[CV-01-028] Lesson Design in Cartography Education

Abstract

This entry describes six general variables of lesson design in cartography education and offers some practical advice for the development of materials for teaching cartography. First, a lesson's scope concerns the set of ideas included in a lesson and helps identify different types of lessons based on the kinds of knowledge that they contain. Second, learning objectives concern the things that students should be able to do following a lesson and relate to different cognitive processes of learning. Third, a lesson's scheme deals with the organizational framework for delivering content. Fourth, a lesson's guidance concerns the amount and quality of supportive information provided. Fifth, a lesson's sequence may involve one or more strategies for ordering content. Sixth, a lesson's activity concerns what students do during a lesson and is often associated with different learning outcomes. These six variables help differentiate traditions for teaching cartography, elucidate some of the recurring challenges in cartography education, and offer strategies for designing lessons to foster meaningful learning outcomes.

Keywords: Bloom's taxonomy, cognition, education, higher education, problem-based learning

Author & citation

Howarth, J. T. (2020). Lesson Design in Cartography Education. The Geographic Information Science & Technology Body of Knowledge (3rd Quarter 2020 Edition), John P. Wilson (Ed.). DOI:10.22224/gistbok/2020.3.6.

Explanation

1. Definitions

- **active learning:** requires students to actively engage with the learning materials
    - **behavioral activity:** requires physical actions during a lesson, such as interacting with a human-computer interface
    - **cognitive activity:** requires cognitive processing during a lesson, such as

selecting key information, organizing verbal and pictorial models, and integrating models together and with prior knowledge
        - **self-explanations**: lesson prompts students to explain procedures
- **learning assessments:** methods to discern if students and/or lesson have achieved learning objectives
    - **rote learning:** learning that deals largely with remembering
        - **remember:** ability to retrieve information from long-term memory
    - **meaningful learning:** learning that organizes new information and integrates it with previous knowledge
        - **understand:** ability to organize information into coherent models and connect these models with prior knowledge
        - **apply:** ability to independently carry out either a familiar or novel task
        - **analyze**: ability to independently break down material into key components and determine different relationships between these components
        - **evaluate:** ability to make judgments based on criteria and standards, particularly judgments that deal with quality, effectiveness, efficiency, and consistency
        - **create**: ability to independently put elements together to form new, coherent, functional wholes
- **learning objectives:** statements of what students should be able to do as a result of a lesson
- **lesson:** self-contained building block of instruction
- **lesson scope:** the set of ideas contained by a lesson, which can be described based on the kinds of knowledge contained by lesson
    - **declarative knowledge:** "knowing that"
        - **factual knowledge:** specific, isolated bits of information
        - **conceptual knowledge:** systems that organize facts into more complex ideas
    - **procedural knowledge:** "knowing how"
    - **meta-cognitive knowledge: a** student's knowledge of their own learning
- **lesson type**: instructional patterns defined by the kinds of knowledge included in lesson's scope
    - **map as artifact:** focus on the look of maps and conceptual understanding of how maps work and function as graphical systems
    - **mapmaking as practice:** focus on procedural knowledge of how to make maps
    - **map as instrument:** focus on the use of maps to convey geographic ideas and emphasize map reading rather than map production
    - **mapmaking as instrument:** integrate procedural knowledge of mapmaking with conceptual knowledge from an application domain
    - **cartography as practice:** integrate conceptual understanding of maps as objects with procedural knowledge of mapmaking
    - **cartography of instruments:** integrate conceptual understanding of maps as objects with conceptual knowledge of an application domain
    - **cartographic practice as instrument**: integrate conceptual understanding of maps as object, procedural knowledge of mapmaking, and conceptual understanding of the application domain.
- **lesson scheme:** a framework to organize ideas in a lesson
    - **concept-based scheme:** organizes a presentation with cognitive structures

