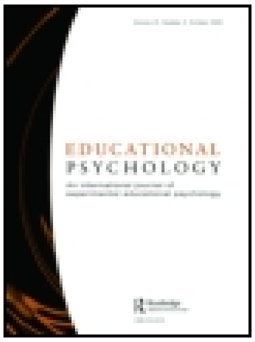

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Effects of different concept map activities on chemistry learning

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ABSTRACT

There is widespread evidence showing that concept maps are effective for learning. However, little is known about the effects of various concept map activities. We conducted an experiment to examine the comparative effectiveness of three concept map activities: (i) translating a complete map to a paragraph format, (ii) filling in concepts in a partial map, and (iii) filling in labels in a partial map. Undergraduate students enrolled in an introductory general chemistry course were randomly assigned to the three groups. Each concept map depicted the relationships between concepts on the topic of reaction enthalpy. Results showed that the map-translation group significantly outperformed the fill-in-concepts and fill-in-labels groups in conceptual understanding indicated by open-ended questions while there were no significant differences among the three groups in conceptual understanding indicated by multiple-choice questions.

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Concept map; chemistry; learning; undergraduate; partial

Introduction

Learners' active engagement when learning science, technology, engineering, or maths is likely to encourage deeper processing and thus more robust learning (e.g. Bransford et al., 2002; Chi et al., 1989; Renkl, 1999). Chi's (2009) Differentiated Overt Learning Activities (DOLA) framework suggests that activities which involve learners manipulating learning materials promote active learning. Well-designed concept maps allow learners to actively plan their learning trajectory, provide learners with potential routes to follow through the learning content (Coffey, 2005; Dansereau, 2005), and keep track of changes in learning (de Jong & Van der Hulst, 2002; Gijlers & de Jong, 2005) encouraging active learning. Hence, studying and constructing concept maps are considered to be effective strategies for organising learners' conceptual knowledge.

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On the other hand, although the use of concept maps, in general, has been shown to be effective in enhancing learners' engagement with learning materials, less is understood about the effectiveness of the use of different concept map forms. Depending on which parts of a concept map are manipulated and how they are manipulated, learners may commit different levels of engagement. Thus, to provide a comprehensive understanding of how to make the most of concept maps, we conducted an experiment comparing the effects of three learning activities: studying a map by re-expressing its meaning in a prose paragraph (translating), filling in concepts in an incomplete map, and filling in labels in an incomplete map.

In addition, to our knowledge there has been no concept map studies investigating the quality of either studying or constructing maps directly. In contrast, research on other generative learning activities have underscored assessing the quality of learners using them (for drawing see Eitel et al., 2013; for self-explaining see Matthews & Rittle-Johnson, 2009) To answer that question, we applied scoring rubrics to assess how well a complete map is translated and a partial map is completed by filling in concepts or labels (for details see 'Measures' section below).

Literature review

Concept maps are a type of graphic organiser that, in turn, are a type of advance organiser (Ausubel, 1968). Ausubel defined advance organisers as 'appropriately relevant and inclusive introductory materials (p. 148)'. Concept maps refer to node-link diagrams using labelled nodes to denote concepts and linking phrases to denote relationships among concepts (O'Donnell et al., 2002; Novak & Cañas, 2006). Concept maps, in Novak and Gowin (1984) early work, are proposed to help learners internally reconstruct their concepts and visually represent their conceptual structures. A substantial body of empirical research, summarised in meta-analyses, has consistently shown that studying or constructing concept maps benefitted learners across a wide range of academic disciplines (Bahr & Dansereau, 2005; Nair & Narayanasamy, 2017; Nesbit & Adesope, 2006; Redford et al., 2012; Schroeder et al., 2018). Results have shown that learners who engaged in constructing concept maps scored higher in retention tests than those who listened to lectures, read text, or wrote summaries and outlines (Nesbit & Adesope, 2006; Schroeder et al., 2018).

