Concept Mapping 2.0:

Rethinking Concept Maps with Context Sensitive Selective Highlighting

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Abstract

Grand social challenges such as climate change, the fresh water crises, and food supply shortages are becoming increasingly prevalent. Such complex issues are novel, and the education of future problem solvers who will be responsible for contributing to solutions will require learning tools and technologies that encourage students to think adaptively to a myriad of ill-structured systems of knowledge. Encouraging adaptive ways of thinking from the time students are introduced to a topic will help combat the development of rigid, inflexible ways of knowing. An essential component of tackling ill-structured topics and issues is context-dependent thinking (thinking that uses specific contexts to inform how concepts are operationalized) as opposed to context-independent thinking (thinking that uses abstract operationalizations to inform specific contexts). The present study took a first step in developing a representational tool called *concept map 2.0* that encourages novice learners of ill-structured topics to understand concepts and relationships as context-dependent. Three novices to the subject of ecology were tasked think-aloud as they learned about an ill-structured topic, the relationship between the vedalia beetle and cottony cushion scale. An epistemic belief inventory, written responses, and interview responses supplemented think-aloud data to illustrate how concept map 2.0 may encourage context-dependent thinking as well as how it may be further developed to better aid in the development of adaptive ways of thinking. Overall, participants produced more context-dependent think-alouds when using concept map 2.0 compared to a traditional, context-independent concept map. Participants also indicated strong preferences for using concept map 2.0 over the context-independent map when learning about the ill-structured topic. Interpretations of each participants' experiences and direction for future studies are discussed

Learning experiences for novices in subjects that are *context-dependent* (subjects with concepts whose operationalizations are dependent upon the specific context in which it is being observed) are often taught using tools which represent knowledge as too abstract. *Environmental ecology* is an example of a field whose concepts are not well-suited for one-size-fits-all definitions (e.g. species population stability, water conservation, CO2 emissions control) cannot be solved by prepackaged, universally applicable solutions. Attempts to represent terms in ecology as universally operationalizable across all contexts has proven troublesome in terms of constructing theoretical frameworks that transcend contexts in the field because of the situational variability in how concepts are operationalized from context-to-context (Peters, 1991). There has been a dearth of research related to the development of conceptual models, such as concept maps, to be used as representational tools that may be used to encourage knowledge encourage novice learners of ecology to view the subject and concepts within the subject as context-dependent. This exploratory study addressed the issue of using overly abstract representations for contexts and concepts in context-dependent by examining three participants as miniature case studies. Results provide valuable insight into how learners construct knowledge in context-dependent domains as well as provide guidance in developing representational tools that benefit learning in context-dependent domains.

Theoretical Framework

Context-dependent subjects are subject best understood via *bottom-up* processing to construct meaning. Bottom-up processing involves constructing meaning of a concept based on the parameters of an individual context. A *context* is a specific, unique situation in a subject. Learners experience similarities and differences among multiple contexts in which a single concept may be defined and operationalized. Using many individual contexts to inform

understanding of a concept encourages learners to construct an ever-changing, adaptive understanding of that concept. In other words, how a concept is defined and operationalized is dependent upon the specific context in which it is being observed.

Context-independent subjects are developed through *top-down* processing. Top-down processing involves constructing contextual and conceptual meaning from a single, one-size-fits-all definition that is operationalized universally across all contexts. Unlike context-dependent subjects, differences among individual contexts are not important in constructing meaning for context-independent concepts.

Ecology is a scientific domain that has been described as a subject comprised of contexts and concepts that are context-dependent. In other words, learners should adopt a bottom-up way of thinking when building knowledge about ecology because contexts and concepts (e.g. adaptation, perturbation, stability) are not operationalized by single definitions nor prepackaged sets of rules. For example, the concept of *stability* has been exemplified as a non-operationalizable term and been subject to many different definitions across several ecological theories (Peters, 1991). Peters argues that research and theory building should not include the term, stability (among many other terms) because it fails to be defined by a single, universally agreed upon definition. According to Peters and like-minded critics, ecological theories would become far too unpredictable and complex if constructed using context-dependent terms.

In contrast to the perspective that theoretical frameworks be kept as context-independent as possible, I argue that developing a perspective which acknowledges context-dependency is not only acceptable but *necessary*. Ecology was chosen as a subject of which to exemplify context-dependent learning because it is a subject with contexts and concepts that are taught in context-independent ways, despite great contextual variability in how concepts are operationalized.

Ecology was also chosen as a knowledge domain because it is also a field where complex issues such as climate change, environmental conservation, and species conservation are becoming increasingly pressing (i.e. Cook et al., 2013). It is imperative researchers and educators work together to develop tools that may help reduce the formation of reductive bias in students studying ecology, not only to help build theoretical frameworks that acknowledge terms as context-dependent but also to equip ourselves with context-dependent ways of thinking to construct creative solutions for problems where abstract, universally operationalizable definitions are not adequate.

Cognitive Flexibility Theory (CFT) is a framework which outlines features of advanced knowledge construction by which learners obtain deep meaning of content material and learn to flexibly apply knowledge in diverse contexts (Spiro et al., 1988). Spiro and Jehng (1990) describe cognitive flexibility in terms of one's ability to restructure knowledge in order to meet the demands of changing situations. In other words, CFT emphasizes knowledge assembly that is adaptive to utilize existing knowledge, specific to unique contexts. The principles of CFT map well onto learning subjects that are context-dependent because of the framework's application to learning about concepts whose operationalizations and relationships to other concepts may hold inconsistent patterns of pertinence and function (Spiro, Vispoel, Schmitz, & Boerger, 1987). CFT provides an insightful lens of which to examine how novice learners construct meaning of context-dependent subjects.

CFT informs this study's design to examine novices to the subject of ecology. Early overgeneralizations and oversimplifications of concepts and relationships may interfere with later attainment of conceptual complexity. In other words, oversimplifying understanding of a topic early may obstruct one from being able to cope with complexity later. Developing adaptive,

context-dependent ways of thinking are important in combating the development misconceptions and rigid knowledge structures that diminish the likelihood that one will value many perspectives and representations of a topic (Spiro et al., in press). Fostering the development of adaptive knowledge structures may also aid in developing flexible epistemic beliefs. Developing adaptive world views *before* inflexible epistemic beliefs are formed is more cognitively manageable than altering existing epistemic stances and prefigurative schemas (Feltovich et al., 1989)

To address the issues of content representation discussed above, CFT includes a feature of which to guide knowledge acquisition in context-dependent domains called *context sensitive, selective highlighting* (CSSH). CSSH refers to situation-specific organization of schemas, organized to individual situations rather than schemas which are prepackaged and generalizable across many situations (Spiro, Klautke, Cheng, & Gaunt, 2017). As a feature integrated into concept maps, CSSH allows case-specific visual reorganization of concepts and relationships based on pertinence. In other words, CSSH allows for context-dependent representations of contexts through adaptive concept map configurations that represent context-specific relationships among concepts. CSSH also allows for context-dependent *highlighting*, or emphasis, on concepts and relationships. Highlighting can consist of color differentiation, word boldness, word size, and transparency. It is hypothesized that knowledge representation made possible by CSSH in concept maps encourage novice learners to build understandings of ecology that are context-dependent by affording learners to visually observe the flexibility and fluidity in how concepts within ecology are operationalized differently across an ecological context. I also hypothesize that the use of CSSH in concept maps would discourage the development of reductive biases that have been shown to develop as a result of knowledge representation that is inappropriately context-independent (Spiro et al., 1988).

Concept maps are tools that visualize how concepts are organized and interact with each other in a knowledge domain (Novak, 1984) and assist individuals in visualizing the journeying nature of a concept's development (Butler-Kisber & Poldma, 2010). Concepts (in concept maps) are perceived regularities in situations and/or objects, and records of events or objects, which are designated by labels (Novak, 1984). Concept maps represent concepts as *nodes* and relationships of concepts as *links*. The structure of nodes and links in traditional, context-independent concept maps are static and are also often structured in a hierarchy, with the most important concepts placed towards the top of the map. Traditional concept maps serve as effective visualization tools to support learning in context-independent domains. For example, context-independent concept maps and their application to learning science concepts housed within context-independent knowledge domains is appropriate. Teaching the concept of gravitational force as applied to Newtonian physics, independent of context, is possible because regardless of context, gravity in this domain is operationalized by a single definition. But for context-dependent domains like ecology, the use of traditional, context-independent concept maps may contribute to the development of knowledge representation issues such as the development of overly abstract conceptualizations of contexts and concepts.

This study presented learners with a new kind of concept map called *concept map 2.0*. Concept map 2.0 differs from traditional concept maps in that it does not represent contexts and concepts' meanings as abstract, rather concepts' level of pertinence and operationalization is situated in individual context. CSSH is used to highlight concepts and relationships based on specific context. Because concept map 2.0 is adaptive in how it represents contexts and concepts, each individual context used in this study was represented by a unique concept map of context-dependent configuration.

Epistemic beliefs are beliefs an individual holds about the structure of knowledge and the nature of learning (Kitchener 1986; Schommer, 1990). Epistemic beliefs can be unconscious and are thought to influence the processes in which learners access prior knowledge while constructing knowledge and solving problems. Learners may be unaware of the influence of how their own epistemic beliefs enable or constrain germane cognitive activity and how knowledge is organized. It has been suggested that epistemic beliefs which preference simple views of knowledge (as opposed to complex) while learning in context-dependent domains have contributed to misconceptions (Feltovich et al., 1989), and have been suggested as significant factors in predicting how well learners are able to construct knowledge in context-dependent domains (Spiro, Feltovich, & Coulson, 1996; Bråten & Strømsø, 2009). Because of these notions, it is important to explore learners' experiences using tools such as concept map 2.0 with epistemic beliefs in consideration. This study collected participant data of pre-existing epistemic beliefs that were examined in conjunction with other qualitative data to gather preliminary observations about how epistemic beliefs influence learner use of concept map 2.0.

Literature Review

Ecology

Colinvaux (1977) provides a plethora of contexts in ecology where concepts (i.e. stability, diversity, niche, etc.) are highly relevant at different times or in different relationships and asserts that theories which have attempted to fit context-dependent concepts into a one-size-fits-all definition fail to adequately explain all ecological contexts. Though many concepts are readily identifiable as important in a variety of situations throughout the book, there is are no single definitions of concepts that adequately address every context in which they are

operationalized. In other words, many contexts in ecology operationalize similar concepts, but operationalization of concepts and relationships is often unique to individual context.

For example, one of the earliest and still-debated arguments in ecology is whether or not higher species diversity predicts stable species populations (Elton, 1958) (in this case, *diversity* and *stability* are the concepts whose operationalizations are debated.). There have been arguments for (i.e. Elton, 1958; Haddad, Crutsinger, Gross,Haarstad, and Tilman, 2011) and against this notion (i.e. May, 1974; McCann, 2000 ;Gross, Rudolf, Levin, & Dieckmann, 2009). For critics of overly abstract operationalizations, like Colinvaux, the argument surrounding whether species diversity equates to species stability is an issue related to a lack of consistency in how diversity and stability are operationalized in empirical studies for proponents of each side of the debate. In other words, stability and diversity are not being used with consistent operationalizations among members of the ecology community, and it is this lack of consistency that contributes to disagreements in how concepts should be defined. Proponents of adopting a context-dependent perspective in ecology argue that allowing for context-specific operationalizations of concepts and relationships among concepts eliminates the need for debate over single best definitions. Equally important, proponents for a context-dependent perspective argue that the bottom-up type of processing that characterizes context-dependent thinking is better suited to adapt to understanding the subject of ecology and all the unique contexts within it.

Another example of how over-abstraction in ecological theory contributed to difficulties in operationalizing concepts was the mapping of *information theory* onto species diversity and stability. Mathematical calculations made by telephone engineers in the 1950s compose what became to be known as *information theory*, a theory of how information flows through branching

channels. Information theory relied heavily on a formula called the *Shannon-Weiner information measure* which describes how the number of channels in a system and the capacity for a channel to hold information act as characteristics that determines a system's diversity and stability. Previously, ecologists have used the Shannon-Weiner information measure as an analogous formula to determine diversity and complexity in an ecosystem. Analogous errors result when one attempts to equate how the information theory operationalizes terms such as diversity and stability, which exist in a telephone engineering domain, with how stability and diversity exist in an ecological domain (p. 201-202). The analogous error of operationalizing stability in terms the abstract, context-independent formula that information theory provides into the context-dependent, context-dependent domain of ecology exemplifies an issue in approaching context-dependent domains with an eye for recognizing context-independent patterns.

The case for a more context-dependent approach to operationalizing ecological concepts can also be observed in research surrounding variation in interspecies interaction. Chamberlain, Bronstein, and Rudgers (2014) conducted a meta analysis of how different species dynamics may predict context-dependency. Their analysis resulted in calling for further investigation of different types of context-dependence *per se* (individual instance) rather than mean outcomes-this type of investigation reflects the notion of bottom-up knowledge construction, a principle of developing meaning of context-dependent concepts.

