An Introduction to the Cognitive Refraction Model for Instructional Design

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The cognitive refraction model is a classification system for learning objectives that helps you understand the cognitive requirements necessary to achieve your learning goals. Learning objectives are grouped into conceptual bins based upon the work required to meet them, as estimated based on: the number of elements involved in the process, the choices that are to be made, and the concreteness of the information being presented. In the following presentation, I will address classifying learning objectives in the cognitive refraction model and using the classifications to guide instructional tool and techniques choices.

Introduction to the Cognitive Refraction Model

It is a complex endeavor to determine what instructional methods will make learning objectives accessible for learners. Great material is lost in droning lectures, ill-fitting reading assignments, and off-topic discussion questions. The design process is so difficult that some educators never undertake the challenge, instead accepting textbooks or premade curriculum that does not align with their learning goals. The cognitive refraction model supports the process of aligning instructional methods with instructor's desired learning objectives. It classifies cognitive tasks into groups based on intrinsic load, the cognitive work inherent in conducting the task (Chandler & Sweller, 1991). Once learning objectives have been classified, it is easy to determine the activities and tools associated with improving learning in that category of load.

The cognitive refraction model is an applied cognitive load organizing framework for instructional design. The basic premise of cognitive load theory is that learning is work and we have limited cognitive resources with which to perform it. When the cognitive load of a task is too great, learners' work quality suffers (Chandler & Sweller, 1991). This can lead to incomplete understanding, difficulty applying concepts, and inability to determine how to proceed in problem-solving. Luckily, instructional tools can help with these issues; they can ease the process of content acquisition, provide practice in the procedures and skills associated with a competency, and support the development of self-monitoring skills. To share this information, I will discuss classification rules for the model, the work associated with each category and how to support its learning, and tools that can be used to support learning in a task or simplify the processing of a category.

Intrinsic Load Based Classification

The cognitive refraction model classifies information in a cognitive load framework, looking at the intrinsic load of the task to be performed. The definition of intrinsic load used with this model is more complex than traditional definitions. Past models of intrinsic load measured load by examining the number of elements of interactivity in the task--the elements being held in the mind and used for interaction during task completion. The evidence that elements of interactivity influence intrinsic cognitive load is robust (Sweller & Chandler, 1994).

Elements of interactivity are a necessary measurement for intrinsic load because if the interacting elements are not processed together, the intended understandings will not develop (Sweller, 2010). For example, when considering possible factors affecting the velocity of a vehicle, attention needs to be paid to both the speed of the vehicle and the direction the vehicle is going. Looking at only one of those factors will not provide you with the velocity. Thus, velocity has at least three elements of interaction (speed, direction, and the interaction between the two).

The number of elements of interactivity in a task is not absolute. The number is affected by expertise in a subject matter: experts will group chunks of information together to be processed, thus reducing the number of elements and reducing the cognitive load (Kalyuga, Ayres, Chandler, & Sweller, 2003). Other than this effect of expertise, many researchers consider intrinsic load to be fixed for a given task. I argue that there are other elements that we can establish as influencing intrinsic cognitive load. For example, tasks related to the same content and elements of interactivity might have very different intrinsic loads when using different learning objectives (Sweller, 2010). To refine the classic conceptualization of intrinsic load, I suggest two other factors that have been evidenced to have cognitive loads that relate intrinsically to the task. These are 1) choice/decision-making associated with the learning task and 2) loads of orienting information.

The first additional factor in the model is decision-making. The literature does evidence the importance of decision-making in intrinsic cognitive load. For example, your accuracy reduces when the extraneous load is increased with interruptions for complex decision-making, but not for simple decisions (Merrienboer, Kester, & Paas). This is evidence that the decision carries a load. This is easy to evidence experientially as well. Imagine the cognitive load associated with listening to a story. Your intended goal is to understand the story, but not to make a decision regarding the learning content. At the end of the story, you are asked to take a pop-quiz on the story's content. Now compare that with the load of listening to the same story after being told that you will be quizzed on it later. For each bit of information in the story, you must determine whether you need to put work into remembering it, and must invest your work where you decide it is useful for your score on the test. That second load is much greater. Even the same choice can carry a higher-cognitive load in different contextual situations: decisions that are "expensive", in terms of resource use or distribution, lead to higher associated cognitive loads, including affect-related cognitive loads (Whitney & Hinson, 2009).

