

**Modeling and Visualizing Causal Mapping Processes That
Achieve Deep Causal Understanding and Systems Thinking**

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A handwritten signature in black ink, appearing to read "Allan Jeong". The signature is written in a cursive, flowing style.

Modeling and Visualizing Causal Mapping Processes that Achieve Deep Causal Understanding and Systems Thinking

Allan Jeong & Hyoung Seok-Shin

Abstract

A growing body of research shows that deeper understanding of complex systems can be achieved by constructing causal diagrams to articulate and refine one's understanding. This study sequentially analyzed students' causal mapping behaviors to distinguish action sequences that students use to create diagrams of high versus low accuracy. The findings provide directions on how to standardize causal mapping software so that such tools can be used effectively to assess students' understanding of complex systems.

Introduction

Causal diagrams can be used in science education as a tool to teach and assess learners' understanding of complex phenomena. Given that causal maps in theory represent learner's cognitive structures, complex reasoning, and conceptual development, causal diagrams have been used to elicit, articulate, refine, assess, and improve understanding of the causal mechanism underlying complex problems. In addition, maps can be used in particular to support collaborative learning when students compare their maps to identify, trigger, and focus group discussions around key differences in viewpoints. A number of studies have formulated metrics to measure the accuracy and structural attributes of students' maps. Studies have been conducted to determine how different constraints imposed on the map construction process affect student's maps and learning, as well as to develop software tools to automate and reliably measure both the accuracy and the structural attributes of maps.

However, maps should not be used for large-scale assessments until students' prior knowledge/skills with using maps are thoroughly examined. One way to address this problem is to identify and model the processes that lead students to produce more accurate causal diagrams. However, no prior research has empirically identified, tested, and validated specific action sequences despite the variety of existing guidelines on how to create causal maps, conduct root cause analysis and engage in systems thinking. As a result, this study addressed the following questions:

1. What patterns exist in the sequences of actions used by students that produce causal diagrams that are high versus low in accuracy?
2. Which sequences of actions help students create more accurate causal diagrams?

