Analyzing the syntax and salience of causal links embedded within semantic links in concept maps: Implications for temporal flow and learning transfer

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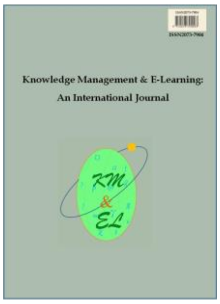

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Analyzing the syntax and salience of causal links embedded within semantic links in concept maps: Implications for temporal flow and learning transfer

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Abstract: Including causal links in concept maps enables learners to meaningfully relate concepts to a larger context or problem in terms of how and where concepts apply within the chains of causal events that lead to a given goal or outcome. Given that higher quality maps are produced when students link and sequence events to flow temporally and sequentially in a consistent direction towards a target outcome in a map, it is highly plausible that students can improve learning transfer (the ability to apply concepts to diagnose and solve problems) by including and making more salient the sequences of causal links nestled in the semantic links in concept maps. To lay the groundwork to empirically test this proposition in future research, this study: 1) analyzes 16 concept maps presented in the Proceedings of the 8th Int. Conference on Concept Mapping to codify the diverse and sometimes incongruent syntaxes used to convey causal relationships; 2) examines how the causal link syntaxes combined with semantic links work jointly (or against each other) to create temporal flow; and 3) explore how causal and semantic links can be integrated to increase the saliency and quality of the causal networks connecting concepts to outcomes. A better understanding of how causal links are expressed, integrated, and made more salient in concept maps can reveal ways to help students create concept maps that are more accurate, meaningful, and effective in improving the ability to apply concepts to solve complex problems.

Keywords: Concept maps; Casual links; Semantic links; Temporal flow; Learning transfer

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1. Introduction

Concept mapping is used to engage students in the process of identifying and relating new concepts, for example, to super-ordinate and subordinate concepts and relating concepts to other concepts that impact or are impacted by the concept (Cañas et al., 2015). These maps can then be shared between students to improve and build shared understanding (Campbell, 2022). In concept maps, relationships are made explicit by connecting concepts with links and labelling each link to describe the nature of the relationship between two concepts. The recommended process for constructing such concept maps is to avoid imposing constraints on how learners are to link concepts and label the links (Ruiz-Primo et al., 2001). The goal is to reduce cognitive load and maximize opportunities for students to fully articulate and explore their current understanding of a concept or a problem in relation to their prior knowledge. This recommended process, however, not only makes scoring concept maps more difficult (Yin et al., 2005), this process can produce concept maps that, for example, use one syntax to link one set of concepts (e.g., A-impacts→B, with node A containing both subject and verb to identify an event) while using an alternative syntax, for example, arrows pointing in the opposite direction (e.g., B--is impacted by→A) elsewhere in the same concept map. What variety of syntaxes are used to convey causal (or functional and dynamic) relationships, how are they juxtaposed with semantic links within the same map, and how do they affect students' ability to articulate and grasp higher-level meaning from their maps (and from the maps of others) has yet to be examined in the research on concept mapping.

What is known from prior research is that map quality and accuracy increase as the proportion of causal links pointing towards (rather than away or orthogonal to) the outcome positioned in the concept map increase (Jeong & Lee, 2012). Maps with a higher proportion of links pointing toward the outcome than away from the outcome can be described to exhibit more temporal flow. Correspondingly, the maps where the outcomes are placed closest to the edge of the map (e.g., top centre, far right) also help to increase temporal flow (Jeong, 2020). Maps that are structured in a network format with one outcome node positioned in the center of the map exhibit less flow and accuracy on average. Similarly, identifying and positioning the outcome node at the start of the mapping process and working deliberately backwards from the outcome to flesh out the chain of events downstream from the outcome (iteratively asking "what causes C", "what causes B" and "what causes A" to reveal the event chain A→B→C) produce the most accurate maps (Hinkelmann, 2004; Jeong & Kim, 2022; Seok-Shin & Jeong, 2021). These findings altogether suggest that more consistent use of one syntax to convey and make causal links more salient in concept maps can help produce maps with more temporal flow, and in the process, help students construct more accurate concept maps.