Vedalia Beetle and Cottony-Cushion Scale

The relationship between the *vedalia beetle* and the *cottony-cushion scale* is a exemplar of a context-dependent topic in ecology. Depending on specific context, these insects interact with each other and their environments differently, and the concepts used to illustrate their

relationship vary in pertinence and operationalization. The relationship can be divided into four contexts:

1. Cottony-cushion scales exist without a predator to control their population. The scales ravenously feed on a citrus tree farm which results in the desecration of that farm because the damage done by the scales out paces the rate in which the citrus tree crop can recover.
2. Vedalia beetles discover/are introduced to the citrus farm hosting the cottony cushion scales. The beetles are extremely effective as a control predator; even in relatively small numbers, the beetles feast on the scales, decreasing the scale population and increasing their own population. As the number of scales decreases, the citrus tree crop begins to recover
3. The scale population has decreased so much that the beetles are having difficulty finding enough to feed their own population which is now exponentially larger than when they discovered the scales. Struggling to find sufficient food, the beetles now struggle to exist, and their population begins to decrease. The rogue scales that managed to survive the beetle's onslaught have sought refuge in a new crop of citrus trees. With numbers too small to be detected by the beetles, the refugee scale population begins to increase.
4. The beetle population has decreased to a new low point. The few remaining beetles desperately search new crops of trees to find prey. Just as the beetle population is on the brink of extinction, the refugee scale population has become large enough to be detected by the remaining beetles, thus, bringing the cycle back to context number 1.

These four contexts outlining relationship between the Vedalia Beetle ad Cottony-Cushion Scale are the subject of study for the case studies.

Cognitive Flexibility Theory

Highly influential to this study is the work conducted by Spiro, Coulson, Feltovich, and Anderson (1988) which provided early demonstration of CSSH. The authors integrated CSSH into a hypertext environment called the *Cardio-World Explorer* which allowed medical students to visualize how individual medical contexts are often not adequately addressed with context-independent, one-size-fits-all solutions, rather diagnoses of and solutions to each specific medical context are most successful when concepts in the hypertext were highlighted based on their pertinence to a particular context. CSSH in the Cardio-World Explorer insured that learners experienced heightened awareness that contexts in the knowledge domain of the medical field are often context-dependent and a require bottom-up approach to constructing solutions rather than a top-down approach which is characteristic of context-independent domains.

CFT findings (e.g., Feltovich et al., 1989; Spiro et al., 1989) have indicated that early oversimplifications obstruct later attainment of complexity and impede adaptive knowledge application. Spiro et al. (1988) identified several content representation errors characterized by participants' tendencies to over rely on context-independent analogies. This study considered the content representation errors (listed below) when examining participant data. Consideration consists of discussion regarding how concept map 2.0 can be used help to prevent the formation of content representation errors. Discussion surrounding content representation errors in this study is acknowledged as exploratory and intended to guide future, more quantitative analyses of how concept map 2.0 can influence the formation of errors.

oversimplification of complex and irregular knowledge structures: Treating contexts and concepts of a subject as compartmentalized and functioning independent of each other. The pertinence of concepts in ecology (i.e. competition, climate, predation, etc.) vary in how they

influence other concepts' operationalizations as well as overall understanding of individual contexts. Failure to acknowledge variability in how concepts are operationalized from case-to-case may encourage novice learners to view contexts as overly similar and concepts as universally operationalized rather than context-dependent.

overreliance on top-down processing: Much like a context-independent concept map represents a knowledge domain is represented hierarchically and highly structured, when learning about a specific context or concepts in ecology, over reliance on top-down processing may encourage a learner to apply overgeneralized operationalizations to concepts of instead of using the details of a context which distinguish it from other contexts to inform operationalizations.

content-independent conceptual representation: Treating contexts and concepts as having universal pertinence and functionality. In ecology, learners may conceptualize concepts' relevance as uniform, regardless of situation. Context-independent conceptual representation also encourages learners to conceptualize different contexts as overly similar. Deriving universal definitions of stability and diversity in the domain of ecology has already been discussed as a troublesome and unnecessary task, and efforts to apply universal definitions of other concepts (which also may not be capable of being universally operationalized) to explain concepts, such as stability and diversity, would only worsen the degree to which learners develop persistent and inappropriate context-independent epistemic beliefs about the domain of ecology.

Concept Maps

Concept maps have been shown to be useful for improving knowledge retention and integration (O'Donnell, Dansereau, & Hall, 2002; Nesbit & Adescope, 2006). Glowacka et al. (2013) developed an interactive, adaptive search platform called *the Reinforced Learning Retrieval* (RLR) system to investigate how visualization of terms may influence the

reconstruction of existing knowledge. The RLR provided an interactive concept map which was used to search for a greater quantity, diversity, and quality of knowledge sources. The RLR provided a network of resources based on user-controlled search criteria such as level of interest and level of relevance. In other words, this system is dynamic and context-sensitive, with their results suggesting that learning with a medium that represents the pertinence of different sources of knowledge as dynamic and context-dependent is more effective in increasing expression that concepts are operationalized adaptively to individual contexts, while context-independent search queries produced little diversity and almost no context-sensitivity. Their work supports the notion that a system integrated with CSSH may improve how adaptively one is able to construct context-dependent operationalizations across the domain of ecology.

Constructing knowledge representations through concept maps based on individual situations within a domain has been suggested by Novak "Therefore, it is best to construct concept maps with reference to some particular question we seek to answer or some situation or event that we are trying to understand..." (2004, p. 15). Other work has echoed Novak's suggestion by indicating that viewing problem environments from multiple perspectives increases how flexibly people can deal with novel contexts (e.g., Bransford et. al, 1990; Spiro et al., 1987). Lee, Jonasen, and Teo (2011) suggest that visually modeling systems of a context-dependent subject improved participants' abilities to problem solve in that subject and contributed to conceptual change. Concept maps have also been useful in helping students to recognize and modify faulty knowledge structures (Feldsine, 1983; Novak & Gowin, 1984). Lastly, concept mapping not only helps conceptual change but also helps learn how to learn (Novak 1985). The process of concept mapping has been studied both in terms of knowledge construction of content and its impact on future learning behavior.

Study Goals

This study served as an exploratory account of concept map 2.0 with three study goals. The first goal was to document a preliminary account of the how concept map 2.0 may influence novice learners to view a subject and contexts within a subject as context-dependent. The second was to gain a better understanding the perceived usability of concept map 2.0 in novice learners, that is, to what degree do users perceive concept map 2.0 as productive to their learning experience? The third was to explore how epistemic beliefs may factor into the contexts of the first two goals.

Think-aloud data was used to examine how novice learners build an understanding of an ecological context that includes several widely used concepts that are difficult to universally operationalize. Think-alouds also helped to gauge attitudes towards the usability of concept map 2.0. Documentation of think-alouds provided insight into how concept map 2.0 influences participants' verbalizations of each ecological context and concepts within each context as context-dependent. Measures of epistemic beliefs taken before and after the study were not quantitively analyzed, rather data derived from the CFI provided supplemental information that was considered in conjunction with think-aloud data, written responses, and an end of study interview. Results from this study inform future research that examines how concept maps featuring CSSH can be utilized as learning tools in science education.

Research Questions

1. Does the use of concept map 2.0 encourage novice learners of ecology to develop context-dependent understandings ecological concepts as context-independent or context-dependent, and how does that affect their understanding of the cases?

2 In what ways do novice learners of ecology think that concept 2.0 is “highly usable”, or has design features that make it hard to use? How does facility of use relate to epistemic beliefs?

3. How do preexisting epistemic beliefs inform research questions one and two

Method

Study Design

Three participants served as case studies. This study adopted a case study approach to accommodate the wide variety data to be collected (think-alouds, surveys, written responses, and interview responses) (Yin, 1984, p. 20). This study’s case study approach was also similar to that outlined by Charters (2003) where data collection and analyses were conducted with the goal of describing and explaining (rather than prediction based on cause and effect). As an exploratory effort, this study acknowledged that it would be impossible to identify all important variables ahead of time (Merriam, 1988, p. 7) and made it a goal to document as many observations without a framing such observations into a preconceived hypothesis.

First participants completed the *Cognitive Flexibility Inventory* (CFI; Spiro et al., 1996; see Appendix A), a measure of epistemic beliefs. Data gathered from the CFI was used in conjunction with think-aloud and interview data to construct detailed accounts for each of the three cases.

After completing the CFI for the first time, participants completed the *ecology learning task*. Participants were instructed to think-aloud during this task as a means to produce verbal transcripts which were examined for expressions that suggest participants think about the concepts present on the concept maps (context-independent concept map and concept map 2.0) as more or less context-dependent differently from condition-to-condition. Ericsson and Simon

(1980) reached the conclusion that concurrent verbalization remains a nonreactive and effective procedure, and researcher prompts were performed so as not to coerce a participant response (Fox, Ericsson, and Best, 2011).

The ecology learning task consisted of three conditions stages: An initial context-independent map stage; a second context-independent stage; and a concept map 2.0 stage. During each stage, participants read a set of texts that outline four major contexts that depict the dynamic relationship between the *vedalia beetle* and the *cottony cushion scale* (see Appendix B). For each of the four contexts, there was an accompanying set of questions that asked participants to construct a written response. Each context's written response prompt was unique to that context. Participants were instructed to think-aloud for the entirety of the ecology learning task. In other words, think-aloud data was collected while participants are reading text, reading concept maps, and composing their written responses (see *procedure* section for thorough discussion of the ecology learning task)

The number and order of conditions was chosen so that concept map type could be more isolated as a factor for possible changes in context-dependent verbalizations. Mere exposure to content could be a factor in increases in context-dependent verbalizations, regardless of concept map type. Conducting two consecutive conditions with the context-independent concept map provides extended exposure to the content. The rationale for introducing the concept map 2.0 condition last was so that if a major change in context dependent verbalizations occurred between the second (context-independent concept map) and third conditions (concept map 2.0) and not between the first (context-independent concept map) and second (context-independent concept map), the potential link between concept map type and increases in context-dependent verbalizations can be explored without the variable of content exposure contaminating.

After completing the ecology learning task, participants were asked to complete the CFI for a second time. Participants were prompted to think-aloud while selecting values for items. Participants were asked to consider and verbalize the impact, if any, that the different types of concept maps have on their thought processes as they completed the CFI. Asking participants to think-aloud retrospectively about their experience served to triangulate think-aloud data from both the ecology learning task and CFI results (Charters, 2003). With that said, this study did not comparatively analyze epistemic beliefs as a mediator of verbal data, rather it gathered preliminary insights to help guide future research that utilizes more thorough quantitative analysis of the influence concept map 2.0 has on context-dependent learning.

Lastly, to gauge participant attitudes regarding the usability of concept map 2.0, a semi-structured interview was conducted in which the researcher asked participants questions about what aspects of concept map 2.0 helped and or inhibited their learning. Participants were encouraged to provide suggestions of how they would modify aspects of concept 2.0 to improve its utility as a learning tool. I acknowledged that participant usability suggestions may reflect attitudes that favor either context-independent or context-dependent thinking (see Appendix C for interview protocol). For example, a suggestion to simplify the map by keeping links consistent throughout all contexts, or a suggestion to structure concepts in a more hierarchical manner would reflect a desire to make concept map 2.0 more context-independent. An example of a suggestion of how to improve the utility of concept map 2.0 so that it aligns with context-dependent learning might be suggesting to use more differentiating features such as a wider variety of color to indicate varying levels of pertinence. Consideration of all suggestions (context-independent and context-dependent in nature) is valuable in informing the design of concept map 2.0 in future research. Implications of participant attitudes regarding usability were

discussed in relation to other participant think-aloud data (think-aloud data collected during CFI and ecology learning task) and ecology learning task writing responses.

Participants

This study gathered data from three participants. Selection of participants were in part a matter of convenience in that participants will not be chosen from an anonymous sample population, rather they were chosen as individuals of whom I have prior knowledge regarding their academic and professional experiences. The participant selection process were based on the following 4 considerations:

First, because this study seeks to examine how novice learners learn about ecological concepts, participant could not have prior academic nor professional experience in the field of ecology or other environmental sciences. Filtering out those with experience in fields related to the study topic was a measure to reduce the possibility that prior content knowledge did not confound interpretation of data.

Second, participants could note have had extensive prior knowledge in the fields of cognitive psychology, educational psychology, or fields in which learning in context-dependent domains may be a topic of study. Prior experience in these fields may have predisposed participants to be more likely to recognize concepts as context-dependent than people who do not have such experiences.