The second additional load I suggest be incorporated is an orienting load. This load is associated with abstraction of conceptual information, mentally aligning concepts, and contextualization of information. Of these three load processes, abstraction is the most load inducing, so it provides the categorical rule for this load, even though, in actuality, all three orienting loads will influence an individual's learning. Conceptual abstractness influences cognitive load related to the learning task in both visual (Brady, Konkle, & Alvarez, 2011) and written information (Crutch & Warrington, 2005). This is another intrinsic load that is easy to experientially evidence and logically intuit. The load of decision-making about a problem related to concrete information, such as estimating the percentage of room a table takes in the overall room, is obviously going to be less than the load of decision-making about an abstract problem, such as estimating the amount of freedom in a nation. It is harder to identify what information is important in evaluating abstract concepts, and, similarly, it is difficult to estimate these factors' values. Thus, the cognitive refraction model categorizes concrete versus abstract cognitive processes in distinct categories of intrinsic load. Similarly, the load of mental alignment is an understood intrinsic load associated with the cognitive load involved in spatial rotation and map alignment (Tversky, 1993). If a map is oriented to the physical location of the map user, reading the map involves a lower cognitive load than if the user needs to mentally rotate the image to interpret it. Contextualization of information is also important, especially for experts (Grossman, 2017). Embedding learning in its contextual application can reduce the work of determining how to apply it. This can be interpreted as making the abstract more concrete by simplifying understanding its application.

The Cognitive Loads of the Learning Tasks

The cognitive refraction model is a tool to categorize intrinsic load of tasks based on these three factors: elements of interactivity, choice/decision-making, and conceptual abstractness. The categorization rules have been simplified for you in a decision tree in Figure 1, and will be explicated here, as well. To categorize learning objectives, you begin by determining if the learning objectives involve decision-making. If the answer is no, that information is categorized as structure processing. This is the processing associated with conceptual understanding. The cognitive load associated with it is the work of keeping track of information, activating the right information, and inhibiting incorrect information. This load can be small with very narrow, simple topics or heavy with interconnected and contradicting information.

If the answer is yes, there is some decision-making in the process, you must determine if the process requires only one decision or many decisions. If the processing requires only one decision, you next look at the outcome of the decision. Is this a concrete outcome, with a right or wrong answer, or is it a more abstract outcome, with multiple possible correct responses? If there is a right answer, this is categorized as action processing. The information from structure processing is still a cognitive load, but action processing adds the loads of identifying that a decision needs to be made and making the right decision. If the decision involves abstract information, the load is greater yet, with the additional loads of identifying important factors, estimating values of factors, and choosing a path. This is classified as heuristic processing.

If you need to make multiple decisions, those decisions must be connected into a procedure that organizes them. That imposes a cognitive load as well. That load is different if the steps involve reasoning about a more concrete product rather than a more abstract product. If the end product is concrete, such as a paper or other material object, then, as you organize, you can compare to a conceptualization of the concrete end product. This is design processing. It involves all of the loads associated with the decision-making on different steps of the process, as well as the additional load of connecting the product being designed to some concrete, constraining principles. The ability to check each step for accuracy limits the load of this category to some degree.

The final category of processing is share processing. The work associated with share processing involves communicating information to other audiences. This work is sharing abstract information while comparing it to an abstract set of requirements, so the processing is very resource intensive.