associated with understanding, including classifications, enumerations, and explanations
    - **skills-based scheme:** an ordered list of actions that produce a predetermined answer
    - **problem-based scheme:** template for problems that involves setting the problem, planning a solution, implementing the plan, and evaluating the solution
- **lesson sequence:** the order that a lesson presents ideas
    - **knowledge-based**: order from simple to complex knowledge (from primitives to higher-ordered concepts)
    - **process-based:** order from simple to complex cognitive processes (from understanding to creating)
    - **problem fading:** sequentially removes supportive content of lesson
    - **just-in-time:** presents conceptual knowledge when called upon by procedure
- **problem guidance:** supportive information provided by lesson in problem-based schemes
    - **ill-defined problem:** lesson provides no support for any stage of problem
    - **well-defined problem**: lesson provides support for setting the problem, but not for planning, implementing, or evaluating
    - **blueprint problem**: lesson provides support for setting the problem and planning the solution, but not for implementing or evaluating
    - **critique**: lesson provides support for setting, planning, and implementing, but not for evaluating the solution
    - **case example:** lesson provides support for all stages of the problem
    - **cookbook:** lesson demonstrates but does not explain procedures
    - **worked-out example:** lesson demonstrates and explains procedures

2. Introduction

While there is no single script to develop educational materials in cartography, there are perhaps some general variables that instructors should consider when designing materials for a particular audience and learning environment. Table 1 lists six variables for designing a cartography **lesson**, or a self-contained building block of instruction. Larger units of instruction, like modules, courses, and curriculums, can be considered collections of lessons.

Table 1. Major Decisions for Lesson Design in Cartography Education

Scope	What content should be included in a lesson?
Objectives	What should students be able to do with ideas from the lesson?
Scheme	What framework should organize the lesson?
Guidance	What supportive information does the lesson provide?
Sequence	In what order should the lesson present ideas to students?
Activity	What should students do during the lesson?

3. Lesson Scope

The **scope** of a lesson concerns the set of ideas it contains. This can be described quantitatively based on the number of ideas involved, which conveys the degree that a lesson is short versus long or light versus dense. The lesson's scope can also be described qualitatively by the kinds of knowledge that it contains (Anderson et al., 2009). This quality relates to how a lesson may feel "academic" or "practical" and it underlies a core problem in academic cartography education: how to bring together knowledge about maps, knowledge of how to make maps, and knowledge of how to use maps to investigate and understand the world.

In their revision of Bloom's Taxonomy, Anderson et al. (2009) described four general kinds of knowledge. The simplest type of knowledge is **factual**, because it deals with specific, isolated bits of information. In contrast, **conceptual knowledge** deals with systems that organize facts into more complex ideas. Factual and conceptual knowledge both represent kinds of **declarative knowledge** ("knowing that") and differ from **procedural knowledge** that deals with "knowing how" to do things. For example, knowing that a degree is a unit of measurement and that latitude is a dimension of measurement are both facts, knowing that the distance represented by a degree changes with latitude is conceptual, and knowing how to calculate the distance represented by a degree at specific latitude is procedural. While these three kinds of knowledge are all intrinsic to the ideas themselves, a fourth kind of knowledge concerns the student's knowledge of their own learning, called **meta-cognitive** knowledge. Anderson et al (2009) decomposed each type of knowledge into 2-3 sub-types. Tables 2 and 3 describes the taxonomy and provides examples for each sub-type from cartography.

Table 2. Taxonomy of Declarative Knowledge with Examples from Cartography

FACTUAL KNOWLEDGE: Basic elements that learners must know as a prerequisite for developing knowledge of a domain. Discrete, isolated bits of information.		
Terminology	Knowing the essential terms of cartography that are expressed in specialized language.	Knowing definitions for terms like hue, saturation, and value, or terms like graticule, latitude, longitude, and loxodrome, or for acronyms like DEM, CSS, and API.
Specific Details and Elements	Knowing specific facts about cartography, including events, locations, people, dates, and sources of information.	Knowing that Minard made a flow map, or that NED and SRTM are both DEMs, or that Natural Earth is a data portal, or that a theodolite is a surveying instrument.
CONCEPTUAL KNOWLEDGE: More complex, organized forms of knowledge, that involve relationships, connections, and organizational schemes.		
Classification & Categories	Systems for structuring and organizing phenomena into classes, groups, and wholes.	Knowing that hue, saturation, and value are all kinds of visual variables, or that hue, saturation, and value are three distinct components of color.
Principles & Generalizations	Builds on and brings together classifications and categories that help describe, predict, explain, or determine appropriate and relevant actions or directions to take in a study or while solving problems.	Knowing that hue is used as a visual variable for nominal levels of information to select or associate classes, while saturation and value are better used for ordinal and quantitative levels of data.
Theories, Models, & Structures	Builds on and connects principles and generalizations, helps experts describe, understand, explain, and predict phenomena.	Knowing Bertin's (1983, 48) theory of functional differences in retinal variables for selecting, associating, ordering, and quantifying; knowing Munsell's theory of balance and harmony based on principles of using hue, chroma, and value (Cleland et al., 1921).