Third, because transcripts derived from think-alouds served as a primary data source for this study, it was crucial that participants possess a high level of ability to verbalize their thinking processes. Participants were considered based on their self-perceived comfort level of thinking out loud while they participate in the study.

Fourth, because this study examined learning in context-dependent domains-a process that requires high order cognitive function-participants must have either possesed a degree from or have been enrolled in an institution of higher education.

Materials

The Cognitive Flexibility Inventory. The CFI is a validated measure of epistemic beliefs and was chosen as a measure because of its ability to assess beliefs regarding learning about context-dependency-the specific dimension of complexity this study explored (see Appendix A). CFI data helped inform discussion of how think-aloud data and written responses collected during the ecology learning task may be informed by epistemic beliefs.

Text passages and writing prompts for the ecology learning task. Text passages describing the relationship between the Vedalia Beetle and Cottony Cushion Scale were developed by the researcher with heavy consultation to Colinvaux's text *Why Big Fierce Animals Are Rare* (1977)-a book that describes, in detail, concepts related to these animals' relationship. The Vedalia Beetle-Cottony Cushion Scale dynamic was chosen as a setting of which to exemplify context dependent concepts because individual contexts, or contexts, housed within this dynamic are best represented using a bottom-up approach. In other words, concepts and relationships among concepts that are used to build understanding of the Vedalia Beetle-Cottony Cushion Scale dynamic are best defined by considering individual contexts, rather than applying universal definitions (aka context-independent definitions) to understand individual contexts. Four texts were used to describe four unique contexts that represent the context-dependent relationship between the Vedalia Beetle and Cottony Cushion Scale. The texts were composed to depict how varying contexts influence the pertinence and meaning of several concepts present throughout all contexts.

Each of the four ecology learning task texts had an accompanying set of writing prompt questions which were submitted through Qualtrics. Writing prompt questions were composed to gauge the degree to which participants understood the context and concepts in each text as context-dependent or context-independent. Writing prompt questions served as an opportunity to gather think-aloud data regarding how concept map 2.0 may be referenced when making statements that reflect context-dependent performance. Writing prompt questions themselves were context-dependent in that they address specific contexts (see Appendix B for ecology learning task writing prompt questions)

The Visual Understanding Environment. The Visual Understanding Environment (VUE; Version 3.3.0; Tufts University, 2015) was used to construct the context-independent concept map and all four concept map 2.0 representations for the ecology learning task. VUE was chosen because of the its features which provide great flexibility in how concepts are visualized in terms of physical proximity to each other, text color, text size, box color, box size, and concept relationships.

Types of concept maps. Two types of concept maps were used, a *concept-independent concept map* and *concept map 2.0*. Several nodes used in the concept maps depicting stability and diversity in Peters (1991) were used. Peters argues that because of inabilities to be operationalized in context-independent ways, many concepts in ecology such as stability, diversity, and other hard-to-operationalize concepts, have no place as concepts in research in the field of ecology. The concept map he presents (1991, p. 95) is intended to support the notion that concepts can be defined by a multitude of different concepts. Although Peters' views several ecological concepts' multidivisional nature as problematic for using them as a terms in research, I argue that the particular concept map he has constructed to argue against implementation of

hard-to-operationalize concepts actually supports the assertion that context-dependent concepts *should* be implemented in research interested in better understanding how ecological contexts vary from situation-to-situation. By designing the concept maps used in this study off Peters' maps, I hoped to demonstrate that even with materials constructed to argue against use of hard-to-operationalize concepts as researchable, context-dependent concepts can and should be studied in research in the field of ecology.

The context-independent concept map will represent ecology in a universally generalizable manner, there was a single version of a context-independent concept map that to be used to accompany the Colinvaux texts. Figure 1 illustrates the context-independent concept map. The rationale for diverging from what one may call standard features of traditional concept maps in constructing the context-independent concept map used in this study is that this study is interested in a examining a specific dimension of complexity, that is the dimension of context-dependency. Features often characteristic of traditional concept maps such as hierarchical structure of nodes would likely increase the likelihood that participants would view concepts as overgeneralized and static. By using a context-independent map that is not hierarchical in nature, differences among the context-independent map stage and the concept map 2.0 stage can not be attributable to hierchilizability, and think-aloud data that indicate context-dependent thinking can be more directly discussed as influenced by CSSH.

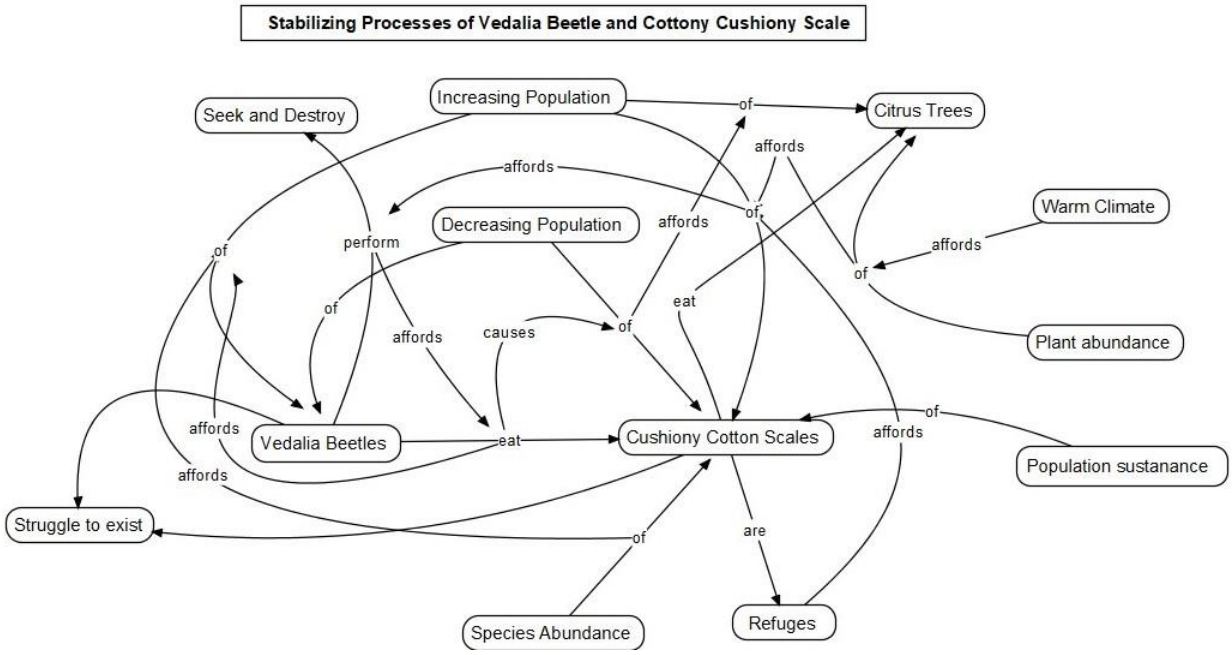

Figure 1. context-independent context map

Concept map 2.0 maintains the same concepts present in the context-independent concept map, meaning the number and content of nodes did not vary among the context-independent concept map and concept map 2.0s. Consistency regarding the presence of concepts across all concept maps is intentional, and serves as a delimitation to the argument that concept maps that vary in content and quantity of content cannot be analyzed under the same variable (type of concept map used).

Concepts were operationalized differently across each of the four contexts represented by concept 2.0. VUE's visualization capabilities to *highlight* nodes and increase the transparency of nodes were used as major features of difference when comparing them to the context-independent concept map. For each text, there was a concept map 2.0 that will highlight the most pertinent nodes in terms of their importance in operationalizing the relationship between vedalia beetles and cottony cushion scales. Highlighted nodes were colored yellow, bolded, and relationships among nodes were bolded, while other nodes and relationships, which are to some

degree relevant to but not most pertinent, will still be visible but their nodes were made more transparent.

Concept map 2.0 is a tool to encourage context-dependent ways of describing contexts and concepts by representing the relationship between the vedalia beetle and cottony cushion scales differently across each of the contexts. It was hypothesized that the features of concept map 2.0 would encourage each participant to construct unique individual insights regarding the nature of concepts in each context. In sum, concept map 2.0 did not encourage context-dependent descriptions by changing the quantity of nodes nor content of individual nodes, rather it achieved context-dependent representation by reorganizing how relationships among the nodes are represented according to individual contexts (see Appendix D for all concept maps used).

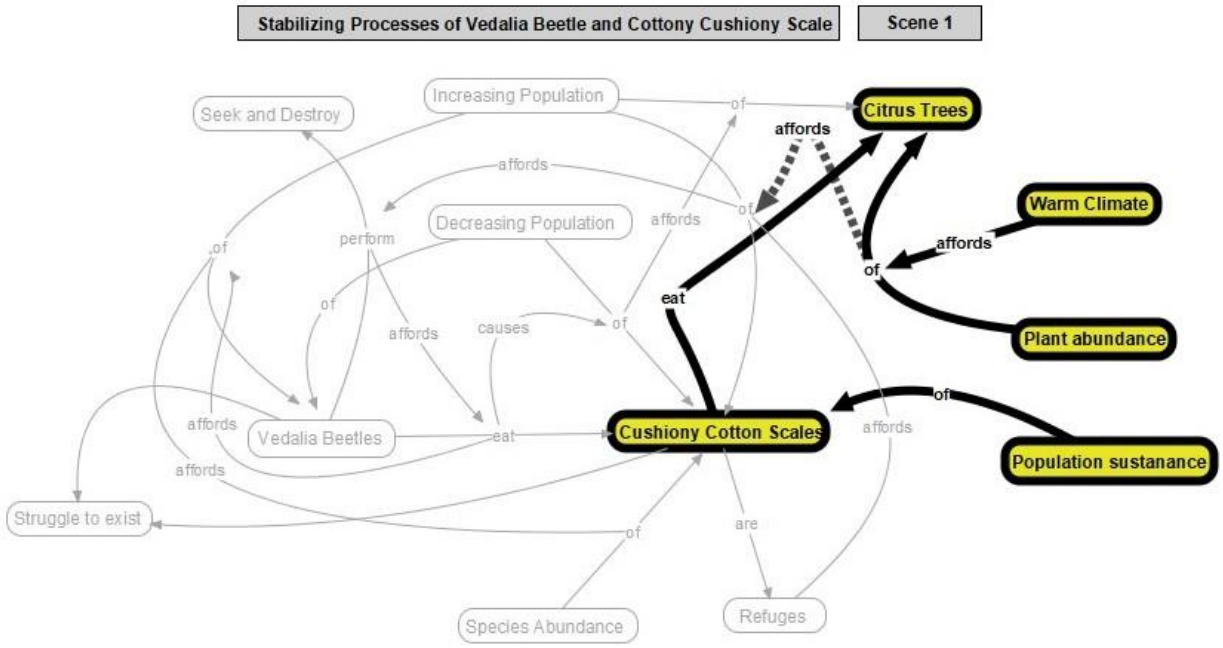

Figure 2. Example of concept map 2.0

Procedure

The researcher began each study session by explaining the practice of think-alouds to each participant. Participants were informed that there were to verbally express what they were thinking for all portions of the study after the first CFI (ecology learning task, second CFI, and usability interview). To ensure that the participant was comfortable verbally expressing all types of thought processes and to encourage verbal reports that are not overly biased towards one type of thinking (i.e. mostly comprised of statements of confirmation or statements of confusion), participants were reminded that it is okay to express difficulties in comprehension, connections to prior knowledge, and any other type of thought processes.

Participants' first task was to complete the Cognitive Flexibility Inventory (CFI). Participants were informed that the CFI is a test to help gauge their existing beliefs about how learning and the nature of knowledge and that there were no right or wrong answers.

After the first completion of the CFI, participants were introduced to the *ecology learning* task. Participants were told that their task was to learn as much as possible about four different contexts involving the relationship between the Vedalia Beetle and Cottony Cushion Scale and to compose a corresponding written response for each (see Appendix B for texts and writing prompt questions). Each stage lasted 15 minutes. During each stage of the ecology learning task, participants were reminded to continue to think-aloud as they read. If a participant was silent for more than a minute, they were reminded to continue to think a loud. Between each stage, there was a five minute break. These breaks were implemented to alleviate potential mental fatigue participants may experience during the ecology learning task. Participants composed writing responses to the four questions following the third stage.

Before beginning the first stage, participants were provided a brief overview of how to read the context-independent concept map. During this explanation, the researcher showed the participant the context-independent concept map so that they may follow along. Explanation of how to read the context-independent concept map consisted of explaining that the map is a visual representation of which to think about concepts involved in representing the relationship between the vedalia beetle and cottony cushion scale.

The first stage of the ecology learning task were a context-independent map stage where each participant were given a context-independent map to accompany all four texts and writing prompt questions. Participants were given all four texts and the context-independent map at the same time. Participants were instructed that they may take notes but were asked to not compose their writing response questions until all three stages have been completed.

