Spatial Analysis in Forestry

Course notes

—by Glen Jordan

Forest and natural resources management, generally, are endeavors that rely heavily on spatial data and as a result have a long history of geoprocessing use. Today, forestry professionals employ a diverse array of geoprocessing and analytic applications. This course presents a small sample.

The course is composed of four lessons, each with a series of three to five lab exercises. The lessons include *Forest Inventory*, *Forest Analysis Techniques*, *Assessing Clearcutting Activities*, and *Calculating Forest Values*. The lessons aren't presented as an exhaustive treatment but simply address some obvious applications in forestry in logical groupings.

Forest Inventory explores the nature of forest data and how a GIS stores, accesses, manipulates and edits it. *Forest Analysis Techniques* introduces forest reclassification and characterizing concepts and broadly applicable geoprocessing methods. *Assessing Clearcutting Activities* and *Calculating Forest Values*, on the other hand, are theme-based lessons that employ the array of forest analysis techniques introduced in *Forest Analysis Techniques*.

With the exception of the *Forest Inventory* lesson, you'll note that course emphasis is clearly on spatial analysis. That's different from many geoprocessing courses, where the focus is often on basic theory and methods, offering little for developing analytic and problem-solving skills. Knowing theory, tools, and basic methods is critical, but knowing how to use and orchestrate them to solve a problem or conduct a forest analysis is what separates the expert from the novice.

The following *Course lessons* and *Course deployment* sections will help you orient yourself and decide how best to proceed in deploying the course material.

Course lessons

Lesson I—Forest Inventory

This lesson, consisting of five lab exercises—*Building a Geodatabase, Documenting a Geodatabase, Building an Elevation Surface, Updating With GPS, and Updating With Imagery,* addresses the question, How do we use GIS to store, document, and maintain a forest inventory?

The lesson introduces a typical forest inventory—in this case, the woodlot inventory that is employed throughout the course's remaining lessons. Regardless of what lessons and labs you decide to deploy, this lesson's first exercise is a good starting point for your students. The second, fourth and fifth exercises get into some of the more challenging aspects of forest inventory maintenance, including georeferencing imagery and digitizing and editing features.

Students experience a variety of geoprocessing operations and gain know-how in building a geodatabase and working with various types of spatial data, as detailed in table 1.

Table 1. Geoprocessing in the Forest Inventory exercises

Geoprocessing	*Building a Geodatabase*	*Documenting Data in a Geodatabase*	*Building an Elevation Surface*	*Updating With GPS*	*Updating With Imagery*
• create a geodatabase	√				
• import shapefile, coverage, raster, image, and table into a geodatabase	√				
• build an image mosaic	√				
• create a feature dataset	√				
• add attribute field		√			
• delete attribute field	√	√			
• calculate attribute field		√			
• assign feature class alias	√				
• assign attribute alias and domain		√			
• assign and transform coordinate system	√				

Geoprocessing	***Building a Geodatabase***	***Documenting Data in a Geodatabase***	***Building an Elevation Surface***	***Updating With GPS***	***Updating With Imagery***
• create mass point feature class			√		
• build a DEM raster			√		
• build a hillshade raster			√		
• create 3D display			√		
• convert TIN to raster			√		
• compute slope and aspect rasters			√		
• compute contours			√		
• georeference an image					√
• rectify an image					√
• digitize and edit features					
- digitize polygons					√
- move vertices				√	
- cut polygons					√
- merge polygons					√
- copy and paste				√	√
• definition query		√			

Geoprocessing	***Building a Geodatabase***	***Documenting Data in a Geodatabase***	***Building an Elevation Surface***	***Updating With GPS***	***Updating With Imagery***
• select features by attribute					
- simple				√	
- arithmetic					
- wild card					
• merge features				√	
• overlay features					
- polygon-on-polygon					
- polygon-on-line				√	√
- polygon-on-point					
• buffer features					
- fixed				√	
- variable					

Lab 1—Building a Geodatabase

1 Create a personal geodatabase.

2 Batch import shapefiles, delete their useless fields, transform them to the NAD83 datum, and assign aliases in place of their actual names.