Table 3. Taxonomy of Procedural and Meta-Cognitive Knowledge with Examples from Cartography

PROCEDURAL KNOWLEDGE: Knowing "how," includes knowledge of steps, sequences, schemes, and conditions for doing things.		
Skills & Algorithms	Step-by-step procedures that produce predictable answers or solutions. Knowing how to use specific tools and datasets. Performed automatically, or with very little cognitive effort.	Knowing how to draw a line with different weights using a pen, a pen tool, or with a cascading style sheet.
Techniques & Methods	General procedures that lack a predetermined answer or solution, a general scheme for thinking and problem-solving that can be implemented with many different tools.	Knowing how to mix colors and control hue, saturation, and value with a color space (CMYK, RGB, CIELab, etc.), or knowing how to use a color wheel to define complementary colors.
Criteria for Application	Knowing when to use a procedure, often by knowing the conditions or situations that make a procedure appropriate to use.	Knowing how to select an appropriate projection, or how to develop an appropriate color palette.
META-COGNITIVE KNOWLEDGE: Self-awareness of cognition and knowledge of general strategies for learning.		
Strategies	Knowledge about learning, planning, monitoring, and regulating cognition, and heuristics for problem-solving (means-ends analysis, working backward from desired goal state).	Knowing how to use flashcards, self-reflection, and backwards problem-solving.

Contexts & Conditions	Knowing the difficulty of different tasks and the conditions or situations for using different cognitive strategies.	Knowing that a project that requires you to gather your own data may be more difficult than a project that provides you with a dataset to use.
Self-knowledge	Knowing your own strengths and weaknesses for learning and your motivation for learning.	Knowing that the domain focus can influence your interest in certain maps (an economic geographer may not be motivated to learn about topographic contour maps).

4. Lesson Types

A **lesson type** can be defined by the kinds of knowledge included in a lesson's scope (Table 4). The simplest lessons include only one kind of knowledge. In Table 4, the first lesson type (**map as artifact**) largely deals with the look of maps and conceptual understanding of how maps work as graphical systems. The second lesson type (**mapmaking as practice**) largely deals with procedural knowledge of how to make maps. The third lesson type (**map as instrument**) concerns the use of maps to convey geographic ideas in an application domain (for example, reading a topographic map in a geology lesson or a weather map in a climatology lesson) and emphasizes map reading rather than map production. Taken alone, each of these lesson types has been criticized for incompleteness (McMaster and McMaster, 2002, 313; Crampton and Krygier, 2010, 21).

The next three lesson types in Table 4 aim to integrate two kinds of knowledge. The fourth lesson type (**mapmaking as instrument**) brings together procedural knowledge of mapmaking with conceptual knowledge from an application domain, or learning "with" mapmaking (Sui 1995). Examples include a participatory mapping workshop or a lab on isoline procedures for geosciences. The fifth lesson type (**cartography as practice**) aims to integrate conceptual understanding of maps as artifacts with procedural knowledge of mapmaking. An example is a lecture on conceptual foundations of map projections paired with a lab exercise on how to produce Tissot's indicatrix and plot them with different map projections. The sixth lesson type (**cartography of instruments**) integrates conceptual understanding of maps as artifacts with conceptual knowledge of an application domain. For example, a lesson compares how different graphical schemes employed by different maps affect understanding of a particular topic, like climate change or poverty.

The seventh type (**cartographic practice as instrument**) brings together conceptual understanding of maps as artifacts, procedural knowledge of mapmaking, and conceptual understanding of the application domain. Examples include cartographic design for a particular topic, like geosciences or environmental justice.

