Visual Mapping to Enhance Learning and Critical Thinking Skills

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Abstract

Visual mapping allows the learner to explicitly explore, analyze, synthesize and share ideas. This paper reviews mapping tools suited for brainstorming and picturing the thinking process (mind mapping), exploring the structure of knowledge (concept mapping), developing premises, counter arguments and conclusions around a contention (argument maps), exploring the learner's own thinking process (®Thinking Maps), seeking the inter-relation among variables (general systems thinking) and developing simulation models (system dynamics). The paper also presents the evidence on the effectiveness of these tools in promoting recall, comprehension and general critical thinking skills.

Key Words: *critical thinking, recall, comprehension, visual map, mind map, concept map, thinking map, systems thinking, system dynamics*

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Background

Critical thinking dates back more than 2,000 years at the birth of Western civilization. Socrates' dictum "The unexamined life is not worth living" subsumes the ultimate value of critical thinking in human life. Plato's Dialogues epitomizes not only a method but also a way of living that is still relevant to our time.[1] Critical thinking skills involve the processing of information through analysis, synthesis, interpretation, explanation, evaluation, generalization, abstraction, application, comparison and contrast.[2] Critical thinking skills are, like common sense, not very common. Studies indicate that 70% of high school graduates are deficient and only 28% of four-year college graduates possess excellent skills. Yet, it is considered to be the most important asset sought by human resource professionals.[3]

Across the globe, many university educators use the lecture format assisted with PowerPoint slides as the main delivery method. More than a generation of students has suffered "death by PowerPoint,"a term describing the use of slides cluttered with text, often with irrelevant embellishments, leading to student boredom and little meaningful learning[4,5]. Although these presentations can be improved, there is an inherent limitation to these traditional methods. Lectures and text slides are inevitably linear representations that hide the rich inter-relations among the concepts. As Davies explains: "This paradoxically usually results in less meaningful learning, not more. It results in linearity rather than connectivity out of which genuine understanding arises … It also fosters a lack of engagement critical to the development of meaningful understanding … To meet assessment demands, students begin to rely on memorization techniques and cramming, not meaningful activities to ensure engagement and learning, and ultimately — via a transformative learning cycle — expertise."[6]

David Ausubel, an educational psychologist, saw the primary responsibility of the educator as the presentation of learning materials in a meaningful form, not as a list of facts. He indicated that educators must find procedures allowing the learners to tie new knowledge into their prior cognitive structure. He proposed visual mapping as a tool par excellence to promote meaningful learning.[7] His view on meaningful learning has been supported by research on the organization of knowledge by experts as compared to novices: "Studies in areas such as physics, mathematics, and history also demonstrate that experts first seek to develop an understanding of problems, and this often involves thinking in terms of core concepts or big ideas such as Newton's second law in physics. Novices' knowledge is much less likely to be organized around big ideas; they are more likely to approach problems by searching for correct formulas and pat answers that fit their everyday intuitions."[8]

Marzano completed a meta-analysis of research on instruction and strategies that significantly affect student achievement. Nonlinguistic representations, questions, cues and advanced graphical organizers were among those that were correlated with effective learning.[9] Prince reported that activities that promote student engagement like thinking about their own learning (metacognition) and explicit instruction in problem-solving enhance student learning outcomes.[10]

This paper reviews visual tools that can potentially increase students' comprehension, meaningful learning and critical thinking skills. Although most tools have received experimental corroboration of their effectiveness in schools, undergraduate, graduate and medical education, there is still very limited use in optometric education.[11] It is hoped that this paper will stimulate further study, experimentation and implementation in our schools and colleges of optometry.

Picturing the Thinking Process: Mind Maps

Mind mapping is the graphical representation of text content. It has been proposed as a technique to brainstorm and summarize information as well as a study method. The originator and main proponent of mind mapping is Tony Buzan.[12] He argued that typical note-taking is linear, while thinking involves an interlinked network. Furthermore, note-taking emphasizes the verbal component (a left-brain process) while ignoring imagery (a right-brain process). He concluded that mind maps tap into the natural nonlinear thinking process. He also concluded that mind maps potentiate learning by using both left and right brain capacities.

McClain proposed the use of mind maps in optometric education. In particular, she recommended that students be given a skeletal map (with blank terms) at the beginning of the lecture. Students would be required to fill the blanks as they listened to the lecture. She indicated that mind maps would allow teachers to stay on task, allow students to add their personal ideas to the topic, and increase comprehension.[11]

Paykoc et al. described the successful use of mind maps by faculty members in the process of brainstorming curricular changes. The map was projected to the group and the progress of the discussion was reflected in the mind map.[13]

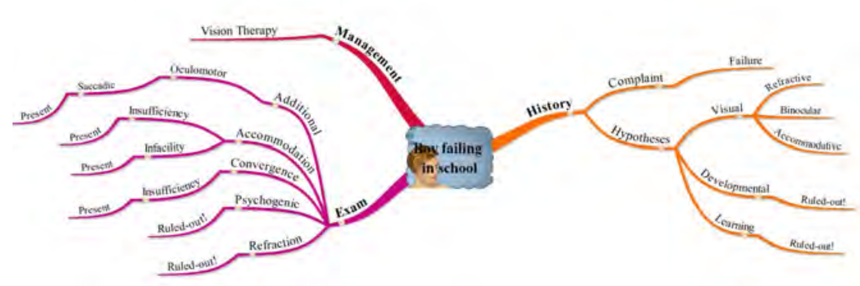
The construction of mind maps follows specific guidelines.[12] The map itself has an organic appearance, similar to a tree with a trunk, branches around the trunk and smaller branches outgrowing from the main branches. **(Figure 1)** The map is started with an image at the center of the page (landscape mode) representing the core idea. Branches are drawn, beginning at the top right of the page and following a clockwise direction. The branches contain keywords that are subheadings of the main topic. Out of these bigger branches grow smaller branches detailing the information. Each branch line should contain only one keyword. Ideally, lines closer to the center should be thicker than those far from the center. The use of images tagged to the branches is encouraged. The use of color, especially for grouping and encoding is also recommended.

Although mind maps can be produced using paper and color pens or pencils, several companies have developed mind-mapping software that facilitates drawing and allows saving of the maps. The original organic version of mind maps is ©IMindMap. Mind Map is a registered trademark of the Buzan Organization Limited 1990 (www.thinkbuzan.com). An alternative and less organic version of mind maps allowing for multiple words and phrases have been developed by ©MindJet (www.mindjet.com). Free versions of mind maps software include ©SciPlore (http://www.sciplore.org/software/sciplore_mindmapping/) and ©FreeMind (http://freemind.sourceforge.net/wiki/index.php/Download). These programs permit the attachment of documents, images and Internet links to the branches of the maps.

Figure 1 is an organic mind map (©IMindMap) based on an optometric case scenario.[14] The case was a 9-year-old student who came with his mother complaining about poor academic achievement that started in the third grade. Diagnostic hypotheses included a visual problem (related to refractive error, binocular or accommodative dysfunction), a developmental (information-process-

Figure 1

A Buzan organic mind map (®IMindMap Software, www.ThinkBuzan.com) of an optometric case scenario of a third-grade boy failing in school. The map is read clockwise, starting at the top right. It shows the hypotheses derived from the case history, diagnoses corroborated or ruled-out through testing, one additional diagnosis and the final management of the case. Software-derived map used with permission.



ing) disorder and learning disability. Case history showed that the boy started having problems in the third grade, had no word recognition problems, and had good handwriting, ruling out both the information-processing disorder and the learning disability. He claimed that his eyes got tired frequently, he did not have double vision, had headaches in the afternoon and reported having passed a recent vision screening (distant visual acuity test). Tests revealed a low refractive error requiring no correction, convergence insufficiency, as well as accommodative insufficiency and infacility. Additional tests revealed a saccadic (oculomotor) dysfunction). The boy was scheduled for vision therapy.

