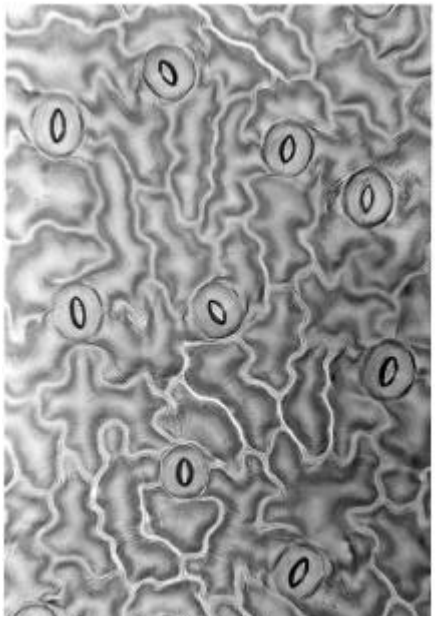
Experiments to Teach Ecology, Volume 2.

Teaching Issues and Experiments in Ecology (ESA - TIEE Web).

Environmental Correlates with Leaf Stomata Density

Instructor's Supplement



stomata impressions from a leaf underside made using clear nail polish viewed at 400x (photo by Marc Brodkin)

Contributed by:

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Contents:

Keyword Descriptors

Principal Ecological Question Addressed:

Effects of biophysical environmental conditions on the adaptive design of plant leaves.

Ecological Topic Keywords:

plant physiological ecology, biophysical ecology, environmental adaptation, stomata, photosynthesis, autecology.

Science Methodological Skills Developed:

field work, hypothesis generation and testing, microscopy, statistics, t-test, graphics, data analysis, scientific writing, oral research presentations.

Pedagogical Methods Used:

student-directed inquiry, cooperative learning, bounded inquiry.

Class Time Required: three 3 hour lab periods.

Outside-of-Class Time Required: 4-12 hours during which students collaborate to generate their written reports and prepare for their oral presentations.

Lab Setting: Outdoors on campus for data collection, back in lab for data analysis.

Season: Any (we do this lab in mid-winter).

Student Products for Assessment: Students are assessed based on their oral and written presentations, on their written proposal, on their data collection and management skills, and on their participation in discussions in the results symposium.

Course Title: Introduction to Organismal Biology (BIO 162).

Class Size: 12-16 per lab section.

Class Level: Undergraduate freshmen.

Institutional Description: Regional private primarily undergraduate comprehensive university.

Comment on Activity Transferability: This activity is HIGHLY TRANSFERABLE. It could be modified to run in any undergraduate introductory biology lab course (major or non-major) at any college or university. It also could run in introductory lab courses in botany, ecology, environmental science, or upper division courses in a variety of sub-disciplines. It could also be modified to run in biology lab courses in grades 8-12.

Comments by Contributing Authors

Comments On the Lab Description.

Comments On Introducing the Lab to Your Students.

We introduce this lab using a "call and response" activity in which we ask the students to list and explain factors that affect the temperature of a leaf. Two categories quickly emerge – characteristics of the environment (sunlight, air temperature, humidity) and characteristics of the leaf (size, shape, color, orientation, evaporative water loss rate). We specifically guide the discussion to an explanation of leaf stomata - what stomata are, and we review their roles in gas exchange with their environment (CO_2 and O_2 exchange, and H_20 loss). Stop and poll your students to recall from where the water comes that exits via the stomata (i.e., uptake at the roots). We then talk about principles of leaf design, and we project images of photos of different types of leaves (desert shrubs, tropical understory plants, etc.) to reinforce a few basic morphological themes in biophysical adaptation. Students are now thinking about leaf design and are ready to think about hypotheses that they can test with the plants on our campus.

Comments On the Activities in the Lab.

Try to move the students toward a novel project, but advise against taking on too ambitious a variation since the rate limiting step is always the drudgery of making the slides and counting stomata. The key consideration is to not let anyone out the door to collect their plants who does not have a very clear idea of what they are doing. We have had much success sending students out to look around and talk with each other with the explicit understanding that they will return to class for a second consult session BEFORE collecting plants.

DO NOT SUGGEST A PROJECT FOR THEM TO DO.

Remind everybody which way is north – it never ceases to amaze us how disconnected many students are from basic compass directions; however, in our students' defense, we are all in an urban environment where there is little need to know this kind of thing.

Another consideration is about the plants on campus. Some students may not know that it is less than a good idea to cut daffodil leaves from beneath the window of the President's office for their sample. Again, this reinforces the importance of the consult session with the instructor PRIOR to collecting plant samples.