Table 4. Lesson Types by Scope

Lesson Type	Cartographic Concepts	Cartographic Procedures	Application Domain
1. Map as artifact	X		
2. Mapmaking as practice		X	
3. Map as instrument			X
4. Mapmaking as instrument			X
5. Cartography as practice	X	X	
6. Cartography of instruments	X		X
7. Cartographic practice as instrument	X	X	X

5. Lesson Objectives

Lessons should have **learning objectives** that identify what a student should be able to do as evidence of learning. These objectives should be tied to **learning assessments** that allow instructors to evaluate student learning and the effectiveness of different lesson designs. Each entry of this Geographic Information Science and Technology Body of Knowledge concludes with a set of learning objectives that inform educational lesson design and learning assessment. Both learning objectives and assessments can be tied to cognitive processes described by Anderson et al. (2009) and, ideally, to cognitive processes employed by geospatial professionals.

Rote learning deals largely with the process of **remembering**, or the ability to retrieve information from long-term memory (Table 5). This does not involve expanding on an idea beyond the way that it was presented to a student in a lesson.

Table 5. Learning Objectives and Assessments for Remembering

Recognize	To match a prompt to a memory	Set up: Three maps are included in a reading. Prompt: Which map from the reading was made by Minard?
Exemplify	To retrieve something largely from memory	Set up: Prompt: Describe the map in the reading that was made by Minard.

Meaningful learning involves the ability to do things with bits of knowledge beyond simple retrieval. For conceptual knowledge, meaningful learning tends to be associated with cognitive processes associated with **understanding**, or the ability to organize information into coherent models and connect these models with prior knowledge. Table 6 describes seven different measures of understanding (Anderson et al. 2009) and provides examples for each from cartography.

Table 6. Learning Objectives and Assessments for Conceptual Knowledge

Interpret	To convert information from one representational form to another.	Set up: a coordinate (X,Y) and three different pictures of the mapped point, one of which shows the correct location Prompt: Which pictures correctly shows the location of this point?
Exemplify	To provide a specific example for a general concept or principle.	Set up: a type of visual contrast (Tait, 2018) Prompt: Please identify a map in the David Rumsey collection with a visual hierarchy that uses this contrast type.
Classify	To recognize that something belongs to a certain category and being able to articulate the membership criteria.	Set up: a map from a current newspaper story Prompt: What kinds of contrast types does the map use to develop its visual hierarchy?
Summarize	To produce a single statement that generalizes a theme or the main points of a presentation.	Set up: a map without a title Prompt: What is a good title for this map?

Infer	To find consistency or a pattern across a series of examples.	Set up: the same place name in series of different fonts Prompt: Identify all the serif fonts.
Compare	To identify similarities and differences between two or more things.	Set up: two different maps Prompt: How are these two maps similar and how do they differ?
Explain	To develop and use a cause-and-effect model of a system.	Set up: a map with roads low in visual hierarchy Prompt: Why are the roads in this map colored white? or Set up: a simple choropleth map with raw values Prompt: What's problematic about this map and how could you fix it?

For procedural knowledge, meaningful learning tends to be associated with the ability to apply, analyze, evaluate, and create (Table 7). To **apply** knowledge means that a student can independently carry out either a familiar or novel task. To **analyze** means that a student can independently break down material into key components and determine different relationships between these components. To **evaluate** means that a student can make judgments based on criteria and standards, particularly judgments that deal with quality, effectiveness, efficiency, and consistency.

Finally, to **create** means that a student can independently put elements together to form new, coherent, functional wholes.

Table 7. Learning Objectives and Assessments for Procedural Knowledge

APPLY	Execute	To use routine procedures of a common task.	Apply specified class breaks to a dataset.
	Implement	To select a procedure in order to perform a novel task.	Apply an appropriate and legible color ramp to a classified dataset.
ANALYZE	Differentiate	To distinguish the parts of a whole based on relevance and importance.	Identify the different thematic layers that compose a map.
	Organize	To identify how the parts fit together to make a coherent whole.	Identify the visual hierarchy of the different elements on a map.
	Attribute	To identify the intentions of the mapmaker, including the point of view, biases, or values.	Describe the purpose or bias of the mapmaker based on their design decisions.
EVALUATE	Check	To test for internal consistencies or fallacies.	Critique a map based on cartographic principles, including clarity, legibility, aesthetics of palette, etc.
	Critique	To judge a product based on externally imposed criteria and standards.	Critique a map based on appropriateness for audience, for intended media, for the environment for which the map will be read, etc.
CREATE	Generate	To represent the problem and develop alternatives that meet criteria.	Setting the goal and constraints of a map by identifying the purpose, audience, size and scale, media, etc.
	Plan	Developing a plan to solve the problem.	Identifying datasets, choosing a software, and sketching a layout for a map.
	Produce	Implement the plan.	Producing the map layout.