The map illustrates an obvious issue of traditional organic mind maps: They are typically difficult to interpret by an outsider without proper help from the developer.

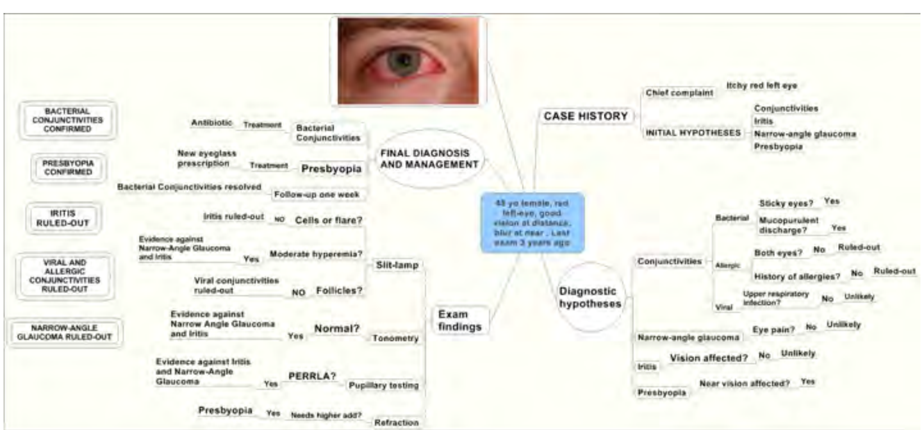
Figure 2 shows a second modified mind map, using ©Mind Manager Software, of a clinical case scenario of a patient visiting an optometrist with a red and itching left eye.[14] The map depicts the clinician's thinking process, including the generation of hypotheses during the case history, the evaluation of the hypotheses during the examination, and the final diagnosis and management of the case. The look of the map is less organic, but it depicts phrases (rather than just a single word) at the branches, allowing for clearer and easier map interpretation. Faculty and students can develop these mind maps from case scenarios to share their clinical decision-making process.

Evidence for the Effectiveness of Mind Mapping to Enhance Learning

Farrand et al. conducted a study on the efficacy of mind mapping to enhance performance in a fact-recall test by medical students. As an additional variable they asked students to self-rate their motivation. In the study, a control group used their preferred study technique (keywords, re-reading the text or underlining keywords). The experimental group was instructed to use mind mapping. Both groups were immediately tested with a 15-question factual test. They were also tested a week after the initial exposure. In general, students allowed to use their own study techniques were more motivated than those told to use mind mapping. However, the mind mappers had better performance than non-mappers on the immediate recall test (13% more) and in the long-term recall test (24% more) when results were adjusted for motivation.[15]

Figure 2

A modified mind map using ©Mind Manager Software accompanying an optometric case scenario showing the case history findings, the initial diagnostic hypotheses developed during the case history, the examination findings confirming or ruling out the diagnoses, and the treatment and management of the case. It summarizes the clinical decision process during the optometric examination. Used with permission.



A study showing no advantage of mind mapping in college students was completed by Shuttleworth using a within-subjects design. Initially, subjects studied a text using their preferred study technique. They completed a multiple-choice and fill-in-the-blank factual test. Then, they were trained in mindmapping study technique and used it while studying a second equivalent text. They completed a second factual test. Test results were not significantly different for the mind mapping technique compared with their preferred study technique. No motivational differences were found in this study. However, some participants found that the 20-minute study period was too short for the mind mapping procedure.[16]

Abi-El-Mona and Adb-El-Khalick compared the performance of two groups of eighth-grade students on a multiple-choice test based on national standards. The experimental group spent one month in mind mapping techniques while the control group spent a month in a note summarization technique. The mind mapping group scores were significantly higher than the note summarization group. This was true for students independently of their previous scholastic achievement. The experimenters also compared mind maps developed at the beginning of their training to those at the end of the training. Students with higher conceptual understanding displayed more accurate links, more colors and more links to minor concepts than other students. This study had two significant differences to the previous two studies. First, participants had a significantly greater mind mapping training period (one month). Second, the experimenters required participants in the control group to use a particular technique (note summarization) rather than their own preferred study technique. This study shows that mindmapping has an advantage over note summarization when participants have significant (one month) experience with the techniques.[17]

An issue related to mind mapping is the development of rubrics with good construct validity and inter-rater reliability to evaluate mind maps. D'Antoni, Zipp and Olson developed the mind map assessment rubric (MMAR) using weighted scores that include concept-links, cross-links, hierarchies, examples, invalid components, pictures and colors. In their study, first-year medical students received a 30-minute presentation on mind mapping techniques. Immediately after the training, they were allowed 30 minutes to read a text passage from the Graduate Record Examination. They were also asked to draw mind maps of the passage. Three different examiners evaluated the maps using the MMAR. The results showed high and significant inter-rater reliabilities for pictures (0.86), colors (0.73) and total score (0.86). The inter-rater reliabilities were moderate and significant for cross-links (0.58) and examples (0.53). The inter-rater reliabilities for concept-links and hierarchies were not significant.This study indicates that the MMAR is an inter-rater reliable rubric for mind maps. Furthermore, the rubric can also be applied to concept maps[18].

In summary, the evidence indicates that mind maps are potentially useful techniques that can enhance learning. Well-motivated students with significant mind mapping practice are the most likely candidates to benefit from its use.

Exploring the Structure of Knowledge: Concept Maps

Concept maps are the brainchildren of Joseph Novak, a noted American educator. Originally, he developed them as a tool to document the changes in the cognitive structure of children taking basic science lessons. Novak was a disciple of David Ausubel, who argued: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."[19]

Concept maps allow explicit recording of what the learner knows and how this knowledge evolves through time. **Figure 3** is a concept map of classical optics.

A concept can be an object, idea or event. It is usually represented by a noun such as "chair," "disease" or "optics." Concepts are related to one another through links, which are usually verbs. Two or more concepts related through links become propositions. For example, in Figure 3, one proposition is "geometric optics implies light as a ray." Concept mapping is the systematic development of the structure of knowledge related to a main concept, tying themain concept to subsidiary concepts via links.

There are two main characteristics that differentiate concept maps from mind maps:

1. **Hierarchical:** Concept maps are hierarchical with the most important concept shown first, usually at the top of the map. Subsidiary concepts are placed below the main concept. Tertiary concepts derived from secondary concepts are placed below secondary ones. This process continues as needed. In mind mapping, the main idea is placed at the center of the map and all other ideas are outgrowths of the main idea with no obvious hierarchy.
2. **Explicit naming of links:** Concept mapping requires that the links between concepts are named explicitly through verbs such as "includes," "is part of," etc. Naming of the links allows for an easier and more accurate interpretation of the map. Mind maps do not name the links and the nature of the relationship is implicit.

While mind maps do not impose constraints on the order of ideas, concept maps require more rigorous thinking, analysis and implementation.

