A basic goal of CTA is to help researchers understand how cognition makes it possible for humans to get work done. This involves capturing what practitioners know about their domain, its concepts, principles, and events. What the practitioner knows and believes about their domain—rightly or wrongly—is critical to their decision. Thus, it is critical to the CTA researcher, who needs to know about what the practitioner knows.

A form of CTA that came to be called “knowledge elicitation” is specifically aimed at helping the domain practitioner in expressing knowledge, and then representing that knowledge in a way that others can understand and put to use. Knowledge modeling has applications in each of the ways in which CTA in general can be applied.

**Marketing.** What does the consumer know or believe, and how does that affect their decisions? Knowledge preservation. In many sociotechnical domains, wisdom walks out the door when the expert moves on, or retires. The preservation of knowledge is thus a concern in many sectors of society.

**Knowledge sharing.** Once captured and meaningfully expressed, the content of a knowledge representation can be used to form the core content of training programs and procedures, so that the knowledge can be re-used or disseminated.

**Decision aiding.** The creation of any new technology to help practitioners make better decisions must to some degree and in some way be an “embodiment” of the concepts, principles, and procedures of the work domain. Imagine, for example, the absurdity of a weather forecasting workstation that does not allow the forecaster to draw lines representing “fronts.” The technology must enable the practitioner to apply their knowledge of concepts and principles, and rely on their knowledge to search for meanings in the data.

**Revealing Skill.** One of the things that domain experts know about is the procedures they use in their practice. They also know many “heuristics” or rules of thumb. Some heuristics are shared knowledge, others others are ones they have created on their own. In addition, many experts also have a metacognitive awareness of their own strategies and how they manage their resources. All of these types of knowledge about processes and procedures are knowledge, and are thus fair game for knowledge elicitation. Once captured and meaningfully expressed, descriptions of proficient skills can be used in training, and aspiring individuals can have a better chance of achieving expertise by “standing on the shoulders” of the experts.

We can think of no CTA process or project where, in some way and to some degree, the CTA researchers did not have to elicit and then represent at least some the domain knowledge. At one extreme, the knowledge comes from unstructured interviews or documentation analysis, and the representation is in the form of written notes or a typed document, which informs and supports the CTA project or helps the CTA researcher in coming to understand the domain, a process
called "bootstrapping" (Hoffman, 1987). At the other extreme, the knowledge elicitation process is a systematic empirical procedure, and results in detailed and sometimes formal representations of knowledge.

Models of knowledge take on different forms from models of reasoning. Models of reasoning usually involve process descriptions. These can fall at a microscale at which decision making is reduced to keystroke reaction time and sequences of hypothetical basic or fundamental mental events. Examples are the tenth of a second it takes to access long-term memory, or the tenth of a second it takes to shift attention. Models of reasoning can also fall at a macroscale of parallel, interacting processes such as problem recognition and sensemaking that are not necessarily decomposable into basic or sequential mental building blocks (Klein, Ross et al., 2003; see Chapter X).

On the other hand, knowledge models express the content over which reasoning operates. Knowledge models express facts, concepts, principles, and event types that occur within the domain. As such, models must express meaningful propositions and will not take a form resembling flow diagrams of mental processes.

In recent years, a technique called Concept Mapping has been adopted by some CTA researchers as a method for both eliciting and representing knowledge. We begin this Chapter by giving a capsule view of the background of Concept Mapping in research and applications. This background is important because the track record of Concept Mapping speaks to its justification and uses in CTA. Next, we present some examples of the applications of Concept Map knowledge models. We then present guidance on Concept Mapping as a procedure for knowledge elicitation interviews, which can be conducted with individual practitioners or with small groups of domain practitioners.

**What is Concept Mapping?**

Concept Maps are diagrams that are used to represent and convey knowledge. Since Concept Maps are a good means of conveying knowledge, we can use a Concept Map in Figure 4.1 to express some of the ideas that we will explore in this Chapter. As with any good Concept Map, Figure 4.1 invites the reader to take the time to read through the propositions and understand the relations among concepts.
Background and Research Foundations

Concept Maps were developed in the course of Joseph D. Novak’s research program in which he sought to understand and follow changes in student’s knowledge of science (Novak, 1977, 1998; Novak & Gowin, 1984). Novak’s work relied on the learning theory of David Ausubel (1963; 1968). The fundamental Piagetian idea is that meaningful (versus rote) learning takes place by the assimilation of new concepts and propositions into existing concepts and propositional frameworks held by the learner. This occurs by processes of subsumption (realizing how something new relates to something known), differentiation (realizing how something new draws a distinction on something known), and reconciliation (of what at first seems a contradiction of something new with something known). These terms designating learning processes should be recognized by those who have been exposed to Jean Piaget’s works.