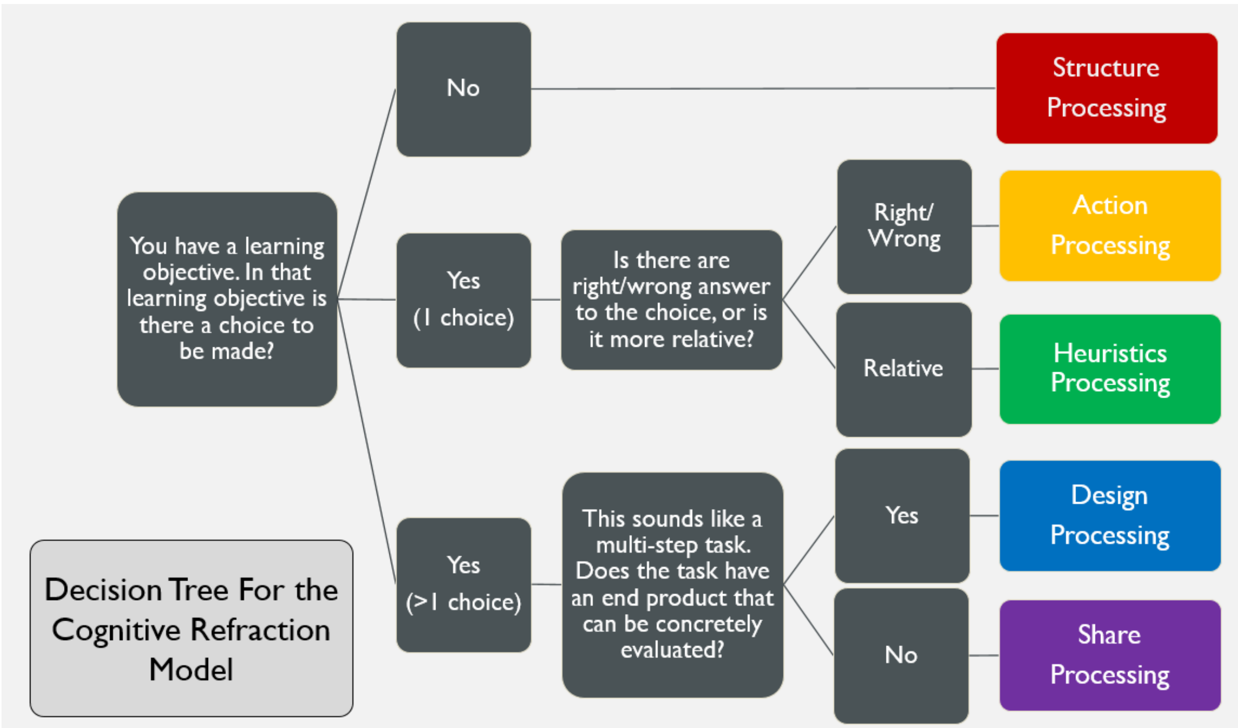

Figure 1. Decision tree for the categorization of the cognitive refraction model.