The second stage of the ecology learning task was identical to the first stage.

Before beginning the third stage, the researcher dedicated a period of time to acclimating participants to concept map 2.0. Specifically, the researcher informed them that concept map 2.0 contains the same nodes and relationships as the context-independent concept map, but instead of nodes being uniform throughout, concept map 2.0 highlights certain nodes. Participants were informed that concept map 2.0 highlights different nodes yellow to indicate which nodes are most pertinent to explaining the relationship between the vedalia beetle and cottony cushion scale for each individual text.

The third stage of the ecology learning task was identical to the first two stages except that the context-independent map with the context-dependent maps (see Appendix D).

After stage three, participants were asked to compose responses to each of the five writing response questions. Participants were able to reference all texts and concept maps while

they composed their responses. For documentation purposes, writing responses were composed and stored on a computer. Participants were reminded to continue to think-aloud as they completed the writing response portion of the ecology learning task.

After completing the ecology learning task, participants completed the CFI for the second time. Similarly to the first time, the researcher informed participants that there were no right or wrong answers and to answer as honestly as possible. During the second CFI, participants were instructed to think-aloud to verbalize their thought processes related to their CFI item evaluations. While taking the CFI for the second time, participants were instructed to consider whether they feel like their experience completing the ecology learning task influenced how they responded to the CFI the second time.

Lastly, to gauge participant attitudes regarding the usability of concept map 2.0, the researcher conducted a semi-structured interview in which participants were asked questions about what aspects of concept map 2.0 helped and or inhibited their learning. Participants were encourage participants to provide suggestions of how they would modify aspects of concept 2.0 to improve its utility as a learning tool (see Appendix C for interview protocol).

Data collection

Data collection took place at the College of Education at Michigan State University. The study setting was isolated from potential distractions that may interfere with their ability to focus on the study at hand. CFI responses were marked on a paper version of the inventory and later imported into an excel spreadsheet.

Using the protocol analysis method outlined by Ericsson and Simon (1993), participants were audio recorded as they think-aloud during the ecology learning task. Specifically, the researcher asked participants to perform concurrent think-alouds where they were instructed to

verbalize the information to which they were attending (Azevedo, Taub, & Mudrick, 2015). Examples of think-alouds could be but are not limited to comparing the texts, justifying understanding through text reference, questioning understanding, and commenting on the usefulness and usability of each type of concept map. Olson et al., (1984) stated that using think-alouds is a powerful method to examine complex thinking processes and that it is useful in comparing differences among participants who are performing the same task. To encourage a robust body of verbal transcripts that yielded data that is productive in addressing the study research questions, participants were prompted to think out loud about their thought processes while reading these texts. To gather data regarding the usability of concept map 2.0, participants were asked to think-aloud about how they perceive the usefulness of both the context-independent concept map and concept map 2.0. Audio recordings were transcribed into transcripts which were imported into an excel spreadsheet.

Data analysis

To address research question 1, transcripts were examined for changes in frequency across ecology learning task conditions that would indicate participants descriptions of contexts and concepts in either a context-independent or context-dependent manner. Indicators of context-independent descriptions could be but are not limited to discussing concepts as universally operationalizable with one-size-fits-all definitions. Indicators of context-dependent descriptions could be but are not limited to discussing concepts as terms in which operationalization is context-dependent and are defined by the context in which they are being observed rather than a single definition. Examination also consisted of examining transcripts for indicators of participant tendencies to either force abstract, overgeneralized definitions into all four contexts or tendencies to adapt how concepts are defined according to a specific context. Patterns of the

former are indicative of context-independent verbalization and description while the latter suggests the presence of context-dependent verbalization and description.

Analysis of think-alouds consisted of sub-themes under the categories of *context-independent thinking* and *context-dependent thinking*. The reductive biases: *oversimplification of complex and irregular knowledge structures, overreliance on top-down processing, content-independent conceptual representation* (Spiro et al., 1988) were used as sub-themes of which think-alouds could have been categorized as context-independent.

An example of think-aloud data that indicates context-independent description would be if a participant were to verbalize that *warm climate* is most pertinent in defining *plant abundance* of *citrus trees* across all contexts (warm climate is most pertinent in context 1.1; predation of vedalia beetles on cottony cushion scales and consequent *decreasing population* of cottony cushion scales is most pertinent in context 1.2). This example would also be classified as content-independent conceptual representation.

Antitheses of the reductive biases stated by Spiro et al. (1988): were used as sub-themes of which think-alouds could have been classified as context-dependent: *awareness of context-dependent concept pertinence, operationalization of concepts using bottom-up processing, and content-dependent conceptual representation*. An example of think-aloud data that indicates context-dependent description is if a participant were to verbalize that *plant abundance* is more significant to *cottony cushion scale* survival in context 1.1 compared to context 1.2-this would be noted as an indication of awareness of *context-dependent* concept pertinence. Another example of when context-dependent description may be noted is if a participant were to verbalize that the concept of *struggle to exist* is defined differently and illustrated by different relationships from context 1.2 to context 1.3 (in context 1.2, predation of vedalia beetles on cottony cushion scales

is most pertinent in defining struggle to exist; in context 1.3, lack of food resources is most pertinent in defining struggle to exist). Verbalization that the context-independent map does not adequately represent the context-dependent nature of the context and concepts in the map would be *operationalization of concepts using bottom-up processing*

Think-alouds reported in the results and discussion sections were chosen based on their significance in answering research questions. For example, think-alouds that illustrate an increase in context-dependent thinking during the concept map 2.0 condition are reported, *and* think-alouds that illustrate persistence of context-independent think-alouds during the concept map 2.0 stage are reported. Think-alouds that indicate context-dependent thinking during the context-independent concept map conditions are also reported.

To address research question 2, transcripts were examined for language relating to opinions of concept map 2.0 in terms of its usefulness in helping to learn about the relationship between the vedalia beetle and cottony cushion scale. Because this is an exploratory study and the pilot for research using concept map 2.0, it was important that all accounts relating to participant feedback concerning concept map 2.0 were interpreted carefully. Data analysis participant feedback served to inform future design modifications to concept map 2.0.

To address research question 3, think-aloud data, written responses, and interview responses were examined for verbalizations of that suggests that the participant understood contexts and concepts as context-dependent. Examination of CFI responses and changes in responses with indicators of either context-independent or context-dependent verbalizations were considered when examining other sources of data and helped construct a rich account of learners experience using concept map 2.0 when learning a context-dependent topic.

Results and Discussion

This section provides an integrated report and discussion of the data collected from the CFI, ecology learning task, and interview. Results are reported to answer the three research questions. Discussion also examines the results within the context of the content representation errors outlined by Spiro et al. (1988): *oversimplification of complex and irregular knowledge structures, overreliance on top-down processing, content-independent conceptual representation*.

Research Question 1: *Does the use of concept map 2.0 encourage novice learners of ecology to develop context-dependent understandings (where needed) ecological concepts as context-independent or context-dependent, and how does that affect their understanding of the cases?*

Participant One

There was an increase in context-dependent think-alouds when comparing the two context-independent concept map conditions to the concept map 2.0 conditions. Think-alouds were exclusively context-independent in nature for both the first and second context-independent concept map conditions. For some context-independent think-alouds, Participant One may have experienced incorrect conceptual operationalizations of concepts. For example:

> [Participant One]: The map shows... these cushiony cotton scales…. they eat citrus trees but they're refugees. They come from Australia. They eat citrus trees. They are refugees. Australia. These vedalia beetles they eat the scales...eat the scales...live to seek and destroy, but they struggle to exist.

Refugees is not a highly pertinent concept to understanding context number one, but as indicated by their think-alouds, Participant One perceived the concept of *refugees* as necessary to understanding cottony cushion scales. Participant One constructs an understanding that the

cottony cushion scales are refugees from Australia and reinforces this notion multiple times throughout the context-independent concept map portion of the ecology learning task.

During and after the concept map 2.0 condition of the ecology learning task, Participant One provided think-alouds that suggest context-dependent thinking. For example:

> Participant One: This flowchart is nice. So vedalia beetles they help the production of citrus trees. They cause problems for the scales to exist but they help the production of citrus trees. That makes a lot of sense.

The think-aloud above suggests that Participant One was focusing on the relationships between the concepts of *increasing population*, *decreasing population*, *plant abundance*, and *struggle to exist* as they exist in *context 2*, specifically as opposed to all four contexts at once. Another example of context-dependent thinking is:

> [Participant One]: This is very similar to these ones...well actually...this doesn't relate to the other ones. So Vedalias...are in context one...they control the problem…In the second concept map...demonstrates the food chain

The think-aloud above suggests that the participant initially overgeneralized but realized that the concept map 2.0 they were referencing is not compatible with the context-text they are reading. Evaluating appropriate concept map-representation of individual contexts suggests they were thinking about concepts and relationships in a context dependent manner.

Think-alouds during the concept map 2.0 condition capture how Participant One went from attempting to fit information from all four contexts into a one-size-fits-all model towards discussing concepts as they appear in specific contexts. The shift in verbalizations towards context-specific discussion and corrections in understanding contexts suggests that concept map

2.0 influenced Participant One to combat *oversimplification of complex and irregular knowledge structures*, and *content-independent conceptual representation*

An interesting theme that persisted throughout the entirety of the study was Participant One's fixation on the notion of cyclical operation. For example, throughout the entirety of the study, Participant One verbalized that they understood all four contexts as being comprised of similar cyclical patterns regarding vedalia beetle-cushiony cotton scale codependence:

> [Participant One]: [context-independent concept map condition] You can kind of see it in the flow chart, it's kind of a cyclical thing; [context-independent concept map condition] It's important to remember the cyclical pattern; [context-independent concept map condition] You can see it's cyclical… Something about the cyclical thing...decrease in vedalias equals increase of scale; [concept map 2.0 condition]…just like the last one...increase of scales equals increase of vedalias...the flow chart shows how that happens.

The Participant recognized that broadly, the relationship between the vedalia beetle and cottony cushion scale can be understood as a cycle, but failed to indicate that the broad cycle they perceived as being comprised of nuanced, context-dependent cycles in which concepts' meanings and operations change - this type of thinking suggests that the participant may have been experiencing an *overreliance on top-down processing*. In other words, Participant One may have been attempting to "fit" information into a one-size-fits-all paradigm, even after being introduced to concept map 2.0. The persistence of think-alouds that echo the notion that there is a universal pattern of operation suggests that the one-size-fits-all context-independent concept map influenced both how the participant made sense of what has been read as well and how they approached new information.

Participant Two

There was an increase in context-dependent think-alouds when comparing the two context-independent concept map conditions to the concept map 2.0 conditions, but context-independent think-alouds persisted throughout the duration of the study session. For the context-independent concept map portions of the ecology learning task, most of Participant Two's think-aloud data indicated context-independent thought processes:

> [Participant Two]: (1) When I had a problem, the trouble is finding which one to start with, but if you start with decreasing population, it kind of helps; (2) It's all for discussing the same situation

The think-alouds above suggest the participant was experiencing context-independent thought processes. Excerpt 1 indicates that the participant may have been experiencing *overreliance on top-down processing* by using the context-independent concept map to inform understanding of the text and other concepts and relationships on the map. In other words, concepts on the concept map were abstracted to apply to the context-texts. Excerpt 2 indicates that Participant Two may have been experiencing *oversimplification of complex and irregular knowledge structures* because the participant verbalized all four contexts as representing the same situation. This is a clear indication that the participant either did not perceive the four contexts as unique to each other or did not think distinguishing each context as unique was important in understanding the concepts present in the texts and context-independent concept map.

During the concept map 2.0 portion of the ecology learning task, Participant Two verbalized context-dependent understanding by discussing how the concept of predation can be operationalized into different, individual contexts as opposed to being operationalized by a single, overarching definition:

> [Participant Two]: For the second one, it talks about the increasing population of those vedalias in the decreased population of the scales and then the third is the opposite of that but without showing the causes and everything in between...so if you put all of those together, it would be the entire cycle, whereas this kind of separates the cycle of the predation into two separate things

The think-aloud above demonstrates that Participant Two may have been combating *content-independent conceptual representation* because they recognized that predation is a concept that can be understood as a single concept but is best understood when the concept is examined in separate contexts. The context-independent concept map portions of the task did not yield think-aloud data that suggests Participant Two thinking in this type of context-dependent manner.

Another indication of context-dependent thinking is observed when the researcher asked the participant how they constructed meaning when using concept map 2.0:

> [Participant Two]: I started with the map but now I'm going back to the text just to kind of find one more concept; how invasive they are. ...what damages they can cause because that's the most important part of these situations. [Researcher]: When you were looking at the second kind of concept map were you more likely to look at the concepts and try to see how each individual situation fit into each concept or you're more likely to try to fit the concept map into the unique parameters of the situation? [Participant Two]: For something like predation you could either think - I know what predation means so I'm going to apply this to this reading, or you can say I'm going to apply this reading to define what the word predation means - I applied the reading

The participant's response suggests context-dependent thought processes. The participant verbalizes that they chose to use the text to inform meaning to the concept of *predation*. In other

words, the participant seemed to switch from using an overreliance on top-down processing during the context-independent concept map conditions towards using bottom-up processing to construct meaning during and afterthe concept map 2.0 condition.