The idea of the Concept Map was created and refined over decades of work aimed at developing a method to support meaningful learning (Ausubel & Novak, 1978). Today, a large research literature pertains to the use of Concept Mapping in educational settings (Cañas, 1999; Cañas et al., 2003). Indeed, Concept Maps are being used in schools and school systems around the world (Cañas et al., 1997; Ford, Coffey, Cañas, Andrews, & Turne, 1996). Concept Mapping as a learning exercise encourages students to use meaningful-mode learning patterns (as opposed to
rote memorization), and encourages learners to engage in critical thinking (Mintzes, Wandersee, & Novak, 2000), which results in measurable gains in knowledge and gives students an advantage that increases over time (Novak & Gowin, 1984).

Building good Concept Maps leads to longer retention of knowledge and greater ability to apply knowledge in novel settings (Cañas et al., 2003; Mintzes et al., 2000; Novak, 1990, 1991, 1998). Concept Mapping also has a role in evaluation. It can be just as effective as more time-consuming clinical interviews for identifying the relevant knowledge a learner possesses before or after instruction (Edwards & Fraser, 1983). Student’s Concept Maps can help the instructor to identify knowledge gaps and the valid and invalid ideas held by the student (e.g., Markham, Mintzes, & Jones, 1994).

Concept Maps have traditionally been made using paper and pencil, or posters and stick-on notes. They sometimes still are (as in some business brainstorming sessions). The ability to create and share Concept Maps has been extended recently by computerization. New software tools allow students to build on their own and on each others’ knowledge base through the medium of distance learning (Chung, O’Neil, & Herl, 1999).

Use of Concept Maps is not limited to primary and secondary education. Concept Mapping is being used by curriculum designers in the U.S. Navy and by university professors preparing course material, including material for distance learning (Cañas, 1999). A number of companies are using Concept Mapping to preserve and share “organizational knowledge,” and also to provide an infrastructure for project management. NASA experts used Concept Mapping to express their views and knowledge concerning the astrobiology, and come to an understanding about their definition of this new field (Cañas, 1998).

Concept Maps have been used in many studies of the psychology of expertise. That work has shown, among other things, that Concept Mapping can support the formation of consensus among experts (Gordon, Schmierer, & Gill, 1993). Evidence from studies of experts versus novices indicates that expertise is usually associated not just with more detailed knowledge, but knowledge that is better organized than that of novices (e.g., Glaser, 1987). Research has used comparisons of Concept Maps made by non-experts to those made by experts to reveal expert-novice differences in knowledge organization. Concept Maps made by domain experts tend to show high levels of agreement (see Gordon, 1992; Graesser & Gordon, 1991). Concept Mapping has proven useful as a tool for creating knowledge-based performance support systems (Cañas et al., 1997; Dodson, 1989; Dorsey, Campbell, Foster, & Miles, 1999; Ford et al., 1991, 1996; Hoffman et al., 1995; Sutcliffe, 1985).

Finally, it is worth note that Concept Maps are being used within the CTA community to capture and express ideas about Cognitive Engineering and Cognitive Task Analysis (Hoffman, et al., 2002). Thus, the Concept Map in Figure 4.2 may have value to the Reader of this book.
Concept Mapping As CTA

Concept Mapping is coming to be used widely as a method for eliciting and representing the knowledge of domain practitioners. In other words, Concept Mapping is now a tool in the CTA toolkit.

In order to conduct CTA in a given domain, the Researcher needs to learn about the domain, that is, they need to “bootstrap” themselves to a sufficient level of understanding (see Chapter 2). Concept Mapping can play a role here. Concept Mapping commonly triggers in the practitioner the recall of past cases in which one or more of the concepts were salient. This can be used as “incident selection” and can feed into other CTA procedures, such as the Critical Decision Method (CDM) (Hoffman et al., 1998).

We mentioned above that one of the things practitioners know about is events, processes, procedures, and their own reasoning strategies. These are “fair game” for Concept Mapping. In this form of diagram, referred to as a “HyperMap,” a description of an event (process, strategy, etc.) is embedded within a Concept Map. An example appears in Figure 4.3. The event description is embedded in nodes and links that provide the context, or the “explanatory glue” that makes sense of the process.
Concept Maps on a given topic can be hyperlinked together. For example, the concept node “The Critical Decision Method” in Figure 4.3 might be hyperlinked to another Concept Map that goes into detail about the CDM. When a set of Concept Maps is linked together this way, and organized by a “Map of Concept Maps,” they form what are referred to as Concept Map Knowledge Models. These can be simple, consisting of a dozen or so Concept Maps, or they can be complex, consisting of hundreds of Concept Maps.

The following examples show what they look like, and what they can be used for.

**Example Knowledge Models**

**Example 1: Rocket Science**

The first example is from work that was performed at NASA Glenn Research Center (Coffey & Carnot, 2003; Coffey, Moreman, & Dyer, 1999). The motivation was the need to preserve lessons learned by retiring engineers, knowledge that would otherwise be lost to the organization. Eighteen Concept Mapping knowledge elicitation interviews were conducted with a senior engineer, who specialized in his knowledge of a Delta rocket motor. The resulting 11 Concept Maps expressed his knowledge. Hyperlinked to the Concept Maps were 140 informative resources (diagrams, photographs, digital video interviews with the expert, etc.) A screen shot from this Knowledge Model is presented in Figure 4.4. This includes views of two of the
Concept Maps and views of some of the digital resources that were linked into the Concept Maps.