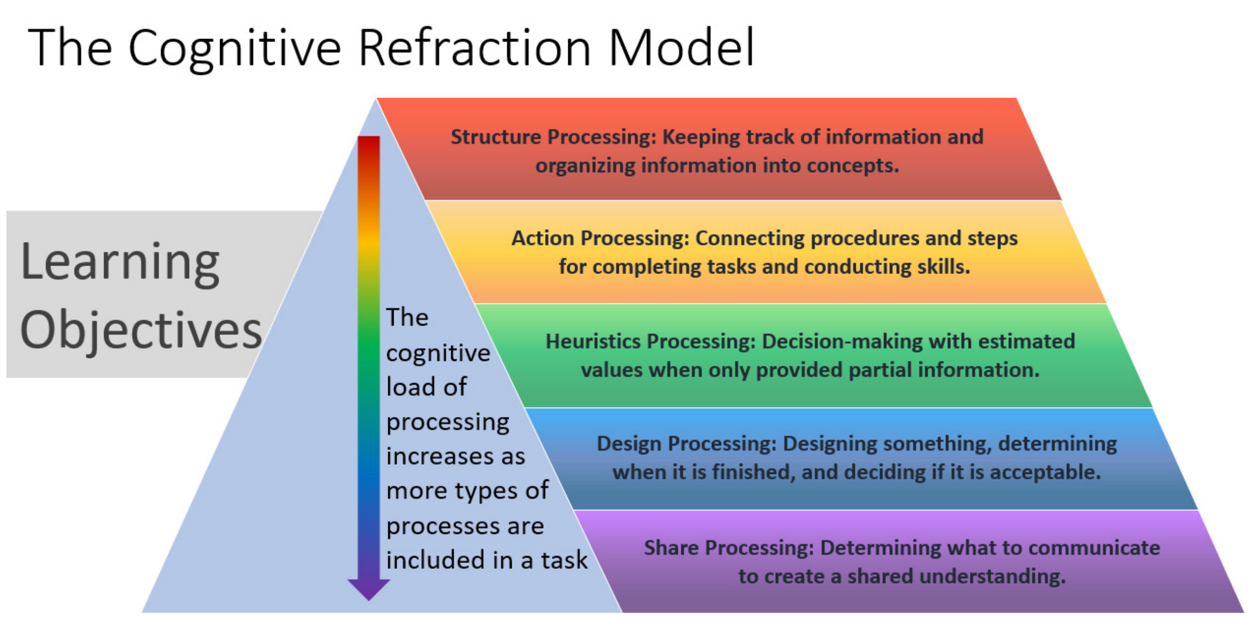

Figure 2. The cognitive refraction model and the work associated with process categorizations.

This categorization process is diagrammed in figure one. The model itself can be seen in figure 2. These categorizations might seem abstract. To make them more concrete for you, let me provide a light-hearted example of categorizations related to learning objectives about big cats.

- Structure: Knowing different types of big cats is an example of structure processing. Knowing characteristics of groups of big cats, like their coat patterns, is also structure processing.
- Action: Being told to choose the tiger from a set of big cat pictures of different species and being able to identify and select the right picture is an example of action processing.
- Heuristics: When shown a set of pictures of big cats with behavioral descriptions, choosing which big cat you would like to be stuck in a cage with for three hours is an example of heuristic processing.
- Design: Designing an approach to your confinement with the big cat as to give you the best chance of health and survival is an example of design processing.
- Share: Being told that your friend will be the one put in the cage with a big cat and that you need to share your design with your friend results in share processing. You have already come up with a great approach to staying alive; now you need to communicate this approach.

There is another load that an applied cognitive science framework incorporates that is not a load in the cognitive refraction model; this is the load of metacognition. Metacognition is thinking about the processing involved with one or more of the previously identified categories: structure, action, heuristics, design, and share. This load is associated with planning future actions, monitoring current actions, and evaluating past actions. These are all very abstract processes that look at two abstract concepts as they change over time. These processes are cyclic and constantly recurring. You can add a metacognitive load to any other process category. This will increase the overall cognitive load, but helps improve the quality of the final product if there are enough processing resources for the task.

Prescriptive Categorizations

Different types of processing are supported by different tools. If you need to understand a category, a list of what is in that category supports this learning well. However, if you need to choose the best option out of a number of possible choices, a list only helps you remember what the options are; it does not help you weigh those choices. A decision tree would support this learning more. Each category of processing has tools and techniques that specifically aid those processes; what those tools are, and how they aid learning, was derived from the cognitive science literature.

To align these tools with the model's categories, I reviewed the cognitive load literature about tools and techniques that improved learning and categorized them based on the types of tasks they influenced. Methods that simplified learning in a situation or improved the learner's accuracy were categorized by the learning tasks they could be applied to and then classified using the cognitive refraction model. From this work, I created a classification chart identifying the tools and techniques that can be used with that category of learning tasks. This allowed the model to be prescriptive: after categorizing the learning objectives, you can choose between the tools that support that category of learning. The logic behind the tool classification involved an analysis of the type of work each tool theoretically influenced and using its predicted influence for instructional design purposes. The following section goes through the explicating logic of tools and techniques associated with each category.

Structure Processing Tools and Techniques

Addressing contradictions: Addressing contradictions in material improves structure learning because overlooked contradictory information will lead to less accurate decision-making. Furthermore, if contradictory information is automated without being addressed, it can lead to ingrained decision-making biases and systematic misidentified or unidentified factors.

Categorization offloading tools: Categorizing offloading tools are tools that make the process of categorizing easier. Examples include guide books and data classification charts. They simplify the process of identifying what fits into a schema and how it gets incorporated.

Categorization practice: Practicing the process of categorization of information improves the automaticity of the schema information, helps identify areas of contradictions, and strengthens the chunking of schema information.

Coherent structure: Having a coherent structure makes learning a schema easier because it provides an example of a successful way to model the schema. The learner can see the model created with the instructional structure and map their structure onto a similar framework.