While there was an increase in context-dependent think-alouds, Participant Two continued to express context-independent think-alouds during and after the concept 2.0 condition.

Participant Three

Unlike Participants One and Two, Participant Three verbalized that they had experience *constructing* concept maps for classes. Familiarity interacting with concept maps was a frequently verbalized theme throughout the study, and Participant Three voiced security in their ability to use concept maps as a learning tool and in their ability to make sense of what concepts in concept maps mean.

Similarly to Participants One and Two, context-dependent think-alouds increased between the context-independent concept map conditions to the concept map 2.0 condition of the ecology learning task. During the first iteration of the context-independent concept map portion of the ecology learning task, Participant Three provided commentary regarding how they view concepts' relationships:

> [Participant Three] I kind of see how they all like affect each other…I kind of look at the text first in this case because you wouldn't know what seek-and-destroy meant. For example unless you read the text and discovered that that was the one bug-the vedalia beetle- going and finding those colonies of the other bug, you wouldn't know what seek-and-destroy meant based off of the chart

The think-aloud above suggests that the participant chose to read the text until they felt like they had achieved a certain level of comprehension that is compatible with the context-independent map. In other words, the participant was seeking out mention of concepts in each context until a specific concept was mentioned and appeared to fit into the context-independent concept map. In the think-aloud above, Participant Three verbalized that they knew what *seek and destroy* meant once they found mention of it that fit into the context-independent concept map's structure-this may have indicated an *overreliance on top-down* processing. The context-independent concept map may have served as a barrier to understanding concepts as context-dependent because although Participant Three began constructing meaning of *seek and destroy* in a context-dependent manner by using a specific context to construct meaning, there is no evidence that the participant thought that *seek and destroy* is operationalized differently from context-to-context. The singular, static representation conveyed by the context-independent concept map may have encouraged the participant to assume that there is a single system of knowing which may indicate that the participant was experiencing *oversimplification of complex and irregular knowledge structures.* In other words, Participant One correctly recognized a single operationalization of *seek and destroy* but failed to indicate that this concept could be defined differently in a different context, or that more than one operationalization is necessary.

Similarly to verbalizations made during the first context-independent concept map condition, the second iteration of the context-independent concept map yielded think-alouds that suggest Participant Three's thought processes follow a "text-to-map" direction:

> I think [reading the text] helps because then you kind of know more about these basic concepts that are on the map whereas before, I feel like the map was kind of a guide

> initially, but now like it's kind of like you can go back and look and like see how they all connect.

The think-aloud above suggests that the context-independent map served as a one-size-fits-all mold for understanding multiple, unique contexts.

While Participant Three's think-alouds that suggest they were following a one-size-fits-all mold, there were verbalizations that indicated context-dependent thought processes during the second iteration of the context-independent concept map condition. Participant Three verbalized difficulty in applying the context-independent map universally to all four contexts:

> [Participant Three] I think altogether, [all four contexts] are represented in the map but if you just had one of these texts, it wouldn't make sense because this context is the one where it talks about seek and destroy

The think-aloud above suggests that the participant perceives the map as inadequate in representing individual texts.

Participant Three continued to verbalize context-dependent thinking related notions during and after the concept map 2.0 condition. For example, they were more likely to use concept map 2.0 as a starting point as opposed to a mold of which to fit the text during the concept map 2.0 condition of the ecology learning task:

> [Researcher] Did you find yourself trying to find a place or fit concepts that weren't necessarily pertinent to an individual text into that text because they were on the first concept map?
>
> [Participant Three] I kind of searched for them but then I kind of assumed maybe they'll be later in these texts, but I think that's information that you didn't need to know at the time that could confuse someone

The “map-to-text” process verbalized by the participant during the concept map 2.0 condition contrasts with the “text-to-map” process verbalized during the context-independent concept map conditions**.** Participant Three repeatedly verbalized sequence differences regarding *text* and *concept map* between learning with the context-independent map and concept map 2.0. It is important to acknowledge that text-to-map processing *could* occur in service to context-dependent thinking, if individual context-text is used to develop meaning of concepts, but in the case of Participant Three, text-to-map processing seems to consist of the participant reading the texts until their understanding of the texts matches the one-size-fits-all context-independent concept map. Conversely, it is important to acknowledge that map-to-text processing *could* occur in service to context-independent thinking, if a concept map were used to predispose an individual to interpreting text in an overly abstract manner, but in the case of Participant Three, map-to-text processing seems to consist of the participant avoiding non-pertinent concepts and relationships before reading texts. By providing the most pertinent concepts and appropriate relationships among concepts, CSSH serves to promote context-dependent thinking by reducing opportunities for accidental misinterpretation of how a concept is operationalized in a specific context.

CSSH also seems to reduce the instance or abstracting a singular meaning for a concept across all four contexts, or *content-independent conceptual representation*:

> [Participant Three] The individual concept maps showed how topics can have different meanings depending on what they are connected to. I think without those individual maps, I wouldn’t have thought about it that way

The think-aloud above shows how concepts were verbalized in terms of specific context after introducing concept map 2.0. This suggests that concept map 2.0's configuration encouraged the participant to develop context-dependent meaning.

Participant Three's familiarity with constructing concept maps may have influenced the likelihood that they would experience dissonance between each individual context and how concepts were represented by the context-independent concept map. Participants One and Two did not verbalize resistance regarding how the context-independent concept map was difficult to map onto all four contexts *during* the context-independent concept map stage. With that said, similarly to Participants One and Two, once concept map 2.0 replaced the context-independent concept map, there was an increase in think-alouds that suggest context-dependent thinking.

Research Question 2: *In what ways do novice learners of ecology think that concept 2.0 is "highly usable", or has design features that make it hard to use? How does facility of use relate to epistemic beliefs?*

To answer Research Question 2, themes related to usability and design features are discussed.

Usability of context-independent map vs concept map 2.0

All participants provided commentary regarding the usability of the context-independent concept map:

> [Participant One]: The first concept chart was too confusing and there was too much information (written response).; The first concept chart did not help me to see all the connections. It was too confusing. Too many strands going everywhere (think-aloud).
>
> [Participant Two]: The [context-independent concept map] is not very helpful...for a novice it wouldn't be ideal (think-aloud).

> [Participant Three]: A lot of people like to see lists or like easy-to-read graphs or images compared to something like [context-independent concept map] or even just a key concepts chart before the reading. I feel like that's a lot easier for people don't have this kind of like background [using concept maps] (think-aloud).

Participants Two and Three support the notion that the context-independent map would not be useful for people who are novices to subject matter and people who have not previously used concept maps. Participant One and wrote and verbalized perceived lack of usability for the context-independent map.

Participants One and Two indicated that concept map 2.0 would be useful as an educational tool for someone learning a new subject:

> [Participant Two]: [concept map 2.0] draws your attention, and it's not overwhelming...it does point out what you should be looking at which makes it a lot easier (think-aloud).
>
> [Participant One]: I would say it was really effective...It showed what we actually need to be looking at and made sure that you are focusing on the important things (think-aloud).

Participant Three verbalized that based on their understanding of general curriculum structure, concept map 2.0 is a useful learning tool, and note that concept map 2.0's context-dependent representations of different contexts allowed them to see how the relationships among concepts already encountered changes or is preserved and built upon:

> [Participant Three]: I think for any subject, [concept map 2.0] would be better because I feel like curriculum in general is built upon.. so you start out with something, and then you get more information... you see how that kind of changes what you already learned or how it adds on to it... so I feel like that's what [concept map 2.0] did for me throughout these contexts. I feel like [concept map 2.0] could be very beneficial (think-aloud).

Features of concept map 2.0

All participants wrote and verbalized strong preferences for concept map 2.0 regarding its utility in helping them during the ecology learning task. The most prevalent reason mentioned for preference of concept map 2.0 over the context-independent map was concept map 2.0's highlighting of pertinent contexts:

> [Participant One]: Highlighting definitely helped. For the [context-independent concept map], everything is shown to you at once, and it's a lot of information thrown at you, especially if you don't know the topic. But for [concept map 2.0], if I would read the reading and come back to [concept map 2.0], it highlights and bolds the interactions. It was a lot more helpful...(think-aloud).
>
> [Participant Two]: I already like how it's highlighted…[highlighting] makes it way less confusing. [concept map 2.0] just makes so much more sense because you can figure out where to start before you are reading. When it's highlighted like that, I'm more likely to use it, and with the [context-independent concept map], it just was kind of more confusing (think aloud).
>
> [Participant Three]: I liked how they were like highlighted like the individual ones so you could really just see the main topics in each thing (think-aloud).

Other reasons cited for preferring concept map 2.0 were concept map 2.0's clarity in representing information compared to the context-independent map and that concept map 2.0 allowed for deeper processing of concepts and relationships:

> [Participant One]: The second concept map made it very clear to me what it was important for the survival of the scales; The second concept maps helped me to

understand more clearly and more in depth. They allow me to have deeper understanding (writing responses).

[Participant Two]: The concept map that was highlighted helped narrow my gaze to the information that was needed for this context (writing response).

[Participant Three]: [concept map 2.0] helped me see the most important pieces of each context that might not have been there in the [context-independent concept map] (think-aloud).

No participants indicated that they perceived features of concept map 2.0 that hindered their learning.

Preference for concept map 2.0

All participants verbalized and wrote that they preferred using concept map 2.0 over the context-independent concept map. Some think-alouds and written responses that indicate preference simultaneously relate to attitudes of usability and helpful features (for example, previously listed think-alouds and written responses that include feelings of preference for concept map 2.0, features such as highlighting, and opinions of high usability). While indicators of preference and positive attitudes regarding usability may be related, it is important to recognize that preference does not equate to context-dependent-thinking. For example, although Participant One consistently voiced preference for concept map 2.0, think-alouds that suggest context-independent thinking persisted throughout the entirety of their study. In other words, preference and perceived usability for context-dependent representation is not enough to avoid development of or eliminate existing context-independent knowledge structures.

Preference may also be related to perceived simplicity of concept map 2.0, especially relative to the context-independent concept map. For example, all participants expressed ideas of simplicity for concept map 2.0 or confusion when using the context independent map:

[Participant One]: The first context map was confusing and had too much information thrown at me all at once.

[Participant Two]: I think the [concept] map [2.0] gives you like kind of the main ideas

[Participant Three]:

Research Question 3: *How do preexisting epistemic beliefs inform research questions one and two?*

Epistemic beliefs were measured using the *cognitive flexibility inventory* (CFI). Participants responded to statements using a 1-5 Likert scale with "1" indicating they *strongly* disagree and "5" indicating they *strongly agree.* Responses that favor viewing knowledge as abstract, neatly organized, and as part of a single system are examples that may indicate the presence of epistemic beliefs that encourage context-independent. Responses that favor viewing knowledge as situated in individual situations, messy, and part of many interconnected systems of knowing are examples that may indicate the presence of epistemic beliefs that encourage context-dependent thinking. Responses to both the pre and post CFIs as well as within-participant changes from pre-to-post CFI are discussed in conjunction with think-aloud data, writing responses, and interview responses.

Participant One

Out of all three participants, Participant One recorded the most static responses from pre-to-post CFI (15 out of 21 items). They also recorded the greatest frequency of responses that indicate strong context-independent-like epistemic beliefs on both their pre and post CFIs. There

were six inventory items in which Participant One responded differently from pre to post CFI-the fewest amount of changes out of all participants. Out of these 6 items, only 2 items were marked differently by more than a single unit of measure (i.e responding “1” on pre and “3” on post).

The relatively high frequency of CFI responses that suggest context-independent thinking provides context for the persistence of context-independent think-alouds during the ecology learning task. It is possible that preexisting epistemic beliefs predisposed the participant to build understanding of the topic using rigid knowledge structures that encourage viewing concepts and relationships as abstract and universally operationalized. In other words, preexisting epistemic beliefs that encourage context-independent thinking encourage the participant to believe there is a rigid, static mold of which knowledge needs to fill. Consequently, the process of fitting information into rigid structures of knowledge may reinforce the notion that that mold is an appropriate framework of which to understand that topic. The cycle of strengthening rigid knowledge structures by fitting information into them provides a great level of resistance to context-dependent thinking.