Example 2: Going to Mars
At the Center for Mars Exploration at NASA Ames Research Center, it was decided to integrate information about Mars so that it might be more effectively distributed to the public, especially to school children. At the time the project started there were many kinds of information, including books, articles, photographs, and so on. But there was no way to make the material hang together so that people might browse and learn from it. Over 100 Concept Maps were created by NASA scientists to organize the material into appropriate sub-topics (e.g., Mars Lander missions, Mars in Science Fiction, Life on Mars, etc.). Hundreds of resources (maps, photographs, URLs, etc.) were linked into the Concept Maps. These Concept Maps were then used as the indexing structure for a CD-ROM released by NASA (Briggs, Shamma, & Cañas, 2001; Cañas, 1999, 2003). The Concept maps can be seen at http://cmex.coginst.uwf.edu

Example 3: Medical Diagnostic Procedures
The use of Concept Maps to create navigable explanations of decision aids was demonstrated by Ford, Cañas, Jones, Stahl, Novak, and Adams-Webber (1991). In first-generation knowledge-based decision aids (or “expert systems”), one could query the system about the inference chain that was used in reaching a diagnostic decision. The result of the query would be a sequence of
formal rules in cryptic computer code, itself not terribly explanatory. Ford et al. used Concept Mapping in 20 knowledge elicitation sessions to elicit the knowledge of an expert at first-pass nuclear magnetic resonance imaging of ventricular function. After deriving the inference rules from the interviews, the researchers realized that the Concept Map representation of the expert's knowledge could be the interface for the decision aid, an interface that would support performance at a meaningful level. The resulting Knowledge Model consisted of 10 Concept Maps and over 200 digital resources. In using NUCES (Nuclear Cardiology Expert System), as one works a given case, one proceeds through the Concept Maps that lay out the various diagnostic features. Along the way one can access resources showing representative images (clear cases, tough cases, etc.) that can be compared to those of the given case. Also included were digital videos in which the expert provided detailed discussion of various things (e.g., subtle cues the journeyman might miss). This innovation represented a milestone in the evolution of expert systems into “knowledge-based” systems. This Knowledge Model can be viewed at http://www.ihmc.us/users/acanas/Publications/ParticipatoryExplanation/ParticipatoryExplanation.htm

Example 4: Electronics Repair Procedures
Another project involved capturing the knowledge and procedural skills of an expert at the maintenance and repair of a particular recording device used aboard US Navy vessels. Eighteen knowledge elicitation sessions yielded 11 Concept Maps and about 140 digital resources. Again, the Concept Maps were used as the interface for a decision aid that used a question-and-answer process to guide the user through a diagnostic procedure. This system was called El-Tech, standing for Electronics Technician. A new idea that this system embodied was that it can be used in both a learning mode and a performance-support mode, that is, it is at once a training aid and a decision aid. Furthermore, it can be used by sailors to sea after being trained in the schoolhouse. This knowledge model can be viewed at http://www.ihmc.us/users/acanas/Publications/ElTech/El-Tech%20Flairs%2098.htm

Example 5: Preserving Knowledge on a National Scale
Our final example is a project that demonstrated how Concept Maps might be used as the infrastructure for knowledge preservation on a national scale (Hoffman & Hewett, 2001). In an effort to preserve traditional folk knowledge—residing in the experience of elder craftspeople in the rural villages of Thailand—a set of Concept Maps was made on the topic of Thai silk weaving. Based on transcripts of interviews with the elders, Concept Maps were made that described knowledge about each of eleven varieties of Thai silk and their methods of manufacture. These were then resourced with photographs showing the silk patterns and illustrating various aspects of the weaving process. A screen shot is presented in Figure 4.8. An interesting feature of the Concept Maps in this project is that a photograph of each of the various silk weaving patterns was used as the background in its Concept Map, so that one could see the pattern while reading the Concept Map about that pattern. This aspect was important for another reason—it reflected the Thai cultural aesthetic, which emphasizes color, pattern, and contrast. This Concept Map project can be viewed at http://www.ihmc.us/research/projects/ThailandKnowledgeBase/
These examples convey the sorts of Knowledge Models that are sought in CTA to support knowledge preservation, knowledge sharing, and the creation of decision support systems.

We can now describe the Concept Mapping procedure. First, we need to say more about what Concept Maps are, and are not.

**What is a Concept Map?**

The idea of using diagrams to express logical statements has a rich history in mathematics, including some works by psychologist-logician Charles Pierce and mathematician Gottlob Frege. The modern idea of Concept Mapping takes this a step further, into the “user friendly” expression of meanings.