Advise the students to collect a few extra leaves for trials to see if the nail polish works – in our experience, some of the brands of nail polish chemically react with some of the epicuticular waxes of leaves (especially so for holly leaves). If so, the nail polish will not harden. We suggest having several brands of clear nail polish on hand, one of which will undoubtedly harden to make the impressions.

Open the classroom windows, because nail polishes often contain some nasty smelling volatiles that should be ventilated. Circulate your Departmental policy on

exposure to potentially toxic chemicals (this is especially important for students who have allergic sensitivities or who may be pregnant). If you do not have a written policy on this – get one!

Instructors should review basic microscope techniques. Assume very little retention about the details of handling, focussing, etc., with the scopes from previous courses.

Advise the students to select the magnification of choice based upon how many stomata they see. Flip to a higher or lower power so as to see about 30-60 stomata per field of view. More than 60 is too many to count, and fewer than 30 introduces too much variation.

Remind the students to apply the nail polish to the leaf undersides where stomata are generally the most dense. Ask you students why this might be so? However, if any of your students happen to select a species of grass, advise them to first find out which side has the most stomata, since some grasses show the reverse pattern (typically when the grass blade during development flips over and actually grows upside down…). This may also prove problematic with conifers and monocots. The rule is to check first.

Remind the students to avoid leaf veins when selecting areas to count stomata.

Instructors will have to demonstrate the use of a stage micrometer to estimate the size in mm^2 of the field of view at various magnifications. Alternatively, the conversions could be worked out beforehand and averages determined for the microscope brands in your lab.

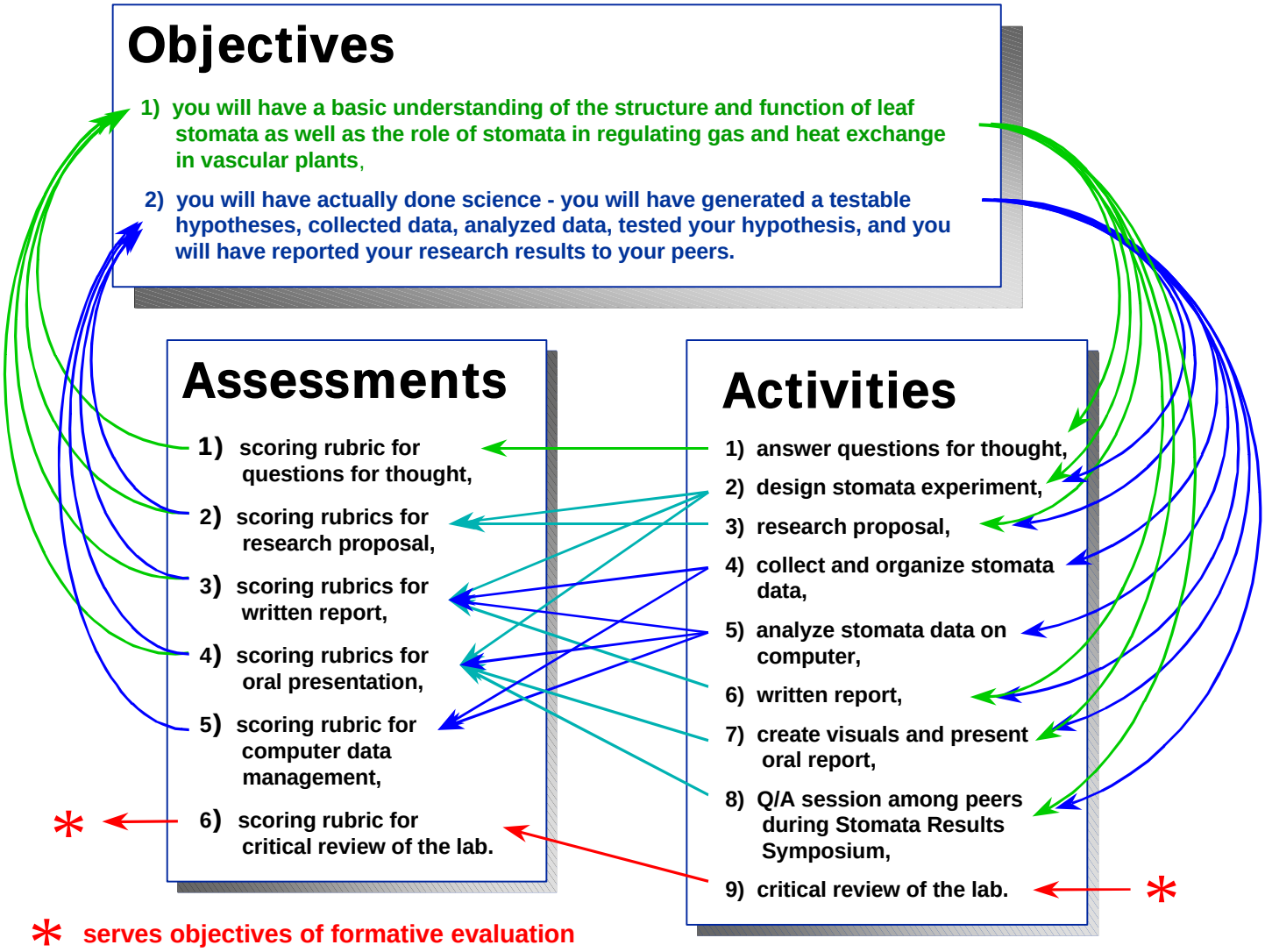
A great deal of very interesting and important statistical content has been omitted from the handout in Appendix 1. For example, there is no discussion of assumptions of normality, non-parametric tests, type 1 vs. type 2 errors, degrees of freedom, or anything about how the t-test critical values are calculated. Put this and other content back for some or all of your students at your discretion.

