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COMPARING TWO FORMS OF CONCEPT MAP CRITIQUE ACTIVITIES TO SUPPORT KNOWLEDGE INTEGRATION IN BIOLOGY EDUCATION

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Abstract. Concept map activities often lack a subsequent revision step that facilitates knowledge integration. This study compares two kinds of concept map critique activities embedded in an evolution unit: Student dyads in one group compared their concept maps against an expert map while dyads in the other group conducted a peer-review. Analysis of the concept maps suggests that both treatment groups significantly improved their understanding of evolution. However, the two groups developed different criteria: The expert-map group focused mostly on concept-focused criteria like concept classification while the peer-review group used more link-focused criteria like link labels and missing connections. This paper suggests that both critique activities can be beneficial to making more coherent connections across different topics in biology.
Keywords: Science education, biology education, knowledge integration, learning by critiquing, Knowledge Integration Map

1 Introduction

Biology is often taught as isolated sub-fields each with its own terminology. As a result, many students leave school with a very fragmented knowledge of biology (Mintzes, Wandersee, & Novak, 1998, 2000; Wandersee, 1989) that does not allow them to understand complex scientific systems and make connections to their everyday lives. Particularly, the core domains of modern biology, genetics, cell biology and evolution, have been found to be conceptually difficult topics to teach and learn (Bahar, 1999; Tsui & Treagust, 2003). One main reason why they are difficult topics to learn is because they form a complex system with multiple interacting levels (Wilensky & Resnick, 1999). Comprehensive understanding of these complex systems requires simultaneous thinking in and connecting across several levels. Concept maps can help making connections within and across levels visually explicit.

Concept mapping has been shown to effectively support student learning and assess understanding of science concepts (Novak, 1996). However, many concept mapping activities used in classrooms miss a subsequent step that supports reflection and leads to a review process that helps refining students' work and integration of their ideas. A critique activity requires students to apply or develop criteria to reflect, revise their work, and self-monitor their learning progress (Chi, 2000). This study compares two different concept map critique activities: Students in one treatment group compared their own maps against an expert concept map while students in the other treatment group provided anonymous peer-review for other students' concept maps.

2 Theoretical Framework

Knowledge integration (KI) (Linn & Hsi, 2000; Linn, Eylon, & Davis, 2004) focuses on connections between ideas (represented as "concepts" in concept maps) and includes the processes of eliciting existing repertoires of ideas, adding new ideas to the repertoire, developing criteria to distinguish ideas, and sorting out various connections and ideas. In a concept map, ideas are represented by concepts, connecting arrows, the labels of arrows, and the placement of concepts in specific areas. Combining several ideas is interpreted as an increase in integrated knowledge. Concept maps as knowledge integration tools allow eliciting and critiquing concepts and relations between concepts (see table 1). The visual format of concept maps can foster critical distinctions between alternative concepts and relations, either individually or collaboratively in communities of learners. Concept maps allow for fast retrieval of information that allows for time-efficient comparisons.

Table 1: Concept mapping for knowledge integration

Knowledge Integration Process	Concept Mapping Activity
Eliciting existing ideas	Concept maps can be used as a pretest activity to elicit' existing concepts.
Adding new ideas and connecting to existing ideas in repertoire	New concepts and relations can be added to existing concept maps. If applicable, students need to decide which concepts to add to the map. If several alternative relations between two concepts are possible, students have to decide which one to use in the map.
Distinguishing/ Critiquing ideas	Students apply or generate criteria to distinguish alternative concepts and relations (arrow directions and labels).
Sorting out ideas/ Refining/ Revising	Students sort out alternative concepts and relations based on different sources of evidence. Concepts can be rearranged into new groups and the concept map network structure might need revision the implemented changes.
Applying ideas	Concept maps can be used as resources to generate explanations of scientific phenomena.

This paper investigates ways to help students connecting different biology concepts to form a coherent view that allows understanding real life phenomena. This study combined learning from a dynamic computer-based inquiry activity with a scaffolded concept map construction and two different critique activities.