6. Lesson Scheme

A **scheme** is a lesson's organizational framework. Academic lectures and textbooks often employ **concept-based** schemes, including classifications, enumerations, and explanations. For the student, the learning experience is a series of exhaustive explorations into conceptual topics, where each topic provides an opportunity for an expert to tell the reader everything that they know about it. Similarly, software tutorials tend to employ **skills-based** schemes where procedures consist of an ordered list of actions that produce a predetermined answer. When education combines these two kinds of lessons, as is common in cartography courses that present instruction with separate lecture and lab lessons, the deep conceptual dives juxtaposed with linear procedural workflows tend to impart a "split personality" to the learning experience (DiBiase, 1996), which makes it difficult for students to bring together conceptual and procedural knowledge.

A **problem-based scheme** provides an alternative to concept- and skills-based lessons. It employs a general template for setting and solving problems that aims to help students integrate conceptual, procedural, and meta-cognitive knowledge while learning. The central idea is that problems deal with methods, which are not simple sequences of actions but rather depend on knowing what kinds of actions are possible and then selecting appropriate courses of action. These choices are based on knowing application criteria and this knowledge tends to relate to conceptual and meta-cognitive understanding.

A problem-based scheme can be broken down into four parts (Pólya, 1971; Schön, 1983):

1. Setting the problem to be solved
2. Planning a solution
3. Implementing the solution
4. Evaluating the solution

Table 8. Components of a Map Design Problem and Associated Cognitive Processes

Problem Component	Map Design example	Understand	Apply	Analyze	Evaluate	Create
Setting problem	Analyze & evaluate the subject phenomena. Define purpose of map and audience. Identify data and tools.	X	X	X	X	X
Planning solution	Plan layout and visual hierarchy.	X		X		X
Implementing plan	Process data. Construct the map.	X	X			X
Evaluating solution	Evaluate map use and effectiveness.	X			X	

Table 8 illustrates how map design problems, adapted from Tait (2018) (see Visual Hierarchy and Layout), fit these four components. It also illustrates how each component relates to different kinds of cognitive processes (Anderson et al., 2009). Setting the problem involves defining a map's purpose, audience, and the environment in which the map will be used. It also involves identifying the datasets and tools to be used. This is a complex process, because it integrates the full suite of cognitive processes. It requires understanding conceptual knowledge, knowing how to apply procedures (or knowing what is feasible in a practical sense), knowing how to analyze a subject into constituent parts, knowing how to evaluate the needs of an audience, and knowing how to create a defined goal or question. Planning a solution involves planning the layout, visual hierarchy, and styles of map features. This integrates conceptual understanding with the ability to analyze and break something down into constituent parts. Implementing the plan involves processing data and constructing the layout. This connects conceptual understanding with the ability to apply skills and methods. Evaluating the solution involves reflecting on the map layout and knowing when the work of map construction is finished. This connects conceptual understanding with the ability to evaluate the layout.

7. Lesson Guidance

Problem-based schemes can differ in the quality of supportive information that they provide learners. This includes the degree that a lesson provides information about a problem component or if it instead requires students to figure it out on their own (Table 9). A lesson that requires students to set a problem and solve it independently is called an **ill-defined** problem. This is a common scheme for final projects in a cartography course, when students are allowed to develop their own idea for a map and given freedom to gather and develop their own datasets, choose the software, tools, media, layout, styles, etc.

A **well-defined** problem presents students with a set problem, but requires them to solve it independently. An example is a lesson that requires students to make a map of a given region for a given purpose and a given audience with a given dataset and tools, but requires students to independently figure out how to develop the layout, style the data, etc.

A **blueprint** problem provides students with a plan for solving it but requires students to independently figure out how to implement the solution and how to evaluate the resulting product. For example, a lesson could provide students with a map that serves as a blueprint and the datasets employed by the map, and require students to independently figure out how to implement the data styles and layout expressed by the map and how to critique the map layout.