Concept maps: Concept maps improve structure learning by making the important information explicit. They also reduce the work of schema organization through the spatial offloading of learning information into a graphical form.

Contextual embedding: Having structure information embedded in the context the information will be used in simplifies the process of identifying interactions between the learning material and the context. This improves the usability of the material being learned.

Embedding in prior knowledge: Schema information that is incorporated into previously learned materials is easier to learn because previously learned information is already incorporated into mental structures, allowing the new information to be attached to prior understandings instead of constructed from scratch (which requires more work).

Reducing unnecessary information: Excluding unnecessary information from a presentation simplifies the process of schema creation. This is because the learner doesn't need to determine how to incorporate the unnecessary information into their understanding.

Rule identification instructions: Information is often classified by rules that guide what information is placed in which category. Providing the learner with copy of these rules to be reviewed whenever needed reduces the work associated with the task of classifying information.

Summaries: Summaries simplify the process of learning schemas because they share an expert's perspective on the important material to cover in the schema. This simplifies the process of determining what is meaningful. It also increases learners' accuracy in identifying important conceptual connections.

Action Processing Tools and Techniques

Checklists: Providing a checklist for action information simplifies the identification of needed steps and reduces the load of keeping track of the procedure being followed.

Flow charts: Flow charts are another way of simplifying the identification of needed steps and reducing the load of tracking the procedure being followed. It does this in a spatial organization, which can further off-load the information for some learners.

Just-in-time guidance: Providing just-in-time guidance during action learning improves learning by reducing the load of remembering the steps of the procedure and reduces the load of remembering the specific directions associated with the procedural learning.

Modeling: Modeling action information simplifies learning because it shows the learner how the task can be successfully carried out in a contextually-embedded format. This reduces the work of identifying what needs to be considered.

Role playing: Role-playing action information allows the learner practice the action in a lower-stakes setting and helps develops automaticity for aspects of the process.

Timely feedback: Providing timely feedback helps with the learning of action information because it strengthens the incorporation of correct action and it enables the identification of incorrect action or contradictory action information. This improves the accuracy of future action practice.

*Video evaluations***:** By viewing a video recording of themselves performing an action, learners can self-evaluate their performance. This is particularly helpful when dealing with physical actions, where kinesthetic and spatial information guide the learning.

Heuristic Processing Tools and Techniques

Feedback: Providing feedback during heuristics processing allows the learner to recognize aspects of the process that they were doing well and to identify aspects that could use some improvement. It allows for the correction of errors and reduces the chance that errors will be regularly practiced and automated.

Graphic organizers: Graphic organizers improve heuristic learning by reducing the work of mentally maintaining representations of multiple factors and their interactions simultaneously. Off-loading the factors to a visual modality reduces the working memory load.

Guiding questions: Guiding questions direct the learner to the decisions and choices that must be made for heuristic processing. They guide the learner in identifying pertinent factors and interactions that influence the heuristic processing. This can simplify mental processing and make end products more accurate.

Mental models: Mental models simplify the process of heuristics learning because they offload the work of representing multiple elements at the same time. This allows the decision-making process to be guided by the model and improves the accuracy of factor identification.

Metacognitive skills training: Training learners in metacognitive skills (planning, monitoring, and evaluating processes) allows learners to strengthen their understanding of the decisions that need to be made and the factors that need to be attended to. Metacognitive monitoring of heuristics can improve the accuracy of the decisions being made and allow for refining of the heuristic throughout the process.

Outline: An outline is helpful for heuristic processing because it allows the learner to self-check that they are following the problem logic well and have identified the important aspects of a problem. The outline can signal important information, guide behavior, and provide a way to self-monitor learning progress.

Partial practice: At times the cognitive load of a whole task is so large that learners quit instead of trying to surmount the work. In these situations, it can be helpful to break problems down into smaller parts and have learners practice part of the task before attempting the full task. This allows learners time to automate aspects of the task and chunk aspects of the schema. Partial practice allows the learners to simplify the learning task through experience before attempting the whole task.

Process guides: Process guides direct the learner by breaking down the learning situation into steps and identifying the different steps in the process being learned. This reduces the work of deciding what to do, and in what order.

