Expert A also did not connect meiosis with genetic variability, arguing that the central concept ‘mutation’ was missing in the list of given concepts and that without mutation meiosis will not enhance genetic variability.

**Biology Expert B.** Expert B was a postdoctoral fellow in neurogenetics at a major U.S. research university and had no prior experience with concept mapping or ‘Inspiration’. Expert B understood the principles of concept mapping quickly after the initial training phase.

Concept map construction task: B began the concept map by clustering the related concepts ‘sex cells’, ‘sperm cells’, and ‘egg cells’. From this starting point, B developed a temporal chain to illustrate meiotic and mitotic cell division. Like both other experts, B noticed the absence of the concept ‘mutation’ in the provided list of concepts. Expert B explained that without mutation there would be no alleles and therefore no variability in meiosis. B stated that a reduction of evolution to the Darwinian view of natural selection and survival of the fittest leads to an inaccurate oversimplification. B suggested that ‘genetic drift’ should be added to the list of concepts. B created an interesting connection between body cells/mitosis/meiosis, by arguing that body cells can undergo either one of these two cell division processes. While working on the

**Table 2.** Concept map development of expert A.



concept map, B tried to construct the concept map from the viewpoint of a high school student, as B perceived the given concepts as a constraint that forced making “over-simplifications and large logical stretches”. B made several connections, especially to evolutionary concepts, which implied several sub-steps (which B explained verbally). These sub-steps were only explained orally and could therefore not be detected in the final concept map. After finishing the first phase of connections, B began adding cross-links. Expert B did not connect the concepts ‘cell division’ with ‘meiosis’ and ‘mitosis’. B’s final map did not show a hierarchical structure but consisted mostly of temporal chains. B invested 27 min on the concept map.

**Biology Expert C.** Expert C was an experienced biology teacher at a U.S. public high school. C has not used concept maps as a personal tool but taught concept mapping techniques to students.

Concept map construction task: C started by grouping the concepts into ‘meiosis’ and ‘mitosis’ under the top-level concept ‘cell division’. Expert C placed chromosomes and chromatids between the two groups, as they belonged to both. The evolutionary concepts ‘evolution’ and ‘natural selection’ were singled out until the end of the activity. C then arranged and connected concepts in each group either according to structure (e.g. cell type, haploid) or function (e.g. crossing over, genetic variability). In a second phase, C rearranged the concepts to follow closely the ‘life-cycle model’ found in biology textbooks (similar to expert A): meiosis → fusion of

gametes → body cells → mitosis. C identified this approach as a deliberate strategy. Throughout the construction phase, ‘chromosomes’ remained the connecting element in the center. Finally, C added multiple cross-links and connected the evolution group with the cell division group, through the concept ‘genetic variability’. Like the other two experts, C noticed the absence of the concept ‘mutation’ and worked around this constraint by referring to mutation in the link label between chromosomes and genetic variability. Concluding, C stated that this activity has been ‘really hard’ and that it provided a better appreciation for tasks assigned to students. Expert C spent 33 min until satisfied with the final concept map. C created the concept map with the most cross-links of all six participants.

### 3.2 Novices

**Novice D.** Student D was high performing 9th grade student. D showed complex and coherent understanding of the topic, despite being in a lower grade than the other two novice participants. D was the most articulate of all three novices and engaged in checking, revising, and investing the most amount of time the concept map (45 min) of all six participants.

Concept map construction task: Like expert C, novice D first grouped all concepts into two groups (‘meiosis’ and ‘mitosis’) and placed the concept ‘chromosomes’ in-between them. D then arranged and linked the concepts in each groups according to procedural criteria (see Table 3, stage 3). D correctly linked ‘evolution’ to the meiosis cluster, but did not create connections between the related concepts ‘genetic variability’, ‘random segregation’, and ‘random fusion of gametes’. D created a proposition that genetic variability leads to natural selection, which would have to be considered incorrect at first. However, after prompting, D provided a comprehensive oral description of the relations between meiosis, genetic variability, natural selection, and evolution. Finally, D added several cross-links and checked each proposition again (see Table 3, stage 4). D revised the validity of every proposition again each time after adding another concept. D’s approach was thorough and systematic.