Different explanations have been proposed by scholars to account for the benefits of studying or constructing concept maps. Some explanations are concerned with intrinsic properties of concept maps such as dual coding or verbal encoding while other explanations deal with properties such as organising and summarising that studying or constructing concept maps share with other learning activities (Nesbit & Adesope, 2006, 2011). In short, the advantages offered by concept mapping may be largely due to its potential to facilitate efficient cognitive processing (Furtado et al., 2019; Nesbit & Adesope, 2011). For example, according to Blunt and Karpicke (2014), creating concept maps might serve as an effective retrieval-based learning activity producing mental processes involved in recollecting the context of a prior learning episode. To provide a clearer picture of the building blocks of concept mapping, Schroeder et al. (2018) categorised the various explanations as promoting meaningful learning, reducing cognitive load, or both.

Concept mapping, an effective approach to externalising knowledge structure, may take different learning forms. Even though a typical use of concept maps is presenting learners with concept maps constructed by experts, there is a wide consensus that concept maps can be either studied or created in different forms to aid learning (Adesope & Nesbit, 2013; Cañas & Novak, 2012; Liu, 2014; Novak & Cañas, 2010). For instance, Nesbit and Adesope (2006) recognised constructing, modifying, and viewing concept maps as three ways to learn with concept mapping and derived effect sizes for constructing and studying maps ($g = .819$ and .373 respectively, $ps < .05$). Chang et al. (2001) might be the first to compare the effectiveness of the constructive partial (fill-in-the-blank) and complete concept mapping and found that the partial concept mapping had a better effect on learning than complete concept mapping. Nevertheless, Novak and Cañas (2010) recommended against using only partial concept mapping for substantial learning. In spite of the disparity in findings and recommendations, this line of research has been relatively stagnant since. That said, several studies on this topic have been done in the field of computer science education. For example, Mühling (2016) presents a novel way of investigating the state and development of knowledge structures of beginning computer science students using concept maps. Sharma and Chawla (2014) identified and compared different tools for developing concept map networks in the field of computer science education. Given that learners may invest different levels of engagement in constructing maps and viewing maps (Chi & Wylie, 2014), it is important to more closely examine the comparative effects of different levels of active engagement encouraged by varying concept map formats.

We chose enthalpy as the topic participants would study in the present experiment because there is research evidence showing that students often struggle with understanding enthalpy and other related thermodynamics concepts (Bain et al., 2014; van Roon et al., 1994). It appears that undergraduate students find the idea of enthalpy difficult due to their incomplete or even incorrect prior knowledge acquired in secondary education, which has been widely acknowledged by researchers (e.g. de Jong, 2000; Tsaparlis, 2007). Indeed, Bain et al. (2014) noted that 'students' responses regarding enthalpy did not improve … Most students provided incomplete or imprecise explanations of enthalpy' (p. 325). In addition, as Nilsson and Niedderer (2014) pointed out, students' understanding of enthalpy in higher education failed to receive sufficient attention among researchers in chemistry education.

While recent empirical studies have consistently demonstrated the value of concept maps and their extensive applications in a variety of fields, the present study aimed at extending the existing knowledge base on concept maps in one important respect. That is, we purposefully created two variations of partially constructed concept maps revolving around two key constituting elements of a complete concept map: concepts and labels. More specifically, we provided an incomplete concept map with the concepts intentionally left blank and a map with the labels intentionally left blank for the student to fill in. A justification for such design is derived from Nesbit and Adesope (2006) who argued that constructive or generative activity of concept mapping is particularly effective. In addition, our third variation is the conventional expert concept map studying condition with the twist of students translating the map into a paragraph. This variation was expected to have two benefits. First, it would provide evidence of if and how learners studied the expert map and secondly, translating a complete expert-built map could encourage the student to self-explain, allowing for higher-order cognitive processes to emerge while they are translating. Hence, with this design, we hope to address the research gap pertaining to efficacy comparison of different forms of concept maps (that require different levels of engagement) as well as investigate the effectiveness of these varying formats in an authentic class environment.

This manipulation was also generally consistent with the research paradigm comparing constructing and studying concept maps (Nesbit & Adesope, 2006; Schroeder et al., 2018; Wang & Dwyer, 2006) with two exceptions. Participants were required to make complete the partial concept maps (with concepts or labels missing) presented to them rather than required to create their own maps. Such adjustment was made as there is evidence (e.g. Haugwitz et al., 2010) showing that creating maps based on textual information plausibly requires high levels of cognitive processing, which may cause cognitive overload for low prior knowledge learners. Thus, filling in the missing parts of a partial concept map with the other parts visible serving as cues may invoke a moderate level of cognitive processing for constructive activity. Second, participants were asked to translate a concept map rather than simply studying it (i.e. going through noun-verb-noun propositions), thus avoiding a passive mode of learning engagement (see Chi & Wylie, 2014).