In terms of their nature as a type of diagram (or directed graph), Concept Maps involve nodes and links. The nodes represent concepts, which are enclosed in boxes. The label for most concepts is a word or just a few words, although one can also use symbols. Concepts are related to one another by meaningfully labeled linking lines. Using the link labels to express relations between two concepts, the node-link-node triads in Concept Maps form propositions, that is, they can be read as “stand alone” simple and meaningful expressions. Example propositions in Figure 4.1 are: “Concept Maps represent Knowledge,” and “New Concepts must be fit into Existing Knowledge.” Those who are new to Concept Mapping benefit from a bit of practice at understanding the difference between propositions and sentences. For example, the single sentence, “My son plays with a red truck” has four propositions: I have at least one son, that son engages in play, that play is with a truck, that truck is red.

Concept Maps differ from other types of diagrams that utilize combinations of graphical and textual elements to represent or express meanings. For example, diagrams that Ackerman and Eden (2001) refer to as “Cognitive Maps” are large web-like diagrams with up to hundreds of “ideas” represented by the nodes. “Ideas” are typically expressed as sentences and short paragraphs. While a type of meaning diagram, these differ considerably from Concept Maps.

Differences among forms of meaning diagrams involve their expressiveness (semantics and syntax), their shape (or morphology), shape-meaning interactions, and dynamics. Understanding these aspects of Concept Maps is important if the goal is to create good knowledge models.

**Expressiveness.** In some forms of diagrams, the linking lines are unlabeled—all of the links mean the same thing. Specifically, in semantic networks and associative graphs, the lines represent the single relation: “Concept X is related to Concept Y.” The length of the lines is sometimes used to indicate degree of associative strength or degree of semantic relatedness. PATHFINDER networks (Reference) and Buzan and Buzan’s (1996) “Mind Maps” are such a type of meaning diagram. The links between nodes are unlabeled, and tacitly represent “connections” among ideas.
In Sowa's “Conceptual Graphs” (1984), the concepts can be connected using only certain kinds of logical relations such as “is a” and “has property.” Concept Maps do not impose restrictions on semantics, hence their great expressive power. While logical relationships can and often do appear in Concept Maps, those relationships are regarded as just one kind of “subsumption-differentiation” relationships. Concept Maps can express many kinds of relations other than hierarchical classification, such as “explains” or “comes before.” One could very well use expressions that include quantifiers, such as:

\[
\text{[NODE — “is a likely cause of (factor weight = 0.07)” — NODE]}
\]

There is no restriction or imposed limitation.

An example might clarify the difference between classificational diagrams (“is-a” trees in graph theory), and subsumption-differentiation diagrams. A diagram might contain the following propositions:

\[
\begin{align*}
&WATER \text{ is necessary for LIFE} \\
&WATER \text{ is necessary for EARTH's ATMOSPHERE} \\
&WATER \text{ includes OXYGEN} \\
&OXYGEN \text{ is necessary for LIFE}
\end{align*}
\]

None of these relations involves categorization. So, while LIFE is subsumed under WATER, LIFE is not “a type of” WATER. LIFE and EARTH's ATMOSPHERE together differentiate things for which WATER is necessary. The OXYGEN in WATER is also necessary for life, but OXYGEN is subsumed under WATER and differentiates a constituent of WATER that is necessary for LIFE, but OXYGEN is not a “type of” WATER.

**Shape.** In “Semantic Networks,” as defined by Fisher (1990), the most basic concept is located in the center of the diagram and the subordinate concepts radiate out in all directions. Concept Maps, on the other hand, are more like hierarchies in terms of their shape. There is a reason for this. In good Concept Maps the more general or most important concepts appear toward the top and provide the context or the “big picture” for the Concept Map, while the more particular concepts tend to appear toward the bottom. One reads a Concept Map by beginning toward the top and then working downward through the levels of the Concept Map that express subsumption, differentiation, and other relations.

**Shape-Meaning Interactions.** The shape of meaning diagrams interacts with the semantic and syntactic features. For example, in Buzan and Buzan's (1996) “Mind Maps” the radiating shape combined with the impoverished semantics (unlabeled links) severely limit the diagrams' expressive power. Concept Maps are unique relative to other forms of meaning diagrams in that Concept Maps have “cross-links.” Cross-links express relations that cut across the clusters or regions within a Concept Map. Examples in Figure 4.1 are the propositions “Assimilation and Accommodation are processes that begin in Infancy,” and “Ausubel’s Theory of Meaningful Learning postulates Processes.” Cross-links are used for a reason: In real-world domains of complexity, anything can relate to anything, and in some cases, everything does relate to many other things. Furthermore, creative insight has been defined as the result from a deliberate search.
for new relationships between concepts and/or propositions in one sub-domain with those in another sub-domain. The expression of cross-relations is facilitated by the fact that in a Concept Map one can see all of the important concepts at once.

**Dynamics.** We note one final feature of Concept Mapping. This has to do with Concept Mapping as a process, as much as the qualities of finished Concept Maps. Technically stated, when creating a Concept Map, the Mapper uses spatiality as a tool to de-convolute meanings. As nodes and partially-linked sets of nodes are grabbed and moved around in the Concept Mapping space, the Mapper considers various relations and ideas to be expressed. The Mapper struggles to add in cross-links while at the same time avoiding the creation of a spaghetti graph having too many overlapping cross-links. Clusters of nodes will be parked somewhere, and that region of the Concept Map space becomes, in effect, a memory aid.