Sharing rules of thumb: Rules of thumb are the guiding logic of decision-making that others rely on. By having experts share the considerations and estimations they use in heuristic processing, the learner is provided with expert guidance for making the same decision themselves. This reduces the work of deciding what to do and monitoring decision making.

Worked examples: Providing worked example problems reduces the work associated with heuristics learning because examples show the steps needed and the information to include in order to solve a particular problem. This reduces the work of maintaining this information in the mind while processing.

Design Processing Tools and Techniques

Contextualization of information: Contextualization of information reduces the work of design processing because in design processing context can be very important for final design. If the context of the design is provided, the learner does not need to imagine or create a representation of the proper context.

Feedback: Feedback reduces the work of design processing by identifying areas in the design or the design process where attention needs to be paid or errors have been made. It allows the designer confirmation that their internal representation of the process is similar to outside criteria.

Graphic organizers: Graphic organizers reduce the work of the design process because they can organize work into steps, off-loading the working memory load required to hold multiple elements in mind at the same time. They can also store important structure information, such as where items are located or how systems are interconnected, so that the designer doesn't need to be experts in those systems.

Rubrics: Rubrics reduce the work of design processing because they make it easier for the designer to recognize important design constraints and reduce the load associated with evaluating whether the created product meets the desired specifications.

Skill simplifying tools: Skill simplifying tools can reduce and improve the work of design work by making the quality of the design better, making the work easier, or both. For example, when designing a yearbook, having to cut physical pictures out is more work and harder work than using a digital design program (one you have the skills to use them). The caveat here is that the load of learning to use the tool needs to be low enough for the use of the tool to be possible. If learning to use the tool is too hard, then the tool will not be used, or its use will reduce the quality of the end product.

Time management offloading tools: Time management offloading tools help organize time in larger projects to reduce the load associated with figuring out what to do, when. Setting a calendar that notifies you of an upcoming meeting, setting incremental due dates for portions of projects, and having a project timeline are all examples of time management offloading tools for design processing.

Visual representations: Providing visual representations of the design product can reduce the work of design processing because it makes mentally representing the product in the mind easier. However, making the mental representation more concrete might also lead the learner to constrain their product and reduce creative or novel design processing.

Share Processing Tools and Techniques

Graphic organizers: Graphic organizers simplify and improve share processing by creating visual/spatial representations of share information. This does a number of things: 1) it gives the audience information in a different modality to reduce their load; 2) it supports the building of shared understanding through visual information organization; and 3) it creates a spatial representation of the information that can be referred to as a place holder for that information in information sharing.

Rubrics: Rubrics simplify share processing by explicitly providing evaluation criteria to evaluate the share processing. They highlight important information for the involved parties and simplify the process of determining what is necessary to share to create a shared understanding.

Self-assessment practice: Self-assessment practice improves share processing by improving skills in determining how successful a sharing process was and helping to automate parts of the self-assessment process.

Self-assessment guides: Including guides for self-assessment of the share processing can improve the work associated with sharing because it forces the learner to slow down and think about the process of information sharing. This improves the designing of future communications and helps the learner self-identify areas where work is needed.

Shared communication tools: Shared communication tools reduce the load associated with share processing by making the sharing more powerful through the use of technological tools. An example of this is a webinar that includes visual and auditory information to ease the work of creating a shared understanding.

Sharing guidelines: Sharing guidelines improve share processing by creating agreed-upon constraints on how collaboration and sharing are conducted. These guidelines allow the participants to simplify figuring out what to share and how to understand shared material. Guidelines might constrain what information is to be shared, the organization of the share processing, who is to be involved in the share process, or timelines associated with the sharing. Creating system constraints reduces the work of determining what to include.

Templates: Templates simplify share processing by guiding the learner in what information to share and when to share it. The template provides structure and organization information for the share processing so that the process of determining how to create a similar sharing is simplified.

Time management offloading tools: Time management offloading tools improve share processing by simplifying the work of having multiple parties share information, both synchronously and asynchronously.