3 Import the volumes table.

4 Import coverages into a feature dataset.

5 Batch import raster datasets.

6 Import orthophotos into a mosaic.

7 Retrieve online data.

Lab 2—Documenting a Geodatabase

1 Examine attribute coding in the cover types feature class.

2 Define a coded domain for the TYPE attribute.

3 Define a range domain for the HC attribute.

4 Define a coded domain for the MS attribute.

5 Define a domain for the CLASS attribute.

6 Define and assign domains for the CC, AGE, TV, and VH attributes.

7 Define and assign a domains for the management compartments attribute.

8 Assign attribute aliases to cover types feature class fields.

9 Map a coded domain attribute in the cover types feature class.

Lab 3—Building an Elevation Surface

1 Create a mass points feature class using the *ASCII 3D to Feature Class* tool.

2 Build a DEM raster from the feature class using the *IDW* tool.

3 View the DEM in 2D in ArcMap.

4 View the DEM in 3D in ArcScene. Drape feature classes.

5 Compare raster and TIN surfaces.

6 View the TIN in ArcScene.

7 Create an elevation surface raster from the TIN using *TIN to Raster*.

8 Calculate slope surfaces and a contours feature class.

Lab 4—Updating with GPS

1 Using ArcGIS Explorer, save GPS track data (gpx file) for a new city street as a shapefile.

2 Merge GPS shapefile with *basemap,* and then using ArcMap's Editor, connect its ends to existing roads.

3 Copy and paste the new street from *basemap* into *proads* and connect to existing roads.

4 Buffer the new street feature to 15 m, union overlay with *cover*, and then remove polygons inside the buffer to create a 30 m right-of-way feature.

Lab 5—Updating with Imagery

1 Using ArcMap's Georeferencing toolbar, georeference aerial photo *l20_114u.*

2 Using ArcMap's Editor toolbar, correct the digitizing error in the secondary roads feature class.

3 Create a new feature class and then digitize two recent clearcuts outlined on the photo.

4 Update the cover types feature class with the clearcuts using a union overlay.

Lesson II—Forest Analysis Techniques

This lesson, consisting of four lab exercises—*Assessing Balsam Fir Tipping Potential*, *Evaluating Economic Timber Amounts*, *Comparing Fixed- and Variable-Width Riparian Buffers*, and *Determining Insect Vulnerability*—addresses the questions, What is forest analysis? and What general geoprocessing procedures are involved?

The lesson's lab exercises explore a range of timber and nontimber forest analyses. Although these four may be instructive in themselves, their main purpose is illustrating broadly applicable geoprocessing techniques in forest analysis. The lesson introduces concepts of forest reclassifying and characterizing and associated geoprocessing techniques. These are a necessary foundation for any sort of meaningful forest analysis.

The lesson uses the Woodlot geodatabase, either generated by your students in the Forest Inventory lesson or as provided in the course dataset. The latter is your best choice.

Table 2. Geoprocessing in the Forest Analysis Techniques exercises

Geoprocessing	*Assessing Balsam Fir Tipping Potential*	*Evaluating Economic Timber Amounts*	*Comparing Fixed- and Variable-Width Riparian Buffers*	*Determining Insect Vulnerability*
• *Sort an attribute field*				
• *Add attribute field*		√		√
• *Calculate attribute field*				
- *Simple*		√		√
- *Formula*	√	√	√	√
- *Visual Basic*				√
• *Calculate field statistics*	√	√	√	
• *Rasterize an attribute field*				
• *Join tables by attribute*				
- *One-to-one*	√	√	√	√
- *Many-to-one*				
• *Join tables by location (spatial join)*				
- *One-to-one*				√
- *Many-to-one*				
• *Summarize an attribute field*				
- *Simple*		√		√
- *Case field*	√			

Geoprocessing	Assessing Balsam Fir Tipping Potential	Evaluating Economic Timber Amounts	Comparing Fixed- and Variable-Width Riparian Buffers	Determining Insect Vulnerability
• Compile a chart	√	√		√
• Edit/Format a table				
• Definition query	√	√		
• Select features by attribute				
- Simple			√	√
- Arithmetic				
- Wildcard				
• Select features by location				
• Select features by clipping		√		
• Merge features				
• Dissolve features				
- Polygons				√
- Lines				
• Overlay features				
- Polygon-on-polygon	√		√	
- Polygon-on-line			√	
- Polygon-on-point				
• Buffer features				
- Fixed	√		√	
- Variable			√	
• Perform map algebra				
• Reclassify a raster			√	
• Calculate a slope surface				
• Measure continuous distance				
- Simple		√		
- Weighted				
• Calculate neighborhood statistics				
• Calculate zonal statistics		√	√	
• Calculate a viewshed				