It is possible that both preexisting epistemic beliefs as well as prior exposure to the context-independent concept map are partially attributable to the persistence of overreliance of top-down processing. Participant One was a novice to the topic at-hand, meaning their initial understandings were developed using the first concept map-the context-independent concept map. It is possible that the context-independent concept map contributed to the development of knowledge structures that encouraged overreliance on top-down processing and created resistance to the development of knowledge structures more compatible with context-dependent thinking. Evidence that some patterns of context-independent thinking persisted, even after using concept map 2.0, supports the notion that it is imperative that educators provide novices with

context-dependent representations of context-dependent topics when first learning about those topics to avoid hard-to-change, context-independent knowledge structures.

Participant Two

Participant Two recorded the least amount of consistent responses from pre-to-post CFI (6 out of 21). Out of the six unchanged items, two items indicated epistemic beliefs that encourage context-dependent thinking, and four items indicated epistemic beliefs that encourage context-independent thinking.

There were 15 inventory items in which Participant Two responded differently from pre-to-post CFI. Out of these 15 items, 10 items were marked differently by a single unit of measure. Out of the items marked differently by a single unit of measure, seven items were changed from pre-to-post towards epistemic beliefs that encourage context-dependent thinking, and three items were changed towards indication epistemic beliefs that encourage context-independent thinking. Four items were marked differently by more than a single unit of measure. Out of these four, one was changed from pre-to-post towards indication of epistemic beliefs that encourage context-dependent thinking, and three were changed from pre-to-post towards indication of epistemic beliefs that encourage context-independent thinking.

From pre-to-post CFI, there were many small changes made towards context-dependent encouraging epistemic beliefs and a few large changes made towards context-independent encouraging epistemic beliefs. There was no discernable pattern of change indicated for the responses that were changed. It is not likely that a single experience influenced preexisting epistemic beliefs to change so much so that most of the responses would be altered. With consideration to think-alouds, written responses, and interview responses, CFI responses seemed to vaguely correspond to the overall increase in context-dependent think-alouds produced by

Participant Two in that the majority of CFI items favored context-dependent encouraging epistemic beliefs, but the inconsistent pattern of change in CFI responses suggests that similarly to Participant One, evident preference for concept map 2.0 does not equate to context-dependent thinking nor epistemic beliefs that encourage context-dependent thinking.

Participant Three

There were nine inventory items for which Participant Three did not change from pre-to-post Out of these nine, seven items indicated epistemic beliefs that encourage context-dependent thinking, and two items indicated epistemic beliefs that encourage context-independent thinking.

There were twelve inventory items for which Participant Three responded differently from pre-to-post CFI. Out of these 12 items, 11 items were marked differently by a single unit of measure. Out of the 12 items marked differently by a single unit of measure, nine items were changed from pre-to-post towards indication epistemic beliefs that encourage context-dependent thinking, and two items were changed towards indication epistemic beliefs that encourage context-independent thinking.

One item was marked differently by more than a single unit of measure. This item was changed from pre-to-post towards indication of epistemic beliefs that encourage context-dependent thinking.

Out of all participants, Participant Three indicated the most context-dependent encouraging epistemic belief responses. Items that stayed consistent from pre-to-post were mostly context-dependent, and items that changed were mostly moved towards context-dependent encouraging epistemic belief responses. The total number of context-dependent-related epistemic belief responses and patterns of change from pre-to-post CFI correspond to their relatively high frequency of context-dependent think-alouds. Similarly to Participants One

and Two, Participant Three's preference for concept map 2.0 should be considered carefully when examining CFI scores and changes. Although context-dependent think-alouds, CFI responses, and attitudes of preference correspond in the instance of Participant Three, the outcomes of Participants One and Two must be considered, and connections among experiences using concept map 2.0, think-alouds, and CFI responses should be kept within the scope of individual case accounts.

General Discussion

Although all participants were not familiar with the relationship between the Vedalia Beetle and Cushiony Cotton Scale, there may have been varying levels of familiarity across participants in terms of experience using context maps. Participants One and Two did not verbalize prior experiences using concept maps as part of their academic experiences. Participant Three indicated current and previous experiences using concept maps as constructive tools for learning content but not as a preconstructed representation such as the concept maps presented in this study.

All participants verbalized and wrote that they strongly preferred to use concept map 2.0. Reasons for preference such as highlighting, increased clarity, and affording deeper understanding may be related to the increase in context-dependent think-alouds during and after the concept map 2.0 stage. It is important to acknowledge that preference alone does not indicate context-dependent thinking. For example, Participant One, who produced persistent context-independent think-alouds and indicated more context-independent-related epistemic beliefs, verbalized in both the ecology learning task and interview that they found concept map 2.0 more usable than the context-independent map-it is possible that preference for concept map 2.0 was developed simultaneously as existing rigid knowledge structures (developed during context-

independent stages) and preexisting epistemic beliefs obstructed context-dependent patterns of thinking from developing, even with the aid of concept map 2.0.

All participants produced more context-dependent think-alouds during and after the concept map 2.0 stage of the ecology learning task than the preceding stages. Increases in context-dependent think-alouds were not uniform across the three participants. Participant One produced the least amount of context-dependent think-alouds, Participant Two produced the second most, and Participant Three produced the most. Participants One and Two only produced only context-independent think-alouds during the context-independent concept map stage, and while context-dependent think-alouds increased for Participant Three during the concept map 2.0 stage, they produced *some* context-dependent think-alouds during the context-independent map stage. Unlike Participants One and Two, Participant Three had previous experience constructing concept maps, and out of the three participants, Participant Three agreed with the greatest number of context-dependent-related CFI items. Although Participant Three was a novice to the topic, previous experiences using concept maps may have scaffolded their experience so that they were able to more quickly acclimate themselves to how concepts and relationships were represented on both types of concept maps. In other words, Participant Three may have required less cognitive effort dedicated towards understanding the structure of the concept maps compared to the other two participants, and as a result, Participant Three may have been able to dedicate more cognitive resources towards understanding the contexts.

Results from this study inform the design of future studies using concept map 2.0. Future studies should consider familiarity with concept maps (both in constructing concept maps and using them as learning tools) as a variable of analysis, and a more comprehensive analysis of CFI responses (including changes in responses) should be conducted to supplement other sources of

data such as think-alouds and written responses. Future work should also gather data from a larger sample to adequately accommodate more quantitative methods of data analyses (e.g. more quantitative CFI and protocol analyses).

The design and function of concept map 2.0 should also be adjusted so that it can be studied in diverse educational roles (i.e. preconstructed tool like this study *or* assessment tool where learners construct their own concept map 2.0 while developing knowledge structures). Design changes could include adopting a hypertext system approach that would allow users to view context-dependent representations of contexts via an interactive system that automatically employs CSSH to concepts and relationships in a knowledge domain based on the parameters of a specific context. Another design feature for future consideration in concept map 2.0 is an ability to adjust the physical positioning of concepts and relationships in a context-dependent manner. For example, in addition to highlighting and varying transparency, concept map 2.0 would bring the most pertinent concepts and relationships of specific contexts “to the top”. This feature would not encourage top-down processing because the concepts at the top would be ever-changing to each individual context. In other words, this type of feature would encourage bottom-up processing because user would be developing understanding of a topic using many unique configurations of representations that are defined by individual contexts rather than abstract definitions.

A next step in exploring how features like highlighting encourage context-dependent thinking is to examine learning across multiple subjects. For example, this study examined a single topic (the relationship between the vedalia beetle and cottony cushion scale). Future studies could examine participants learning a topic like concept map 2.0 to learn a topic and then introduce participants with a new topic in a different subject area (but still ill-structured in

nature) with the use of different concept map conditions (context-independent concept map, concept map 2.0, no concept map). Examining think-alouds of learning multiple topics could inform understanding of how features of concept map 2.0 influence processes related to transfer (i.e. do learners express context-dependent think-alouds in new topic after using concept map 2.0 in previous topic?).

Future research should continue to collect data regarding usability, preference, and aspects of modification as concept map 2.0 becomes a more refined learning tool. Accounts from both novices, intermediate learners, and experts should be collected to better understand how prior knowledge influences how users interact with and are influenced by how concept map 2.0 represents knowledge. In addition to continuing to examine concept map 2.0 in higher education settings, research should also consider examining concept map 2.0 in school settings as a tool to supplement how context-dependent topics in existing curriculums may be enhanced in terms of encouraging context-dependent understanding of concepts and relationships in students.

Limitations

This study was an exploratory effort which sought to provide valuable insights into participant experiences and reactions to using concept map 2.0. I acknowledge that the study's qualitative nature and that small sample sacrifice external validity, but I believe the think-aloud method served as the best method for gathering data to inform the study goals, and I believe the protocol analysis of this data was an appropriate form of analysis to answer the research questions. I acknowledge that a limitation of the think-aloud method is that in interpreting and categorizing verbal data to patterns of cognition in which I am interested, there may be oversimplification of sections of verbal transcripts to a single pattern of interest (Johnson, 1992; Ranking, 1988). To avoid oversimplification of verbal data, when possible, data analyses of

protocols considered how verbalizations could be considered both context-independent and context-dependent.

Though considerations of participation are established to mitigate effects of prior knowledge, participants were chosen in part by a matter of convenience which increases the possibility that personal disposition towards the researcher may impact the way the participant approaches the study. The ecology learning task is not counterbalanced for order, meaning all three participants underwent the three stages in the same order. It is possible that presenting the ecology learning task with the same conditions, ordered differently would yield data that either confirms or denies conclusions drawn from this study. It is my hope that with the help of insights gathered from this study, future studies interested in similar phenomena will utilize larger sample sizes and employ counterbalancing to conditions to allow for more quantitatively and qualitatively sound conclusions. I also acknowledge that the think-aloud method of data collection provides data regarding participant performance (verbalization), and that performance is not necessarily indicative of awareness. In other words, think-aloud data that reflects context-dependent thinking does not necessarily indicate understanding of a concept or context as context-dependent. Ericsson and Simon (1999) caution that recognition and description of concepts can but should not be interpreted as indicative of awareness of concept function (p.143). This study collected data from think-alouds, CFIs, written responses, and interview data in-conjunction to illustrate participant experiences. Constructing accounts from several modes of data collection serves to triangulate observations and researcher interpretations (Stake, 2005).

I acknowledge that context-dependent performance (verbalizations) could have partially been influenced by extended exposure to content. The three-stage design of the ecology learning task was implemented to demonstrate a higher increase of context-dependent performance from

stages two-to-three compared to stages one-to-two. If mere length of exposure to content results in increased context-dependent performance, the rate of increase in context-dependent performance from stages one through three should be relatively steady. The argument that concept map 2.0 positively influences context-dependent performance is strengthened, if the increase in context-dependent performance is greater between stages two-to-three relative to stages one-to-two.

Preference and increased context-dependent verbalizations were also expressed during the concept map 2.0 condition of the ecology learning task and interview. Think-alouds related to simplicity as a feature that factored into participant preference for concept map 2.0 indicate that concept map 2.0's highlighting feature helped participants focus on pertinent concepts, ignore non-pertinent concepts, and expend less cognitive effort on determining which concepts were most pertinent at during each context. Despite implementing the condition order (context-independent-context-independent-concept map 2.0) as a means to hone in on the effect concept map 2.0 has on context-dependent verbalizations, it is possible that preference for and increased context-dependent verbalizations while using concept map 2.0 are partially attributable to a *simpler* concept map relative to the context-independent concept map (highlighting inherently decreases the amount of nodes and links of which to focus). More research is needed to better understand how context-dependent verbalizations may be influenced by features of concept map 2.0 (such as highlighting) *and* simplicity.

Conclusion

With the completion of this study, I hope to shed light on how CSSH integrated into concept maps in the form concept map 2.0 may be utilized to enhance knowledge construction in context-dependent Subjects. Findings will help inform future work interested in investigating

how concept map 2.0 functions as tool to help develop context-dependent ways of thinking. As researchers continue to build a body of work concerning the phenomena relating to observations made in this study, a more developed framework will form, allowing for these processes to be observed by a wider array of quantitative and qualitative methods. I also hope that this study paves the way for future research related to concept map 2.0 to explore how tools that integrate CSSH may also be used to assess learning objectives associated with context-dependent thinking. For example, future research may investigate processes related to this study, but include additional novel texts for different conditions which could produce implications for how processes of transfer are influenced by CSSH. Future work may also flip the role of the participant so that they must construct their own concept map that integrates CSSH. Investigating how participants map their thinking in the form of concept map 2.0 has interesting implications for assessing context-dependent thinking, a skill that is becoming increasingly important in the discussion of 21st century skills. It is my hope that concept map 2.0 will become developed to the point where it can be implemented into classrooms as a technological tool to support the development of context-dependent thinking and 21st-century problem solving skills.