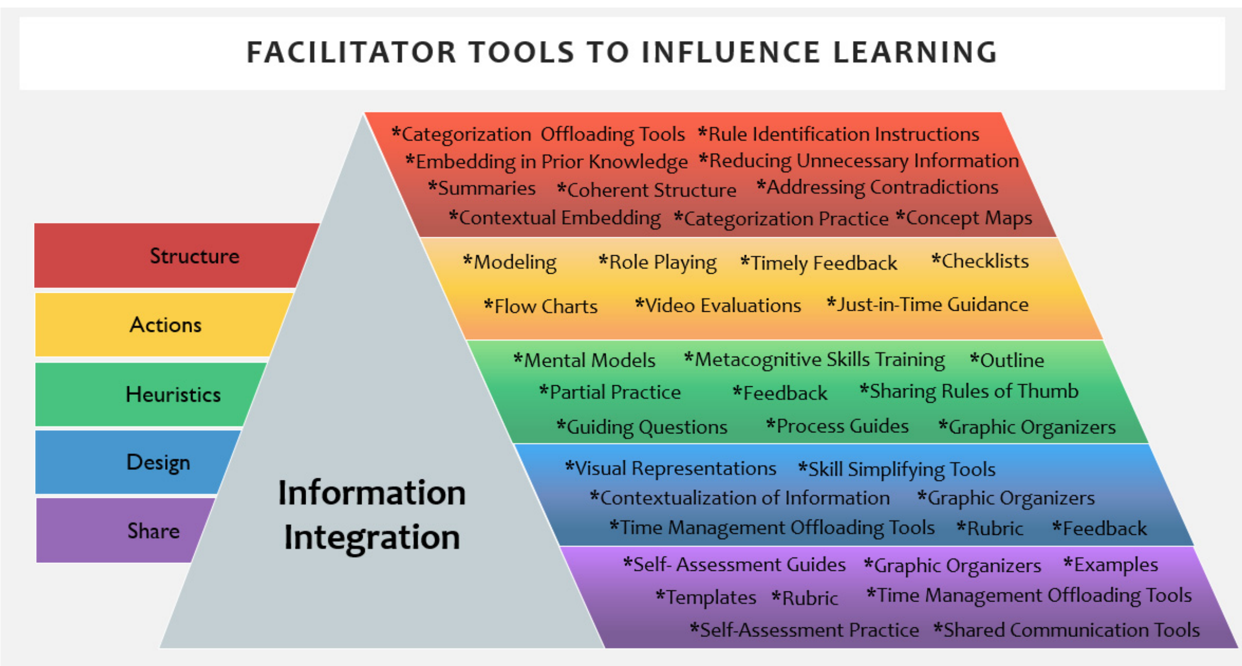

Figure 3. A classification chart of the tools and techniques associated with each process category.

Discussion

The cognitive refraction model was created to align child trauma curriculum with professional mental health competencies. The project initially attempted to use Bloom's taxonomy for the task (Krathwohl, 2002), but that proved to be not suitable for the work. Bloom's taxonomy made predictions that did not align with a cognitive load framework on learning, and its predictions were not as directive as desired for a flexible training curriculum facilitated by mental health experts instead of educators. The cognitive refraction model was constructed as a part of a larger cognitive load framework that I call the Cognitive Ecocultural Framework. This framework uses instructional design concepts from problem-based learning (Barrows, 1986) and experiential learning (Kolb, 2014) to shape instruction and learner/facilitator interactions in this collaborative, ecoculturally-embedded approach. The framework allows instructional designers to align their instruction with the realities of the learning setting. The model is part of this framework, but can be applied alone to determine instructional tools to support curriculum or to recommend successful techniques to use with your planned instruction.

In this presentation I have provided the basics for getting started using the cognitive refraction model to categorize learning objectives and to select tools and techniques for instruction. The model can also be used to adapt existing curriculum for better learning or to determine appropriate assessment methods. While this instructional model was initially designed for mental health professionals around child traumatic stress, it is applicable across subject matters. Two of its most promising applications are to support trainings in other professional capacities and, as translated into classroom practice, to support next-generation science standards. There are many promising areas to explore and places to apply the model to improve learning.

To validate this model, we are using design-based research instead of an experimental approach. We want to show its validity its usability. I am also presenting about a curriculum improvement project (Grossman & Layne, 2018) and how we used heuristic graphic organizers to support complex problem-solving in a problem-based learning curriculum (Grossman & Layne, 2018). These studies both support the model's usability and utility.

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