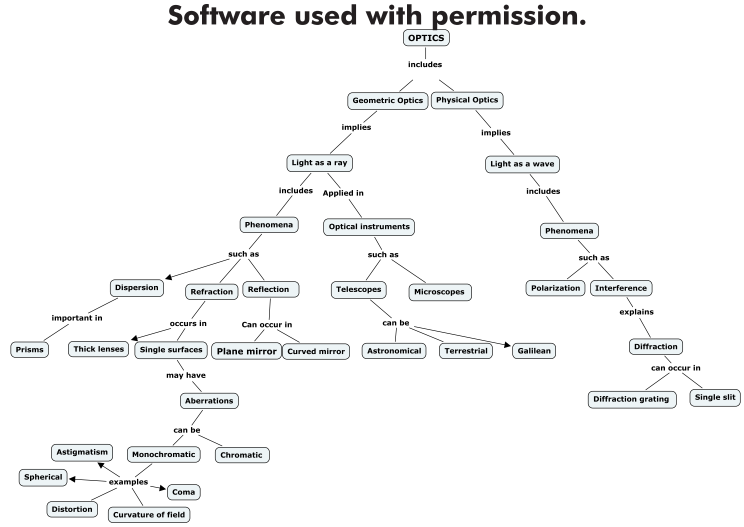
Novak and Gowin describe a well-defined process to build concept maps as follows:

1. Find a focus question or concept. Identify 10-20 concepts that relate to the main concept and place it around the main concept.
2. Arrange the concepts so that the broader ones occupy the top of the map.
3. Continue and add concepts as needed.
4. Connect concepts by line links. Name the links to define the relationship between the two linked concepts.
5. Modify the structure of the map as you add, delete or modify concepts or links and as you gain insights.[20]

The Institute for Human and Machine Cognition, affiliated with the Florida University System, developed specific software for concept mapping, ®IHM-CCMap Tools, a free Web-based program. Students can develop their concept maps, work collaboratively, and share them. The program allows mappers to attach documents, images and Web site links to their maps (http://cmap.ihmc.us).

An excellent and sophisticated group of concept maps was developed by the NASA Ames Research Center. The maps are related to the exploration, geology and climate of Mars.[21] The elements of the maps provide links to documents, photographs, diagrams and films related to the topic at hand.

Figure 3
A concept map related to optics using IHMC ®CMap Tools software. Software used with permission.



These concept maps convey the power of Web-based concept maps to display scientific information.[22]

Although the basic knowledge about the construction of concept maps can be explained in minutes, mastery requires significant practice. Daley et al. described the development of concept mapping proficiency of nursing students, finding significantly better maps at the end of a semester of a clinical course.[23] Rendas, Fonseca and Rosado-Pinto used computer-generated concept maps as a problem-based learning tool for medical students. The main strategy was the presentation of clinical cases along with incomplete mind maps, where students had to provide the missing concepts. They reported better quality maps at the end of their problem-based training.[24]

Evidence for Concept Mapping Effectiveness in Enhancing Learning and Critical Thinking Skills

Vacek considers concept mapping a fundamental tool in developing critical thinking in nursing education.[25] Many (but not all) studies show that concept mapping enhances problem-solving skills or course achievement of students. Esiobu and Soyibo found that Nigerian secondary school students trained in concept mapping and a technique called Veediagramming outperformed students in a conventional environment (lecturing without concept mapping) when tested using multiple-choice achievement tests. The difference was quite robust, five standard deviations (SD).[26] Bascones and Novak reported a study of secondary school physics students in Venezuela where students trained in concept mapping outperformed students without concept mapping training in tests measuring problem-solving skills. In another study, high school physics students in the United States showed significant advantages in achievement tests when using concept mapping throughout a course as opposed to using single-shot concept mapping at the end of the course.[27] However, even students using concept mapping at the end of the course had significantly better achievement than those who did not use concept mapping at all.[28] Similar results were shown in an elementary physical science course by students who were trained in concept mapping.[29] University chemistry students who had significant concept mapping training outperformed control groups in their ability to form concepts and relationships during structured interviews.[30] Zittle found that, for a population of college students, concept mapping is more effective, but only when the learner has to actively construct the maps, rather than examining pre-built one.[31] Chang, Sung and Chen had an opposite conclusion for elementary school children: Students who were required to develop full-fledged maps performed worse than students who were required to correct a map provided by the experimenters.[32] This result suggests that active concept map construction only benefits the learning performance of students who have achieved a significant level of mastery. Coleman found that requiring students to use higher level learning strategies (such as evaluating, comparing and contrasting) enhances their concept mapping advantage even further.[33]

There is also evidence that concept mapping enhances free recall by college students when the material is presented in a concept map versus ordinary text.[34] This is especially true of propositions at the top of the map, i.e., superordinate concepts.[35]

Gonzalez et al. trained a group of medical students in concept mapping. They practiced their skills with the help of a mediator during case presentation sessions. A control group of medical students followed the traditional case discussion sessions. All students took multiple-choice examinations and problem-solving exams (based on clinical scenarios). The students receiving concept mapping training performed significantly better than the traditional students in the problem-based exam but not in the multiple-choice exams. This was particularly true for lower-achieving students.[36] West et al. trained medical residents in concept mapping techniques and immediately after asked them to develop a concept map on the topic of seizures. The residents completed three one-hour education sessions on the same topic and were asked to develop a concept map again. Using their rubric, they found that the second maps had significantly better quality. However, the mapping scores were not significantly correlated to residents' in-training board exams.[37]

On the other hand, a smaller number of studies shows limited or no advantage of concept mapping over other procedures. For example, Schmid and Telaro divided high school Canadian students of low, medium and high academic ability into a treatment group (concept mapping) and a control group (no concept mapping). Students' performance was determined using achievement tests. The post-test also included a test measuring the ability of students to use cross-linking. They found that concept mapping was only significantly better in the low academic ability group and only in the concept-linking test.[38] Spaulding obtained a similar result, mainly that concept mapping only benefitted lower ability science high school students.[39] No advantage of concept mapping over outlining on a high school biology course was found by Lehman, Carter and Kahle.[40] Rewey et al. found that concept mapping improved free-recall performance only in low ability students using a cooperative learning situation.[41]

Like mind mapping, one subsidiary issue is the development of reliable rubrics for the assessment of concept maps. Novak and Gowin proposed the first rubric based on the valid relationships, hierarchy, cross-links and examples.[20] West et al. obtained inter-rater reliabilities ranging from 0.51 to 0.88.[37] Srinivasan et al. reported a study involving internal medicine residents, pediatric residents and fourth-year medical students. They produced concept maps related to diabetes (using 61 concepts) and asthma (using 56 concepts). The authors concluded that good reliability required 4-5 repetitions of the maps. This study is unique due to the high number of concepts used by the participants and that the participants were constrained to use the concepts provided by the experimenters rather than their own.[42]

In general, these studies seem to indicate that concept mapping may enhance learning, recall and problem-solving skills, most especially with students with lower abilities. They also suggest that learners should achieve a significant level of mastery in the construction of concept maps to reap their full benefits. Finally, they indicate that concept maps can be evaluated and graded reliably.

Visual Organizers for Metacognition: Thinking Maps

One of the goals of critical thinking is learners' awareness of their own thinking process (metacognition). One of the most powerful tools for developing metacognition are the ©Thinking Maps, a brainchild of David Hyerle.[43,44]

The method is based on eight map templates that purportedly represent distinct thinking skills: defining, describing, comparing and contrasting, classifying, dividing into parts, sequencing, establishing cause/effect and determining relationships. **(Figure 4)** As generic templates, they can be applied across disciplines and grades.[45] Rubrics for teachers and students have been developed.[44,46] These tools have been implemented in more than 5,000 schools in the United States, New Zealand, England and Singapore.[47] The process can be done as paper and pencil tasks or with the help of specifically designed software (www.thinkingmaps.com).

Figure 4
®Thinking Maps (Thinking Maps, Inc.) are a powerful set of metacognitive visual organizers developed by Dr. David Hyerle. Used with permission.