The specific research questions this study addresses are:

1) *How do expert and peer critique activities impact learning from a dynamic visualization? What connections among biology concepts do students make in each condition?*
2) *What are the differences between peer and expert concept map critique in regards to promoting knowledge integration?*

3 Methods

3.1 Curriculum Design

The curriculum unit, titled *Space Colony – Genetic diversity and survival'* was deployed using the Web-based Inquiry Science Environment (WISE) (Linn, Davis, & Bell, 2004). The unit consisted of seven activities that emphasized connections between cell division, the underlying genetic processes, and overarching evolution principles. The unit included the computer-based visualization 'EvolutionLab' (Leif, 2005) that allowed students to run scaffolded experiments to investigate the connections between mutations and natural selection. Students worked collaboratively in pairs sharing one computer and spent five days (one hour per day) to complete the unit.

3.2 Novel form of concept map

This study took advantage of a novel form of concept map called Knowledge Integration Map (KIM) that incorporates research on knowledge integration and on concept mapping (Schwendimann, 2011, 2014). KIMs divide the drawing area into domain-specific areas to classify and distinguish different concepts. KIMs adapted for this study aim to support the generation and revision of concepts related to evolution by dividing the drawing area into the biology-specific areas 'DNA' (micro), 'cell' (meso), and 'organism/population' (macro) (see figure 2). Genetic concepts were expected to be placed in the 'DNA' area while concepts about the phenotype and natural selection would be placed in the 'organism/population' area. The 'cell' area aimed to serve as a meso-level bridge between the genetic (micro) and the organism/population (macro) areas. Learners received a list of six concepts and were instructed to first classify the concepts by placing them into the corresponding areas and then to construct connections (with labeled mono-directional arrows) within and across areas.