In one study conducted in the DARPA “Rapid Knowledge Formation” project, Concept Maps were made by domain experts but were subsequently “tidied up” overnight by computer scientists. Upon next seeing their Concept Maps so tidied up, the experts were upset because things “weren't where they were supposed to be” (Hayes, personal communication, 2003). The Mappers had been using spatiality as a tool.

Concept Maps are generally referred to as representations of domain knowledge, but knowledge is itself never static, and Concept Maps are not regarded as things that are made to be cast in stone. Indeed, it is wise to always consider Concept Maps as “living” representations rather than finished “things.” In capturing the expert knowledge within an organization, for instance, practitioners can always add to and modify the Concept Maps in the existing pool.

**The Concept Mapping Procedure**

Concept Maps can be made using pencil and paper, chalk boards, white boards, and even large sheets of butcher paper along with marker pens and stick-on notes. It is becoming more common for people to make Concept Maps on computer. A number of academic research groups have built software to support the creation of meaningful diagrams (Chung, Baker, & Cheak, 2002; Hoeft et al., 2002). In addition, a number of commercially-available software packages support the creation of meaningful diagrams. A software suite that was specifically designed to support the creation, resourcing, and sharing of Concept Maps is called CmapTools. It is available free for educational, not-for-profit, and government use at www.ihmc.us. The Concept Maps that appear as Figures in this Chapter were made using CmapTools.

Our discussion presumes that the Concept Mapping process is being conducted using the CmapTools software, though much of what we say is applicable if one were to make Concept Maps in other ways.

Concept Mapping is a skill. Some say that it encourages “nonlinear thinking.” It certainly does take practice. It takes even more practice to begin to understand what makes for a “good” Concept Map. Concept Mapping supports—perhaps even forces—the Mapper to reach for crystal clarity about what they wish to express. It is important for the participating domain practitioner to be given an introductory presentation about Concept Mapping, including its
research foundations. Even with such a presentation, practitioners can go into the process skeptical. But experience suggests that some foreknowledge of what Concept Mapping is all about, as opposed to just “diving in,” can ease the interviewee into the process.

In Concept Mapping knowledge elicitation, the researchers helps the domain practitioner build up a representation of their domain knowledge, in effect merging the activity of knowledge elicitation and the activity of knowledge representation. A caution is in order, however, since the two purposes—domain knowledge representation and knowledge elicitation—can sometimes diverge, mandating differences in the ways that the two forms of interview are conducted.

One researcher acts as a Facilitator and provides support in the form of suggestions and probe questions, the other acts as the Mapper, and captures the participant's statements in the Concept Map. The Mapper needs to be proficient at quickly and accurately conducting the mapping work “on the fly.” This includes a facility at glancing from the computer monitor to and back from the projector screen, to follow the Facilitator's guidance and the participant's statements.

The Facilitator always walks a fine line between supporting and intruding. Recognizing the fact that this is inherently a collaborative, “co-constructive” process, to the greatest extent possible, the Concept Map should express domain knowledge in the words preferred by the practitioner. Yet, the participant invariably benefits from assistance and suggestions. These should be couched as alternatives. So, for example, when a participant is reaching for words to express a relation that the facilitator infers is a causal relation, the facilitator might say, with rising inflection, “leads to?,” “comes before?,” “is a precondition for?,” etc. Typically, the practitioner will latch on the wording that is most fitting.

The Facilitator must be facile at monitoring the state of the Concept Map, and how the Mapper is doing, while at the same time keeping track of the current discussion, and making note of possible future agenda items.

It is not uncommon for a “conceptual block” to arise in a session of, say, 30-60 minutes. It sometimes is helpful to move to a discussion of some other part of the Concept Map. Sometimes, when asked about the troublesome concept(s) at hand, the practitioner says something like, “Well, what I mean here is that. . . .” Quite frequently, what the participant says captures precisely the things that should be changed in the Concept Map.

Typically, Concept Mapping knowledge elicitation sessions last about an hour. When the individual who is making the Concept Map on the fly is facile at the process, one can expect to create in an hour about two semi-refined Concept Maps, each consisting of something on the order of 40 or more concepts and 45 or more propositions. In successive interviews, the Concept Maps can be extended and refined.

Sometimes, the domain practitioner expresses ideas at a rate that overwhelms the Mapper. One can be tempted in such circumstances to audiotape the session so that it can be transcribed and analyzed at a later time to pull out any propositions that were missed during Concept Mapping on the fly. A study of this problem showed clearly that the process of transcription and protocol
analysis was so time consuming that it would have been far more efficient to recapture the “lost” knowledge by subsequent Concept Mapping interviews (Hoffman et al., 2000).