Geoprocessing	Assessing Balsam Fir Tipping Potential	Evaluating Economic Timber Amounts	Comparing Fixed- and Variable-Width Riparian Buffers	Determining Insect Vulnerability
• Delineate a watershed				
• Microsoft Excel spreadsheet - Pivot table - Chart				

Lab 1—Assessing Balsam Fir Tipping Potential

1 Identify balsam fir tipping stands as those between 5 and 40 years of age, with a minimum of 50 percent balsam fir content.

2 Buffer the woodlot's secondary and main road right-of-way features separately and combine them before intersecting with the selected tipping stands to isolate accessible areas.

3 Summarize accessible areas by crown closure classes—fully stocked, canopy gaps, and understocked. A pie chart is produced.

4 Map accessible tipping areas by crown closure classes.

Lab 2—Evaluating Economic Timber Amounts

1 Identify operable stands as those with a minimum volume yield of 75 m^3/ha and less than 25% tolerant hardwood content.

2 Merge secondary and main road centerlines to form a road network, and then use the Euclidian Distance tool to compute a skidding distance surface around it.

3 Use Zonal Statistics, and a table join, to associate each operable stand to an average skidding distance.

4 For each operable stand, compute a 50 m skidding class using the formula: round (skid distance/50 + 0.499)*50.

5 Summarize skidding classes by total volume and area. Chart the tabular results.

6 Map skidding classes using a layout template. Include the chart.

Lab 3—Comparing Fixed- and Variable-Width Riparian Buffers

1 Using Zonal Statistics and a table join, associate mean slope values to each cover types feature in the Woodlot.

2 Overlay cover types features on the stream network.

3 Add a buffer width field in the result, and then assign variable buffer widths depending upon mean slope value.

4 Buffer streams according to buffer field values.

5 Overlay the buffer on Woodlot stands and calculate the total volume located within the buffer.

6 Buffer streams to a fixed width of 50 m, overlay on stands, and then compute a total volume.

7 Compare volume amounts.

Lab 4—Determining Insect Vulnerability

1 Calculate a vulnerability rating for each stand based upon presence of Spruce and Balsam Fir trees.

2 Calculate stand ratings based upon amount of mature Balsam Fire present.

3 Calculate isolation ratings based upon presence of surrounding non-susceptible species, using a spatial join.

4 Multiply the three ratings to arrive at a vulnerability index for each stand.

5 Classify index values into ordinal defoliation classes – low, moderate, high, etc.

6 Summarize defoliation classes by area and timber volume. Build a chart.

7 Map the defoliation classes.

Lesson III—Assessing Clearcutting Activities

This is a theme-based lesson focused on the controversial but common forestry activity of clearcutting. It addresses the question, How can you assess clearcutting activities in a forest?

In this lesson's three lab exercises—*Compiling Harvest Opening Sizes*, *Calculating Visible Clearcut Amounts*, and *Measuring Watershed Effects*—students will examine clearcutting activity in the woodlot from two perspectives, ecological and aesthetic.

In the first exercise, students compile and map clearcut opening sizes as indicators of both ecological and aesthetic impact. In the second, they calculate clearcut exposure and visibility as indicators of aesthetic impact. In the final exercise, they delineate watersheds and assess the ecological impact of clearcutting activity within those watersheds.

Students employ a variety of geoprocessing operations and build their geoprocessing know-how, as detailed in table 3.