**Novice E.** Student E was a 10th grade student classified as an average student.

Concept map construction task: Novice E first divided all concepts into two groups (‘mitosis’ and ‘meiosis’). Like expert C, E placed ‘chromosomes’ between the two cell division subgroups. E singled out ‘evolution’ and ‘natural selection’ and did not connect them until the end of the activity (also similar to expert C). E was not sure about the meaning of the concepts ‘haploid’ and ‘diploid’, but nevertheless used them correctly. E did not use the concepts ‘chromatids’ and ‘crossing over’ as E could not recall their meaning (These two concepts remained unconnected). Like all three experts, E noticed the absence of the important concept ‘mutation’. E worked systematic and fast, finishing the concept map in only 12 min. This supports the assumption that E had an existing understanding of the connections between the given concepts and did not have to newly generate them.



labels were mostly very short, for example *and*, *or*, or *then*. F did not create an overarching order in the map. Even after prompting by the researcher, F failed to identify any cross-links between the three separate chains (see Table 4, stage 4). F spent 25 min on constructing the map and expressed satisfaction after all links were “somehow connected”. The map, as well as F’s knowledge of the domain, seemed to be very fragmented and incomplete.

**Table 4.** Concept map development of student F.

<b>Stage 1</b>	<b>Stage 2</b>
<b>Stage 3</b>	<b>Stage 4</b>

4 Discussion

This section discusses observations made during each stage of the concept map construction process, proceeding from initial layouts and revisions to the final product. During the initial construction process, the three experts and novices D and E (high performing participants) fluidly generated their concept maps, which suggests that they had previously existing knowledge of propositions. All high performing participants



demonstrated their ability to move between the two modes of reasoning by switching back and forth between the big picture view of model-based reasoning ('gestalt' effect) to arrange and re-arrange their concepts into clusters and the more detailed view of constraint-based reasoning when creating individual propositions. Experts and knowledgeable students demonstrated their awareness of given constraints by noting that the provided concepts allowed only a limited representation of their actual understanding. However, they found ways to work around this limitation, for example by introducing the omitted concept 'mutation' in a link label. It is noteworthy that all three experts, but only one of the students, mentioned that the important concept 'mutation' was missing. Identifying central concepts (or noticing their absence) can be seen as an indicator of expertise.

In contrast, the academically weakest student F progressed slowly and struggled creating connections, which suggests that F's knowledge of biology concepts was not well integrated and that connections had to be newly constructed. F showed the greatest difficulties and created a fragmented, mostly linear concept map. F accepted the given constraints without questioning and used a constraint-based approach by adding one concept at a time. F seemed more focused on task completion than using concept maps to creatively express one's understanding. These observations suggest that concepts map construction can allow for both constraint-based reasoning and model-based reasoning, depending on the level of expertise of the participant. More knowledgeable participants were able to move fluidly back and forth between constraint-based and model-based modes of reasoning.

During the revision process, the high performing participants commended that they hesitated at times adding more links to avoid "making a mess". This suggests that aesthetic reasoning (in addition to constraint-based and model-based reasoning) can also influence concept map construction.

Initial groupings and hierarchies disappeared during the further development of the concept map. These intermediate stages are not accessible in the final concept map. During concept map construction and revision, some initially correct propositions were changed to invalid propositions, and vice versa.

Interestingly, the final concept maps constructed by the participants differed much less from each other than anticipated. The construction processes and final concept map of high performing students did not noticeably differ from expert-generated maps. Teacher-expert C created the most complex map, followed by novices D and E. Experts and novices did not significantly differ regarding their ability to create clusters and hierarchies. Maps of knowledgeable students showed as many cross-links and network complexities as maps created by experts.

Comparing talk aloud utterances to the developing concept maps provided valuable insights. Several times, oral explanations clarified concept map propositions that would otherwise have to be considered invalid (for example, expert A created the proposition "mitosis contributes to evolution" but then argued that without mitosis there would be no higher organisms and their evolution, as their bodies developed through mitotic cell division). Such an additional elaboration may reveal more extensive conceptual knowledge than the condensed and constrained form of the concept map propositions reflect. Expert participants provided more detailed oral explanations than novice participants. Experts' link labels were often shorthand for several intermediate steps

(which they explained orally). Further analysis of talk aloud utterances also revealed several noticeable differences between the experts. The research-experts expressed greater difficulties generating their concept maps than the teacher-expert or the students. Several factors could contribute to this observation: The research-experts had only limited prior experience in generating concepts maps. The two research experts experienced it as a challenge to express their complex and sophisticated understanding in the constrained format of a concept map. In contrast, teacher-expert C showed fewer difficulties representing conceptual understanding in the shorthand form of concept maps because concept maps are frequently found in biology textbooks.