In addition to improving accuracy and quality, clearly conveying the causal chain of events (or chain of subject-verbs) that lead to a given outcome in a concept map (and at the same time, semantically linking concepts to causal events) may help students achieve learning transfer – the ability to recognize where and when to apply a specific concept to address a specific part of the problem and understand how this all fits within the entire chain of events that produces the problem. A significant challenge in learning and instruction is that concepts can be taught in isolation from the application of the concepts. Concept maps are constructed primarily to link and identify semantic relationships (instead of causal relationships) to learn concept definitions. The focus on semantic relationships can strengthen a student's ability to define and better understand concepts. However, it does not necessarily strengthen students' ability to understand the deeper meanings, the functional value, and functional relationships between concepts to enable them to use concepts to understand, break down, diagnose, and solve a problem (Chen et al., 2021; Wang et al., 2018; Wu & Wang, 2012). It is for these and other reasons that research be conducted on finding ways to combine semantic and causal relationships within a single concept map (Safayeni et al., 2005) and finding specific structures that can help students better identify and convey both semantic and causal relationships (Derbentseva et al., 2004).

To empirically study the effects of using specific syntaxes and conventions to convey causal relationships, one initial and necessary step is to operationally define causal links (particularly the directionality of causal links) by identifying, articulating, and classifying the variety of syntaxes used in concept maps to convey causal relationships. Such operational definitions are necessary to distinguish causal links from semantic links and the directionality of causal links so that students' concept maps can be assessed and scored on temporal flow. In doing so, future studies can examine how differences in the syntaxes students use to convey causal relationships affect the temporal flow and how flow in turn affects learning transfer. A cursory glance at concept maps in the research literature reveals how causal links are conveyed using a large variety and combination of syntaxes (some used frequently, and some not so frequently): links using arrows with single, double, or no arrowheads; link labels with verbs or verbs with subject or verbs with qualifiers; links that point towards or away from the impacted concept depending on the choice of wording in the label; links that vary in density to convey differences in impact or contingency; and nodes with subject and verb or subject only.

The purpose of this study was to identify the variety of syntaxes (i.e., words and phrases arranged in nodes with labelled links presented with or without arrowheads) used in concept maps to convey causal relationships and to examine to what extent these variations in causal link syntax combined with semantic links work jointly (or work against each another) to create and reveal intact and visually salient event chains within a concept map that lead to a given outcome. Such an analysis can, for example, help determine when semantic links and specific syntaxes used to convey causal relationships might visually obscure the causal event chains in a concept map (e.g., forcing event chains to circumnavigate around semantic propositions), reduce temporal flow, and create disjointed causal event chains. Findings from this analysis may help determine when to use specific syntaxes and how to mix semantics with causal links to minimize disturbances in temporal flow, maximize the visual salience of causal event chains, and ultimately, increase learning transfer. As a result, the purpose of this study was to address the following research questions:

RQ1: What syntaxes are used to convey causal relationships in concept maps?

RQ2: How do the variety of syntaxes used to convey causal links and the semantic links included in a concept map work jointly (or work against one another) to reveal causal links with the temporal flow?

RQ3: How salient are the causal event chains and how well are they connected (not disjointed) to the resulting outcomes in concept maps?

2. Method

2.1. Data collection

A total of 22 concept maps were retrieved from all 22 English-only papers containing a concept map published in the Proceedings of the 8th International Conference on Concept Mapping (Cañas & Reiska, 2018). Of the 22 concept maps, 7 were omitted from the analysis because 3 did not possess causal links, 2 did not possess a high-level outcome or culminating event, and 1 was a concept map presented with intentional errors. As a result, a total of 16 concept maps on a variety of topics created by researchers, teachers, and students (see Table 1) were analyzed in this study.

Table 1
Descriptions of causal links in 16 concept maps sorted from highest to lowest in flow, per cent of causal links, and total links