Table 3. Geoprocessing in the Assessing Clearcutting Activities exercises

Geoprocessing	*Compiling Harvest Opening Sizes*	*Calculating Visible Clearcut Amounts*	*Measuring Watershed Effects*
• *Sort an attribute field*	√		
• *Add an attribute field*	√	√	√
• *Calculate attribute field*			
- *Simple*	√	√	
- *Formula*	√		√
- *Visual Basic*			
• *Calculate field statistics*	√	√	
• *Rasterize an attribute field*		√	
• *Join attributes tables*			√
- *One-to-one*			
- *Many-to-one*		√	
• *Join tables by location (spatial join)*			
- *One-to-one*			
- *Many-to-one*			
• *Summarize an attribute field*			√
- *Simple*	√		
- *Case field*	√		

Geoprocessing	***Compiling Harvest Opening Sizes***	***Calculating Visible Clearcut Amounts***	***Measuring Watershed Effects***
• *Compile a chart*	√		
• *Definition query*		√	√
• *Select features by attribute* - *Simple* - *Arithmetic* - *Wildcard*	√	√	√
• *Select features by location*	√	√	
• *Select features by clipping*			√
• *Merge features*			√
• *Dissolve features* - *Polygons* - *Lines*	√	√	
• *Overlay features* - *Polygon-on-polygon* - *Polygon-on-line* - *Polygon-on-point*			 √ √
• *Buffer features* - *Fixed* - *Variable*			
• *Perform map algebra*		√	√
• *Reclassify a raster*			√
• *Calculate a slope surface*			
• *Measure continuous distance* - *Simple* - *Weighted*			
• *Calculate neighborhood statistics*			
• *Calculate a viewshed*		√	
• *Delineate a watershed*			√

Lab 1—Compiling Harvest Opening Sizes

1 Identify clearcuts as those stands with low volume yield (≤ 30 m^3/ha) and young age (≤ 10 years).

2 Merge adjacent clearcut stands into larger harvest openings.

3 Reclassify opening sizes into 10 ha classes.

4 Compute a harvest opening size distribution.

5 Map harvest openings by size class..

Lab 2—Calculating Visible Clearcut Amounts

1 Select clearcuts in the Woodlot as those stands harvested within the last 5 years.

2 Get an initial assessment of their visibility by determining how many are adjacent to main roads.

3 A more detailed assessment, however, requires determining what boundary lengths clearcuts share with main roads, and calculating a frequency distribution. That involves using a polygon neighbors analysis.

4 A final assessment looks at visibility of clearcuts beyond those immediately adjacent to main roads. This involves a viewshed analysis using the Spatial Analyst extension, whereby main and public road centerlines are the viewers and elevation plus stand heights form the viewing surface. Clearcuts are then classified as visible or not using a map algebra overlay of the viewshed.

Lab 3—Measuring Watershed Effects

1 Select clearcuts as those stands harvested within the last 5 years.

2 Delineate a Woodlot stream network and associated watersheds using ESRI Watershed Delineation tools.

3 Using map algebra, overlay clearcuts on watersheds and compute clearcut amounts by watershed.

4 Compute kilometers of road per hectare for each watershed, using an intersect overlay of watersheds on roads.

5 Another intersect overlay locates road and stream crossings, and they in turn are overlaid with watersheds to determine their frequency by watershed.

Lesson IV—Calculating Forest Values

What types of values do forests have, and how can we quantify them? Generally, forest values fall into three categories—economic, social, and ecological—that share very little common ground. Managing forests for these often-conflicting values is a special challenge but starts with characterizing forests in quantifiable terms. That's where spatial analysis is particularly helpful.

In this lesson's four labs—*Calculating an HSI for an Old-Growth Species*, *Summarizing Timber Value by Stand Type and Accessibility*, *Evaluating Maple Sap Production Potential*, and *Assessing Forest Recreation Value*—students will measure forest values in economic, social, and ecological terms. In the first exercise, they'll examine the woodlot's ecological value by calculating a habitat suitability index (HSI) for an old-growth species. In the second exercise, they'll summarize economic timber value in the woodlot and compare amounts accessible by road and those that are not. In the third exercise, they'll evaluate the economic value of the woodlot from a nontimber product perspective. In the fourth and final exercise, they'll measure the woodlot's potential social and economic value for forest recreation.

Students will experience a variety of geoprocessing operations and build their analytic know-how, including Visual Basic coding in the first two exercises. Table 4 indicates specific exercise coverage.