In our investigation, we seek to add to the literature delineating the relationship between concept map quality (defined by accuracy and completeness) and learning outcomes, particularly since collecting and analysing the quality of learners' self-explanations are crucial to understanding the effects of self-explanation (Atkinson et al., 2003; Hausmann & Chi, 2002). Further we include time on task as one of the dependent variables in addition to the quality of task completion as time on task is considered as an indicator of learning engagement (Goldhammer et al., 2014; Guthrie et al., 2004). Thus, in our study, we examine the time on task, quality of task completion, and subsequent learning outcome between three concept map tasks. We expect that fill-in-concepts and fill-in-labels types of maps, considered as partially generative, might result in greater learning than merely studying a completed map.

Research questions

The present study designed three different ways of learning with concept maps: translating an expert-built concept map, filling in concepts in a partial expert-built map, and filling in labels in a partial expert-built map. The primary purpose of the present study was to explore the effects of the three different concept map activities on students' conceptual understanding in chemistry. Hence, the study seeks to answer the following research questions:

1. Is the quality of concept map activity positively related to learning performance in chemistry?
2. Do fill-in-concepts and fill-in-labels types of maps result in greater learning than translating a completed map?
3. Are there any differences among the three concept map activities regarding time spent in studying or constructing a concept map, time spent in answering posttest questions?

Method

Participants and design

Two hundred and twelve undergraduate students (89 female, 123 male, M_{age} = 18.42 years) from an introductory general chemistry course at a large public U.S. university voluntarily participated in the experiment, as part of their coursework. A majority of the participants (97%) reported English as their first language. All of them were STEM majors. The present study employed a randomised between group experimental design and participants were randomly assigned to one of three groups: map-translation ($n = 77$); fill-in-concept ($n = 73$); and fill-in-label ($n = 62$). Those in the map-translation group received a complete concept map and were required to translate the map using their own words. Those in the fill-in-concepts group were presented a partial map and were required to fill in the concepts missing in the map. Those in the fill-in-labels group were presented a partial map and required to fill in the labels missing in the map. It should be noted that we did not include a control group (not receiving a concept map) as there is sufficient evidence that supports the apparent advantage of using concept maps as compared to non-mapping instructional activities including restudying text, writing summaries, and other less constructive activities (e.g. Chiou, 2008; Hwang et al. 2013, 2014; Khoii & Sharififar, 2013; for a meta-anlaysis, see Nesbit & Adesope, 2006; Schroeder et al., 2018). In particular, Nesbit and Adesope (2006) found statistically detectable effects of studying and constructing concept maps. Schroeder et al. (2018) also revealed that learning with concept and knowledge maps generated a moderate and statistically significant effect.

This study was reviewed and considered exempt by the University's Institutional Review Board.

Materials

The intervention was administered through Qualtrics, an online survey software. The material pertained to reaction enthalpy, a topic previously covered in class the same week as the experiment. The link consisted of intervention material including a set of guiding questions, the intervention concept map, and measures including a demographic survey and two sets of posttest questions (i.e. multiple-choice and open-ended questions). Four guiding questions (e.g. what does the ΔHo for a reaction tell us? How is calorimetry used to measure ΔH^{o} for a reaction?) were used to prompt participants to recollect what they had learned in the previous class. These questions were dealing with different principles applied to enthalpy and its change and covered a range of complexities, from simple to overarching principles.

The concept maps' guiding questions were developed in collaboration with the lead instructor (a co-author) keeping in mind the lesson's key learning objectives. All terms included in the concept map were covered during the classes on Monday and Wednesday and students reviewed the topic with a concept map on Friday. The Monday and Wednesday classes were conventionally a lecture by the instructor punctuated with quick quizzes for engagement points that were auto-graded (i.e. no feedback was provided on these questions). However, not all concepts covered in class were included in the concept map. The concept map was restricted to the central concepts relevant for the learning objective.