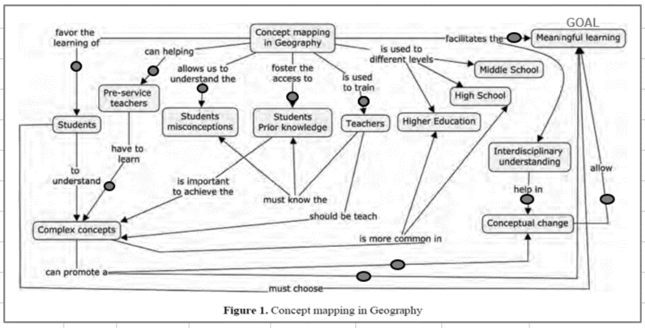
Map	Topic of Concept Map	Cause → effect	With arrowhead	With action	Qualified	Causal links	Total links	% Causal links	Outcome position	Percent of A → B with flow	Percent of B → A with flow	Author identity	2018 CMC Proceeding page #
1	Regenerate skin tissue	24%	100%	6%	0%	17	52	33%	Top	0%	93%	Researcher	96
2	Oncologist map to assess cancer risk	25%	100%	50%	75%	9	25	36%	Top	33%	100%	Researcher	387
3	Deliver course on concept mapping	13%	100%	60%	27%	15	16	94%	Top	0%	100%	Researcher	395
4	Motivate students to choose science career	52%	57%	52%	5%	21	33	64%	Top right	100%	0%	Teacher	259
5	Benefits of concept mapping	91%	100%	36%	27%	11	19	58%	Top left	36%	100%	Researcher	71
6	Conservation of energy	75%	100%	25%	0%	4	10	40%	Right	33%	0%	Researcher	76
7	Achieving machine safety	20%	100%	0%	40%	10	15	67%	Right	100%	67%	College	30
8	Motivations behind improving teaching	73%	100%	18%	47%	11	15	73%	Right	25%	100%	Interviewer	61
9	What is internet banking?	33%	100%	50%	0%	4	12	33%	Bottom	0%		Researcher	315
10	Mapping field of adult education	69%	46%	31%	0%	13	80	16%	Bottom	100%		Researcher	266
11	How teachers handle combative students	89%	0%	56%	0%	9	21	43%	Bottom			Teacher	232
12	How to implement cmap to complete report	87%	47%	62%	33%	15	19	79%	Bottom rt	100%	50%	Researcher	119
13	Protect nature	100%	100%	100%	0%	1	13	8%	Bottom rt	100%		Elementary	201
14	Women of science activity to achieve equity	42%	100%	17%	0%	12	35	34%	Bottom rt	80%	0%	College	223
15	Defining customer-order database	50%	50%	50%	0%	2	10	20%	Left	50%		Researcher	351
16	Effects of drinking milk	96%	27%	65%	17%	23	33	70%	Top left & bottom	40%		High school	160
	Average	59%	77%	42%	17%			48%		53%	61%		

2.2. Research question 1: Identify causal links & link syntax

Each concept map was copied into a spreadsheet (Fig. 1) and each link in the concept map was coded as either a link that conveyed a semantic relationship or a causal relationship. A causal link was defined as a proposition that describes a person or thing that gives rise to an action, phenomenon, or condition (e.g., A-caused→B or A→B), or inversely, when B is caused by A (or B→A where B "needs" or "depends" or "involves" A). All other links were coded or tagged as semantic links. When coded as a causal link, a coloured circle (light grey for A→B links and black for B→A links) was placed on the link in the concept map, and the text presented in the link's label was entered verbatim into the spreadsheet. Next, the keyword in the label used to convey the causal relationship was identified, along with other information on each causal link. A determination was made for each link on whether the relationship was conveyed using the A→B or B→A syntax (marked with light grey and black circles in Fig. 1); if the link possessed an arrowhead; if the label included a verb or action performed by the subject; what qualifiers were presented with the verb or action. Of the links that were identified as causal links in three concept maps selected randomly from the 16 concept maps, there was substantial inter-rater agreement in coding causal links as either A→B or B→A syntax, Cohen's κ = 0.69. Inter-rater agreement was fair in coding links as a causal link versus semantic link,

κ = 0.327. Also recorded for each map were: the total number of causal links; the total number of all links in the map; the percentage of links that were causal links; if the map possessed a possible goal or culminating outcome (determined by close examination of the map's title, purpose, and scanning for nodes positioned at the top, right, and bottom); where the goal was positioned in the concept map; a longest unbroken chain of causal links; and the percentage of causal links that point towards or in the general direction of the given outcome.