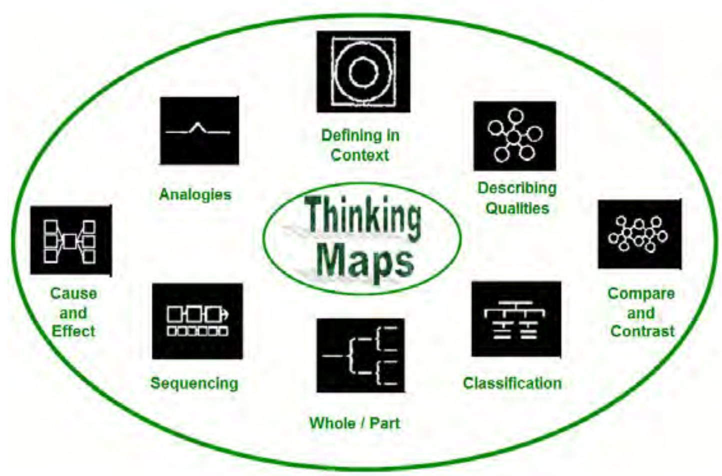


Figure 5
The compare and contrast visual organizer used for the concepts of myopia and hyperopia.

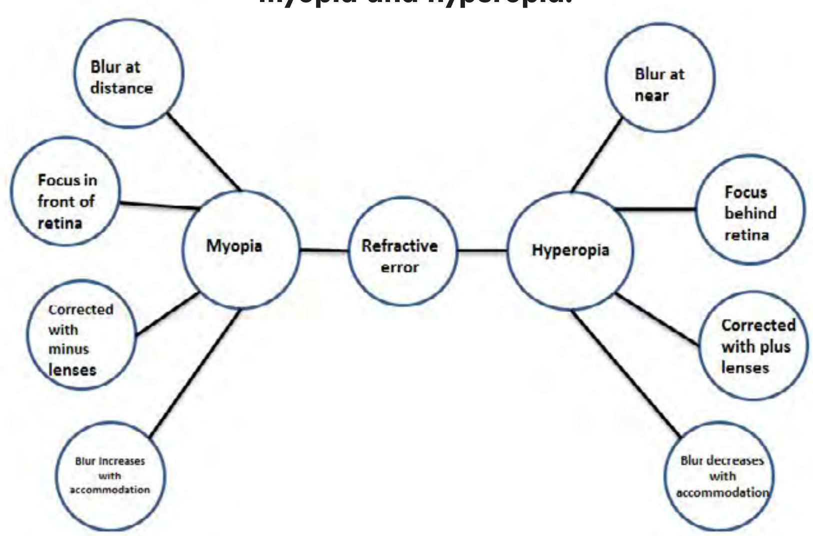


Figure 5 shows an optometric example of a double-bubble map where two refractive errors (myopia and hyperopia) are compared. The central bubble identifies them as concepts related to refractive error (common characteristic). The peripheral bubbles show the unique, contrasting characteristics of each one. The construction of this simple map requires a sound knowledge of the concepts. The details can be modified as the learner gains sophistication.

It is not difficult to imagine other uses of the double-bubble map, such as comparing and contrasting the signs and symptoms of two ocular diseases. Other maps can also be applied to optometric subjects. For example, the multi-flow map can be used to depict the risks (antecedents) and the consequences of a particular disease.

Spiegel indicates that one of the benefits of the practice of thinking maps is that students may become teachers, as they share their maps with their classmates, creating a sense of empowerment.[48]

Evidence for the Effectiveness of Thinking Maps in the Improvement of Learning

The research literature on thinking maps is mostly related to school children in the area of reading and language skills. For example, Blount tested a group of 17 fourth-grade students, all below grade level in reading performance. During the first two weeks they had a typical teaching unit. After finishing a teaching unit, they completed a multiple-choice test. They also wrote an essay related to the unit. During the second two weeks, they had a different teaching unit. Students were familiarized with the flow, bubble and double bubble maps. They were requested to apply these maps to the material taught in the teaching unit. At the end, like in the previous unit, they completed a multiple-choice exam and wrote an essay related to the new teaching unit. There were increases in the performance on the second test as compared to the first test in main ideas, details, sequencing and inferences.[49] Unfortunately no statistical tests were conducted to verify if the differences were significant. Manning describes the experience of a school for learning-disabled children in Massachusetts. The thinking map tools were applied in all school subjects and all grades in this school. Students were required to take the Massachusetts Comprehensive Assessment System Retest, which includes Language Arts and Mathematics. Within a year, the passing rates in English Language Arts increased from 17.3% before introduction of the thinking mapping tools to 68.3% after their introduction. Mathematics passing scores increased from 11.5% to 45.6% during the same period.[45]

Worsham and Austin conducted a study with 139 high school students with low Scholastic Aptitude Test (SAT) verbal scores. The control group (52 students) received no mapping training while the experimental group (87 students) spent 20% of their English class developing their mapping skills. The experimental group had significantly higher achievement in all verbal measures of the SAT (vocabulary, reading comprehension and total score).[50]

Ball conducted a study on the effects of the use of thinking maps visual tools on performance in a standardized reading test. The subjects were college students taking a reading course. All groups received training in thinking skills such as descriptors, contrasting, comparisons, analogies, cause/effect and classification. The experimental group also received training in the use and application of the visual mapping tools while the control groups did not receive this second training. All students were tested with the Stanford Diagnostic Reading Test Form G at the beginning of the course and with the Form H at the end of the course. This test provides data on reading comprehension, vocabulary, fast reading, phonetic analysis, structural analysis, word parts and skimming/ scanning performance. The experimental group (using the maps) had significantly better performance than the control group (no map use). Further analysis revealed better performance in all areas except phonics and scanning.[51]

A study in England in a school system using these visual tools found that 77% of teachers and 62% of students agree or strongly agree that these tools help students learn. Sixty-six percent of teachers and students agree or strongly agree that the tools are easy to use. Interestingly, administrators had lower opinions of their effectiveness in facilitating learning (58%) or ease of use (42%).[52]

In general, the literature indicates that these tools are effective, particularly with students having lower achievement. They help organize the learners' thinking, providing a platform for better comprehension. Most importantly, learners enhance their own appreciation of their thinking processes (metacognition).

Facilitating Judgments: Argument Mapping

Argument mapping is a graphical representation of a contention where arguments can be explicitly presented for and against the contention. Argument mapping is especially useful in the discussion of complex and sometimes controversial issues such as those presented in an ethics course.