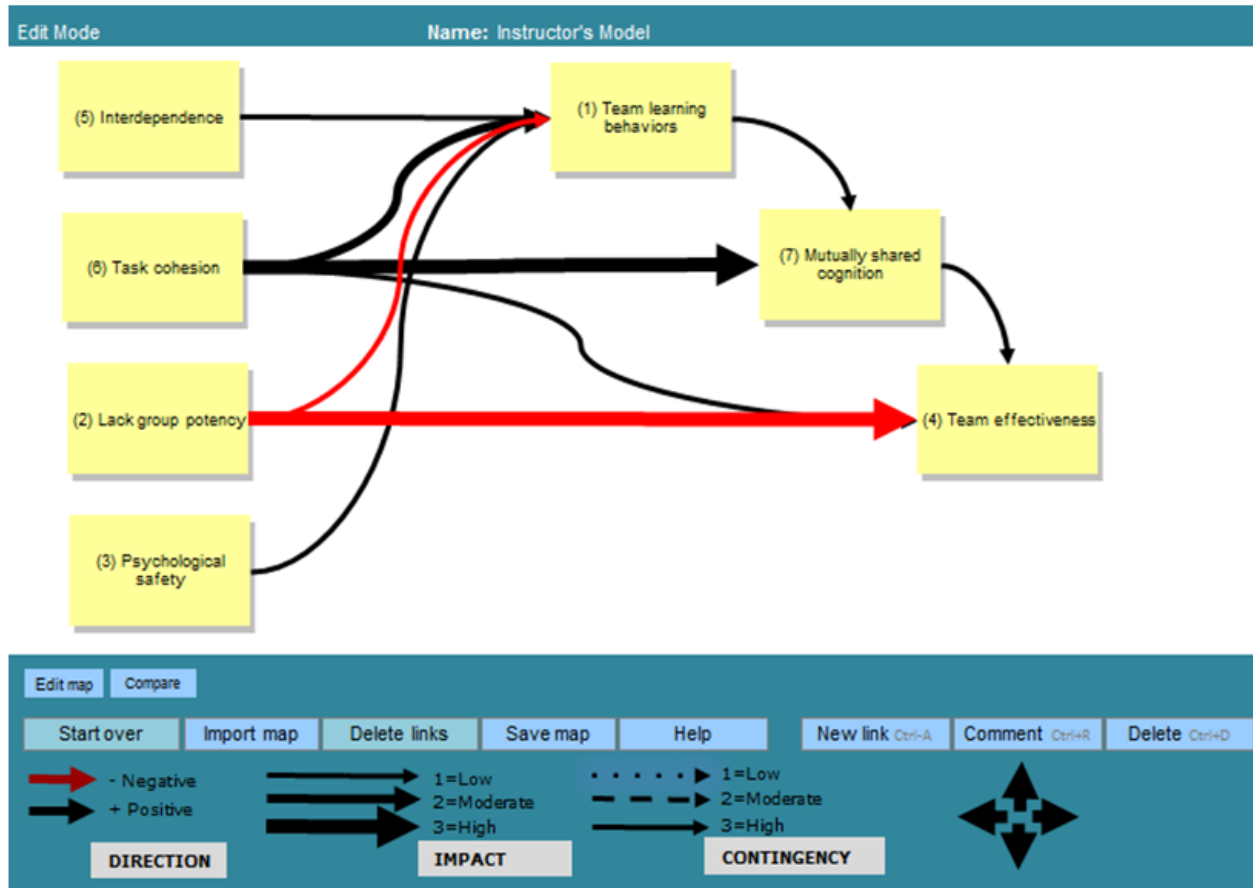
Method

Procedures

Seventeen graduate students in an online course on collaborative learning at a large south-eastern university were presented with an activity to formulate their personal theory in collaborative learning. Students were instructed to use jMAP (Figure 1) to individually create a causal diagram containing seven pre-defined variables believed to influence team effectiveness in collaborative learning groups. The goal was to construct a diagram to convey each student's personal theory as to how the six variables directly/indirectly affect team effectiveness. Students were presented a video and practice activity to learn how to move and re-position nodes, insert

links between nodes and affected nodes, change the density of the link to convey relative level of impact (high, medium, low), and change direction of the causal relationship (positive = black, inverse = red). They logged into an Elluminate web-conferencing session to record the entire map construction session (limited to 45 minutes maximum). At the same time, the jMAP software logged each action students performed on their diagram from start to finish.

Figure 1. Instructor’s diagram used as criterion for assessing the accuracy of students’ diagrams



Data Analysis

The fourteen causal diagrams completed and submitted by students were imported into jMAP to assess each students’ diagram (Figure 2) in relation to the instructor’s diagram. The instructor’s diagram was based entirely on the findings from an empirical study that determined the relationships between the variables using path analysis. Six criterion measures/scores were each multiplied by 10 and summed to determine each students’ total score (Figure 3). The diagrams produced by students that achieved the top five and bottom five scores were selected for analysis. The jMAP software captured 26 types of mechanical actions students performed on their causal diagrams (Table 1). These 26 actions were collapsed and reduced to six codes to facilitate the process of identifying overall patterns in students’ actions and action sequences. The codes sequences were imported into the DAT software to: a) compute transitional probabilities between action pairs; b) compute z-scores at $p < .01$ to identify behavior “patterns”; and c) generate transitional state diagrams to visually convey and compare behavioral patterns exhibited by students that achieved high versus low scores on their causal diagrams.