M	Map topic & Link Labels	Keyword	Cause ->Effect	With arrow head	With action	Qualified	Causal links	Total links	% Causal links	Goal or outcome node	Outcome position	Longest chain w/ any link direction	% Links contribut-ing to flow	Author
1	**Benefits of Concept Mapping**		91%	100%	36%	27%	11	19	58%	1	TL	3	27%	researcher
1	favor the learning of	favor	1	1										
1	can promote a	promote	1	1		can								
1	can help	help	1	1										
1	have to learn	<action>		1	1	have to								
1	can promote a	promote	1	1		can								
1	allows us to understand the	allow	1	1	1									
1	foster the access to	foster	1	1	1									
1	used to train	use	1	1	1									
1	facilitates the	facilitate	1	1										
1	facilitates the	facilitate	1	1										
1	allow	allow	1	1										
4	**Achieving Machine Safety**		20%	100.0%	0%	50%	10	15	67%	1	R	3	60%	college
4	which may be the cause of	cause	1	1		may be								
4	often involve	involve		1		often								
4	involves	involve		1										
4	involves	involve		1										
4	involves	involve		1										
4	needs	need		1										
4	often requires	require		1		often								
4	requires	require		1										
4	is needed because of	because		1		needed								
4	can be acted by	acted by	1	1		can be								



Note. Light circle = B-caused-A causal link, dark circle = B→A causal link, goal = high-level outcome in concept map, cause→effect column = 1 for causal link using B→A orientation and blank for using A→B or "caused-by" orientation

Fig. 1. Excerpt from the spreadsheet used to code causal links in the concept maps

These and other noted characteristics were incrementally added to the coding scheme at the time new characteristics were observed in a concept map. Each time a characteristic was added to the coding scheme, the concept maps previously coded were revisited to score them across all newly added characteristics. Any unique syntaxes observed in a specific causal link (but not commonly observed in the concept maps by and large) were eventually noted and flagged only in the causal link's entry in the spreadsheet (not added as a new code or link characteristic in the coding scheme). For example, In one case, the subject, verb, and object were placed into their node to present the proposition A ・ verb ・ B. Only the verb ・ B could be counted as a causal link and this anomaly was noted in the link entry. Any observed characteristics that could not be clearly articulated and operationally defined were removed from consideration so that the final coding scheme used in this study (and in future studies) can produce coded causal links with high feasibility and reliability.

2.3. Research question 2: The temporal flow of causal links in concept maps

To determine temporal flow in each concept map, the number of causal links that point towards the outcome (within a 90-degree radius) is divided by the total number of causal links (Jeong, 2020). To account for the two syntaxes used to convey a causal relationship, the sum of A→B links with arrowheads pointing *towards* the outcome *plus* the number of all B→A links with the *tail* of the link (*not* at the head of the link) pointing *towards* the outcome was divided by the total number of causal links in the concept map. Large fluctuations in the number of A→B versus B→A links within each map did not make separate reporting and comparisons on the flow between the two types of links possible. When causal links possessed two arrowheads to convey a bi-directional relationship and any one of the two arrowheads pointed towards the outcome, that link was counted positively in the measuring of flow. When a causal link did not include an arrowhead, the link's label was used to determine which end of the link was attached to the affected person, place, or thing and the direction in which that end of the link was pointing. All links presented in a concept map were accepted and coded as given (even if a possible error or incongruency was detected) because the researcher could not claim to possess sufficient knowledge of the content to make such corrections or guarantee that the researcher's interpretation of the causal link matches the intended meaning of the causal links produced by the original author of the concept map.