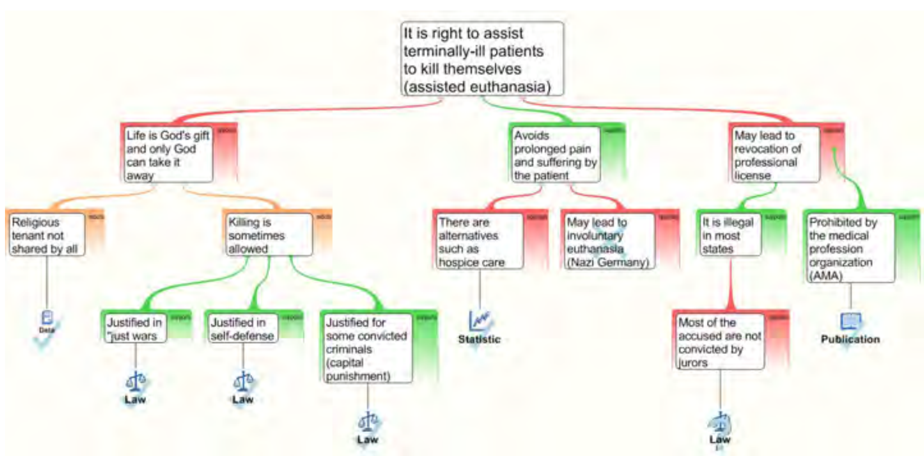
An argument map starts with a contention. The rest of the argument map strives to answer why the contention should be accepted or rejected. A reason is a statement supporting a contention. An objection refutes a contention, a reason or another objection (rebuttal). The evidence basis for the reasons and objections can be added to the argument map. Evidence basis may be data from experiments, publications, a known statistic, personal experience, the law, expert opinions and examples among others. Finally, the reasons, objections and evidence basis should be evaluated (accepted, rejected or in some difficult cases undecided). At the end, the evaluator must decide, if in light of all the evidence, the primary contention should be accepted, rejected or left unresolved until better evidence is obtained.[53]

As an example, **Figure 6** depicts an argument map on the ethics of assisted euthanasia using ©Rationale software. This contention was considered to be the most important ethical issue during the second half of the 20th century.[54] Reasons based on religious values, compassion, professionalism and the laws are presented on the argument map. As the map is developed, the student must research questions such as:

- What do religions have to say about assisted euthanasia?
- What does the professional organization (American Medical Association) consider ethical?
- Is assisted euthanasia legal?
- What are the personal and professional consequences of assisted euthanasia?
- Are there reasonable alternatives to assisted euthanasia?

These questions require that students conduct a thorough search on the historical context of the issue, the impact of religious beliefs, the professional stand of the medical profession, the ap-

Figure 6
Argument map regarding assisted euthanasia developed in an ethics course with ®Rationale software. Software used with permission.



plicable federal and state laws, the availability of alternatives such as hospice care, and current outcomes in states that allow assisted euthanasia among others.

Weinstein proposed a useful model for resolving ethical dilemmas.[55] The four steps of his model are:

1. Obtain the objective facts about the situation.
2. Identify the values (personal and societal) involved in the situation.
3. Describe the options to the dilemma.
4. Based on the values, make a judgment of the best option.

In this model, the best option is the one that satisfies the most important values. The method can be best applied using an argument map.

Halpern has described a set of skills necessary for the construction of argument maps:[56]

1. identification of the premises (reasons), counter arguments and conclusion
2. developing strong arguments that show good thinking and communication skills
3. judging the credibility of the information, including knowing the source of the information and its validity
4. understanding the difference among opinions, reasoned judgments and facts.

Kee and Bickle provide an example of argument mapping applied to epidemiology.[57] While argument mapping is best suited for issues related to the issue of validity or truthfulness of a contention, clinical decision-making is best assisted through similar methods, such as hypotheses mapping or analysis of competing hypotheses.[58,59]

Argument mapping and decision-making can be facilitated by the use of software. ©Rationale is a commercial product that provides useful tutoring support for students and educational guidelines for educators (http://rationale.austhink.com/). Compendium is a free argument mapping tool useful for group deliberations (http://compendium.open.ac.uk/institute/). There are also online collaborative argument tools for debate such as TruthMapping (www.truthmapping.com).

Evidence of Argument Mapping to Improve Recall and Critical Thinking Skills

Dwyer et al. have argued that argument maps decrease the cognitive burden by combining the text (reading) and structure of the argument. They hypothesized that argument mapping would significantly increase comprehension and memorization of an argument compared to a pure text reading. In an experiment, they presented written (text only) arguments compared to arguments maps to groups of university students. Students' reasoning ability was initially assessed with the Differential Aptitude Test. Six experimental groups were tested using a multifactorial design with two levels of complexity (arguments with 30 propositions and 50 propositions) and three conditions (text only, black-and-white maps, and color maps). Subjects were tested for comprehension by being asked whether a subset of the propositions supported or denied the main argument claim. Each subject also received a fill-in-blank memory test.

The results indicated that there was no difference in the comprehension level across all experimental groups. However memory performance was better for the smaller (30 proposition) complexity in the text-only, black-and-white map and the color map conditions. Also, both the black-and-white and color map conditions were superior to the text-only condition. No difference was found between the black-and-white and the color map condition. In short, argument maps produced better recall than text-only arguments. Subjects in this experiment were only allowed a 10-minute presentation of the maps. It is possible that longer presentations by subjects experienced in argument mapping techniques may lead to better comprehension.[60]

Butchart et al. used computer-assisted mapping software in a 12-week undergraduate course. The course included a one-hour lecture and a two-hour tutorial session per week. Participating students took one version of the California Critical Thinking Skills Test at the beginning of the course and a second version at the end of the course. The test itself has 34 items for testing the student's skill in analyzing, evaluating, drawing inferences, deducting and using inductive arguments. The difference between the post-test and the pre-test was an indication of the critical thinking skills gains. Results showed that students had the equivalent of 0.45 SD improvement in these skills.This result compared favorably with gains of 0.19 SD with a standard course (without the use of the mapping software).[61]

Van Gelder et al. used an argument mapping software in a one-semester undergraduate critical thinking course. They hypothesized that students would have significant gains in their critical thinking scores as measured by the California Critical Thinking Skills Test (CCTST). They also hypothesized that the gains would be significantly correlated to deliberate practice measured objectively and subjectively. For example, one objective measure of deliberate practice was the actual (measured) number of hours using the software. An example of a subjective measure would be a self-reported estimate of number of completed practice exercises. The results showed a gain of 0.8 SD in critical thinking skills as determined by the difference between the pre-training and post-training scores on the CCTST. The gain of 0.8 SD through the one-semester software-assisted course was equal or better than the gain achieved by students after three years of college undergraduate education. The gains were significantly correlated to the actual number of hours spent using the software and the number of activities related to the use of the software. The correlations were moderate (0.31 and 0.27 respectively). Gains were also significantly correlated with the self-reported amount of effort spent on the subject (0.19).[62]

Guzetti et al. performed a meta-analysis of experimental studies and found that student argumentation had the greatest effect on correcting misconceptions, a 0.80 SD effect compared to student discussion, 0.51 SD, or simple activation of prior knowledge, 0.08 SD.[63]

Alvarez-Ortiz completed a meta-analysis of the impact of philosophy, critical thinking education and argument mapping on performance on critical thinking tests. Students in the control groups had a gain of 0.12 SD within a semester without any specific training. In comparison, philosophy students without argument mapping training had a gain of 0.26 SD while philosophy students with significant argument mapping training had a gain of 0.78 SD.[64]

In conclusion, argument mapping increases critical thinking skills and argument recall when compared with standard procedures.

Seeking Inter-Relationships: General Systems Thinking

The most powerful of all visual mapping tools derives from general systems thinking. General systems thinking was promoted by Peter Senge as one of the characteristics of the effective learning organization.[65] It hypothesizes that in most situations we are aware of single events, the tip of the iceberg, which are occurrences manifesting deeper realities. As we study the sequence of events in time, we discover patterns of behavior just under the surface. These patterns reflect the hidden structure of the system: the beliefs, mental models and culture of the organization.[66] Effective problem-solving requires that we dig below the surface (events) and discover the structure that perpetuates the patterns of behavior and the events we discern from the outside. **(Figure 7)**

While cause/effect analysis is usually linear and unidirectional, systems thinking analysis is based on feedback loops. In **Figure 8**, stress leads to consumption of beer, the plus sign signifying that an increase in the level of stress increases consumption of beer. (Also a decrease in the level of stress decreases consumption of beer.) This is a typical unidirectional relation that does not portray the whole story. However, consumption of beer itself produces changes in the levels of stress. The minus sign implies that increasing levels of beer consumption leads to decreases in the level of stress. This is also a unidirectional relationship. A feedback loop, as shown, portrays the whole relationship more accurately.