During the students' Stomata Symposium it is absolutely critical that the instructors abstain from dominance – in fact, we play only observer/ discussion moderator/ and time-keeper roles. Let the students who are presenting pick who ask questions, and let them provide their answers, too. And, let the students ask the questions. If you must, ask your ONE question last. Reward your students for asking good questions and make them aware that a reward is available beforehand (see our comments on assessment below). Jump in to encourage the more silent students to engage in the discussion – especially women and minority students. Step in quickly if a pair of presenters too quickly dismisses a valid question. And, react even more quickly to gender-bias or other effects on this type of dismissal. The basic mandate to the instructor is to create a safe classroom and facilitate the interaction among students to become a community of learners, which is what scientists are supposed to do.

Comments by Contributing Authors

Comments On the Assessment of Student Learning Outcomes.

Below is a graphic to illustrate the relationships among the laboratory objectives, activities, and assessment instruments:



Below we explain how we have designed these assessment instruments for our classes. However, instructors should modify, omit, and/or add their own assessment instruments to meet the needs of your students. Keep in mind that:

- there must be a clear and unbroken network of links that map the objectives to the activities, to the assessment instruments, and then back to the objectives, and
- this map as well as all details of how assessment proceeds must be completely revealed to the students beforehand – students will attempt to perform only and exactly those tasks upon which they will be assessed.

Comments on Questions for Thought.

We ask our students to submit written answers to any 4 of the questions. Students should use their texts or any other written references to answer these questions – but they must cite the complete and exact source of any text, web, or other outside material that they used. We strongly recommend that you read out loud to your students your course policy on plagiarism (which should be in your syllabus), and if you do not have one GET ONE!

Each citation of a research article or book should have: Author(s). Year. Title of paper. Journal. Volume: Pages. Each citation of an internet resource page should have: Author(s) if known. Specific Title of the Page. General Title of "Home" page/ Organization Name for the Site. Full "http" address. Date of Your Download.

Answers should be word processed, single spaced, 12 point, 1" margins, minimum ½ page in length, and in some cases including a well-documented Table or Figure. Our scoring rubric follows:

Answers to Questions for Thought.	points
In an ½ page appropriately formatted essay, the author provided a clear, concise, and insightful answer that is substantiated by details of both content and context. If appropriate, additional Tables and/or Figures are clearly presented and well-documented. Appropriate source materials are creatively woven into the narrative using succinct summaries, graphics, and/or short quotes, and all sources are accurately cited. However, the vast majority of the answer is the author's own writing. The prose flows effortlessly and indicates a high level of organization and effort by the author.	5
Similar to above, except that the length and/or format are insufficient, there is a lack of focus and/or over-reliance on source materials with little synthesis, the answer includes poorly conceived graphics, or some sources are inadequately documented. In addition, paragraph structure may be weak and/or containing poorly worded sentences, misspellings, grammatical errors, and/or other evidence of cursory proofreading.	4-3
The answer lacks structure and coherency, lacks credible source materials and/or uses non-credible sources. In addition, paragraph structure is weak and replete with poorly worded sentences, misspellings, grammatical errors, and little evidence of proofreading.	2-1
The authors did not satisfy any of the requirements of the assignment.	0
Plagiarism, which if flagrant will result in failure in the course (see policy in the course syllabus).	X

Since all of our students should be using their own or Widener's computer resources, all have access to word processors with spell checkers. We place a great deal of emphasis on writing in our course (which is a catalog designated "Writing Intensive" course). However, for those students who need a great deal of help with English (such as foreign students), after we return their graded questions and if they score below 3, we allow them to visit Widener's Writing Center and submit a revised version of their responses for a regrade (with a maximum grade of 4 available).

Comments on Scoring Rubric for Research Proposal.