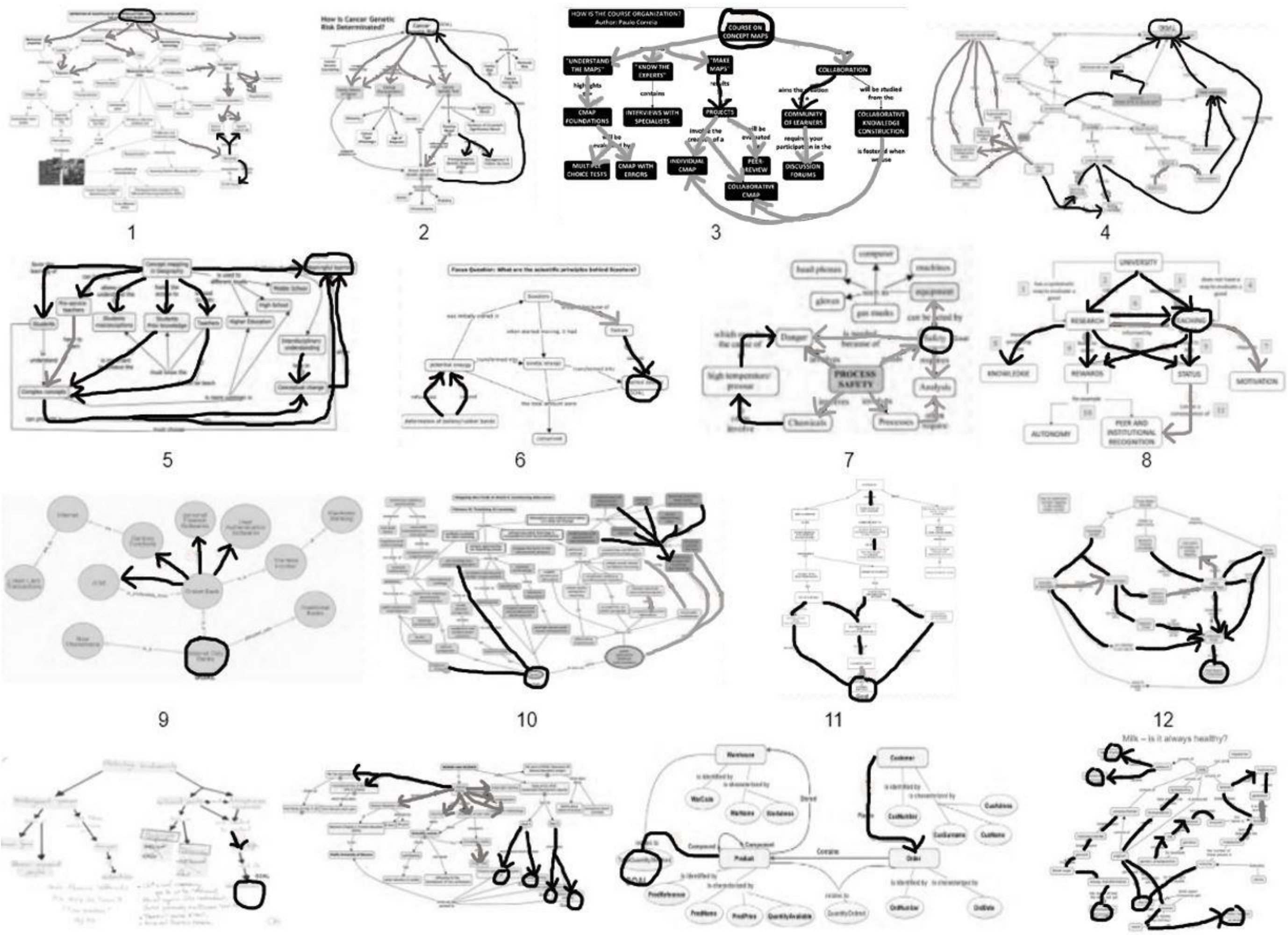
2.4. Research question 3: Causal event pathways to outcomes

In order to evaluate the degree of connection between causal event chains and pathways with the outcome(s) in each concept map, the following annotations were made: 1) black links to identify A→B links with and without arrowheads; 2) grey links to identify all B→A links with and without arrowheads (see Fig. 2); and 3) a large circle placed over the given outcome(s) in the concept map. The contrast between the black versus grey-coloured links in the annotated concept maps helps to visually assess, compare, and reveal the level of disruptions in the causal pathways to the outcome, losses in the saliency of causal links, and temporal flow in the causal event chains when using a mix of causal link syntaxes as opposed to using just the A→B syntax.

3. Results

3.1. Syntaxes used to convey causal relationships

Table 2 lists the keywords and phrases (with observed frequencies) from the 16 concept maps to convey the causal relationships using the A→B and B→A syntax. A total of 32 keywords and phrases were used to label 86 A→B causal propositions (how a person or thing gives rise to an action, phenomenon, and change in status or condition), while 24 causal propositions were labelled using more specific verbs or more detailed action phrases. A total of 16 keywords and phrases were used to label 46 B→A causal propositions along with 14 specific verbs or more detailed action phrases. One characteristic of the keywords and phrases used to label A→B propositions is the use of a single stand-alone active verb, whereas the labels used in B→A links used or added prepositions such as "helped by", "based on", and "after" or used words that convey dependency such as “requires” and “needs”. Labels containing verbs and actions that do not affect the state of the object were not identified as causal links (e.g., “cat *sees* mouse” vs. “cat *eats* mouse”) unless a change in the status of the subject or object is stated in the outcome or child node.