**Step 1. Select the Domain and Focus**

This is a critical step in making the process and product directly pertinent to the research goals. Concept Mapping as a CTA method must be conducted so as to tap into the practitioner’s knowledge that lies at the heart of their task activities. A clear, explicit focus helps to define the context and aids in the process of expressing the knowledge that is pertinent to that context.

The practitioner and the interviewer identify a “focus question” that addresses the problem, issues, or knowledge domain that they wish to Concept Map. Examples would be: “How do thunderstorms form?,” or “What is Cognitive Engineering?”

It is usually valuable to begin with an exercise that focuses on a sub-domain of knowledge that is very familiar to the person whose knowledge is being elicited. It can be useful or helpful to make a first Concept Map that presents the “big picture,” or alternatively, to make a first Concept Map about some very limited a sub-domain of knowledge. Doing this may take the process away from the topics that are important to the immediate research project goals, but the exercise can be critical in acclimating the participant to Concept Mapping.

The focus question can be expressed as an unattached node or header toward the upper left corner of the Concept Map space. The explicit presence of the focus question helps to keep the discussion oriented on the knowledge that is most relevant to the problem or question. Stating an explicit question can be very helpful in identifying the most important concepts to include at the higher levels of a Concept Map. In turn, identifying the most important concepts to include at the top of a Concept Map often leads to a refined focus question.

Guided by the focus question, the participant is asked to identify 5 to 10 of the broadest most over-arching, more general, or most important concepts that are involved in the topic. The initial set can be created through a deliberative process on the part of the practitioner, or through a free-association process. Thus, a train of thought about thunderstorms might be, “They require low-level moisture,” “They can cause tornados,” and so on.

Usually when more than one word is used to label a concept, the participant can consider whether some of the words in the label are also labels for concepts and should be indicated as separate concepts. Our experience in knowledge elicitation is that once concepts are pulled apart, they are typically used later on to tie other things together and express additional meanings. One should avoid “sentences in the boxes” since this usually indicates that an entire subsection of a Concept Map could be constructed just from the statement in the node.

Figure 4.5 is a Step 1 Concept Map. The focus question was selected because the forecasting of thunderstorms was the participant’s specialty, on the one hand, and because the question focused on the researcher’s interest in getting at the local “rules of thumb” used in forecasting, on the other hand. Note that this Concept Map includes nodes that have embedded concepts that would eventually be pulled apart.
Step 2. Set up the “Parking Lot” and Arrange the Concepts

Next, the concepts are arranged in what is called a Parking Lot. The concepts are moved around in the Concept Map space, to place the most inclusive or most general concepts (those that seem to be most important or most closely related to the topic) toward the top of the Concept Map. In addition, more important concepts are added. An example appears in Figure 4.6.
Figure 4.6. The Concept Map about Thunderstorms at Step 2, of arranging the Parking Lot and adding more concepts.

Some individuals who are new to Concept Mapping, and some individuals who have had experience at it, have a style that short-circuits Step 2. They prefer to lay out a few high-level concepts and immediately begin linking up the concepts (see Step 3, below). This is perfectly acceptable as a style, although it has been noticed that individuals who skip Step 2 and jump right to Concept Map construction tend to “dig down into the weeds” prematurely and lose sight of the larger picture.

Step 3. Begin to Link the Concepts.

At this Step, the Mapper begins to link the concepts. A linking word or short phrase should define the relationship between the two concepts, so that the node-link-node triple reads as a proposition. This Step in the Concept Map process, and the importance of the link labels, are both illustrated in Figure 4.7 Even for such a simple Concept Map, without the relations, the meaning and communication value disappear. One can guess at some of the relations (in this case, as the nodes under “land-sea Breeze”), but even in this simple Concept Map one can see the value of the linking relations (e.g., how is “CAPE” related to “Temperature inversion”?).
It is necessary to try and be precise in identifying linking words, although there is no limit to the sorts of terms that can be used as relational links. They could be categorized in any number of ways. Links can express causal relations (e.g., “leads to,” “produces”), classificational relations (e.g., “includes,” is an example of”), nominal relations (e.g., “is known as”), property relations (“can be,” “has defining feature,” “consists of”), explanatory relations (e.g., “is a reason for”), procedure or method relations (e.g., “results in,” “is done by,” “is a way to do”), contingencies and dependencies (“requires,” “often is), probabilistic relations (“is more likely,” “rarely is”), event relations (e.g., “comes before”), and uncertainty or frequency relations (e.g., “is more common than”).

Individuals who are new to Concept Mapping sometimes comment that it is difficult to come up with appropriate words to use as links between concepts. This is sometimes because they have yet to achieve a clear understanding of the relationship between concepts, and it is the linking words that specify this relationship. Once people begin to settle on good linking words, and also identify good cross-links (see Step 5, below), they can see that every concept could be related to many other concepts. This also produces some frustration, and they must choose to identify the most prominent and most useful links.

**Step 4. Refine the Concept Map**

A number of activities are involved in creating a refined Concept Map. This includes adding, subtracting, and changing superordinate concepts and adding, subtracting, and changing the link labels that express the various subsumption and differentiation relationships. It includes checking to see that all the node-link-node triples express propositions. Good Concept Maps usually are those that have undergone several waves of refinement, although with practice one can make good a Concept Map in a single pass through these Steps.