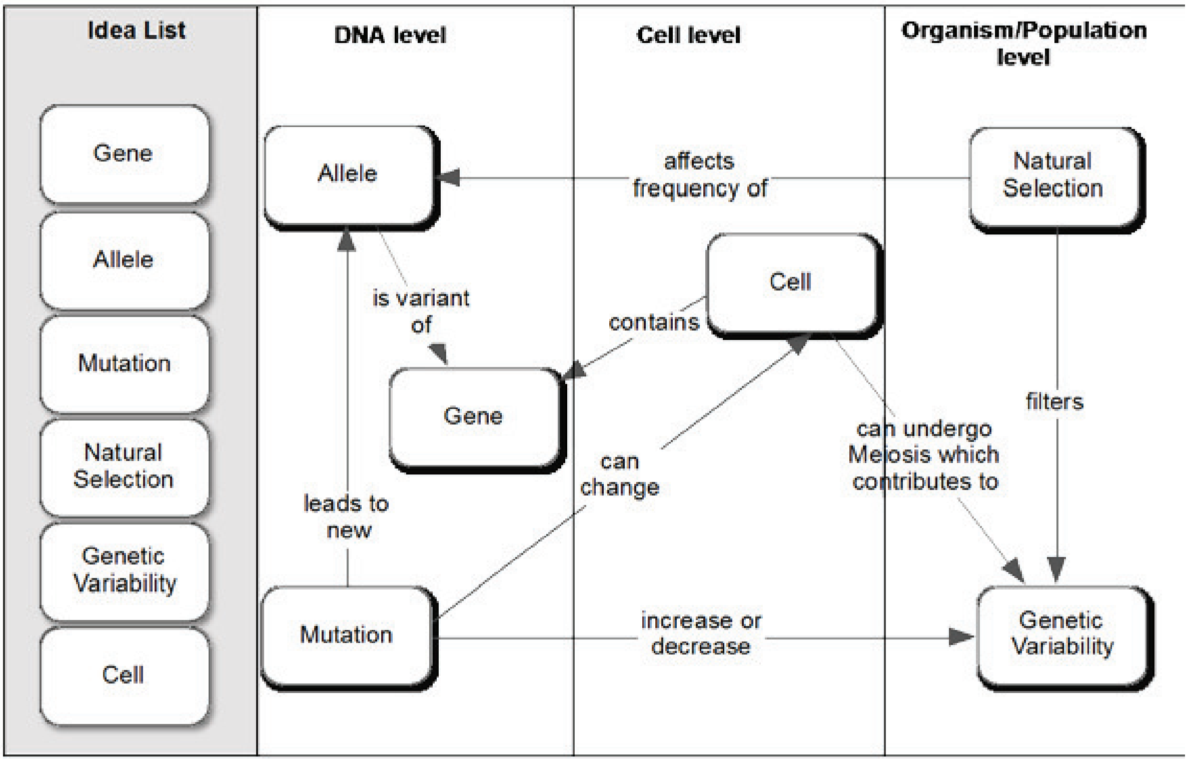

Figure 2: Knowledge Integration Map (KIM)

3.3 Data Sources

Pre/posttests measured students' improvements in connecting genetics, cell biology, and evolution. The pre/posttests consisted of nine explanation items that required students to apply the principles of the genetic basis of evolution to novel contexts. Pre/posttests were scored according to a five-scale knowledge integration rubric (Linn, Lee, Tinker, Husic, & Chiu, 2006).

Concept maps: All students received initial training in the method of concept mapping. A paper and pencil KIM activity was administered after completing the 'EvolutionLab' activity. Student dyads created a KIM out of six given concepts: Gene, allele, mutation, cell, natural selection, and genetic diversity. Students were instructed to classify the concepts by placing each in one of three areas (DNA level, cell level, organism/population level) before connecting the concepts with labeled mono-directional arrows (see figure 3).

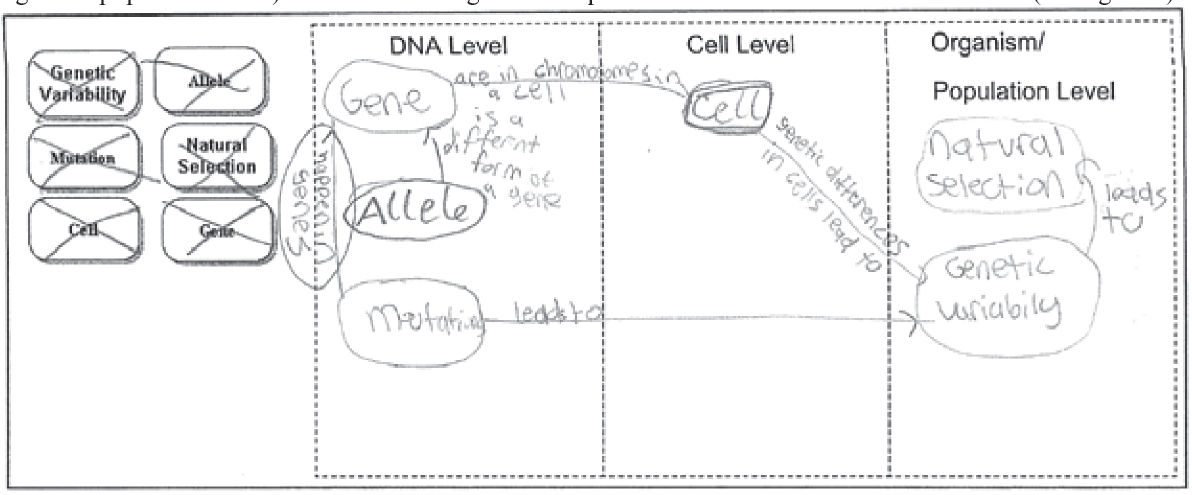

Figure 3: KIM student example (from the peer map group)

KIM propositions were coded using a knowledge integration rubric for concept maps (table 2) (Schwendimann, 2008) on a scale from 0 to 5, a higher score indicating a more complex connection. The rubric distinguished between link label and link arrow. Additionally, the placement of concepts in one of the three areas (DNA, cell, organism/population) and cross-links (links between areas) were evaluated.