Table 4. Geoprocessing in the Calculating Forest Values exercises

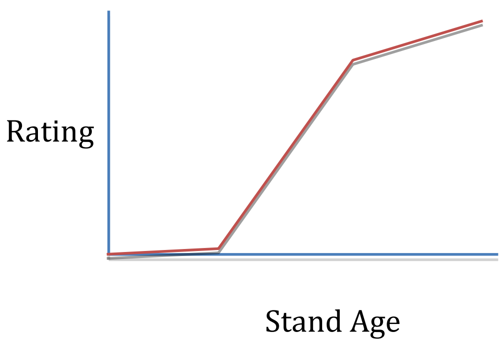
Geoprocessing	*Calculating an HSI for an Old-Growth Species*	*Summarizing Timber Value by Stand Type and Accessibility*	*Evaluating Maple Sap Production Potential*	*Assessing Forest Recreation Value*
• *Sort an attribute field*		√		
• *Add attribute field*	√	√	√	
• *Calculate attribute field*	√		√	
- *Simple*		√	√	
- *Formula*				
- *Visual Basic*	√	√		
• *Calculate field statistics*		√		
• *Rasterize an attribute field*				√
• *Join attribute tables*				
- *One-to-one*	√	√	√	
- *Many-to-one*				
• *Join tables by location (spatial join)*				
- *One-to-one*				
- *Many-to-one*				

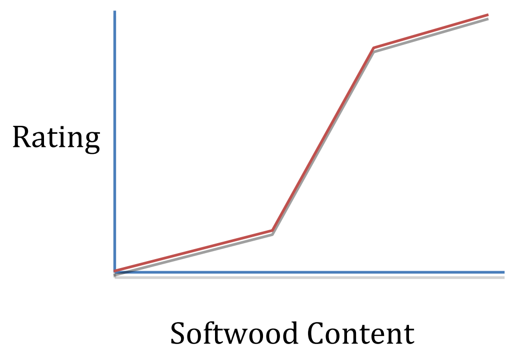
Geoprocessing	***Calculating an HSI for an Old-Growth Species***	***Summarizing Timber Value by Stand Type and Accessibility***	***Evaluating Maple Sap Production Potential***	***Assessing Forest Recreation Value***
• *Summarize an attribute field* - *Simple* - *Case field*	 √ 	 √ √	 √	
• *Compile a chart*		√		
• *Edit/Format a table*				
• *Definition query*	√			√
• *Select features by attribute* - *Simple* - *Arithmetic* - *Wildcard*	 √ 	 √	 √ 	
• *Select features by location*		√		
• *Select features by clipping*				
• *Merge features*			√	
• *Dissolve features* - *Polygons* - *Lines*	 √ 			
• *Overlay features* - *Polygon-on-polygon* - *Polygon-on-line* - *Polygon-on-point*			 √ 	
• *Buffer features* - *Fixed* - *Variable*			 √ 	
• *Perform map algebra*				√
• *Reclassify a raster*				√
• *Calculate a slope surface*				√
• *Measure continuous distance* - *Simple* - *Weighted*				 √
• *Calculate neighborhood statistics*				√

Geoprocessing	*Calculating an HSI for an Old-Growth Species*	*Summarizing Timber Value by Stand Type and Accessibility*	*Evaluating Maple Sap Production Potential*	*Assessing Forest Recreation Value*
• *Calculate a viewshed*				
• *Delineate a watershed*				
• *Microsoft Excel spreadsheet*				
- *Pivot table*		√	√	
- *Chart*		√		

Lab 1—Calculating an HSI for an Old-Growth Species

1 Using the following Blackburnian Warbler habitat relationships as guides, assign Woodlot stands age and softwood content ratings on a scale of 0 (worst) to 5 (best).





2 Multiply ratings, producing composite values ranging from 0 to 25.

3 Classify composite values into HSI values ranging from 1 (worst) to 8 (best).

4 Form HSI patches (Dissolve tool) where adjacent stands share the same HSI value.

5 Summarize HSI patches by area sum and average.

6 Last, calculate patch densities (#/100 ha).

Lab 2—Summarizing Timber Value by Stand Type and Accessibility

1 Calculate dollar value of each Woodlot stand as m^3/ha * $/$m^3$ * ha.

2 Sum dollar value of individual stands to get a gross timber value for the Woodlot.

3 Isolate stands accessible by main or secondary road and calculate a dollar value, and compare to the gross value.

4 Classify stands into categories of accessibility (accessible, inaccessible) by stand type (softwood, hardwood, mixedwood, treed bog, non-forested).