A **critique** sets the problem, plans a solution, and shows students how to implement the plan, but requires students to independently evaluate the solution. For example, a lesson can present students with a model map, describe the map's purpose and audience, and demonstrate the methods used to construct it, but require students to critically evaluate the map on their own. In both critiques and blueprint models of instruction, the choice of example maps is important. Brewer (2008) argued that it is best to present students with positive examples that can serve as models of good practice, rather than showing students examples of "bad maps."

Finally, a **case example** does not require students to figure out any problem component independently and guides students through setting, planning, implementing, and evaluating.

Each of these problem-based lesson schemes may differ qualitatively in the degree to which guidance explains the components of a problem. For example, **cookbook** labs tend to describe goals, plans, and implementations as givens, or similar to following a recipe. In contrast, a **worked-out example** explains the process of decision-making and explicitly makes connections between the different kinds of conceptual and procedural knowledge that are related by the problem (Renkl, 2005). Howarth (2015) illustrates a worked-out example in a GIS course with a lesson that explains how to represent a problem in terms of goals and constraints, how to break a problem into sub-tasks, how to sequence tasks in a workflow, and how to monitor a solution while problem-solving.

Table 9. Types of Problem Schemes Based on the Proponents that Students Need to Figure out Independently

Component	Ill-defined	Well-defined	Blueprint	Critique	Case
Set problem	X				
Plan solution	X	X			
Implement plan	X	X	X		
Evaluate product	X	X	X	X	

8. Lesson Sequence

The **sequence** of a lesson deals with the temporal order that students encounter ideas. This relates to a number of educational scales, including the sequence of ideas in a lesson, the sequence of lessons in module, the sequence of modules in a course, and the sequence of courses in a curriculum and in a learner's overall education (Foote, 2012). Table 10 identifies several major strategies related to sequence in cartography education that are based on theories of cognition and learning.

Table 10. Strategies for Lesson Sequencing

Name	Description
Knowledge-based	From primitives to higher-ordered concepts
Process-based	From understanding to creating
Problem scaffolding	Progressively removing guidance in problem-based schemes
Just-in-Time	Provide supporting concepts at decision points

A knowledge-based sequence aims to order instruction from simple to complex forms of knowledge. This is based on the idea that there is an intrinsic partonomic (part-whole) structure to knowledge, where some concepts serve as building blocks for other concepts. For example, Anderson et al. (2009) framed concepts as constituents of principles. Reg Golledge (1995) similarly defined spatial knowledge with a small set of primitives that served as building blocks for higher-ordered concepts. Similarly, "threshold concepts" are considered to be essential ideas that must be grasped prior to understanding more advanced ideas (Bampton, 2012). Knowledge-based strategies have been applied to the development of age-appropriate sequences (Marsh et al., 2007) and underlie the rational for managing the intrinsic load of learning (Sweller and Chandler, 1994).

A **process-based sequence** similarly aims to order instruction from simple to complex cognitive processes. The basic idea is that you learn to read before you learn to write. In cartography, this suggests that students should learn to read maps before they learn to create maps, or that they should learn to read code before they learn to create code. The central idea again is that there is a partonomic structure to cognitive processes that suggests a progression from lower- to higher-ordered processes.

Problem scaffolding refers to strategies for progressively removing guidance in problem-based schemes. For example, Renkl et al (2004) proposed a “fading” strategy that begins with a worked-out example and moves through a series of analogous problems that are missing guidance for an increasing number of parts in the solution. The learner must figure out these missing parts independently and then receives feedback on their solutions. Problem scaffolding should be guided by a learner’s prior knowledge. For novices, worked-out examples have been shown to foster meaningful learning outcomes by reducing the learner’s use of general problem-solving strategies, like means-end analysis, and by focusing the learner’s attention to knowledge of criteria that are associated with applying methods and skills (Ward and Sweller, 1990). However, worked-out problems are less effective for learners with more expertise in a domain (Kalyuga et al., 2001). Similarly, ill-defined problems and associated discovery-based formats are less effective at fostering meaningful learning outcomes for novice learners (Mayer, 2004), but are more effective for more advanced learners

Just-in-time strategies deal with sequencing conceptual and procedural information in a lesson that aims to integrate the two. The general idea is to consider conceptual knowledge as supportive of tasks and to provide conceptual knowledge when it is related to a task rather than on its own (de Jong and van Joolingen, 1998).