Figure 2. jMAP’s visual and quantitative assessment of a student’s diagram

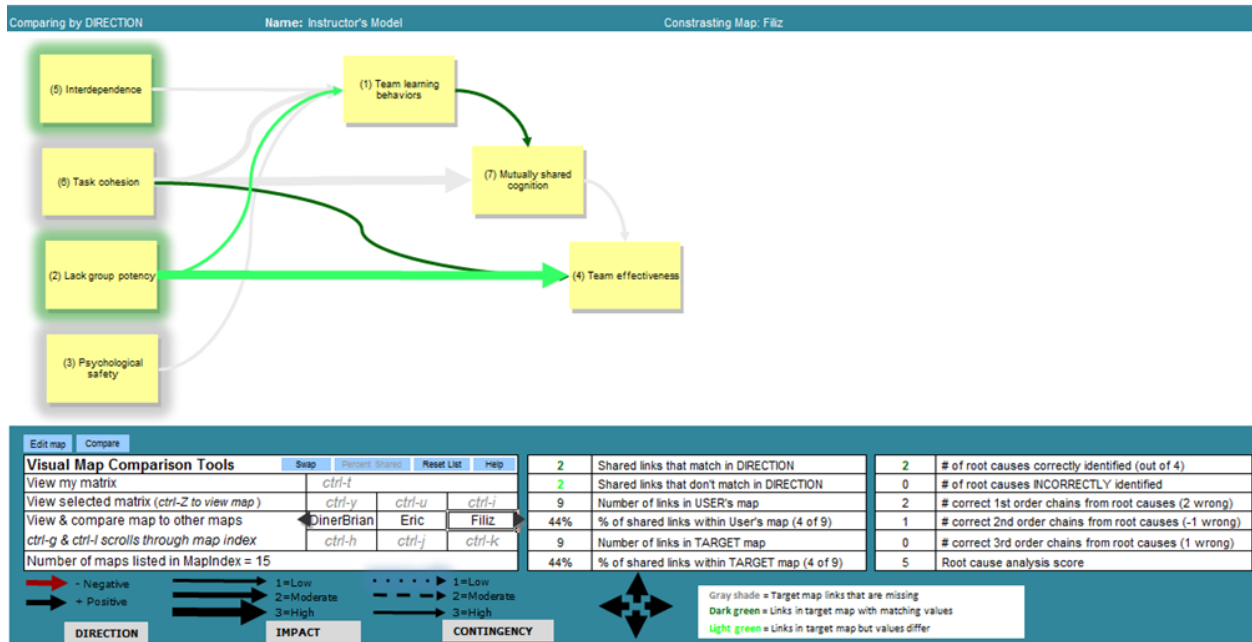


Figure 3. Ranking of students based on causal diagram scores across six criterion measures

	Shared links that match in DIRECTION	% of shared links within User's map	# of root causes correctly	# of correct 1st order root links	# of correct 2nd order root links	# of correct 3rd order root link	Total Score
JosAnn	4	57.1%	2	1	1	1	95.71
Filz	4	44.4%	2	2	1	0	94.44
Fran	7	57.1%	0	0	0	0	75.71
Rodi	6	23.1%	0	0	0	0	62.31
DinerBrian	3	25.0%	1	0	0	0	42.50
Lauren	4	15.4%	0	0	0	0	41.54
Barbara	2	25.0%	1	0	0	0	32.50
Kimberly	2	18.2%	0	0	0	0	21.82
Vade	1	25.0%	0	0	0	0	12.50
Chevanda	1	12.5%	1	0	0	0	21.25
Bryan	1	16.7%	0	0	0	0	11.67
Eric	1	16.7%	0	0	0	0	11.67
Easton	1	14.3%	0	0	0	0	11.43

Note: Student names have been blurred out to maintain anonymity

Table 1. Codes assigned to each mechanical actions students perform and recorded in the jMAP causal mapping software