The meaning of a concept is represented by all of the propositions that link the concept in a given knowledge domain. Thus, to define the meaning explicitly, it is generally preferred to use a given concept label only once in a given Concept Map. A Concept Map that contains the same concept two or more times can usually be rearranged (this takes practice) so that the concept only appears...
once. Sometime this may require reconstruction of other sections of the Concept Map and usually this leads to general improvement.

As a rule of thumb, if there are more than four or five concepts linked under a given concept, this means that there are latent concepts, or some sort of intermediate level that the expert has not yet expressed. Specifying these intermediate concepts often leads to insights, and once the latent concepts are made explicit, they often serve a useful role making it possible to link to other concepts, expressing relations that would have otherwise been difficult or even impossible to express as long as those intermediates had been left tacit. For instance, one Concept Map on weather forecasting included a number of different data types linked as sources of information that support storm forecasting—radar, observation charts, buoy data, satellite images, and so on. In the Concept Map, these data types splayed out under the “Forecasting Products” node like a large fan, consuming a considerable amount of real estate in the Concept Map. It was possible to split these off according to an intermediate level of conceptualization—data types that were graphic products (radar, satellite images, etc.), data types that involved alphanumeric data (charts, buoy reports, etc.), and data types that came from observations (i.e., sky watching, surface observations). The result was a much “tighter” Concept Map, and the intermediate concepts could subsequently be used to advantage.

Figure 4.8 shows the Thunderstorms Concept Map after it has undergone two waves of refinement beyond the version shown in Figure 4.11. Note that this Concept Map still needs work—there is a “fan” coming off the “Land-sea breezes” node. There is a node that needs unpacking (“Release of latent heat from moist (saturated) air”). There is a string that needs fixing: “Southerly onshore flow rises and corkscrews up when it meets westerly flow above and induces rotational shear.” The node-link-node triple, “Westerly flow above and induces rotational shear” is not a well-formed proposition. Finally, there are some concepts left over from the Parking Lot.
Step 5. Look for New Relations and Cross-Links, and Further Refine the Concept Map

At this Step, the Mapper looks for “cross-links” between concepts in different sections of the Concept Map. An example appears above in the Figure 4.8, where the Mapper has created a cross-link between “Land-sea breezes” and “Severe thunderstorms,” and has indicated that “southerly onshore flow” is not the same as “Land-sea breeze.” The Mapper is considering how to phrase a link between the concepts of “Westerly flow above” and ”subsidence.”

This process of refining a Concept Map can go on as one brings to bear additional knowledge. In our experience at Concept Mapping knowledge elicitation with domain practitioners, it almost always happens that at some point in the procedure, the practitioner says something like, “You know, I’ve never really thought out this (concept, relation) in quite this way, but now that it comes up . . .” Here we see that Concept Mapping often serves to elicit knowledge that might have otherwise remained “tacit.”

It is important to recognize that a Concept is never finished. There is no one right way to make a Concept Map for a given domain or sub-domain of knowledge.

Research suggests that a Concept Map that has been created and refined by one expert can expect to have about ten percent of its propositions “altered” when the Concept Map is evaluated by some other expert (Hoffman et al., 2000). This is not because experts disagree (although they can). Rather, it is wordsmithing—a reflection of their differing emphases, judgments of what is
important, and the subtleties of word choice (e.g., “promotes” versus “causes”). As one’s understanding of relationships between concepts changes, so will the Concept Maps. Conversely, the process of Concept Mapping almost always leads to new understandings and insights (e.g., “Gee, I never really thought about that in quite this way…”) on the part of the domain expert who is building the Concept Map.

Figure 4.9 shows the thunderstorms Concept Map after a further wave of refinement, which involved a slight change to the focus question.

![Image of the refocused and refined Thunderstorms Concept Map.](image)

**Figure 4.9.** The refocused and refined Thunderstorms Concept Map.

**Step 6. Build the Knowledge Model**

A set of Concept Maps all on a particular topic and hyperlinked together is referred to as a knowledge model. Resources are another important feature of knowledge models, and the process of resourcing Concept Maps should be considered integral to Concept Mapping as a form of CTA. Note in Figure 4.4 that there are small icons appended immediately beneath some of the concept nodes. These are represent hyperlinked resources. Resources can be any form of digital media, including text, detailed examples, images, charts, links to powerpoints, web pages, digital video, etc. Resources can be URL's that go out and grab data fields and return them for presentation within the context of the Concept Map. Resources can be text pieces that go into detail about the concepts to which they are appended. They can link to operational manuals, Standard Operating Procedures documents, or forms that the practitioner needs to complete. They can present case studies that illustrate and concretize the concepts. In a knowledge model on weather forecasting (Hoffman, Coffey, & Ford, 2000), resources include URLs can take the user to the real-time data that are involved in the practitioner’s task (e.g., radar, satellite images, etc.), but the data are presented in the context of the Concept Maps that provide the explanatory glue that makes the forecasting process hang together.
Our experience has been that domain practitioners almost always keep a file of “special” resources. One weather forecaster, for instance, kept a file of hard copy radar and satellite images for previously-encountered difficult forecasting cases. Such material is a gold mine for the knowledge model because it will contain resources of great potential value to learners.