5 Summarize the categories by dollar value total, area total, and average stand yield.

Lab 3—Evaluating Maple Sap Production Potential

1 Create haul zones of 25, 50 and 75 m around roads and trails in the Woodlot using the Multiple Ring Buffer script tool.

2 Select tolerant hardwood stands and intersect overlay with the buffers.

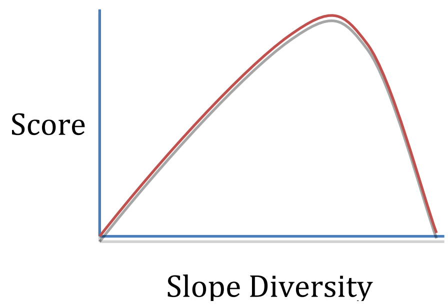
3 Label stands by their sap production potential within each haul zone as follows:

Label	Description	Stand Condition
PP	Present Potential	Large-size Sugar Maple >= 10% of stand volume
FP	Future Potential	Small-size Sugar Maple >= 10% of stand volume
LP	Limited Potential	None of the above

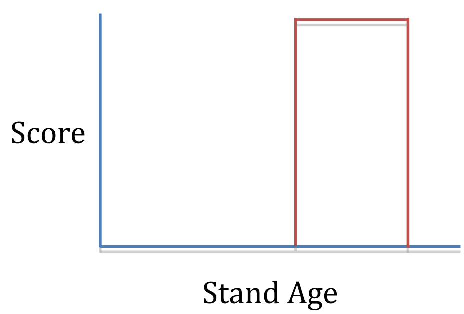
4 Using MS Excel compile a cross tabulation of Woodlot area by sap production potential and haul zone.

Lab 4—Assessing Forest Recreation Value

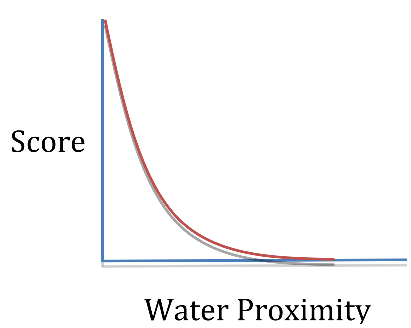
1 Calculate a terrain diversity raster based upon of slope ranges within 200 m, and then create a recreation score raster by reclassifying – 1 (worst) to 10 (best), using the following relationship.



2 Based upon the following relationship, calculate a recreation score raster by reclassifying all stands age 60 – 100 with a 10.



3 Calculate a wetlands proximity raster by measuring distances around bogs, marshes and ponds to a maximum of 200 m, and then create a recreation score raster by reclassifying – 1 (worst) to 10 (best), using the following relationship.



4 Calculate a streams proximity raster by measuring distances around streams to a maximum of 200 m, and then create a recreation score raster by reclassifying – 1 (worst) to 10 (best), using the above relationship.

5 Calculate a final recreation score raster by adding the four individual score rasters.

6 Compute amount of Woodlot area with a score of at least 20. Chart its distribution by score.

Course deployment

First, course material has been constructed so that you may implement the entire set of lessons as a course, use just selected lessons, or even pick single lab exercises. Each lesson, and each lab within a lesson, is independent.

Each lesson package, in addition to its scripted lab exercises, contains a lesson background. There, you'll find details on geoprocessing concepts and associated techniques specific to the lesson. It's this material that you'd typically deliver in the classroom using slides and computer demos. Use the material in preparing your students for a lesson's lab exercises.

In addition, each lesson package provides a list of learning points as well as suggested student deliverables for each of its lab exercises. These are critical to effective student learning. Simply running students through a scripted lab exercise, with no follow-up, accomplishes little, if anything.

Ultimately, as with any instruction, you want your students to advance their *knowledge* and *know-how*. What should students learn in working through the lessons and exercises in the Spatial Analysis in Forestry course? Generally, students should gain knowledge about how forestry professionals apply geoprocessing in their work when performing forest analyses and solving problems. More specifically, and more importantly, students should gain knowledge of basic forest analysis procedures and associated geoprocessing techniques that have broad application.