9. Lesson Activity

Cartography labs are often considered to be **active learning** environments because they involve a degree of **behavioral activity** when students interact with the graphical user interface of a computer system by pointing and clicking. In contrast, **cognitive activity** concerns the degree of active cognitive processing that students do while learning. This connects to constructivist models of learning as an active process of sense-making, where students actively try to make sense of new information by relating it to things they already know. Mayer (2009) described three key cognitive processes of active learning (Table 11). They involve selecting relevant words and pictures from a presentation, organizing these into coherent verbal and pictorial models, and integrating these verbal and pictorial models together and with prior knowledge.

Table 11. Three Cognitive Processes for Active Learning (adapted from Mayer, 2009, p. 71)

Name	Description
Selecting	Paying attention to relevant words and pictures in a presentation
Organizing	Making connections among selected words to create a coherent verbal model and among pictures to create a coherent pictorial model
Integrating	Building connections between verbal and pictorial models and with prior knowledge

Mayer (2009, 21-23) indicated that meaningful learning outcomes tend to be associated with lessons that foster cognitive activity and depend less on behavioral activity (Table 12). Academic textbooks and lectures are both examples of learning environments that tend to be characterized by low levels of behavioral and cognitive activity. For a textbook, students scan the words and pictures with their eyes, perhaps adding marks to the pages with something like a pen or highlighter, but there is often little guidance or support for organizing this new information and integrating it with what students already know. Traditional lectures are similar. Behaviorally, students look and listen while the instructor talks and moves through slides or writes on the board. They may take notes, but often this involves copying the words and diagrams that are printed in the presentation. Traditional “cookbook” labs involve more behavioral activity, but often present students with detailed directions through a sequence of steps and thus involve little cognitive activity.

Table 12. Levels of Activity and Learning Outcomes

Behavioral Activity	Cognitive Activity	Learning Outcomes	Example
Low	Low	Rote	Traditional lectures, academic textbooks
High	Low	Rote	Cookbook labs
Low	High	Meaningful	Explanations, multimedia learning principles
High	High	Meaningful	Puzzles and games

There are several strategies for encouraging cognitive activity that can foster meaningful learning outcomes. One approach is to prompt students to provide **self-explanations** while they work through a lesson. These should encourage students to make connections between conceptual and procedural knowledge, to provide reasons for making a move in a solution, to evaluate alternative moves, and to monitor their self-knowledge about the lesson (Chi et al., 1989). An example of this in a cartography lesson is to have students “think through” a problem before they “click through” (Howarth, 2015). A second approach is for instructors to design their lesson materials with presentation methods that honor cognitive principles of multimedia learning (Mayer 2009) which have been empirically shown to foster meaningful learning outcomes.

Lessons that involve higher levels of both behavioral and cognitive activity are typically games or activities that are rooted in cognitive processes of understanding, applying, analyzing, evaluating, and creating (Table 6 and 7). It is often easy to create these kinds of activities by repurposing figures from an educational text. For example, Figure 1 shows a puzzle created from Tait (2018, Table 1). The original table described different kinds of visual contrast by pairing a stronger and weaker picture. In the game, students are given a blank table and an envelope of each individual picture. Students are prompted to first identify pairs based on the idea of showing “stronger” versus “weaker.” They are then asked to organize these pairs into groups and to discuss what the groups have in common. Finally, they are asked to describe the pairs and groups with words by filling out the table. The activity connects to several of the cognitive processes associated with understanding, including interpreting (choosing words to describe the pictures), classifying (placing pairs in groups), summarizing (describing what the pairs in a group have in common), and comparing (identifying stronger and weaker instances of a type).

Figure 1. Contrast Puzzle. For materials, cut out the individual pictures in Table 1 of Tait (2018) and provide students a blank table. Prompt students to identify contrast pairs and organize these pairs into groups. Finally, ask students to describe the pairs and groups with words by filling out the table. Source: author.

10. Summary

This entry describes six general variables of lesson design for cartography education. This contributes towards a framework for describing educational materials and comparing different pedagogical strategies. Such a framework can be useful for sharing teaching strategies and for developing empirical research programs in cartography education. Though this entry focused primarily on lesson design, additional research should identify variables of learners and learning environments in cartography education.