The concept maps were created by the instructor of the introductory chemistry course. The complete map (see Figure 1) composed of 10 key concepts related to reaction enthalpy and 12 linking phrases (labels) elucidating the relationships between the concepts. The partial map was the same as the complete map except that either the concepts or linking phrases were removed (see Figures 2 and 3). Numbers were used to identify the missing concepts or phrases to enable easy completion and scoring.

Measures

Prior knowledge

Prior knowledge was assessed by a free-response question: 'Please list 5 concepts you have learned in this chemistry class about reaction enthalpy'. One point was assigned for each related concept (as provided by the instructor) yielding a possible score ranging from 0 to 5 points. After the initial scoring by one of the authors, the other author randomly scored 30% of the answers. The inter-rater reliability for the two raters was high ($r = 0.92$).

Time spent

Time spent on the concept map activity was recorded using a timing question on Qualtrics as the difference between the first click on the activity page and its' submission.

Conceptual understanding

Conceptual understanding was assessed by five multiple-choice and three open-ended questions.

The *multiple-choice questions* (with four choices) were chosen by the instructor to closely resemble standardised American Chemistry Society examinations. Each question had one correct answer for which one point was assigned yielding a possible score ranging from 0 to 5 points. One example question was, 'Why can Hess's Law be used to accurately predict ΔH for a reaction, when given ΔH values for other reactions that add up to the desired reaction? (A). Because Hess's Law uses ΔHo of Formation values. (B). Because Hess's Law is based on calorimetry. (C). Because Hess's Law is an application of the state function concept. (D). Because Hess's Law is based on standard

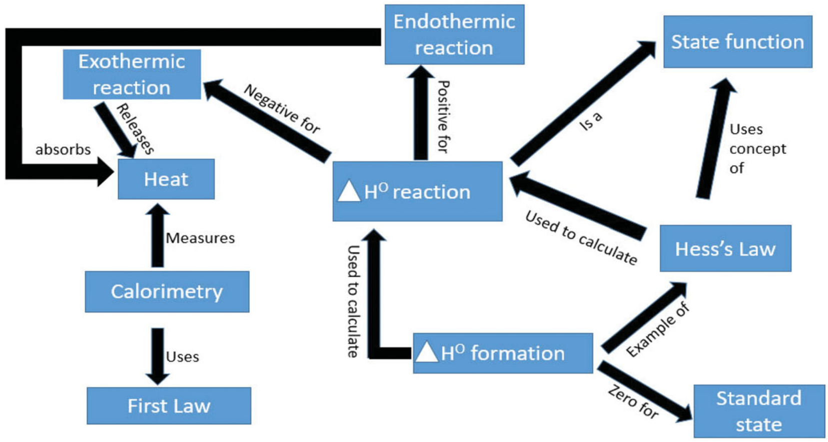

Figure 1. Complete map.

states.' The internal consistency for the items ($\alpha = 0.74$) was acceptable for research purposes.

The *open-ended questions* were developed to target the free-response performance. For each question, different points were assigned depending on the extent to which the answer written by each participant was acceptable (e.g. 3 points for a fully acceptable answer and 0 points for an unacceptable answer). The possible score for each participant ranged from 0 to 9 points. One example was, 'What is the standard state of an element?'

Concept map quality

For those in the map-translation group, map quality was assessed based on how well they translated the concept map by a scoring rubric we developed. The rubric used the completeness and accuracy dimensions described by Wu et al. (2012). Completeness refers to the extent to which relevant concepts were included (so as to respond to the guiding question) and accuracy refers to the extent to which the linking phrases were correctly placed between concepts. Specifically, one point was assigned to the answer for one relevant concept and another one point for one correct linking phrase, which produced a possible score from 0 to 22 points (10 for completeness and 12 for accuracy) for map quality. The scores were then tailored on a 10-point unit (for example, 3 points on completeness and 5 points on accuracy made the total score of 8 points, which was transformed to be 3.6 points according to the formula 8/22*10). No point deductions were made if the translation occasionally mentioned irrelevant or unnecessary concepts. One of the authors independently scored all translations. Another researcher randomly scored 30% of the translations. The inter-rater reliability for the two raters was high ($r = 0.88$).