Table 2: Concept map scoring rubric

KI Score	Link label quality	Link Arrow	Example
0	None (missing connection)	None	
1	Wrong label	Wrong arrow direction	*Genetic variability includes mutation*
2	Inconsistent/vague: a) Only line b) Correct label c) Incorrect label	 a) Only line b) Wrong arrow direction c) Correct arrow direction	 *a) Mutation -- genetic variability* *b) Genetic variability – contributes to > mutation* *c) Mutation – includes > genetic variability*
3	Correct arrow (but no label)	Correct arrow direction	*Mutation -> genetic variability*
4	Partially correct, but weak	Correct arrow direction	*Mutation – increases ->genetic variability*
5	Fully correct, strong	Correct arrow direction	*Mutation – causes random changes in the genetic material which in turn increases > genetic variability*

Critique activity: A worksheet instructed student dyads to compare their KIM to a reference map – either an expert-generated map or a map constructed by a peer dyad. Students had to develop their own criteria, select the most saliently different element in the map, and then explain their choice. The authors were asked to respond to the critique by describing their intended response (for example revising the KIM accordingly or ignore the critique). A rubric for the different kinds of concept map critique criteria has been developed (table 3). All rubrics showed a high inter-rater reliability.

Table 3: Rubric for different concept map critique criteria

Kind of critique	Example
Missing	
Off-Topic	*I am tired*
General	*Make more links between your concepts.*
Critique of concept placement	*'Mutation' should be in DNA-Level*
Critique of missing concept	*You forgot to add 'mutation'.*
Critique of arrow-direction	*Your arrow should go in the other direction*
Critique of missing link	*You missed to connect 'mutation + allele'.*
Critique of missing link-label	*You should add a label for the link 'mutation + allele'*
Critique of existing link-label	*Connection between 'allele' and 'mutation' should be 'leads to' and not 'includes'.*

3.4 Participants

The WISE unit '*Space Colony – Genetic diversity and survival'* was implemented by two teachers each with two classes in one US public high school. One class of each teacher got randomly selected for one treatment (expert map comparison or peer-review). All students were in 9th and 10th grade and came from a variety of ethnic and economic backgrounds. Only students who completed the concept mapping activity and the pre/posttest were included in this study (n=81). T-test analysis showed that the prior knowledge as measured in the pretest did not significantly differ between the classes of the two teachers [$t(80) = -0.67$, $p>0.05$ (two-tailed).

4 Results and Discussion

Research question #1: *How do expert and peer critique activities impact learning from a dynamic visualization? What connections among biology concept do students make in each condition?*

A paired t test indicated that students in both treatment groups gained significantly in their understanding of evolution ideas from pre- to posttest. [Paired $t(80) = 4.15$, $p<0.0001$ (two-tailed)]. Effect size (Cohen's d)=0.52 (SD pretest=2.78, SD posttest=3.17)] (see figure 4)

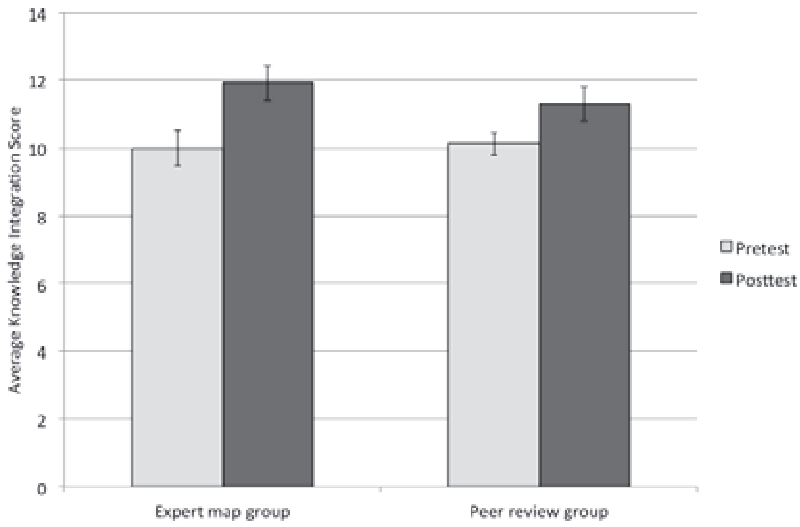

Figure 4: Pretest-posttest gains (by group)