Note. Black links with or without arrowhead = A→B causal link; Gray lines with or without arrowhead = B→A causal link; Circle = outcome

Fig. 2. Annotated concept maps to visually assess temporal flow and continuity in causal link pathways to outcomes, Adapted from Cañas and Reiska (2018)

Table 2
Keywords and phrases used in the labels of causal links using the A→B and B→A syntax

A--caused --> B Frequency of key words and phrases				B -- caused by --> A Frequency of key words and phrases	
10	causes	2	acted by	11	requires
8	leads to	2	basis for	6	needs
6	results in	1	relieves	6	involves
4	promotes	1	protects	4	with
4	increases	1	prolongs	3	uses
4	help	1	manifests	3	follows
3	rise	1	influences	3	determined by
3	facilitates	1	improves	2	important
2	forms	1	fosters	1	values
2	determines	1	favors	1	impacted by
2	and	1	empowers	1	helped by
2	allows	1	takes place	1	developed by
2	used to	1	supports	1	consequence of
2	provides	1	sets up	1	because of
2	aims at	1	values	1	based on
2	affects	1	undervalues	1	after
Specific verbs or action phrases (*n* = 24)				Specific verbs or action phrases (*n* = 14)	
means producing new, liberation, is consistently revised into, construct, annotate on each other's, could be organized as a, breaks down, result of that the body will get, take part of the process, production will get, which damages, lack of it disturbed the, by drinking a milk causes, toilet paper companies get, for the money they will buy, can take part, reaction, learned, sent to, re-focused, continued, develops, building, used in, install				have to learn, is somehow informed by, it is break down by, using, develops, talking, visiting, places, indicates the presence of, presents, highlights the, will be evaluated by, requires your participation in the, will be studied from the	

The average percentage of causal links using the A→B in syntax was 59% across the 16 concept maps (see Table 1). Also, the average percentage of causal links that were labelled with specific verbs or more detailed phrases was 42%, and the average percentage of causal links with a headed arrow was 77% (with 10 maps using arrowheads in all causal links and 1 map using no arrowheads), and the average percentage of causal link labels that included a qualifier was 17%. The words used to qualify the verbs and actions in the labels (16 total) included the following: can or can be (10), will (5), lack of (3), should (2), often (2), more (2), may (2), less (2), sufficient (1), somehow (1), produce (1), may be (1), highly (1), have to (1), consistently (1), believed (1). The A→B causal links possessed 58% of the qualifiers and the B→A causal links possessed the remaining 42% of the qualifiers, hence qualifiers were used equally between the two syntaxes.

3.2. Causal link syntax and temporal flow

The summary data in Table 1 do not reveal any notable trends to indicate that using one syntax or the other (A→B or B→A) influences how a concept map might convey more versus less temporal flow, or that the higher proportion of semantic links to causal links might obscure and reduce temporal flow. One pattern revealed from the summary table is that the concept maps with both the highest and lowest flow were those that possessed the fewest number of causal links in absolute numbers and had the lowest number of causal links in proportion to the number of semantic links.

3.3. Causal link saliency and pathway connection to outcomes

The annotated concept maps in Fig. 2 (with black- and grey-coloured arrows to identify causal links with the A→B and B→A syntax, respectively, and to visually distinguish causal from semantic links) reveal that only 4 maps (3, 5, 12, and 16) possess a fully or almost fully closed network of causal links where all or nearly all causally linked nodes can be traced through the network of *directional* links to arrive at the outcome. Maps 2, 4, 7, and 8 appear to also show a closed network of causally linked nodes, but these maps contained more causally linked nodes that are orphaned and isolated from the outcome than maps 3, 5, 12, and 16. A total of 8 maps showed a disjointed network of causal links containing orphaned nodes that cannot be traced to the outcome (maps 1, 6, 9, 10, 11, 13, 14, and 15). Fig. 2 also shows how the maps that use both syntaxes tended to cluster and spatially separate the causal links of one syntax from those using the other syntax (maps 1, 2, 4, 7, 14).