For those in the fill-in-concepts group, mapping quality was assessed based on the number of concepts that were correctly put in the boxes (see Figure 2). For those in the fill-in-labels group, mapping quality was assessed based on the number of labels that were correctly put along the corresponding arrows (see Figure 3). The possible

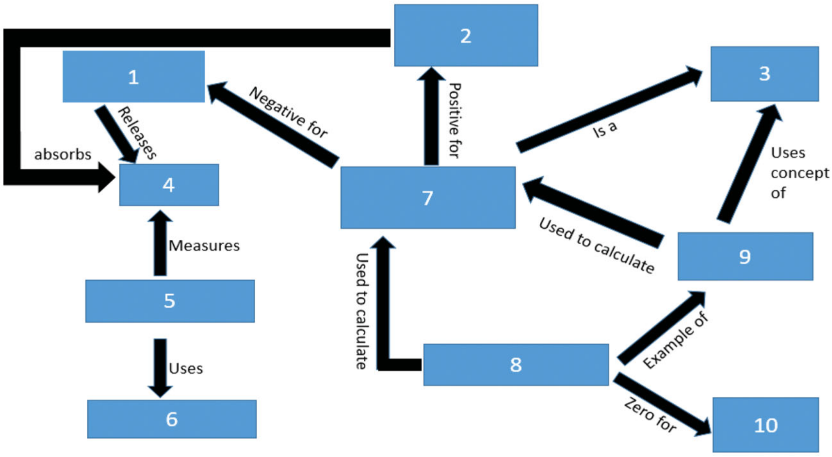

Figure 2. Partial map fill-in-concepts.

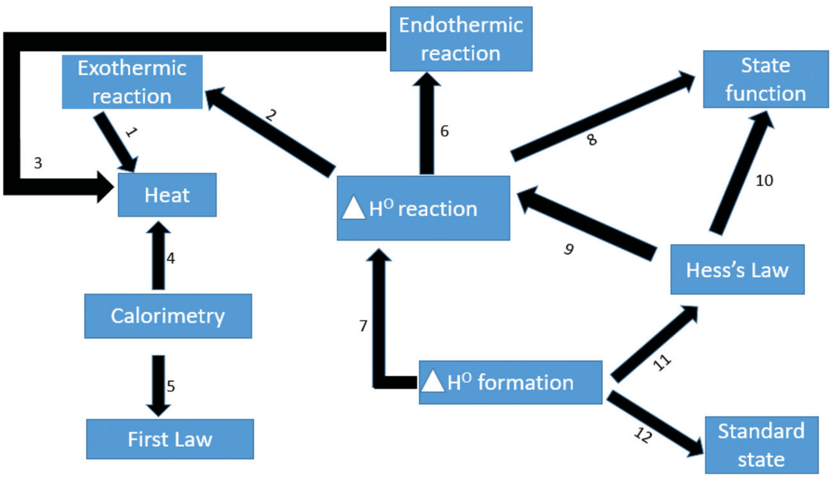

Figure 3. Partial map fill-in-labels.

mapping quality score for the fill-in-concepts group ranged from 0 to 10 points as there were 10 missing concepts and 0 to 12 points for the fill-in-labels as there were 12 missing labels.

Procedure

The study was administered through a Qualtrics link which students accessed in the course's regular meeting place – a large stadium-seating classroom. Initially, the link for each condition were randomly assigned to participants through the learning management system prior to the experiment and reached equal sample sizes for the three conditions. Due to the absence of a few participants or computer failure at the experiment, however, each condition contained a little fewer participants than expected and thus resulted in unequal sample sizes (77, 73, and 63 respectively). First, participants were welcomed and given a brief description about the study's purpose by the instructor. Participants then accessed the randomly assigned condition. Each participant went through five phases regardless of the condition. The five phases were 1) prior knowledge test; 2) memory activation; 3) map studying or constructing; 4) posttest phase; and 5) demographic survey. It should be noted here that memory activation refers actually to reading guiding questions. It was expected that reading and reflecting on the guiding questions enable participants to retrieve relevant knowledge they had acquired from the previous class. However, they did not have access to the map at this phase. The detailed instructions typed on PowerPoint slides for each phase were displayed on a big screen in the front of the class. The instructor turned the page and reminded participants to pay attention to the instructions at appropriate moment for each phase. First of all, participants were informed about the purpose and rules of the experiment. Second, they were asked to list five concepts and then read and reflect on the guiding questions. Third, they were instructed to start the map activity depending on the condition (the specific instruction for each map activity can be seen in the question part typed on the Qualtrics page). Finally, they were asked to answer posttest questions and then thanked and dismissed. The instructions given by the slides were exactly the same across the three conditions. The entire experiment was self-paced, meaning that participants decided when to pace forward to the next phase. Participants were thanked for their participation and dismissed when they reached the last page of the learning material. The entire experiment lasted for about 50 min from the moment the instructor began to welcome the participants to the moment they finished the experiment and left.