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Appendix A

The Cognitive Flexibility Inventory

- Each of the following items contains two opposing statements about learning.
- Please select the degree to which statement matches how you think.
- Only one option on each item (or line) can be selected.
- There is no right or wrong answer, and we just want to know how you think

1. When phenomena appear disorderly, it is probably because a system for organizing them has not yet been found. But, it is likely that such a system exists.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

2. Different aspects of sub-topics of knowledge should be highly interrelated in the mind along a variety of different dimensions. Although this is not a very neat way to organize knowledge, keeping knowledge interconnected in this way were beneficial to you in your later uses of that knowledge.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

3. There tends to be a lot of heterogeneity within the parts of any whole system. Many parts are not like the whole. Uniformity of explanation throughout a system, while nice, it not essential; a plurality of the explanation types is all right and sometimes necessary.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

4. I do not find ambiguity in situations too troubling. It's all right if things don't always have a clear answer.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

5. Complex topics should be broken apart and each individual part or component should be studied separately. In most areas of study, the whole topic is usually equal to the sum of the its parts.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

6. When placed in a new situation in which previously learned information has to be applied, people should not count on remembering some plan for what they should do in the new situation (whether it's from some general rule they've been taught or from some very similar example that was taught). Instead the emphasis should be on figuring out how it might be necessary to apply their knowledge in a somewhat new way that fits the new situation.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

7. A Greek poet said: "The fox knows many things, but the hedgehog knows one big thing." Are you like a hedgehog? Would you say that you generally try to relate what you are learning to a single central vision, one system, in terms of which you try to understand and think?

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

8. I have a strong preference for simplicity and orderliness. Whenever possible, I prefer not to encounter complex concepts in school (although I deal with complexity when I have to).

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

9. The notion that ideas could "come to life" makes no sense. Concepts are merely abstractions.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

10. Learning is essentially a process of receiving information and recording it accurately in memory for later retrieval and use.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

11. A Greek poet said: "The fox knows many things, but the hedgehog knows one big thing." Are you like a fox? Would you say that when you are trying to understand and learn about some topic you try to look at subject matter from different perspectives, rather than trying to related everything to a single central system of viewpoint?

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

13. When phenomena appear disorderly, it is probably the case that a single system for organizing them will not be found. The facts of the world are frequently quite hard to account for by grand, unifying systems.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

14. Breaking apart complex topics to study each individual part or component separately is often misleading because components of complex topics tend to interact and affect each other. In most areas of study the whole is usually not the same as the sum of the parts.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

15. You have learned some topic best when you have examined its various phenomena form the points of view of various different explanatory systems or perspectives.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

16. I find it very hard to tolerate ambiguity. I like things to have a clear answer.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

17. Learning is essentially an active process in which you personally construct understandings and acquire the ability to apply your knowledge in new ways to various kinds of new situations.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

18. I am highly motivated by internal factors (e.g., what I intrinsically want to do and think is best).

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

19. The parts of a whole system tend to be alike (i.e., systems tend to be homogeneous). Uniformity of explanation throughout a system is very desirable.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

20. I have a strong preference for complexity. I enjoy encountering difficult and disorderly concepts and find them challenging.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

21. You have learned some topic best when you have accounted for all of its various phenomena using some single, more abstract, explanatory system or perspective.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

22. Different aspects or sub-topics of knowledge should be compartmentalized, separated into different mental "boxes" so they don't interfere with each other. Keeping knowledge neatly organized in this way helps avoid confusion if the knowledge has to be used later.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

Appendix B

Vedalia Beetle and Cottony-Cushion Scale Context Texts and Writing Response Questions

CONTEXT 1 (corresponds to concept map 2.0-1)

The cottony-cushion scale is an Australia-native insect that is believed to have come to California by sea in a cargo of fruit. The cottony-cushion scale is small pest for many species of plants, but they have been most heavily researched in the context of citrus tree farms which are most commonly found in regions with warm climates.

Although not native to California, cottony-cushion scales have shown little difficulty in adapting to a new geographical region, and the abundance of citrus farms throughout the warm regions of California have afforded population sustenance of the scales. Colonies of scales will feed on the leaves and limbs of citrus trees, usually killing the plant in the process. If citrus plants are in abundance across farms, there may be just enough time for new trees to be planted and grown before an existing or new scale colony finds the newly grown trees, only to feast again, thus, providing stability for the cottony-cushion scales. While citrus farmers may experience a break from the scales that lasts long enough to plant new trees, scales still present issues regarding crop production, and breaks from infestations are usually not long enough for farmers to yield product worth their investment in plants.

As an invasive species, the cottony-cushion scales experienced little to no resistance in terms of predators when first introduced to the citrus farms of California. Because farmers realized that the cottony-cushion scale population was stable, to their crops' detriment, action was taken to control the scale population down to a level where crops could survive.

CONTEXT 1 WRITING RESPONSE QUESTION: Using terms and relationships present in the concept maps, in your own words:

1. Summarize the phenomena that occurred during *CONTEXT 1*.
2. What are the most important concepts in terms of understanding the phenomena in CONTEXT 1? List the concepts and describe why these concepts seem most important.
3. If the most important concepts you chose for *CONTEXT 1* are similar to concepts chosen for *CONTEXTS 2, 3,* or *4*, please explain why you think these concepts are most important across multiple contexts.
4. If the concepts you chose for *CONTEXT 1* are different than concepts chosen for *CONTEXTS 2, 3,* or *4*, please explain why you think different contexts are best represented by different most important concepts.
5. How do the different types of concept maps influence how you understand the phenomena in *CONTEXT 1*.? Do the different types of concept maps help you think about concepts in ways you would not have with no concept map?

CONTEXT 2 (corresponds to concept map 2.0-2)

A Californian entomologist went to Australia to look for enemies of the scale. He found an Australian ladybird beetle called the Vedalia. Even in small numbers, the Vedalia has been observed as a highly successful pest control, particularly in the context of controlling cottony-cushion scales. From an evolutionary perspective, the Vedalia has developed into an extremely skilled “seek and destroy” predators of scales. Once a scale population has been found by a member of a Vedalia colony, the discovering Vedalia is able to signal the scale location to the rest of the colony. It only takes a few Vedalias to effectively decimate massive scale colonies. The Vedalias skills as a seek and destroy predator are likely to have developed through evolutionary adaptation.

On the brink of a crisis, the citrus industry found salvation in the Vedalia, as it decimated cottony-cushion scale populations, thus, helping to stabilize the citrus tree population by allowing numbers to increase back to profitable quantities. The Vedalias are so effective in controlling scale populations that within a year of being introduced to farms plagued by scales, Vedalias had almost completely eradicated all scales.

CONTEXT 2 WRITING RESPONSE QUESTION: Using terms and relationships present in the concept maps, in your own words:

6. Summarize the phenomena that occurred during *CONTEXT 2*.
7. What are the most important concepts in terms of understanding the phenomena in CONTEXT 2? List the concepts and describe why these concepts seem most important.
8. If the most important concepts you chose for *CONTEXT 2* are similar to concepts chosen for *CONTEXTS 1, 3,* or *4*, please explain why you think these concepts are most important across multiple contexts.
9. If the concepts you chose for *CONTEXT 2* are different than concepts chosen for *CONTEXTS 1, 3,* or *4*, please explain why you think different contexts are best represented by different most important concepts.
10. How do the different types of concept maps influence how you understand the phenomena in *CONTEXT 2*.? Do the different types of concept maps help you think about concepts in ways you would not have with no concept map?

CONTEXT 3 (corresponds to concept map 2.0-3)

Although the scale infestation has been largely addressed by Vedalias, there comes a point in the predation cycle when the Vedalias become the species that experience struggles to survive. As the number of scales decreases as a result of Vedalia predation, Vedalias,

themselves, begin to struggle because of dwindling food resources. Even after most scales have been eaten by the Vedalias, if you look hard enough you will likely find a colony of scales somewhere in the orchards.This is because typically, a few scales escape the attack of the Vedalias and find refuge in a new patch of citrus trees. Initially, the number of scale refugees is too small to be detected by the predator Vedalias. At this point, the scale population is increasing, and the Vedalia population is decreasing, but just as the Vedalia population is on the verge of extinction due to lack of food scarcity, the growing population of the refugee scale colony usually grows just large enough for the few remaining Vedalia to discover via seek and destroy predation - a method of hunting akin to hide and seek. On the verge of eradication, Vedalias find stability in discovering the new scale colony.

CONTEXT 3 WRITING RESPONSE QUESTION: Using terms and relationships present in the concept maps, in your own words:

11. Summarize the phenomena that occurred during *CONTEXT 3*.
12. What are the most important concepts in terms of understanding the phenomena in CONTEXT 3? List the concepts and describe why these concepts seem most important.
13. If the most important concepts you chose for *CONTEXT 3* are similar to concepts chosen for *CONTEXTS 1*, *2*, or *4*, please explain why you think these concepts are most important across multiple contexts.
14. If the concepts you chose for *CONTEXT 3* are different than concepts chosen for *CONTEXTS 1*, *2*, or *4*, please explain why you think different contexts are best represented by different most important concepts.

15. How do the different types of concept maps influence how you understand the phenomena in *CONTEXT 3*? Do the different types of concept maps help you think about concepts in ways you would not have with no concept map?

CONTEXT 4 (corresponds to concept map 2.0-4)

Once one of the few remaining Vedalias discovers a new scale colony via seek and destroy predation, the newly discovered scales can do little to defend against an impending onslaught by the Vedalias. With the number of Vedalias being low, there are plenty of scales (who have had time to grow in numbers while in hiding) to support growing numbers of Vedalias. The number of Vedalias continues to rise until there are not enough scales to sustain this pattern. Once the ratio of scales to Vedalias becomes too small, the Vedalia population will experience a plateau, followed by a steady dip, eventually leading to a struggle for survival until the Vedalias can, once again, seek and destroy a new scale colony.

CONTEXT 4 WRITING RESPONSE QUESTION: Using terms and relationships present in the concept maps, answer the following prompts:

16. Summarize the phenomena that occurred during *CONTEXT 4*.
17. What are the most important concepts in terms of understanding the phenomena in CONTEXT 4? List the concepts and describe why these concepts seem most important.
18. If the most important concepts you chose for *CONTEXT 4* are similar to concepts chosen for *CONTEXTS 1*, *2*, or *3*, please explain why you think these concepts are most important across multiple contexts.
19. If the concepts you chose for *CONTEXT 4* are different than concepts chosen for *CONTEXTS 1*, *2*, or *3*, please explain why you think different contexts are best represented by different most important concepts.

20. How do the different types of concept maps influence how you understand the phenomena in *CONTEXT 4*.? Do the different types of concept maps help you think about concepts in ways you would not have with no concept map?

ALL CONTEXTS WRITING RESPONSE QUESTION: Using terms and relationships present in the concept map, in your own words:

1. Summarize the relationship between the Vedalia Beetle and Cottony Cushion Scale.
2. Are there concepts that are always most important to understanding the relationship between the Vedalia Beetle and Cottony Cushion Scale? Are there concepts that are more important in some contexts but not others?
3. How do the concept maps influence how you perceive the nature of the relationship between the Vedalia Beetle and Cottony Cushion Scale? Do the concept maps help you think about their relationship in ways you would not have with no concept map?
4. How do the concept maps influence how you perceive the meanings of concepts relationships among concepts? Do the concept maps help you think about concepts and relationships among concepts in ways you would not have with no concept map?
5. Do you have a preference between two types of concept maps? If so, what aspects of each type of concept map do you think help or hinder your understanding of the relationship between the Vedalia Beetle and Cottony Cushion Scale?

Appendix C

Semi Structured Interview Protocol

Both context-independent and concept map 2.0 maps were available for participants to reference while answering interview questions.

1. Did either type of concept map help or hinder your learning of vedalia beetles and cottony cushion scales?
    a. If yes…
        i. In what ways did each type help or hinder?
    b. If no…
        i. Why do you think neither type of concept map influenced how you learned?
2. Do you perceive one type of concept map as either more helpful or hindering to learning? If so, which one is more helpful/hindering, and what specific features influence your opinion?
3. When using the first map (context-independent map), were you more likely to perceive concepts as used in a universal manner across all four texts, or were you more likely to perceive them as defined by each individual text?
    a. Which features make you say this?
4. When using the second set of maps (concept map 2.0), were you more likely to perceive concepts as used in a universal manner across all four texts, or were you more likely to perceive them as defined by each individual text?
    a. Which features make you say this?

5. Did the design of the first concept map (context-independent map) (uniform transparency, color, boldness) influence the nature in which you conceptualized concepts as you were reading and writing? If so, do you think these features are helpful in building your understanding of the texts?
    a. Do you feel the design of the first concept map (context-independent map) hindered your understanding of the texts?
        i. If so, how would you improve upon the design of the first concept map to address these hindrances
6. Did the specific features of the second set of maps (concept map 2.0) (highlighting, transparency, boldness) influence the nature in which you conceptualized concepts as you were reading and writing? If so, do you think these features are helpful in building your understanding of the texts?
    a. Do you feel any features of concept map 2.0 hindered your understanding of the texts?
        i. If so, how would you improve upon the design of concept map 2.0 to address these hindrances
7. How would you evaluate the usability of the first concept map (context-independent map) in an educational setting such as a school, workplace, or other professional development environment?
    a. Do you have any suggestions relating to how you would modify this type of concept map to increase its value as an educational tool?