Feedback loops can be reinforcing, where there is continuous growth or decline in a variable. Feedback loops can also be balancing (like the one in Figure 8) where an explicit or implicit goal (level of stress) is maintained. Some effects may take significant time to be seen, and this is depicted by a delay in the feedback loop.

System thinkers have found that many situations can be explained through generic templates called, appropriately, "system archetypes." These archetypes are a combination of feedback loops that can be applied across many fields, such as economics, psychology, science and sociology. As an example, **Figure 9** (left) depicts the "shifting the burden" archetype. A symptom creates a need for a short-term, symptomatic solution.

Figure 7

Systems Thinking allows recognition of the patterns below unique events. It also promotes the examination of the mental models, beliefs and culture that support the systems behavior.

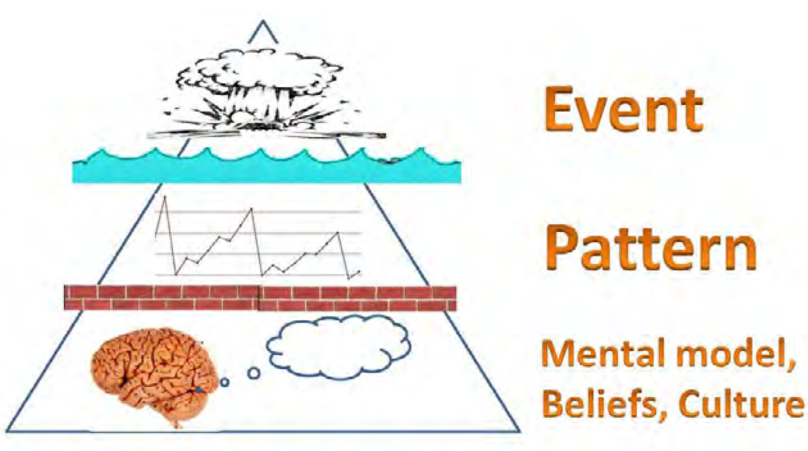
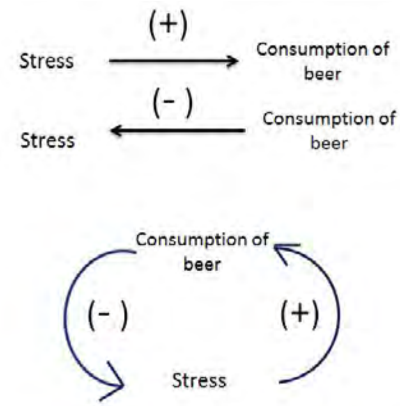


Figure 8

Top: Two typical unidirectional relationships. Stress level affects consumption of beer, while consumption of beer affects stress levels. Bottom: A feedback loop is a more accurate representation of the inter-relationship.



A better, fundamental solution is available, but this solution requires more effort and time (delay). In the meantime, reliance on the symptomatic solution has unintended and undesirable effects. Consider the following two scenarios as applications of this archetype.

Scenario 1 (Figure 9, middle)

Paul is a freshman optometry student. He is having serious difficulties keeping up with his classes and his grades are poor. As he ponders his future, he is very tense and stressed-out. He knows that he can have counseling and tutorial help through the Office of Student Affairs. However, he believes that this would detract from his study time and his busy schedule. On weekends, he can relax and enjoy drinking beer with his friends. He discovers that drinking beer on weekdays helps him to cope with the stress. His drinking habit increases every week. Soon, his grades plummet and he fails the semester. Paul's symptoms (stress) led him to a symptomatic solution (drinking). This led to a temporary reduction of his symptoms. A more effective solution was available through counseling and tutoring (fundamental solution), but this solution would take more time to achieve (delay). Unfortunately, the symptomatic solution (drinking) led to alcohol addiction (unintended consequences) which decreased the perceived need for the fundamental solution.

Scenario 2: (Figure 9, right)

Dr. Rogers has a healthy optometric practice and the number of examinations has been steadily increasing during the past few years. However, the number of patients buying optical devices (eyeglasses and contact lenses) from her optical dispensary has been slowly but steadily decreasing. Dr. Rogers may hire another optician and send the current dispensing technician for additional training. However, this would take significant investment and time. She decides to hire an advertising agency and spend money on a campaign with an emphasis on her dispensing services. Initially she sees an increase in the number of sales in the dispensary, but after a few months the sales drop to old levels. She decides to invest additional funds on a stronger marketing campaign. Again, sales increase for several weeks, and then drop again. In this second scenario, the problem was the drop of sales at the dispensary. The symptomatic solution was the hiring of an agency to launch an advertising campaign. The fundamental solution was to increase the quality of services at the dispensary by hiring additional staff and training her current staff. However, this solution would take more time to take effect (delay). The advertising campaign worked temporarily creating the perception that there was no need to apply the fundamental solution. It led to a dependence on an intervenor (outside advertising agency) and erosion in the capacity of her staff to resolve the problem.

In both scenarios, the best strategy would have been the application of the fundamental solution. If the symptomatic solution is ever applied, it should be used only once or for a very short time. The power of systems thinking is the explanatory ability of the archetype, allowing exploration of the variables and feedback loops in the systems. It gives useful insights into optimal ways to apply leverage so that the problems at stake are resolved satisfactorily.[65]

Other examples of archetypes:

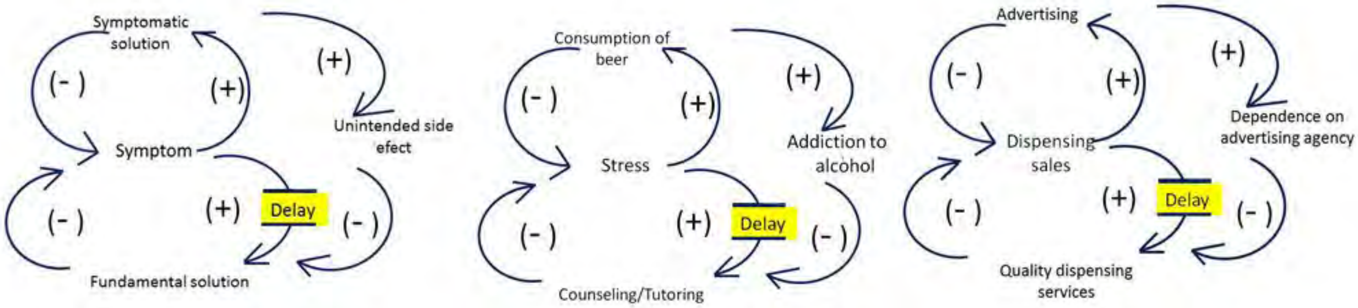
- **Limits to growth (limits to success):** A process starts with a period of increasing growth. After some time, the growth slows down or reverses due to a limiting condition.
- **Success to the successful:** Two processes or activities compete for finite resources. The more successful process gains an increasingly bigger share of the resources and eventually obliterates the weaker one.
- **Tragedy of the commons:** Units within an organization share common finite resources or assets. The more they use these assets, the bigger the rewards as they develop more activities. Soon, the return on the use of resources decreases, forcing them to request additional resources. Eventually, the resources diminish dramatically or are exhausted.
- **Eroding goals:** A version of a shifting the burden archetype, where a fundamental goal of an institution is sacrificed in order to fulfill a short-term gain.