Overall, this case study suggests that concept maps can reveal differences in knowledge of experts and (low performing) novices. High performing participants (experts and novices) demonstrated their ability to fluidly move back and forth between a big picture view (model-based reasoning) and a more detailed view when creating individual links (constraint-based reasoning). Concept map construction processes and the final products indicated few differences between high performing novices and experts. Nevertheless, experts expressed their deeper understanding orally, because they could not adequately express their extensive knowledge due to task and aesthetic constraints of concept maps. The shorthand form used to describe relations between concepts allows keeping an aesthetic big-picture view but limits capturing explanatory depth. Experts and novices often used the same link labels to describe a relation between concepts, but oral elaboration revealed that experts often compressed more knowledge into a link label (called higher “epistemic density” by [18] and used the same linking words to represent different meanings [19]. Accompanying explanations are needed to further explain understanding represented by a proposition.

## 5 Implications and Limitations

As a case study with a small sample size, analysis can offer only limited insights. However, several suggestions can be offered.

Concept maps are used as assessment tools to track changes in students’ understanding, for example in standardized large-scale assessments in the U.S. National Assessment of Educational Progress (NAEP) [20]. Usually, only the final concept maps are evaluated. Results from this study highlight the possible divergence between the concept map construction process and the finished product. During the construction process, most participants created meaningful clusters of related concepts and/or followed a temporal flow. However, these clusters or temporal flows were often no longer identifiable in the final product. A teacher or researcher who evaluates only the final product will often lack this additional information. Final concept maps elicit only a limited snapshot of a learner’s integrated knowledge. Participants’ oral explanations of their thought processes often diverged or expanded the reasoning leading to certain propositions. Some link labels might even have to be considered incorrect without the accompanying oral explanation. One way to triangulate this hidden understanding could be looking at written assessments (e.g. essays) or oral explanations that cover the same concepts. In such longer explanations, learners can express their understanding in more detail and provide supporting evidence.

This study used a concept map form that represents a compromise between open and heavily constrained formats by providing a list of concepts but leaving link generation to the participant. Open-ended concept maps, where students can choose their own concepts and links, might reflect students' knowledge structures more accurately, but they are more difficult to compare, require more time, and could be more challenging especially for weaker students [21]. On the other hand, more constrained forms of concept maps can lead to ceiling effects [10, 22]. Due to the constraints of the concept mapping task (for example, provided list of concepts; only one relation between two concepts, short link labels), a high performing student's map can be difficult to distinguish from an expert's map. Many participants generated only short link labels (maybe due to aesthetical graphical restrictions (limited space between two nodes) that did not represent the same understanding as their oral elaborations. Accompanying explanations (oral or written) could provide valuable insights into the meaning of propositions and the reasoning process during construction.

Experts were very selective about which propositions to include. Experts' selection processes could serve as scaffolds for novices to support their critical reflection and informed decision-making on which connections are relevant to include in their maps.

Expert-generated concept maps are often used as references for evaluation. Using expert-generated maps benchmark maps might falsely suggest that there is only one correct answer [23]. Findings from this study suggest that there is no single expert reference map. Each expert in this study generated a valid map but constructed different propositions and structures. Expert maps can differ from one another [24], even when using a limited number of provided concepts. This also raises the question of who is considered an "expert". There are many different kinds of experts, for example researchers, practitioners, proficient amateurs, and science teachers [25]. More research is needed to address the "expert problem" by providing better descriptions of what constitutes an "expert" and distinguishing different types and levels of experts.

As a compromise, an expert reference map could be created as an aggregate of several expert-generated maps [10]. However, even an aggregated expert map represents only one of many possible valid solutions and should only be used with caution for a direct comparison with novice-generated maps. Multiple concept map analysis strategies can be used to complement each other and triangulate changes in learners' understanding [26]. Concept map generation and analysis should reflect the constructivist perspective that knowledge can and should be constructed and represented in many different ways.

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