SuperCodes	Codes	Definitions
-	STRT	reset the map and/or deleted old map
LINK	ADDR	added new link pointing to the right
	ADDL	added new link pointing to the left
	ADDU	added new link pointing up
	ADDN	added new link pointing down
RELINK	LK2	attached link to the affected node
	RLK1	redirected the existing link to a new causal node
	RLK2	redirected the existing link to a new affected node
-	ULK1	detached the beginning tail of the link
-	ULK2	detached the end of the link
ATTR	ATT-	changed link to the color red to convey a negative or inverse relationship
	ATT+	changed link to the color black to convey a positive relationship
	ATT2L	changed link to low level of impact
	ATT2M	changed link to moderate level of impact
	ATT2H	changed link to high level of impact
DEL	DEL	deleted the link
MOVE	MS	moved a node (which was the same node as the last moved node)
	MDn	moved node to the north of the previously moved node
	Mdne	moved node to the NE of the previously moved node
	Mde	moved node to the East of the previously moved node
	Mdse	moved node to the SE of the previously moved node
	Mds	moved node to the South of the previously moved node
	MDsw	moved node to the SW of the previously moved node
	MDw	moved node to the West of the previously moved node
	MDnw	moved node to the NW of the previously moved node
COMM	COM	added a comment to the link to explain how the causal node affects the affected node
	CREV	revised the existing comment on the given link
-	SAVE	clicked the save button

Note: The symbol ‘-’ identifies actions omitted from the sequential analysis

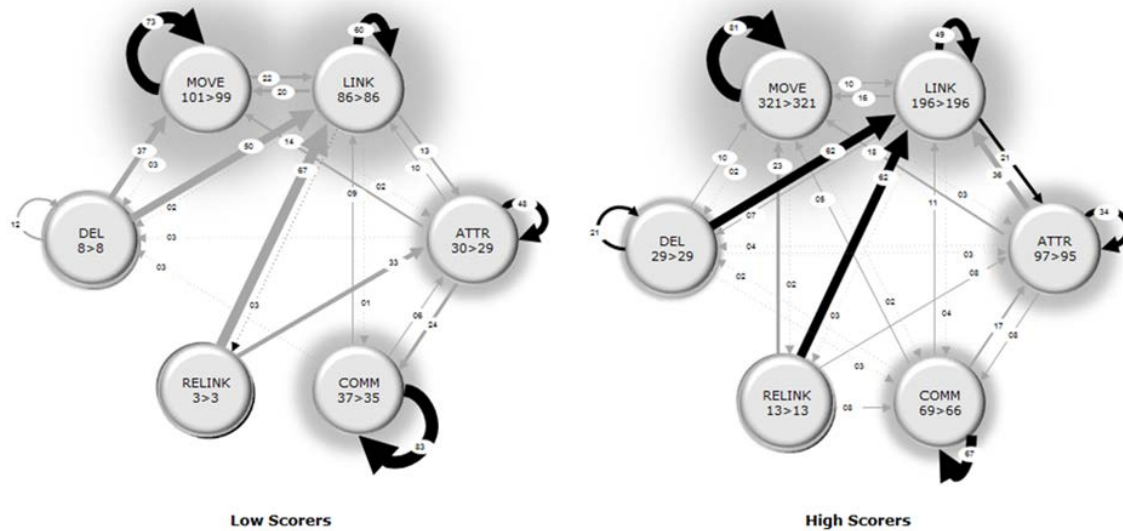
Discussion of Main Findings

Four behavioral patterns were exhibited by the low performers (Figure 4). The state diagram for high performers also revealed the same patterns. However, they exhibited four additional patterns. These patterns help to explain the processes students can use produce more accurate diagrams. The high performers exhibited the tendency to: 1) specify the attributes of a causal link is inserted between two nodes; 2) add a new link immediately after they re-direct an existing link and 3) they deleted a link; and 4) delete another link immediately after deleting a link. These patterns serve as possible indicators to show when students may or may not be applying logic rules like the ones embedded within the REASON software – logic rules that can help students come to the important realization.