Simulation Models: System Dynamics

System dynamics applies general systems thinking via mathematical simulation models. These models allow the exploration of different scenarios based on the changes of the variables of the model. This allows students to design experiments and answer specific questions on their model: "The move from a static model in an inert medium, like a drawing, to dynamic models in interactive media that provide visualization and analytic tools is profoundly changing the nature of inquiry… Students can visualize alternative interpretations as they build models… in ways that introduce different perspectives on the problems. These changes affect the kinds of phenomena that can be considered and the nature of argumentation and acceptable evidence."[8]

System dynamics uses three basic graphical units: stocks, flows and converters.[67] Stocks are the nouns of system dynamics and are symbolized by a rectangle. They represent variables that accumulate through time. Examples are number of patients, clinic income, knowledge, population and gasoline in car tank. Flows are the verbs of system dynamics and they are symbolized by a pipe, flow regulator and a spigot. The direction of the actual flow is shown by an arrow at the end of the pipe. Typically, a flow can move toward a stock, increasing its accumulation, or move away from a stock, decreasing its accumulation. Examples are births, deaths, patients to clinic, patients leaving, expenses and hiring. Converters are the adverbs of the system and are symbolized by a circle. They represent variables

Figure 9
The "shifting the burden" archetype (left) and two examples of its application in psychology (center) and optometric practice management (right).



that do not accumulate through time. Examples are birth rate, dispensing rate, new patients per year and consumption per capita.

Consider the following example, close to the colleges and schools of optometry. One of the main challenges of optometric institutions is to maximize the income of their clinics while maintaining the breadth and quality of the education. This helps maintain tuition costs as low as possible. A systems model allow us to critically examine the variables that impact clinic income and experiment with scenarios as the values of the variables change through time. These "experiments" allow us to determine the best strategies for maximizing income. **(Figure 10)**

The model of Figure 10, using iseesystems inc.'s ©Stella Software (available at www.iseesystems.com), depicts two main stocks: clinic income and number of patients. As shown at the bottom of the model, the "number of patients" at the clinic increases by the flow "patients to clinic" and decreases by the flow "patients leaving." The flow "patients to clinic" depends on two converters: new patients per year and thereturn patient fraction (the fraction of all patients at the clinic who return for an examination within a year). As the model shows, because the income of the clinic is directly affected by the number of patients seen at the clinic, the "number of patients" stock at the bottom feeds into the "producing income" flow that increases the "clinic income"stock. The income flow is affected by the "exam income per patient" (cost of the eye exam per patient), the "dispensing rate" (fraction of patients who acquire eyeglasses, contact lenses, low vision devices and other optical devices) and the "dispensing income per patient"(gross income from the sales of optical devices). This last variable depends on the "dispensing mark-up" (a number indicating the multiplying factor for the cost of optical devices to the patient) and the "dispensing cost per patient." On the other hand, the "clinic expenses" flow is affected by the "cost of utilities," "staff salaries," "faculty salaries," "dispensing cost," and "interest expense" (assuming the institution is paying off a loan for the facility). In the depicted model, "faculty salaries" are affected by the mixture of "faculty days for third year" and "faculty days for fourth year." This is a fairly complex model that incorporates many of the main variables that affect clinic income. The model can be adjusted to add or delete variables or represent them in alternative ways.

The model allows us to experiment with changes in the values of the input variables and determine how they affect stocks such as clinic income and number of patients through time. The first set of inputs is the initial values of the stocks (clinic income and number of patients). The second set of inputs representsthe values of the converters. The values of the converters can be set through sliders **(Figure 11)**. The values on the sliders can be changed into a virtually infinite number of positions within a range.

Figure 10

System dynamics model of a college optometry clinic developed with ©Stella Software. Used with permission.

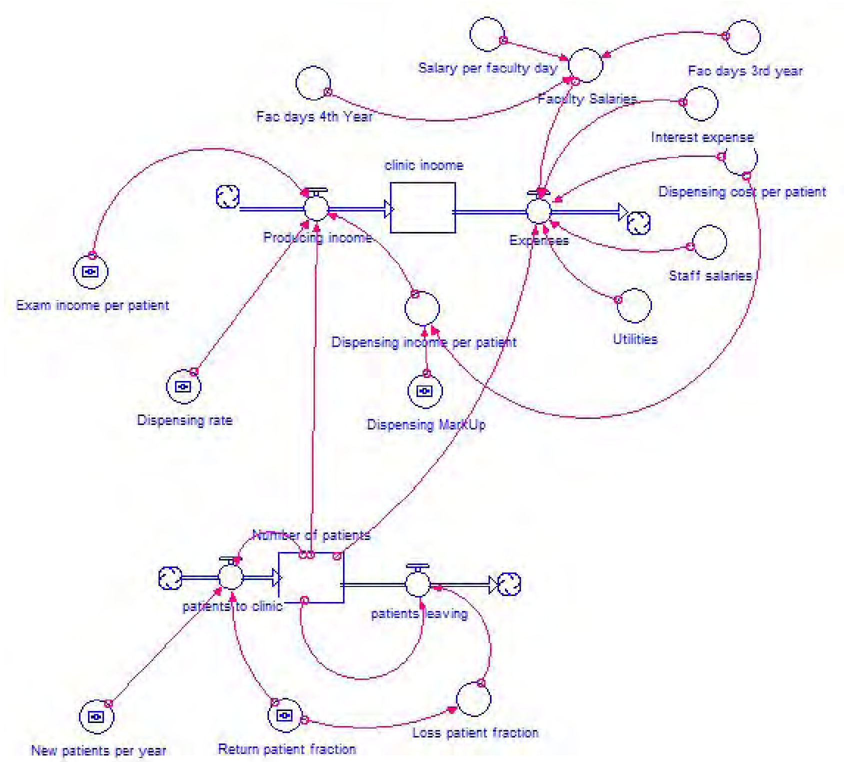


Figure 11

Sliders allow a continuous variation of the system parameters within limits for a college optometric clinic. Simulation allows us to determine which combination of parameters maximizes a critical variable such as clinic income. Diagrams developed with ©Stella software. Used with permission.

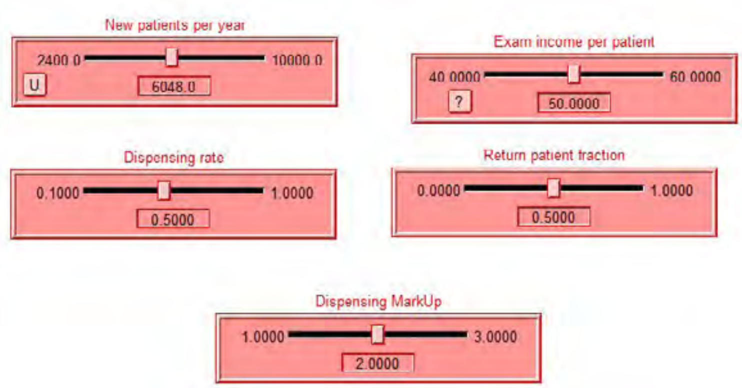


Figure 12 shows the effects of changing dispensing rate from 0.3 to 0.6 on clinic income during the first 25 years of operation. The values of the other converters are maintained constant. For example, exam fee at $50, new patients per year at 6,000, return patient fraction at 0.5, and dispensing markup (multiplying factor of sale vs. cost of dispensed devices) at 2.0. The graph shows that a dispensing rate of 0.3 (30% of patients acquiring optical devices at the clinic) will lead to increasing losses throughout the years (if everything else remains equal). A dispensing rate of 0.6 will lead to a net cumulative gain at the beginning of the seventh year. Strategically, one can increase the dispensing rate by training the dispensing staff, providing better frame and lens options to patients and counseling of patients by the optometrist. Besides the graphs, the program can produce detailed tables by year of operation.