Results

Preliminary analyses

Prior to data analysis and testing the hypotheses, all variables were examined for accuracy of data entry, outliers, and normality of distributions. Results showed that there were no significant outliers and data were normally distributed. To control for potentially confounding effects of prior knowledge, learners' prior knowledge was examined first. A one-way analysis of variance (ANOVA) showed that there was no significant differences among the map-translation ($M = 3.61$, $SD = 1.22$), fill-in-concept ($M = 3.51$, $SD = 1.31$), and fill-in-label ($M = 3.67$, $SD = 1.09$) groups, F (2, 210) $= .306$, $p = .736$; $\eta^2 = .003$. Therefore, prior knowledge was excluded from subsequent analyses.

Predictive relationships between map quality and learning performance

In order to explore the predictive relationship between the quality of concept map and learning outcomes, we ran two sets of regression analyses (each set of regression was conducted for the three groups separately). In the first set of regression analyses, learning performance indicated by the multiple-choice question score was used as the dependent variable and map activity score was used as the predictor for the three groups respectively. The results did not show any significant prediction effects of map quality on learning performance, $ps > .05$. Regression statistics are presented in Table 1.

Table 1. Regression statistics for multiple-choice score for the three experimental groups.

	Unstandardized B	Coefficients Std. error	Standardised coefficients beta	*p*
Map-translation	.088	.054	.185	.107
Fill-in-concepts	.048	.050	.114	.336
Fill-in-labels	.007	.040	.023	.856

Table 2. Regression statistics for free-response score for the three experimental groups.

	Unstandardized B	Coefficients Std. error	Standardised coefficients beta	*p*
Map-translation	.188	.082	.255	.025
Fill-in-concepts	.116	.089	.152	.198
Fill-in-labels	.086	.063	.171	.180

In the second set of regression analyses, learning performance indicated by free-response question score was used as the dependent variable and map quality was used as the predictor for the three groups respectively. The results did not show any significant prediction effects of map quality on learning performance for both the fill in concept and fill in label groups, *ps* $> .05$. However, turning to the map-translation group, map quality significantly affected learning performance, $\beta = .188$, $t = 2.284$, $p = .025$. Regression statistics are presented in Table 2.

Differences in learning performance

First of all, ANOVA was employed to examine if there was a significant difference on map quality among the three groups. The results showed that there was a significant difference, F (2, 210) $= 5.085$, $p = .007 < .05$; $\eta^2 = .038$. In addition, Bonferroni post hoc tests revealed that the map-translation group significantly outperformed both the fill-in-concepts ($p = .02$, $d = .51$) and fill-in-labels ($p = .021$, $d = .44$) groups while there was no significant difference between the latter two groups ($p > .05$, $d = .01$).

Since more than one dependent variable was involved (multiple-choice and open-ended), a multivariate analysis of covariance (MANOVA) was used. First of all, the covariate, prior knowledge, was significantly related to open-ended performance, F (1, 208) $= 8.92$, $p = .003$; $\eta^2 = .041$. Wilks' Lambda statistic indicated that there was a significant difference among the three groups after controlling for the effect of prior knowledge, Wilks' Lambda $= .73$, F (8, 410) $= 8.61$, $p < .001$; $\eta^2 = .144$. Univariate tests indicated a significant difference in open-ended performance, F (2, 208) $= 4.133$, $p = .017$; $\eta^2 = .038$, time spent in map activity, F (2, 208) $= 15.464$, $p < .001$; $\eta^2 = .129$, and time spent in answering posttest questions, F (2, 208) $= 17.514$, $p < .001$; $\eta^2 = .144$.