The unique behavioral patterns observed among the high performers suggest that re-directing and deleting links are a critical part of the mapping process. To determine when Relink and Delete actions should be performed in relation to the most immediate preceding action, the historical state diagram (Figure 5) shows that: a) the event that was most likely to precede the Relink action was the Move action (62% of all preceding events) and Link action (100%) among the high and low performers, respectively; b) the event most likely to precede the Delete action

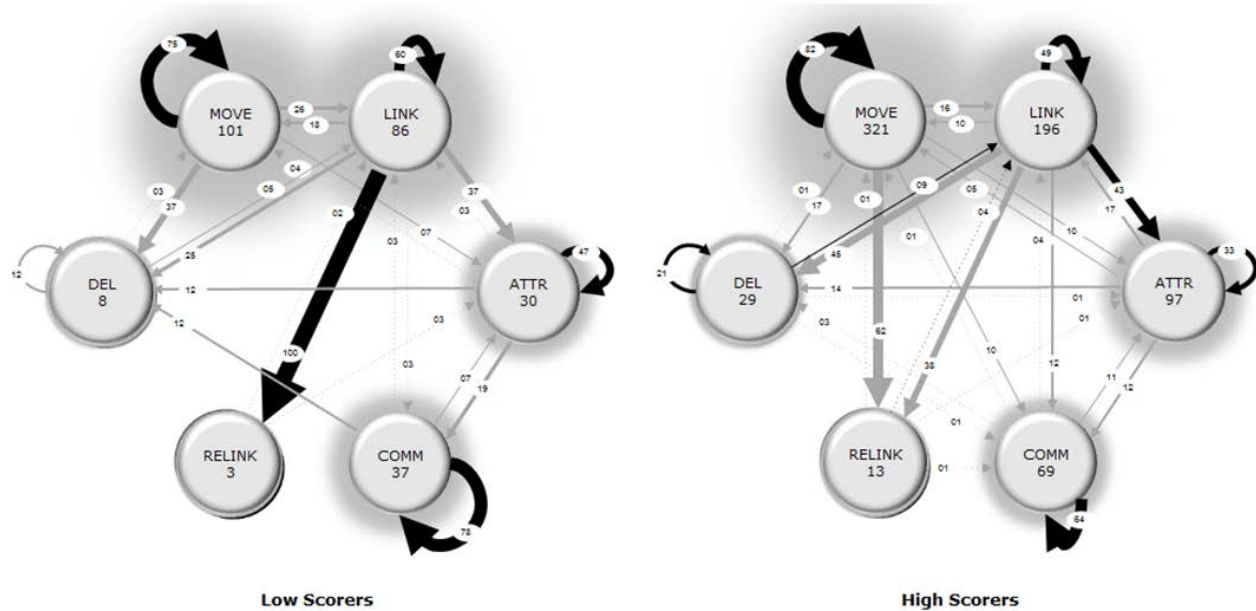
was the Link action (45% of all preceding events) and Move action (37%) among the high and low performers, respectively. At the time of presentation, we will also present findings on the extent to which students used a backward/deductive vs. forward/inductive approach and depth vs. breadth-first approach and whether one particular approach produced more accurate causal maps.

Figure 4. Transitional state diagrams of action sequences performed by low vs. high performers



Notes: Black and gray arrows identify probabilities that are and are not significantly greater than expected. Arrows are weighted in direct proportion to the observed transitional probability. The first and second numerical value displayed in each node identifies the number of times the given action was performed and the number of events that followed the given action. The size of the glow emanating from each node conveys the number of times the given action was performed.

Figure 5. Historical state diagrams of actions most/least likely to elicit target actions



Directions for future research

The findings provide preliminary ideas as to what actions sequences should be facilitated to help students achieve more accurate and deeper understanding of complex systems. Some issues that require further research are: a) replicate this study with a larger sample; b) integrate the target action sequences directly into causal mapping software interface to conduct a controlled experimental test and determine if the target processes increases map accuracy regardless of students' prior knowledge/understanding; c) examine to what extent the target processes are effective across different domains or topics that are or are not temporal in nature; and d) test other criterion measures for assessing accuracy.