In this analysis, determining whether the causal links form a complete and unbroken chain to the outcome(s) was not a straightforward process. B→A links had to be mentally reversed to point in the opposite direction to see if all arrows lay a pathway to connect each causal event to the outcome. If a map contained more B→A links than A→B links, the A→B links instead were mentally reversed to point in the opposite direction to assess the pathways connecting the events to outcomes. Worth noting here is that tracing the links from the outcome node to every causally linked node (where the location of each can appear to be haphazard at times) was a significantly more difficult mental process than tracking each causally linked node to the outcome. Tracking nodes to outcomes is easier because there is a fixed number of outcomes and that these outcomes are often positioned at a prominent location on the map. As a result, reviewing the network of causal links with the A→B syntax was a simpler process when evaluating concept maps containing causal links using both syntaxes. Furthermore, examining the causal links with no arrowheads to clearly mark the causal direction required a close reading of each node-label-node proposition to determine the direction of the causal relationship.

4. Discussion

The purpose of this study was to identify the syntaxes used to construct and differentiate causal links from semantic links in concept maps, then examine how the variety of syntaxes used in causal links mixed with semantic links work jointly (or work against one another) to produce causal links with temporal flow, and to produce causal pathways that are visually salient and fully connect all causal events to (not disjointed or orphaned events) to outcomes. The first finding in this study is that the structural analysis of causal propositions revealed the existence of two contrasting syntaxes used to add causal links in concept maps – each using arrowheads that point in opposite directions. The A→B syntax was used slightly more often than the B→A syntax, and the most common words used in the A→B labels were “causes”, “lead to”, and “results in”. In contrast, the labels in B→A links often presented a propositional word immediately following the verb, using prepositions like “by”, “of”, and “on”. They also used more passive forms of actions and verbs that convey dependency like “requires”, “needs”, and “involves”. The constructed list of observed keywords and characteristics of causal link labels can be used to provide students with guidance on how to add causal links using either syntax and guidance on how to accurately interpret the direction of causal links when reviewing and evaluating their own or other students' concept maps. This and any future refinements to such a list of suggested syntaxes can help students better distinguish semantic links from causal links better than the level of inter-rater agreement (fair) achieved in this study.

In examining the temporal flow in the concept maps, no specific patterns emerged from the data to show possible relationships between causal link syntax (and the other characteristics related to causal links) to temporal flow. This suggests that the choice of the syntax used to convey causal relationships might have little or no impact on the temporal flow when constructing concept maps. The annotated concept maps in Fig. 2 present a feasible method for visually assessing maps for temporal flow, particularly when all causal links are presented with arrowheads to explicitly convey their causal direction. In this study, only three-quarters of the causal links on average were conveyed with arrowheads. The data provide some indication that the concept maps with the high flow were those with the outcome positioned at or near the top of the concept map – consistent with prior research findings (Jeong, 2020; Seok-Shin & Jeong, 2021). The data also indicate that the concept maps with both the highest and lowest flow were those that possessed the fewest number of causal links in absolute numbers and had the lowest number of causal links in proportion to the number of semantic links, respectively. Although the sample size is too small to make this and the other finding definitive, this pattern suggests that concept maps that contain few causal links (perhaps in maps representing less complex problems) can more easily navigate around semantic links to align and point all causal links towards the outcome.

As for the salience of causal pathways that help relate concepts to outcomes, this study found that nearly all the concept maps contained a portion of causal links that were disjointed with no intact pathways to trace all causal events and their associated concepts to the outcome. The annotated concept maps clearly show how causal pathways can be interrupted, severed, and obscured when inserting semantic propositions to define concepts embedded within each causal proposition. Although the concept maps analyzed in this study may not have been constructed with the goal of breaking down specific outcomes into complete event chains, the disjointed nature of the causal pathways nevertheless identifies ways to improve the quality of concept maps. It also identifies missed opportunities to better articulate and refine our understanding of where and when concepts are applied in context to specific problems. Related to this finding was that the process of tracing the pathways from each causal event to outcome was further complicated when concept maps used causal links written with both A→B and B→A syntax (with or without arrowheads). The main implication here is that the difficult process of tracing through causal links with different syntax can potentially and negatively impact the concept mapping process itself - an iterative process of creating, evaluating, revising, and improving the concept map. As a result, promoting the use of one and only one syntax when adding causal links can potentially alleviate this problem.