On the open-ended test, post hoc Bonferroni tests revealed that the map-translation group ($m_{\text{adjusted}} = 4.21$, $sd = .21$) significantly outperformed the fill-in-concepts ($m_{\text{adjusted}} = 3.49$, $sd = .22$), $p = .048$, $d = .39$, and fill-in-labels groups ($m_{\text{adjusted}} = 3.42$, $sd = .24$), $p = .039$, $d = .46$, while there was no significant different between the latter two groups. The map-translation group ($m_{\text{adjusted}} = 386.24$, $sd = 27.94$) spent significantly more time than the fill-in-concepts ($m_{\text{adjusted}} = 221.75$, $sd = 28.72$), $p < .001$, $d = .57$, and fill-in-labels groups, ($m_{\text{adjusted}} = 167.36$, $sd = 31.16$, $p < .001$, $d = 1.97$, while there was no significant difference between the latter two groups. Lastly, the

Table 3. Descriptive statistics of dependent measures for the three experimental groups.

	Map-translation ($n = 77$)		Fill-in-concepts ($n = 73$)		Fill-in-labels ($n = 62$)	
Experimental groups	M	SD	M	SD	M	SD
Prior knowledge	3.61	1.22	3.51	1.31	3.67	1.09
Multiple-choice	2.21	1.16	2.11	1.15	1.94	1.13
Open-ended	4.22	1.80	3.46	2.07	3.39	1.80
Map activity quality	8.08	2.43	6.77	2.74	6.73	3.60
Time in map activity[a]	386.75	136.60	219.70	389.44	169.14	76.49
Time answering questions[a]	210.26	285.45	363.28	151.10	409.37	157.50

[a]Time measured in seconds.

map-translation group ($m_{\text{adjusted}} = 210.58$, $sd = 24.10$) spent significantly less time than the fill-in-concepts ($m_{\text{adjusted}} = 361.99$, $sd = 24.77$), $p < .001$, $d = -.67$, and fill-in-labels groups ($m_{\text{adjusted}} = 411.19$, $sd = 26.87$), $p < .001$, $d = -.86$ in answering the post-test questions while there was no significant difference between the latter two groups. Descriptive statistics are presented in Table 3.

Discussion

The present study represents an initial endeavour to compare the effects of three different concept map activities among university students studying reaction enthalpy. We measured conceptual understanding (multiple-choice and open-ended), time spent in map activity, and time spent in working on posttest questions as dependent variables and our findings point to an overall benefit of concept map translating compared to the other concept map activities.

Results did not show any significant differences among the map-translation, fill-in-concepts, and fill-in-labels groups on multiple-choice question performance. It might be that concept map assists students regardless of the specific activity. In other words, the three concept map activities had an equal impact on conceptual understanding assessed by the multiple-choice questions. However, turning to free-response performance measured by the open-ended questions, the map-translation group scored significantly higher than the other two groups. Taking a closer look at the questions, we found that answering such questions would require the students to not only remember individual facts but also understand the relation of one concept to the other. In addition, the students would need to organise their thinking and write it down in an elaborated way, which is very much likely to expose a higher demand than answering the multiple-choice questions. Thus, one possible explanation is that translating a complete concept map using students' own words might promote deep inquiry and effortful processing and thus make learning more engaging than the other two map activities. As enunciated by Cuevas and Fiore (2014), explicitly prompting self-generated elaboration of concepts has been shown to be associated with increased knowledge acquisition and greater understanding of the domain. The inferiority of constructing a map through either filling in concepts or filling in labels could be attributed to the confusion caused by the lack of feedback. However, the map translation task may have an inherent demand for feedback that the map construction task does not have. Specifically, those in the map translation group were able to adjust their translation to match the complete map (most likely, they took the complete map for reference when translating, making the map a sort of automatic feedback) while for those in the fill-in-concepts or fill-in-labels groups, they might not be sure about the correctness of the concepts or labels they assigned to the numbers. Indeed, past research (e.g. Lachner et al., 2018) has shown that providing concept map feedback in general benefitted students' learning. This finding aligns with the study by Hwang et al. (2011) in that a concept map-oriented mobile learning system with an instant feedback mechanism provided can significantly improve learning achievement. The finding is also aligned with the studies of Hung et al. (2010) and Hsieh et al. (2011) that found that the provision of proper assessment tools can enable students to make reflections and engage in higher-order thinking in the field. It is noteworthy, however, that we caution against interpreting these results in a way that translating a complete map is preferred over any other map strategies given the general modest performance (4.22 points out of 10 points). Regardless of the significant results, our findings should be only taken as indicating that providing a complete map for students to translate might be more ideal than filling in concepts/labels in a map.