As described in the "Guidelines for Your Stomata Density Research Proposal" in the Description of the Lab Activity, there are three parts to this assignment: Introduction, Methods, and Possible Results. In addition, students must generate an hypothetical graph of what their results would look like that would show an answer to their hypothesis about stomata variation.

Our scoring rubrics for each part follow:

Research Proposal: Introduction.	points
In two clear, well-written sentences, the authors stated the environmental difference of interest and clearly described how and why stomata density should vary among environmental types.	5
Similar to above, the authors stated the environmental difference of interest and described how and why stomata density should vary among environmental types; however, their sentences are not clear, contain typos, or their ideas are poorly organized.	4-3
The authors omitted or poorly described either the environmental difference of interest or how and why stomata density should vary among environmental types.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Research Proposal: Methods.	points
In one clear, well-written paragraph, the authors explained exactly where their plants are located (including a map), where on their plants their leaves are located, and other pertinent details needed to replicate the collection of their samples exactly. In addition, only methods unique to their study are given.	5
Similar to above, however, the authors' sentences are not clear, contain typos, or the ideas are poorly organized – or, if the map or description of field sampling are unclear or ambiguous.	4-3
The authors omitted major details of their sampling.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Research Proposal: Possible Results.	points
In one clear, well-written paragraph that refers closely to one clearly labeled figure of hypothetical results, the authors explained and visually demonstrated what their results would look like if their hypothesis were true vs. false. The explanations are clear and precise (whether or not they used the suggestions in the "Guide").	10
Similar to above, however, a few of the authors' sentences are not clear, contain typos, or the ideas are not well organized – or, if the figure has only minor problems in visual clarity or documentation.	9-8
Many of the authors' sentences are not clear, contain typos, and/or the ideas are not well organized – or, if the figure has substantial problems in visual clarity or documentation.	7-5
The text is incomprehensible and/or the figure is uninterpretable.	4-1
The authors did not satisfy any of the requirements of the assignment.	0

Comments on Scoring Rubric for Written Report.

As described in the "Detailed Guidelines for Your Stomata Lab Written Reports" in Appendix 2, there are seven sections for your reports: Abstract, Introduction, Methods, Results, Discussion, Literature Cited (if any), and an Appendix.

Our scoring rubrics for each section closely follow the "Guidelines…" in Appendix 2:

Written Report: Abstract.	points
In a 200-250 word paragraph, the authors concisely summarized the main sections of their report. Relevant details are given, including the hypothesis(es) and critical methods unique to their study, summaries of numerical results, and a cogent synopsis of their discussion. The prose flows effortlessly and indicates a high level of organization and effort by the authors.	5
Similar to above, however, the authors omitted or insufficiently described important information from one of their sections, and/or a few of their sentences are not clear, contain typos, or are not well organized.	4-3
The authors omitted or poorly described important information from more than one section and/or many sentences are not clear, contain typos, or are poorly organized.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Introduction.	points
In 1-2 pages, the introductory comments motivate interest in the research topic in the mind of the reader and lead her or him without digression through the process of constructing the specific research question of the study. The authors stated the environmental difference of interest and clearly and thoroughly described their hypothesis(es) for how and why stomata density should vary among environmental types. The prose flows effortlessly and indicates a high level of organization and effort by the authors.	5
Similar to above, however, the opening prose is uninteresting or laborious, or the environmental difference and hypothesis(es) are stated but the explanation for why stomata density should vary is poorly conceived or unclear, and/or a few of their sentences are not clear, contain typos, or are poorly organized.	4-3
The authors did not clearly state the environmental difference and/or their hypothesis(es) for stomata variation, and/or many sentences are not clear, contain typos, or are poorly organized.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Materials and Methods.	points
In 1-2 pages, this section includes a clear description and a well-documented map (labeled Figure 1) that explain and show exactly where their plants are located, where on their plants their leaves are located, and other pertinent details needed to replicate the collection of their samples exactly. In addition, salient methods from the lab handout are also cogently summarized (but in much less detail than the handout), and any methods unique to their study are explained in sufficient detail to enable all steps to be replicated exactly. Statistical tests to be performed are stated last. The prose flows effortlessly and indicates a high level of organization and effort by the authors.	5
Similar to above, however, some ambiguity remains about exactly where and how their samples were collected and/or their map is unclear, and/or there are minor omissions or ambiguities in explaining any methods unique to their study, and/or if the statistical tests to be performed are not mentioned, and/or a few of their sentences are not clear, contain typos, or are poorly organized.	4-3
The authors did not clearly state where and how their samples were taken and how their stomata were counted, and/or many sentences are not clear, contain typos, or are poorly organized.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Results - Text.	points
In one page, this section presents the numerical results of summary statistics and statistical tests of the hypothesized differences in stomata density. All Tables and Figures are presented in their numbered order (see Appendix 2), and clear and concise sentences point out the key conclusions to be drawn specifically from each one. Statistical tests are specifically cited to reinforce proximate conclusions drawn from descriptive statistics in either Tables or Figures. However, the authors abstained from discussing their results in terms of their hypothesis, which is the subject of the Discussion section next. The prose flows effortlessly and indicates a high level of organization and effort by the authors.	10
Similar to above, however, explanations of some Tables and/or Figures are unclear or inadequate, and/or there are minor omissions or misconceptions in explaining any of their numerical results or statistical analyses, and/or a few of their sentences are not clear, contain typos, or are poorly organized.	9-7
Similar to above, however, explanations of some Tables and/or Figures are inadequate, and/or there are major omissions or misconceptions in explaining numerical results or statistical analyses, and/or many sentences are unclear, contain typos, or are poorly organized.	6-4
The authors omitted or otherwise failed to explain major portions of their results which may include Tables, Figures, or statistical analyses, and/or many sentences are unclear, contain typos, or are poorly organized.	3-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Results – Tables and Figures.	Points
A coherent, well-documented, and visually appealing series of Tables and Figures is presented that enables a reader to quickly perceive the numerical results of summary statistics and statistical tests of the hypothesized differences in stomata density. These graphics complement each other, show a minimum of redundancy, enable a reader to flow effortlessly through the results, and indicate a high level of organization and effort by the authors. All Tables and Figures are presented in their numbered order, and clear, concise, and well-written "legends" appear for each Table and Figure that enable each to stand alone (see Appendix 2 for details).	5
Similar to above, however, some Tables and/or Figures are inadequately documented, poorly conceived, unnecessarily redundant, possibly misleading, or visually confusing. Or, some legends exhibit minor omissions or misconceptions, and/or a few of their sentences are not clear, contain typos, or are poorly organized.	4-3
The authors omitted or otherwise failed to include major portions of their results in their Tables and Figures, and/or many graphics are misleading, and/or many sentences are not clear, contain typos, or are poorly organized.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Discussion.	points
In 1-2 pages, this section interprets the data presented in the Results section in light of the hypotheses presented in the Introduction. Sentences convey insightful and thought-provoking points that are substantiated by details of both content and context (i.e., by referring to the data presented in the Tables and Figures). All interpretations flow logically from the data and analyses presented. Alternative interpretations are insightfully discussed. Implications or extensions of the results of the investigation logically lead from the material presented and elicit clear and interesting directions for future research. The prose flows effortlessly and indicates a high level of organization and effort by the authors.	5
Similar to above, however, some interpretations are choppy, illogical, and/or disconnected, and/or the hypothesis(es) is(are) insufficiently addressed using the evidence from the data collected. In addition, new observations/ interpretations may be presented that should have been made in the Results section. Some explanations of some Tables and/or Figures are unclear or inadequate, and/or there are minor omissions or misconceptions in explaining their numerical results or statistical analyses. Future directions may be unclear and/or uninteresting. Lastly, some sentences are not clear, contain typos, grammatical errors, or are poorly organized.	4-3
The authors omitted or otherwise failed to explain major portions of their results which may include Tables, Figures, or statistical analyses, and/or many sentences are not clear, contain typos, grammatical errors, or are poorly organized.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Literature Cited and Appendix.	points
If previously published material is cited somewhere in the paper, then the format for citations is followed exactly (see Appendix 2: Detailed Guidelines for Stomata Lab Written Reports). The required data Appendix contains a copy of the set of original handwritten stomata data sheets that is well documented (including clear labels for measurement units), and all words and numerical entries are unambiguously legible. In addition, clearly labeled original printouts of all statistical analyses are included as well.	5
Similar to above, however, if there is a Literature Cited section then some of the previously published material is inadequately cited. Or, the required data Appendix contains data that are weakly documented, with some illegible words, symbols, or numbers, and/or the printouts of statistical analyses are incomplete or weakly documented.	4-3
The Literature Cited section and/or data Appendix are incomplete and/or incomprehensible.	2-1
The authors did not satisfy any of the requirements of the assignment.	0

Written Report: Summary Table of Point Totals.

Abstract	5 points
Introduction	5 points
Materials and Methods	5 points
Results (text + graphics)	15 points
Discussion	5 points
Literature Cited & Appendix	5 points
Total	**40 points**

In our experience, for the students' first drafts it is more consistent on our part to read and apply the scoring rubrics for all of the students' Introductions, all Methods, all Results, all Discussions, and then all Abstracts, rather than read each report all the way through and have to re-think out each rubric. Typically, we have about 12-16 students in each lab section, and two lab sections, which translates to 12-16 papers.