In this study, the A→B syntax was used slightly more often than the B→A syntax. One rationale for promoting the A→B over the B→A syntax is that the A→B syntax conforms with the dominant subject-verb-object (SVO) sentence structure applied in many languages (e.g., English, Chines, Dutch, French, German, Italian, Russian, and Spanish). However, the OVS form (which mirrors the B→A syntax) is the dominant structure in other languages (e.g., Apalai and Hixkaryan), while the verb-object-subject is the dominant structure for Irish, Filipino, Arabi, and Hebrew. As a result, the syntax that may be easiest or most natural to apply when adding causal links to concept maps may differ across cultures. At the same time, English speakers often use "cause" and "because" interchangeably, using "cause" as a short form of "because", particularly when used in conversation, but less so in written communication. This and other similar conventions can present a source of confusion when adding and interpreting causal links in concept maps. It also presents one possible explanation as to why the A→B and B→A syntax was found to be used so interchangeably and why the average percentage of causal links of either syntax was nearly equal in number.

Although it goes against the general practice that minimal constraints should be placed on the concept mapping process, promoting the use of arrowheads in causal links is another way to make the causal pathways more salient. By including arrowheads, reviewing concept maps for temporal flow is significantly simplified and avoids the cognitive load brought on by having to closely read every proposition without arrowheads to ascertain its causal direction on each reading and each pass through the create-revise-evaluate concept mapping process. To minimize interruptions in the causal pathways and to make these pathways more salient during and after the concept mapping process, one can distinguish causal from semantic links by doubling the density of causal links, presenting them without labels, and clearly marking and prominently positioning the outcome of interest in the concept map. For example, one alternative is to align all causal link arrows to flow horizontally from left to right with the outcome placed at the far-right edge of the map. Then organize and align all concepts that define or describe a specific event into a hierarchical structure so that concepts are positioned below but in close proximity to the associated event without obscuring the causal pathways linking the event to the outcomes.

4.1. Limitations and directions for future research

The findings in this study revealed particular issues that can arise when integrating causal and semantic links into a concept map – issues that can be examined in more detail in future research. At the same time, the limitations of this study point to additional directions for future research that can build on the findings and the methods presented in this study. Some directions for future research are the following: 1) analyze a larger sample of concept maps across multiple disciplines and user populations; 2) analyze concept maps representing a set of known problems that carry complex hierarchical causal events pathways and not just problems that possess a flat hierarchy that consists only of direct causes; 3) improve inter-rater reliability in the coding and identification of causal links (particularly the challenge of coding subject-verb-object propositions); 4) experiment with alternative measures of temporal flow, like those used in social network analysis tools to measure network structures; 5) include the analysis of maps written in Spanish given that such maps have been found to use more prepositions in labels and as a result, may use more B→caused-by→A than A→causes→B syntax; 6) conduct case studies with think aloud protocol to further refine and validate the noted methodological issues and processes reported in this study; and 7) conduct controlled experiments to test the effects of using one syntax vs both syntaxes on cognitive load, saliency of causal pathways, map revision processes, temporal flow, and most of all learning transfer – the ability to identify how concepts are associated with and apply to a given problem.

5. Conclusion

This study conducted a detailed analysis of concept maps containing both causal and semantic links to gain insights into the syntaxes used to convey causal and semantic relationships and how differences in syntax can potentially affect specific qualities of the concept map that can potentially impact learning transfer. Overall, the main findings showed that: 1) two syntaxes are often used to convey causal relationships; 2) the use of both syntaxes in the same concept map combined with links with missing arrowheads creates difficulties in reviewing a concept map for temporal flow (a characteristic shown to be associated with higher quality maps); and 3) these factors altogether provide one possible explanation as to why concept maps often possess incomplete causal pathways that prevent one from understanding how specific events and associated concepts are linked to a given goal or outcome. Although the findings here cannot be deemed to be conclusive, this study introduces key questions, ideas, constructs, and methods that will hopefully lay the groundwork for further research and development of mapping strategies that will improve the quality of concept maps and in turn improve learning transfer.

Author Statement

The authors declare that there is no conflict of interest.

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