The above exercises brought into practice management would allow students to make rational decisions about strategies to increase their practice success. It is a high level, sophisticated environment that may be used to simulate their own future practices.

System dynamics is not limited to business modeling. It can also be applied to simple and complex modeling of scientific and social issues. For example, it can be used to model the dynamics of glucose regulation in physiology, population dynamics, predator-prey systems, impact of policies on drug trafficking, and epidemiology, among others.[67]

Evidence of Improvement of Decision-Making Skills through Systems Thinking and System Dynamics

There are studies that indicate that systems thinking may enhance decision-making abilities, especially those related to complex situations. For example, Dhawan, O'Connor and Borman completed a study on 26 business school graduate students to determine if systems thinking and system dynamics training could improve the quality of their analysis of a business scenario. The scenario involved an information technology company with revenue oscillations through time. They completed a pre-test and a post-test after 10 hours of systems thinking training. A second post-test was completed after an additional period of 13 hours of system dynamics training (computer simulation). The tests were designed to ascertain their ability to identify stocks and flows, propose a cause for the oscillations, suggest solutions and predict the workforce of the company. The first two tasks are of low or medium complexity, while the last two tasks have high complexity. The researchers found that systems thinking training improved performance in the first two tasks but not the last two. System dynamics (computer simulation) training improved the ability of participants in the last two, high-complexity, tasks. The results suggest that full-fledged benefits are obtained through training on both systems thinking and system dynamics (computer simulation).[68]

Maani and Maharaj were interested in the variables related to decision-making performance and the sequence of systems thinking that would lead to better performance. Ten business school graduate students, versed in system thinking and system dynamics, participated in a computer simulation model of a company. Their objective was to maximize revenues, profits and market share by manipulating variables such as total workforce and spending on marketing. The results showed that better performers had higher levels of understanding as shown by their models.[69]

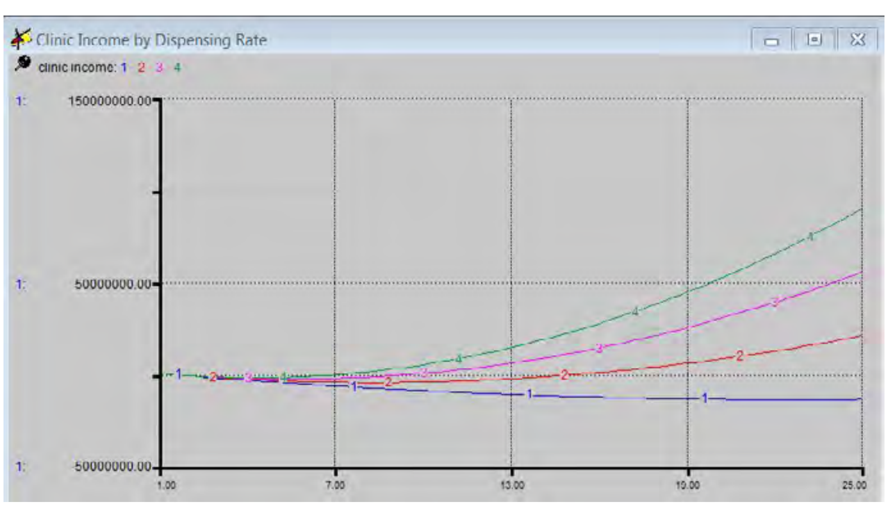
Plate completed two studies assessing the effectiveness of systems thinking in the ability of students to develop causal maps. The first study included 23 undergraduate college students on a topic within a political science course. Post-test maps (at the end of the course) were compared to pre-test maps (at the beginning of the course). At the end of the course the maps had more concepts, more link densities, more complex causal loops and were more similar to expert maps. A second study compared middle school children trained in systems thinking to children without such training. The group trained in systems thinking had maps with higher link densities, more complex causal loops and that were more similar to expert maps.[70]

LaVigne completed a meta-analysis of studies relating systems thinking and dynamic modeling to students' learning. She reported trends indicating that this training enhances the connections between curriculum and real-life experiences, clearer exploration of thoughts and mental models, and increased motivation and engagement.[71]

Systems thinking and system dynamics are promising tools in optometric education. System dynamics is the most sophisticated tool in our armamentarium. Several companies offer commercially available software for dynamic modeling, training and specialized books:

Figure 12

Clinic income by year of operation for four dispensing rates: Curve 1= 0.3, Curve 2 = 0.4, Curve 3 = 0.5 and Curve 4 = 0.6. Graphs developed with ©Stella Software. Used with permission.



- Isee Systems (http://www.iseesystems.com)
- Ventana Systems: (http://www.vensim.com)
- Pegasus Communications(http://www.pegasuscom.com)
- The Waters Foundation, which promotes systems thinking education in schools, offers via its Web site free modeling tutorial lessons as well as detailed lesson plans that can be adapted to college-level courses(www.watersfoundation.org).

Conclusion

The evidence indicates that visual tools may help our students develop better recall, comprehension and critical thinking skills. It is important that the tools be used mindfully and judiciously. Mind mapping is most useful during brainstorming, note-taking and developing clinical scenarios. Concept mapping's strength lies in forcing us to organize knowledge hierarchically. Thinking maps are powerful templates allowing the learner to develop metacognitive skills. Argument mapping is a critical thinking tool to formalize premises, counterarguments and conclusions. Systems thinking provides the ability to observe the deep structure of systems, transcend the simplistic linear cause/effect relationships and apply the language of archetypes across different disciplines. System dynamics allows us to simulate the behavior of systems and determine the effects of changes in critical variables.

Davies proposed a convergence of mapping technologies where students incorporate concept maps, mind maps and argument maps. The concept maps will be the core maps where students are able to depict their present knowledge structure. Some concepts will be linked to mind maps elaborating their associative structure. Other concepts may be tied to argument maps as needed.[6]

One of the main objectives of this paper is to promote educational research activities of optometric educators as they apply these tools in their courses. In the meantime, the available evidence supports the implementation of certain activities: [7,9,11,20,46,47]

1. Construct a concept map or mind map of your entire course and present it to your students on the first day of class. The map will be an expert, holistic representation of the knowledge structure related to your course. It will serve as an anchor throughout the quarter or semester. You may refer back to the map as you develop your topic. It will be a helpful tool as students conduct a systematic review when studying for your examinations or the optometry boards.
2. Train students in the use of mind mapping and concept mapping techniques. Initially, they may use them for note-taking during their own readings. Once proficiency is established, they can be used for note-taking during lectures.
3. Ask students to develop a concept map of their knowledge about your lesson topic before the beginning and at the end of your lesson. The beginning map will allow them to explore their own knowledge base before the lesson. The final map will allow them to explore the expanded knowledge base and how it fits into their cognitive knowledge structure. You may want to periodically review some of your student maps for accuracy and understanding.
4. Ask students to use ©Thinking Maps tools around specific course topics. For example, they may use the classification organizer to represent anterior and posterior segment diseases. The sequencing tool may be used to depict the stages of certain ophthalmic diseases such as diabetic retinopathy. The cause/effect tool may be employed to represent the risk factors and effects of diseases such as glaucoma.
5. Ask students to develop case presentations using mind mapping or concept mapping. They can use free collaborative mapping software such as ®IHCMapTools and post their maps on the Internet. Documents, drawings and Web site links can be attached to their maps.
6. Request that students develop argument maps related to professional ethical dilemmas or policy issues in public health.
7. Consider using system dynamics models for practice management. Students can develop a systems model of their own future practices and simulate scenarios to find out which strategies are more likely to maximize their success.

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