No significant difference of the posttest performance of the two critique groups was found [p>0.05 (two-tailed). t(79) =1.0030 , p>0.05 (two-tailed).]. This could be explained by the short duration of the treatment and the nature of the critique activity that led to more reflection in both treatment groups.

Analysis of the frequency of propositions after the revision indicates that connections between concepts that were learned within the same context were most frequent, e.g. 'genetic variability + natural selection' (evolution concepts) (see figure 5 box on the left). Connections across levels or topics that needed to be newly generated by the students were found less frequently, e.g. 'genetic variability + allele' (see fig 5 middle and right box). Connections across levels can be interpreted as newly created connections as they were not included in the textbook. Findings suggest that the WISE unit *'Space colony'* effectively helped students in both treatment groups making novel connections across levels and biological topics. The peer-review group created more across-level connections, for example 'genetic variability + gene', than the expert map group. This could have been encouraged by the link-focused feedback by peer-review dyads (see research question #2).

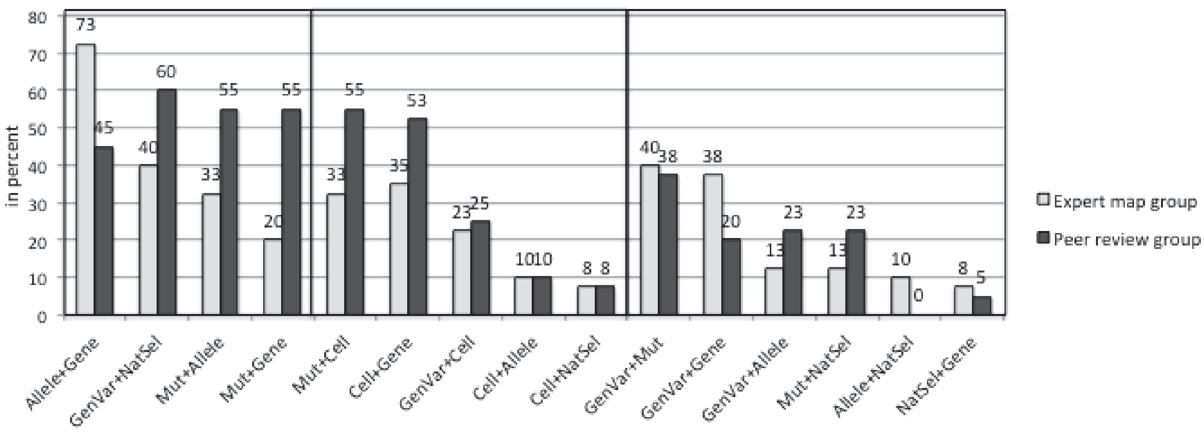

Figure 5: Frequencies of propositions connecting across contexts (left box= within same context; middle box = across one context; right box = across two contexts) (in percent)

Research question #2: *What are the differences between peer and expert concept map critique in regards to promoting knowledge integration?*

Both treatment groups significantly improved their concept maps after the critique activity [paired t(80) = 4.13, p<0.0001 (two-tailed)]. Regression analysis showed that an improvement in the concept maps after the revision is positively associated with an estimated increase in the mean posttest score of 2.5; p<0.001.

Students generated a broad variety of criteria to review different elements of KIMs (see figure 6).