Most of the above, of course, sits at the bottom of Bloom's learning ladder, illustrated in figure 1.

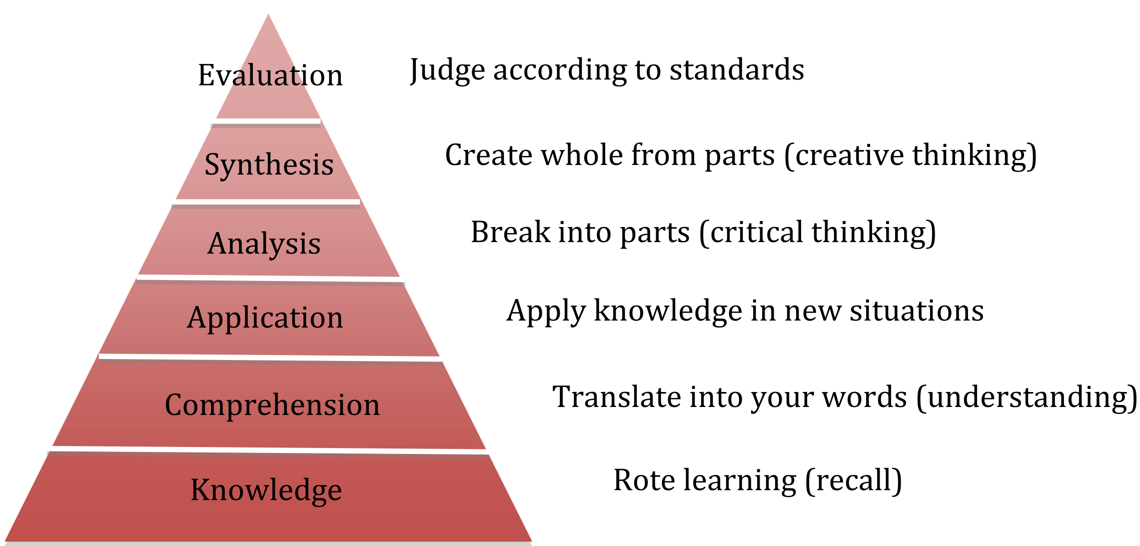


Figure 1. Bloom's Learning Taxonomy

How far up your students climb Bloom's ladder in any given lesson depends very much on you and the lab follow-up you provide.

There are a number of follow-up possibilities that would help your students demonstrate not only knowledge but also know-how—especially *comprehension*, *application*, *analysis*, and *synthesis* skills. Some suggestions follow.

Lab assignments

Each lesson package provides a list of suggested student deliverables for each lab exercise. These provide students with an opportunity to solidify and demonstrate their *knowledge* and *comprehension*.

Beyond those, you may also want to consider the following:

Having students critique the analysis introduced in an exercise is a good way to develop *critical-thinking* skills. Does the analysis overlook some important variables? Is it flawed in some other way? Does it, for example, use the best geoprocessing practices and techniques?

Each lesson package includes ModelBuilder models that implement its exercises. These would allow students to easily redo an exercise and vary key analysis parameters or even modify geoprocessing in some fundamental way.

Lab quizzes

Quizzes are excellent in helping students improve basic *knowledge* and *know-how*. The online variety with short answer, true/false, fill in the blank, and matching type questions that students may take repeatedly with differing questions are particularly good. If your institution has an online course delivery system, learning and using at least its quizzing facility would be worthwhile. Building a question database is made easy with one of a number of PC-based packages. Respondus (www.respondus.com) is a popular one.

Small, short-answer, problem-solving questions are particularly good at improving *application* and *analysis* skills.

Having students make up questions, answer them, and provide feedback to specific lab material is a great way to demonstrate *knowledge* and *comprehension*. If the focus is put on making up small problem-solving questions, *application* and *analysis* skills can be demonstrated too.

Short-answer written questions, where students are required to describe or explain in their own words, are a good way to demonstrate *comprehension*, especially of the conceptual material. Each lesson package provides some possibilities.

Lesson application project

Once your students complete a lesson, have them craft an application (exercise) that addresses questions about some forestry problem or issue different from the lab exercises. This provides students with the opportunity to demonstrate all levels of learning—*knowledge*, *comprehension*, *application*, *analysis*, and *synthesis*.