After we return the first drafts of our students' written reports, our students have two weeks to revise and re-submit (and many are sent to Widener's Writing Center for consultation sessions). The scoring rubrics above apply equally to their first drafts and revisions, and students base their revisions on their section scores and our miscellaneous written comments directly on their manuscripts. We also ask them to turn back in their original submission at the same time as their revision, which although it introduces some bias in our grading of their revision, such bias is offset by our ability to compare their old and new versions and thereby quickly perceive their effort and allocation in their revision. In addition, we feel it is not entirely fair to them to "mark them down" for major new problems we discover in their revision that we should have caught in their first draft (however, this policy does not apply to spelling or grammatical errors that should have been caught by better proofreading on their part to begin with).

Comments on Scoring Rubric for Oral Presentation.

As described in the "Description of the Lab Activity: Guidelines for Oral Presentations", there are four sections for your reports: Introduction, Methods, Results and Specific Discussion, and General Discussion.

Our scoring rubrics for each section closely follow these "Guidelines…":

Oral Presentation: Introduction.	points
Using about 3 minutes, the introductory comments and visual materials motivated interest in the research topic in the mind of the reader and led her or him without digression through the process of constructing the specific research question of the study. The authors stated the environmental difference of interest and clearly and thoroughly described their hypothesis(es) for how and why stomata density should vary among environmental types. The talk flowed effortlessly, was delivered skillfully and comfortably, and indicated a high level of organization, rehearsal, and effort by the authors. Lastly, if PowerPoint was used, their visuals contained appealing color combinations with NO animations or sound effects.	10
Similar to above, however, the length was way above or below 3 minutes, the opening words and visual materials were uninteresting, unfocussed, or confusing, and/or a few of their comments or visuals were not clear, irrelevant, many comments were simply read from notes, and/or the ideas were not well organized. Lastly, if PowerPoint was used, their visuals contained ineffective color combinations and/or distracting animations or sound effects.	9-7
Similar to above, however, the length was way above or below 3 minutes, or the environmental difference and hypothesis(es) were stated but the explanation for why stomata density should vary was poorly conceived or unclear, and/or numerous comments or visuals were not clear, irrelevant, notes were read in monotone, or the ideas were poorly organized. Lastly, if PowerPoint was used, their visuals contained annoying colors, animations, or sound effects.	6-4
The authors did not clearly state the environmental difference and/or their hypothesis(es) for stomata variation, and/or many comments and visuals were unclear, , and poorly organized.	3-1
The authors did not satisfy any of the requirements of the assignment.	0

Oral Presentation: Materials and Methods.	points
Using about 3 minutes, the authors offered a clear description and visual materials (including a well-documented map) that explained and showed exactly where their plants are located, where on their plants their leaves are located, and other pertinent details needed to replicate the collection of their samples exactly. In addition, salient methods from the lab handout were also cogently summarized (but in much less detail than their written report), and any methods unique to their study were explained in sufficient detail to enable all steps to be replicated exactly. Statistical tests to be performed were stated last. The talk flowed effortlessly, was delivered skillfully and comfortably, and indicated a high level of organization, rehearsal, and effort by the authors. Lastly, if PowerPoint was used, their visuals contained appealing color combinations with NO animations or sound effects.	10
Similar to above, however, the length was way above or below 3 minutes, some ambiguity remains about exactly where and how their samples were collected and/or their map is unclear, and/or the statistical tests to be performed are not mentioned. In addition, a few of their comments or visuals were not clear, many were simply read from notes, and/or their ideas were not well organized. Lastly, if PowerPoint was used their visuals contained ineffective color combinations and/or distracting animations or sound effects.	9-7
Similar to above, however, the length was way above or below 3 minutes, and/or there were substantive omissions or ambiguities in explaining critical methods unique to their study. In addition, numerous comments or visuals were not clear, were read in monotone, and/or their ideas were poorly organized. Lastly, if PowerPoint was used their visuals contained annoying colors, animations, or sound effects.	6-4
The authors did not clearly state where and how their samples were taken and how their stomata were counted, and/or many comments and visuals were unclear, irrelevant, and poorly organized.	3-1
The authors did not satisfy any of the requirements of the assignment.	0