8. How would you evaluate the usability of the second set of concept maps (concept map 2.0) in an educational setting such as a school, workplace, or other professional development environment?
    a. Do you have any suggestions relating to how you would modify this type of concept map to increase its value as an educational tool?

9*. (with all concept maps present) The relationship between the Vedalia Beetle and Cottony Cushion Scale is considered context-dependent, meaning that ecological concepts used to describe their relationship change definition from context-to-context. You were presented four different contexts that illustrate the context-dependent nature of the vedalia beetle and cottony cushion scale. Looking at the four concept map 2.0s in front of us, discuss how its features such as highlighting, bolding, and transparency help illustrate the relationship between the vedalia beetle and cottony cushion scale as context-dependent.

10* (with context texts and concept maps present) Now that I have informed you that the relationship between the Vedalia Beetle and Cottony Cushion scale can be thought of as dynamic and comprised of many unique contexts, for concepts that are present in more than one context, are you able to understand how their meaning and pertinence is dependent on the individual situation in which it is being examined? Please look over the texts and concept map 2.0s, and discuss how a single concept can be present across different contexts but be operationalized and emphasized differently in each context.

11* Discuss how a tool like concept map 2.0 helped you understand the relationship, as a whle, between the Vedalia Beetle and Cottony Cushion Scale as dynamic and context-dependent.

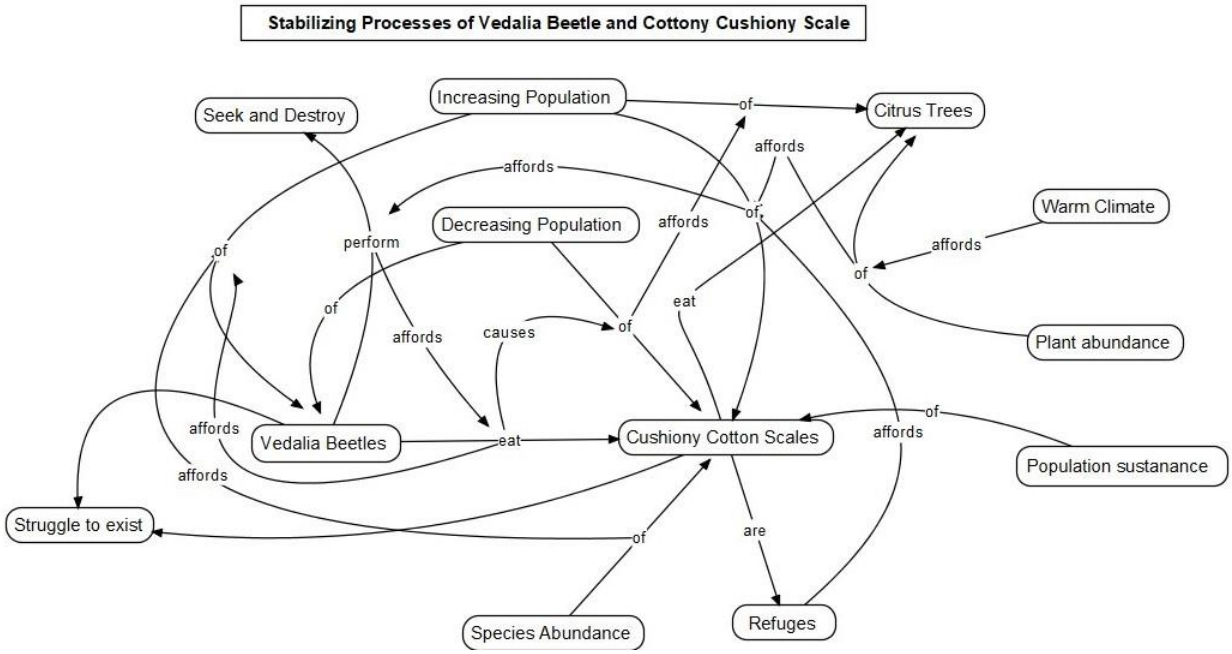
12* Now that I have informed you that the relationship between the Vedalia Beetle and Cottony Cushion Scale is context-dependent, and that the meanings and levels of pertinence of concepts used to illustrate this relationship are not the same from context-to-context, discuss how effectively concept map 2.0 helps to develop understanding of the relationship between the Vedalia Beetle and Cottony Cushion Scale as context-dependent compared to a traditional concept map that does not highlight, bold, or use transparency.

**Use this prompt if participant demonstrated difficulty in understanding connection between features of concept map 2.0 and the context-dependent nature of the four ecological contexts.*

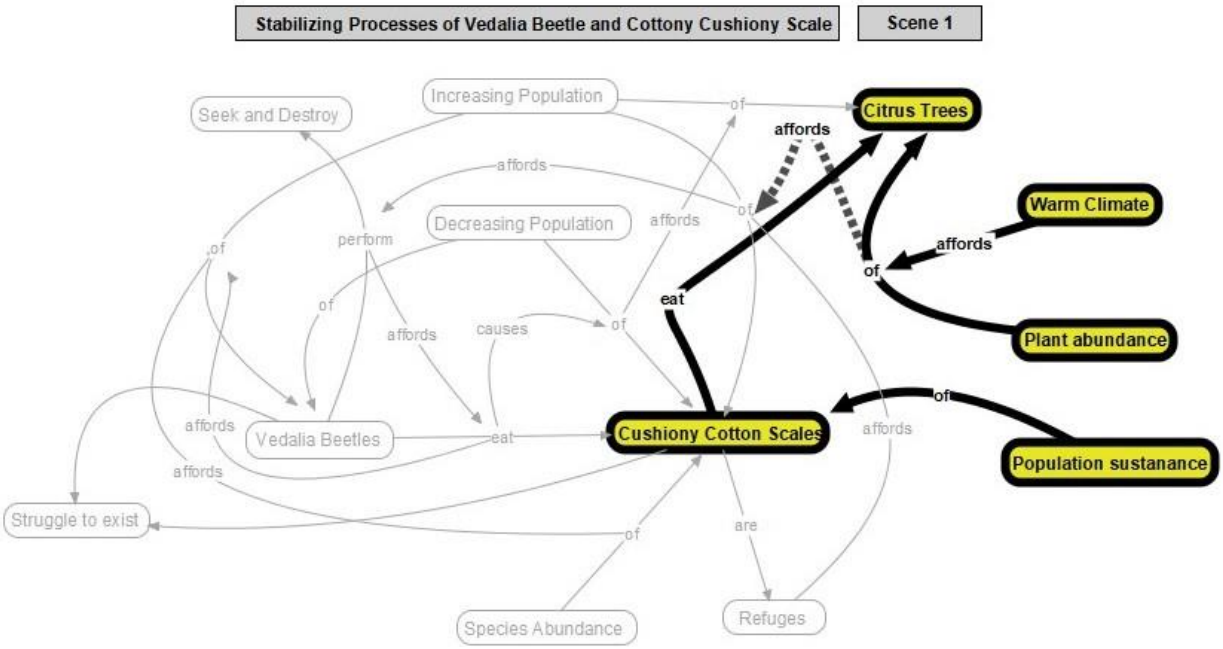
Appendix D

Concept Maps Used

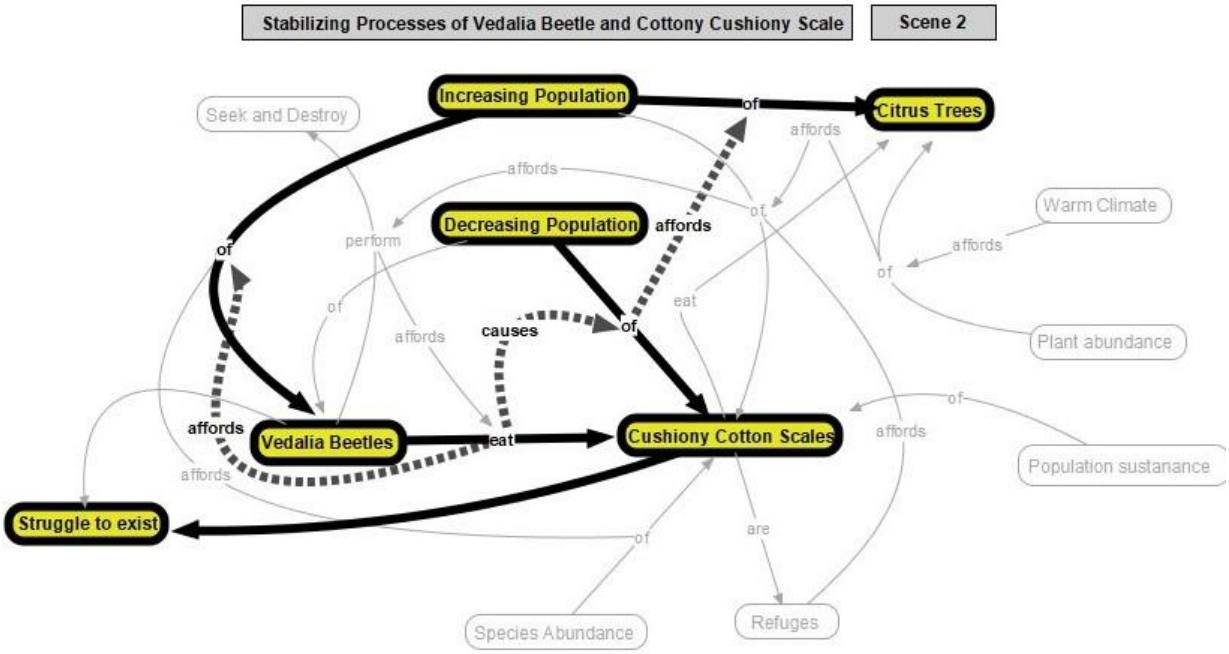
Concept-independent concept map



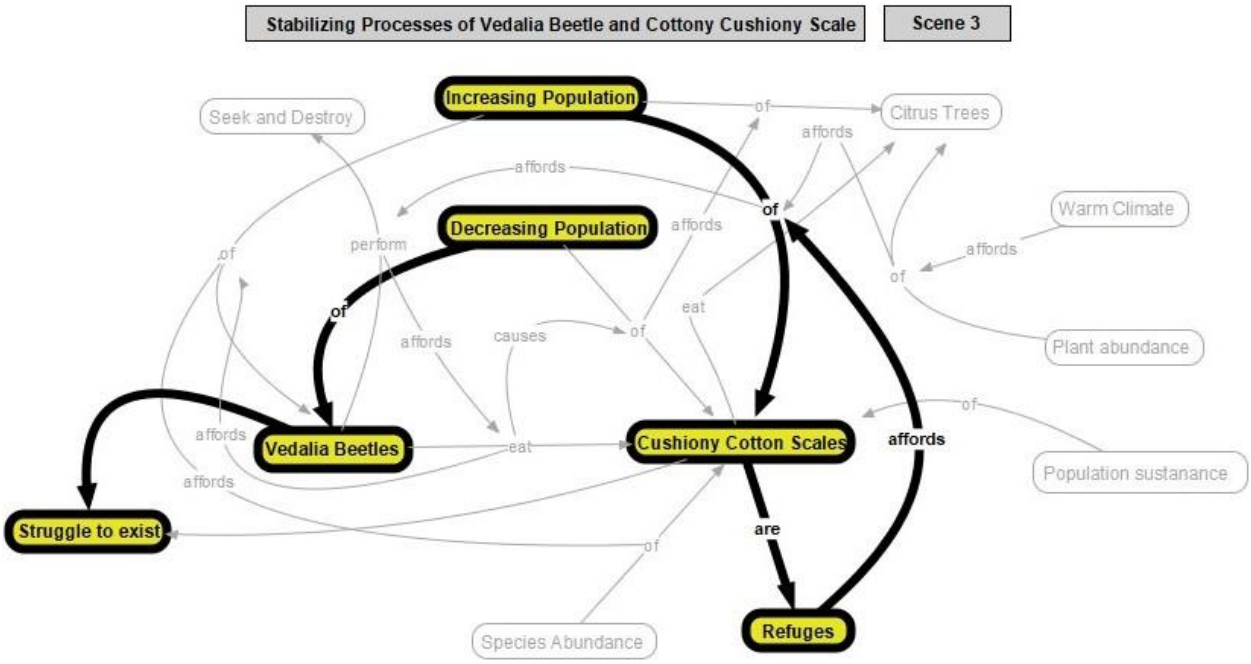
Concept map 2.0 - 1



Concept map 2.0 - 2



Concept map 2.0 - 3



Concept map 2.0 – 4