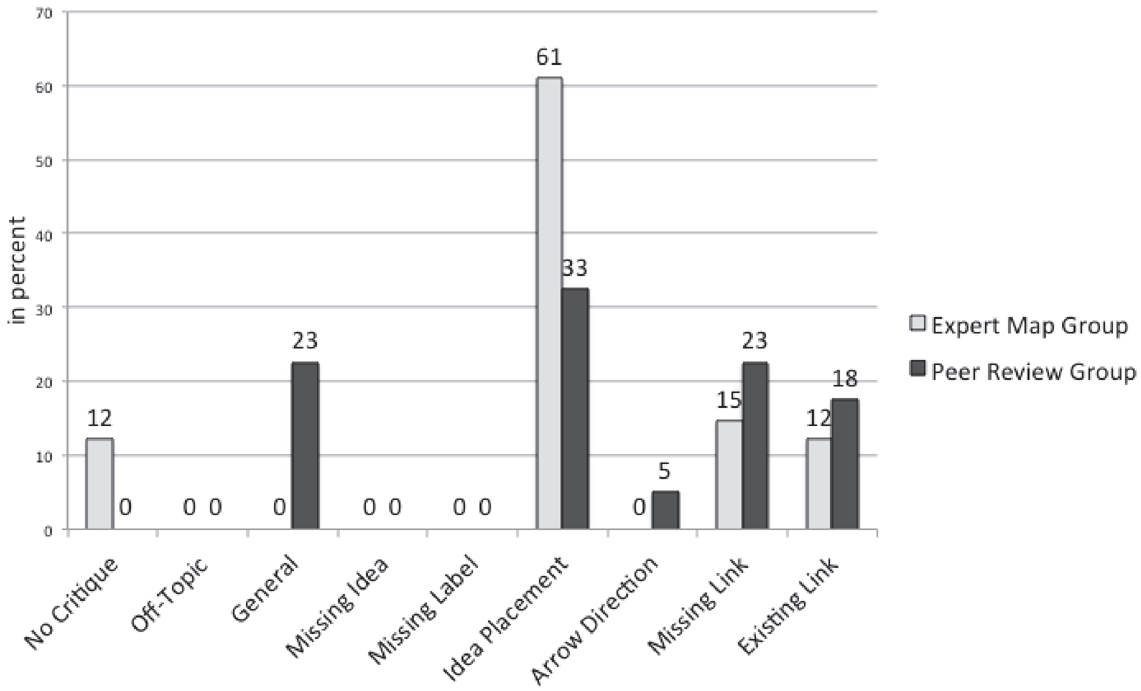

Figure 6: Criteria (by group)

KIM generation: Student dyads in both conditions collaboratively generated their own KIMs from a given list of ideas. The KIM generation activity aimed to elicit existing alternative ideas through idea placement and connections. In their initial KIMs, students in both conditions showed a similar array of alternative ideas. Generating KIMs can elicit alternative ideas as well as missing connections.

KIM critique: While students in both conditions generated similar KIMs, analysis of dyad-generated criteria suggests that students in the expert and peer conditions differed significantly in the ways how they critiqued and revised KIMs. Students in the expert map group used mostly the criteria 'idea placement' (61%), 'missing link' (15%), and 'change existing link label' (12%). Students in the peer map group showed a different distribution: only 33% critiqued idea placements, but 23% critiqued missing links, 18% existing link labels, and 5% link directions. No student dyad critiqued a missing idea or a missing label. This might be explained by the explicit instructions to use all given ideas and label all connections. All students in the peer map group provided some form of critique while 12% of dyads in the expert map group did not provide critique (of their own work). This could suggest that critiquing peers' work is more interesting and engaging than critiquing one's own work.

For further analysis, student-generated criteria were grouped into the three categories 'idea-focused criteria', 'link-focused criteria', and 'non-relevant criteria' (see table 4).

Table 4: Categories of student-generated criteria

Criteria grouping	Category
No Critique + Off Topic + General	**Non-relevant criteria** include missing, off-topic, and general comments.
Idea Placement + Missing Idea	**Idea-focused criteria** allow for a quick visual comparison between KIMs without necessary conceptual reflection (for example "Is the idea placed in the same area as in the expert map?"; "Is an idea from the given list missing?"
Arrow Direction + Missing Link + Existing Label	**Link-focused criteria** provide conceptual feedback by identifying an important missing connection, pointing out that an arrow direction should be reversed, or suggesting the revision of an existing label.