References

Anderson, L. W., Bloom, B. S., Krathwohl, D. R. (2009). A taxonomy for learning, teaching, and assessing. New York, NY: Longman.

Bampton, M. (2012). Addressing Misconceptions, Threshold Concepts, and Troublesome Knowledge in GIScience Education. In D. J. Unwin, K. E. Foote, N. J. Tate & D. DiBiase (Eds.), Teaching Geographic Information Science and Technology in Higher Education (pp. 117-132). New York: Wiley-Blackwell.

Brewer, C.A. (2008). Designed Maps: a Sourcebook for GIS Users. Redlands, California: ESRI Press.

Chi, M.T.H., Bassok, M., Lewis, M.W., Reimann, P., Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. Cognitive Science 13, 145–182.

Cleland, T.M. (Thomas M., Munsell, A.H. (Albert H., Strathmore Paper Company, 1921. A grammar of color; arrangements of Strathmore papers in a variety of printed color combinations according to the Munsell color system; Mittineague, Mass., The Strathmore paper company.

Crampton, J. W. & Krygier, J. (2006). An Introduction to Critical Cartography. ACME: An International E-Journal for Critical Geographies, 4(1), 11-33.

de Jong, T., and van Joolingen, W.R. (1998). Scientific Discovery Learning with Computer Simulations of Conceptual Domains. Review of Educational Research 68, 179–201.

DiBiase, D. (1996). Rethinking laboratory education for an introductory course on geographic information. Cartographica: The International Journal for Geographic Information and Geovisualization 33, 61–72.

Foote, K. E. (2012). Scope and Sequence in GIS&T Education: Learning Theory, Learning Cycles and Spiral Curricula. In Teaching Geographic Information Science and Technology in Higher Education, edited by David J Unwin, Nicholas Tate, Kenneth Foote, and David DiBiase, 81–95. Chichester: Wiley-Blackwell.

Golledge, R.G., 1995. Primitives of Spatial Knowledge. In: Nyerges, T.L., Mark, D.M., Laurini, R., Egenhofer, M.J. (eds) Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems. NATO ASI Series, vol 83. Springer, Dordrecht.

Howarth, J. (2015). Learning by Solving Problems: Cognitive Load Theory and the Re-Design of an Introductory GIS Course. Cartographic Perspectives 80, 18–34.

Kalyuga, S., Chandler, P., Tuovinen, J., Sweller, J. (2001). When problem solving is superior to studying worked examples. Journal of Educational Psychology. Vol. 93(3) 93, 579–588.

Marsh, M. J., Golledge, R. G., Battersby, S. E. (2007). Geospatial concept understanding and recognition in G6-college students: A preliminary argument for Minimal GIS. Annals of the Association of American Geographers 97, 696–712.

Mayer, R.E. (2004). Should There Be a Three-Strikes Rule Against Pure Discovery Learning? American Psychologist, 59, 14–19.

Mayer, R.E. (2009). Multimedia Learning, 2nd Edition. Cambridge University Press, Cambridge; New York.

McMaster, R. B., and McMaster, S. (2002). A History of Twentieth-Century American Academic Cartography. Cartography and Geographic Information Science 29, 305–321.

Pólya, G. (1971). How to Solve It: A New Aspect of Mathematical Method. Princeton, NJ: Princeton University Press.

Renkl, A. (2005). The Worked-Out Examples Principle in Multimedia Learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 229–245). Cambridge University Press.

Renkl, A., Atkinson, R.K. & Große, C.S. (2004). How Fading Worked Solution Steps Works – A Cognitive Load Perspective. Instructional Science 32, 59–82.

Schön, D.A. (1983). The Reflective Practitioner: How Professionals Think in Action. Basic Books, New York.

Sui, D. Z. (1995). A Pedagogic Framework to Link GIS to the Intellectual Core of Geography. Journal of Geography 94, 578–591.

Sweller, J., and Chandler, P. (1994). Why Some Material Is Difficult to Learn. Cognition and Instruction 12, 185–233.

Tait, A. (2018). Visual Hierarchy and Layout. In The Geographic Information Science & Technology Body of Knowledge (2nd Quarter 2018 Edition), John P. Wilson (ed.).

Ward, M., and Sweller, J. (1990). Structuring Effective Worked Examples. Cognition and Instruction 7, 1–39.