Oral Presentation: Specific Discussion of Results.	points
Using about 3 minutes, the authors offered a clear description and a coherent, well-documented, and visually appealing series of Tables and Figures that enabled the audience to follow effortlessly through the numerical results of their study. All Tables and Figures enabled the audience to quickly perceive the findings, and clear and concise comments pointed out the key conclusions to be drawn specifically from each graphic. Statistical tests were specifically cited to reinforce proximate conclusions drawn from descriptive statistics that appeared in their Tables and Figures. In addition, the authors briefly discussed each result in terms of the hypothesis under investigation. The talk flowed effortlessly, was delivered skillfully and comfortably, and indicated a high level of organization, rehearsal, and effort by the authors. Lastly, if PowerPoint was used, their visuals contained appealing color combinations with NO animations or sound effects.	10
Similar to above, however, the length was way above or below 3 minutes, explanations of some Tables and/or Figures were unclear, inadequate, redundant, and/or there were minor omissions or misconceptions in explaining any of their numerical results or statistical analyses. Results were insufficiently related to the hypothesis under investigation. In addition, a few of their comments or visuals were confusing, possibly misleading, were simply read from notes, and/or their ideas were not well organized. Lastly, if PowerPoint was used their visuals contained ineffective color combinations and/or distracting animations or sound effects.	9-7
Similar to above, however, explanations of some Tables and/or Figures were inadequate, and/or there were major omissions or misconceptions in explaining numerical results or statistical analyses, in grounding the results in the hypothesis under investigation, and/or many comments and visuals were very confusing, misleading, or were read in monotone, and/or their ideas were poorly organized. Lastly, if PowerPoint was used, their visuals contained annoying colors, animations, or sound effects.	6-4
The authors omitted or otherwise failed to explain major portions of their results which may include Tables, Figures, or statistical analyses, and many comments were unclear, irrelevant, and poorly organized.	3-1
The authors did not satisfy any of the requirements of the assignment.	0

Oral Presentation: General Discussion and Future Directions.	points
Using about 3 minutes, the authors offered insightful and thought-provoking points that were substantiated by details of both content and context (i.e., by mentioning or listing data presented in the Tables and Figures). All interpretations flowed logically from the data and analyses presented. Alternative interpretations were insightfully discussed. Implications or extensions of the results of the investigation logically led from the material presented and elicited clear and interesting directions for future research. The talk flowed effortlessly, was delivered skillfully and comfortably, and indicated a high level of organization, rehearsal, and effort by the authors. Lastly, if PowerPoint was used, their visuals contained appealing color combinations with NO animations or sound effects.	10
Similar to above, however, some interpretations were choppy and/or disconnected. In addition, new observations/ interpretations were presented that should have been made earlier. Some explanations of some Tables and/or Figures were unclear or inadequate, and/or there were minor omissions or misconceptions in summarizing numerical results or statistical analyses. In addition, a few of their comments or visuals were confusing, irrelevant, notes were simply read, and/or the ideas were not well organized. Lastly, if PowerPoint was used their visuals contained ineffective color combinations and/or distracting animations or sound effects.	9-7
Similar to above, however, some interpretations were illogical, and/or the hypothesis was insufficiently addressed using the evidence from the data collected. Numerous explanations of Tables and/or Figures were unclear or inadequate, and/or there are major omissions or misconceptions in explaining their numerical results or statistical analyses. Future directions were unclear and/or uninteresting. In addition, numerous comments or visuals were confusing, irrelevant, misleading, were read in monotone, and/or the ideas were poorly organized. Lastly, if PowerPoint was used their visuals contained annoying colors, animations, or sound effects	6-4
The authors omitted or otherwise failed to explain major portions of their results which may include Tables, Figures, or statistical analyses, and many comments were unclear, irrelevant, and poorly organized.	3-1
The authors did not satisfy any of the requirements of the assignment.	0

Oral Presentation: Summary Table of Point Totals.

Introduction	10 points
Materials and Methods	10 points
Results and Specific Discussion	10 points
General Discussion	10 points
Total	**40 points**

Comments on Assessing Students' Participation in the Research Symposium.

During the Stomata Research Symposium, students should be rewarded for participation. This can be problematic if your expectations are not made crystal clear to then beforehand. We offer 10 points max for this facet of the activity, which represents 5% of the total grade. Feel free to modify this to meet your needs.

Participation in the Research Symposium (* individual grade ***).**	points
The student asked numerous questions that were insightful, novel, thought provoking, constructive, supportive, elicited important information, and contributed substantively toward building a community of learners. Also, the student was respectful and attentive at all times.	10
The student asked at least one question that was insightful, novel, and thought provoking, and at least several others that were constructive, supportive, and elicited important information. Also, the student was respectful and attentive at all times.	9-8
The student asked at least one question that was constructive, supportive, and elicited important information. Also, the student was respectful and attentive at all times.	7-6
The student was respectful and attentive at all times.	5
Questions were asked, but were of a trivial nature and/or with obvious or uninteresting answers. Also, the student may not have been entirely respectful and attentive at all times (talking, reading his/her own notes, etc.).	4-1
The student did not satisfy any aspect of participation.	0

Comments on Assessing Computer Data File Management.