Idea-focused criteria evaluate the presence or placement of ideas while *link-focused criteria* identify missing links, the direction of a link, or the link label (see figure 7). Student dyads in the expert and peer groups differed significantly in the prominence of criteria for their KIM critique. Z-scores were computed for raw scores in the critique data set. The differences in proportions of the criteria categories between conditions are statistically significant: Idea-focused critique ($z=2.97$. $p=0.001$) and link-focused critique ($z=1.68$. $p=0.046$).

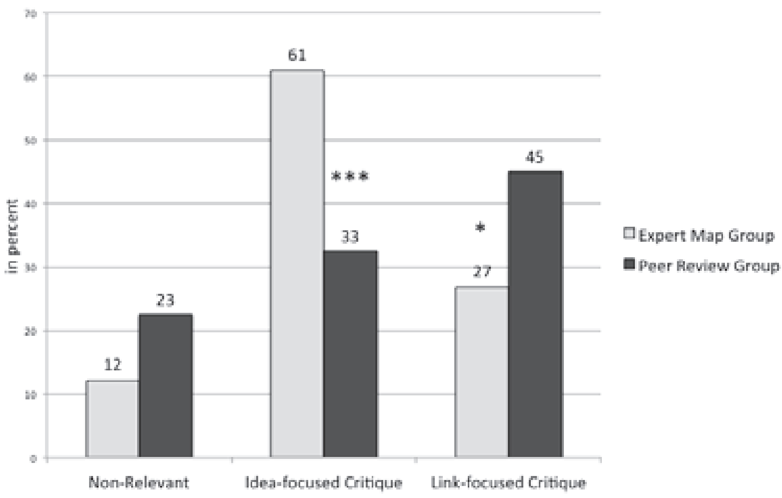

Figure 7: KIM criteria categories (*=p<0.05; **=p<0.01; ***=p<0.001)

In summary, both critique groups did significantly improve their concept maps after their revision and gained from pre- to posttest. As both critique activities led to reflection and revision, the two treatment groups did not significantly differ in their posttest performance. However, the groups differed from each other in the different kinds of criteria used to review their maps. This study suggests different mechanisms and criteria involved in the two critique activities.

- Students in the expert map condition generated more *idea-focused criteria* (61%) that allowed for quick comparisons with the expert map. Aligned with their criteria, most students in the expert-map group decided to revise their idea placement. For example, a dyad in the expert group stated, "We think that the location of 'genetic variability' is most different". They used an idea-focused criterion to compare their map to the expert-generated map and identified the most saliently different element. Consequently, the authors then suggested moving the idea to a different area. Critiquing your own work can be more difficult than evaluating other people's work. Findings suggest that providing students with a normative benchmark helped modeling expert understanding and distinguishing idea-focused issues for revision.

- The peer-review activity engaged students to develop and use more *link-focused criteria* (45%), like missing propositions, link labels, and causal directions. Comparing their own ideas against those of their peers helped students to value their own ideas while developing criteria to critically review them. One explanation for this observation might be students' interest in seeing work created by their peers (although anonymous) and being in an equal position to critique each other's work. Peer-generated KIMs might be easier to compare to one's own than to an expert generated KIM because of the use of familiar language and building on similar prior knowledge. One initial concern for the peer review activity was that students might receive peer-generated work of varying quality and provide feedback that might reinforce non-normative ideas. Results suggest that some peer feedback consisted of non-normative ideas. However, students successfully distinguished alternative ideas, rightfully discarded non-normative suggestions, and expressed confidence in their own ideas.

5 Implications

Both forms of critique can lead to reflection, help students build criteria for self-monitoring their learning progress, and support knowledge integration processes. A combination of the two forms of critique activities could be implemented in a future iteration of this study. Students might also be provided with a critique rubric that allows them to systematically review different elements of their concept maps.

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