We also found that translation quality was positively related to free-response performance, as suggested by the regression analysis, indicating that the more parts of the map that could be accurately translated, the better the free-response performance. We may conclude that it is the quality rather than the merely format of the activity that underlies the effects of translating a concept map. Surprisingly, we were not able to find such a relation for the other mapping activities (i.e. filling in missing parts). It could be that filling in concepts/linking phrases might lessen the engagement and/or challenge levels as students could be cued by the options available to them, which may ultimately reduce the fidelity of the treatment.

Last, learners translating the map spent significantly more time than those who filled in concepts or labels on the map activity, which is intuitively reasonable as translating would require the learner to type a certain amount of words and thus take longer to complete the activity. On the contrary, the translation group spent significantly less time than the other groups on answering posttest questions. This is consistent with what has been found regarding learners' free-response performance. As stated above, those who translated the map might commit more time and engagement to the learning activity, leading to more effortful thinking and subsequently quickly responding to the questions. One explanation for this phenomenon is the idea of desirable difficulties, which posits that learning with more difficult materials leads to deeper processing and better learning outcomes (Bjork, 2013). In this study, learning with and translating the concept map using the learners' own words would be more likely to give rise to processing difficulties compared with participating in a filling in the blanks activity.

Implications and future directions

The study has significant theoretical and practical implications. On the theoretical level, the present research contributes to the growing literature on concept maps in two important ways. As stated earlier, one substantial gap in the existing research body could be that few empirical studies have compared the effects of studying a complete map versus constructing a map. Additionally, the present experiment extents and strengthens prior research on concept maps by taking into account time and effort committed to the map activity. Incorporating and examining such variables may produce more informative findings to gain insights into the mechanisms underlying the effectiveness of concept maps, which would greatly advance the field

On a practical level, instructional designers should consider varying concept map modes to increase the potential of concept maps. Responding to the results of this study, teachers and other educators may encourage students to study expert-built concept maps in an active way by having them translate the concept map for notes. As suggested by the findings of the present study, translating a map using learners' own words may be highly recommended as it could prompt them to spend quality time in transcribing and recoding information, which facilitates deeper thinking with regard to concepts and their relations embodied in the massive and complicated network. Furthermore, caution should be exercised about placing emphasis exclusively on the translating activity itself. Instead, teachers should focus more on investing resources in improving the quality of students' concept map translations. Prompting students to further self-explain the concepts and relations explicitly reflected in their translations may be an appropriate approach as the beneficial effects of self-explanations have been clearly documented for actively constructing understanding (Ainsworth & Burcham, 2007).

Although the results of this research are encouraging, it has several important limitations that need to be addressed in future research. First of all, the prior knowledge test used in the study merely targeted concepts in the domain of Reaction Enthalpy, which calls into question a concept itself reflects the student's real understanding of the concept (e.g. what does it mean, how is this related to other concepts). Second, there were only five multiple-choice questions as a post-test. Due to the limited number of questions, it may be questionable that participants' conceptual understanding can be adequately assessed. Third, the advantage of one group over the other could be ascribed to the different amount of information provided to the participants of different groups (i.e. the translation group was given about twice as much of the information as the other two groups), thereby rendering the theoretical value of the study somewhat limited. Another major limitation of the study is that it failed to consider the effects of essential individual characteristics students' interest and self-efficacy that may hold the potential for moderating the impact of concept maps. Besides, the limited options for the fill-in-concepts and fill-in-labels groups might make the activity less challenging and thus might compromise the anticipated engagement. A final point we wish to state is that since the present experiment focussed only on a narrow chemical domain (i.e. enthalpy), it will be critical to replicate the study using other topics in chemistry or different disciplines.

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