As described in the "Description of the Lab Activity: Guidelines for Stomata Data and File Management on Disk", there are three computer files that constitute this part of the assignment: the manuscript, the presentation/graphics, and the spreadsheet data files. Our scoring rubric follows these "Guidelines" closely:

Computer Data File Management.	points
All three required computer files exactly follow the list of Guidelines for Stomata Data and File Management on Disk.	20
Similar to above, however, a minor oversight or two occurs in one of the files.	19-18
Numerous minor oversights occur in multiple files.	17-15
A major oversight, such as missing or uninterpretable data or analyses, occurs in one of the three files, with minor oversights in the others.	14-10
Multiple major oversights occur one or more files.	9-1
The authors did not satisfy any of the requirements of the assignment, or their disk and its backup were lost.	0

Comments on Assessing the Students' Critical Reviews of the Lab.

As described in the "Guidelines for Student Reviews of the Lab Activities", each student submits an individual review. Our scoring rubric follows these "Guidelines…" closely:

Critical Reviews of the Lab.	points
In an ½ page clear and concise essay, the author conveys reflective and constructive criticism of the lab activity with insightful and thought-provoking points that are substantiated by details of both content and context (i.e., by referring to). The prose flows effortlessly and indicates a high level of organization and effort by the authors.	10
Similar to above, too few and/or too narrow a set of comments are offered, there may be redundancy, and/or some comments are trivial or unconstructive. In addition, some sentences are not clear, contain typos, grammatical errors, or are not well organized.	9-5
Similar to above, however, most comments are trivial, belabored, and unconstructive, or at the opposite extreme overflowing with ingratiating deference. In addition, many sentences are not unclear, contain typos, grammatical errors, or are poorly organized.	4-1
The author did not satisfy any of the requirements of the assignment.	0

Summary Table of Point Totals.

Research proposal	20 points	group
Oral presentation	40 points	"
Written report (1st version)	40 points	"
Written report (revision)	40 points	"
Data management	20 points	"
Questions for thought	20 points	Individual
Symposium participation	10 points	"
Review of Lab	10 points	"
Total	**200 points**	

…which is 20% of the total course grade.

Tools for formative evaluation of this lab activity.

{this section is presently under construction}

Comment on Translating the Activity to Other Institutional Scales.

This activity is HIGHLY TRANSFERABLE. It could be modified to run in any undergraduate introductory biology lab course (major or non-major) at any college or university. It also could run in introductory lab courses in botany, ecology, environmental science, or upper division courses in a variety of sub-disciplines. It could also be modified to run in biology lab courses in grades 8-12.

Comments by Faculty and Student Users

{Comments on challenges to anticipate, troubleshooting tips, assessment and evaluation experiences, and case studies translating this activity to other scales.

- this section is presently under construction}

Credits and Acknowledgements

This laboratory exercise was inspired by an article by Brian Drayton and Prassede Calabi "Long-term plant responses to environmental change: leaf stomata densities" that appeared in Hands On! Spring 1992. Vol. 15, Number 1, published by TERC (Cambridge, Mass), and by the laboratory activity "Responses by stomata on leaves to microenvironmental conditions" by Carol A. Brewer (1992) pages 67-75, in Tested studies for laboratory teaching. Volume 13. (C. A. Goldman, Editor). Proceedings of the 13th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 191 pages. (available at: http://www.zoo.toronto.edu/able/volumes/vol-13/3-brewer/3-brewer.htm).

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Comments on Copyrights and Disclaimers

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Archive of Student Generated Data

Data Set 1 - Widener University (Bruce Grant and Itzick Vatnick)

Below is a data set for stomata for leaves taken from the interior vs. the outside (south side) of the foliage of a large holly tree on Widener's campus from the spring of 1999. The stomata were counted at 400x, and the students estimated the area of their field of view to be 0.152 mm^2.

inside leaves

slide	stomata/ field	stomata/ mm^2
inside 1	41	270
inside 2	55	362
inside 3	40	263
inside 4	40	263
inside 5	42	276
inside 6	40	263
inside 7	38	250
inside 8	40	263

average = 276.4
stan. dev. = 35.3

outside leaves

slide	stomata/ field	stomata/ mm2
outside 1	43	283
outside 2	42	276
outside 3	47	309
outside 4	72	474
outside 5	59	388
outside 6	52	342
outside 7	53	349
outside 8	53	349

average = 346.3
stan. dev. = 63.6

t-test for unequal variances:

t = 2.718 (d.f. = 14), for which
t Critical one-tail = 1.7613, and
P(T<=t) one-tail = 0.0083

The test shows that there is less than 1 in a 100 chance of obtaining this large a t-value at random.

Therefore, the stomata density in the sun is **significantly higher** than in the shade.