An addition to resourcing, Concept Maps on a given theme are hyperlinked together. So, for instance, a Concept Map about “Gulf of Mexico Effects” on region weather might have concept nodes referring to “fog,” “thunderstorms,” and “hurricanes,” each of which is the topic for its own Concept Map. Through the hyperlinks, the user can navigate the knowledge model.

This describes the general procedure for eliciting and representing practitioner knowledge. The procedure carries over to knowledge elicitation with teams or groups.

**Team or Group Concept Mapping**

As with all teamwork, optimal size of the team is never easy to pre-ordain. Experience has been that the optimal size for groups is usually five or fewer. With groups of more than five, especially if one of the participants seems “controlling” or seems intent on running an agenda, “disagreements” can spin up, requiring patience, finesse, and cat-herding. Furthermore, individual differences in style, personality, and pre-existing interpersonal relations can swamp any generalizations about group size. The group needs to be large enough so that most of the important sub-domain knowledge and/or experience is represented in the group, but not so large as to make whole-group discussions difficult.

There are a number of different ways in which Concept Mapping can be conducted with groups of participants. Teams can discuss the Concept Maps made by individuals. A team might assemble a “Global Concept Map” for their domain or organization. A team leader might define the key question and create a preliminary Global Concept Map, and the team can work off of that. Alternatively, a team might be divided into subteams develop Concept Maps for subdomains.

**A Final Word: What Makes for a Good Concept Map in the CTA Context?**

The value of Concept Mapping as a knowledge elicitation procedure lies in achieving a clear, precise description of domain knowledge. Good Concept Maps do that well.

A good Concept Map is comprehensive relative to its focus question and top node. It is important to ensure that all of the concepts associated with the topic and pertinent to the CTA goals are included in the Concept Map. Sometimes basic and important concepts are overlooked. But this raises the question of how big is big, or how big should a good Concept Map be? One heuristic is that there is a threshold, that Concept Maps need to be large or complex enough to maximize the chances for identifying significant cross-links, and yet not so large as to suggest that they be split up into sub-maps. Some Concept Maps are quite large, consuming a great deal of real estate, but these require lots of vertical and horizontal scrolling. In this regard, the heuristic is to rely on the human-scale of the typical computer monitor. A rich Concept Map, one containing on the order
of 40 concepts and 45 or so propositions can, with skill and some finesse, be comfortably fit into
the screen real estate.

A good Concept Map manifests global relevance. Since there is a significant element of
associational thinking in the creation of a Concept Map (“Concept-1 makes me think of Concept-
2”), it can happen that the Mapper introduces concepts that are of relatively low relevance to the
topic at hand. Judgments must be made regarding the relevance of every concept to a particular
topic. The Concept Map in Figure 4.12 includes a node (“Thunderstorms over Texas”) left over
from the Parking Lot that may be thought of as being a bit too far off the central topic. Likewise,
the concepts in Figure 4.? under “Gulf of Mexico” were deemed unnecessary for the refocused
and refined Concept Map (Figure 4.??). That material was eventually split off into a separate
Concept Map just about “Gulf of Mexico Effects.”

A good Concept Map also has the right “granularity.” One type of granularity problem is when a
Concept Map dealing with very specific concepts has a few unnecessary very broad concepts—
in places the Concept Map seems to go “off on a tangent.” Conversely, granularity also becomes
an issue when a Concept Map on a broad topic has some overly specific or detailed concepts—in
places the Concept Map “goes too far down into the weeds” relative to its top node or its focus
question.

There are always trade-off decisions that have to be made concerning comprehensiveness,
relevance, and granularity. In an effort to ensure that all the important information is included (to
be comprehensive) it is possible that ideas of minimal relevance might be introduced (i.e., in
places the Concept Map might go too far down into the weeds or might go off on tangents). Likewise, in an effort to ensure that only relevant concepts and their relations are included, some
concepts that are important might be missed.

Summary

CTA involves capturing what practitioners know about their domain, its concepts, principles, and
events. We can think of no CTA process or project where, in some way and to some degree, the
CTA researchers did not have to elicit and then represent at least some domain knowledge. This
chapter reviews the procedures and applications of Concept Mapping, as a proven knowledge
elicitation methodology in the efficient elicitation of practitioner knowledge. Concept Maps
involve labeled nodes and links, but Concept Maps differ in important ways from other types of
diagrams that utilize combinations of graphical and textual elements to represent or express
meanings. Concept Mapping supports the practitioner to reach for crystal clarity about what they
wish to express. In Concept Mapping knowledge elicitation, the researchers help the domain
practitioner build up a representation of their domain knowledge, in effect merging the activity
of knowledge elicitation and the activity of knowledge representation.