

Supplemental Material

CBE—Life Sciences Education

Hill *et al.*

Appendix A. The rubric provided to all TAs. Grey-shaded lines refer to items in which TAs might attend to students' scientific thinking.

Section	Criteria	Information	pts
Title	dependent variable	hornworm growth	2
	independent variable	dietary components (can be more specific with regard to the component the group used)	2
	organism/sci name	tobacco hornworm (<i>Manduca sexta</i>)	2
	concise and clear		2
Introduction	broad background	what is the big picture context for this study?	5
	study system	general information about <i>Manduca</i> and secondary chemicals	5
	hypothesis and predictions		3
	citations	include several, relevant citations	2
Methods	study system	<i>Manduca sexta</i> - stage of development at which they're used. Rationale for why chosen for the study	3
	test compound	what was it and its final concentration in diet	3
	prep of diet	how was it prepared, solidified, cut up, and distributed	3
	growth determination	measuring of weight and intervals at which weight is determined	3
	data analysis	# of replicates, determination of RGR or % weight gain, stat. tests used	4
	past tense	should be written in past tense	2
	concise and clear	not too detailed	2
Written results	General statement of trends	describe major trends in relation to treatments	3
	refers to figure	parenthetical	2
	stats	stat. values (p, df, t) in Pechenik form included to support statements	3
	data	averages, st. devs, percents - some numerical data included	2
	no interpretation	this comes later - in the discussion	2
Figures and tables	Figure 1 - RGR	The figure should show the means +/- the std. dev of the RGR	5
	legend/caption	study system and question asked, sample size, etc.	4
	labels	variables, units, graph clear and easy to read	4
Discussion	one sentence summary		3
	relate results to hypothesis	what was found; was or was not what expected	5
	discuss implications	interprets results in context of results from other lab groups and in context of literature	5
	alternative hypothesis	possible sources of error, etc (should focus on biology not on trivial issues like sample size)	3
	future directions	future direction is interesting new angle, not just repeating experiment with a small change	4
Acknowledgments			1
Literature cited		alphabetical order, indented, correct format. At least 6 sources, at least 3 primary	5
Overall	Clarity/concise		3
	Spelling/grammar/format		3

Appendix B. Excerpts from Micky’s lab report, Abby’s margin comments and interview comments. [Line numbers] refer to location of comment in the interview transcript and follow a chronological order.

Excerpt of marked report	Margin comments	Interview comments
<p>1. Nitrogen is one of the most important elements for life because it is a derivative of amino acids, which build together to make proteins. Plants absorb nitrogen from the soil and thus contain a large amount of the element (Wagner, 2012). Insects consumer plants to source this essential element for their own needs.</p>	<p>Not a large amount... much less than animals</p>	<p>Plants contain less nitrogen than animals [line 613-616] “She makes a factual mistake” “Plants actually contain considerably less nitrogen than animals do” Experiment has nothing to do with nitrogen [line 618-619] “Her whole experiment has nothing to do with nitrogen” Student is confused about nitrogen [line 622-623] “nitrogen is not the independent variable. But we had talked about nitrogen in the pre-lab, which is maybe people decided it was important to their experiment when it wasn’t”</p>
<p>2. This predator-prey relationship has created a pattern of co-evolution between plants and herbivores for millions of years. Plants have evolutionary developed mechanisms to protect themselves from consumption such as secondary chemicals. These special chemicals include phenolics, such as phenolic glycoside (also known as salicin), and alkaloids, such as nicotine (Orians, 2013). Phenolics are the most diverse group of secondary metabolites. Specifically, salicin is present in woody plants and may be toxic to insects. Nicotine, an alkaloid, is a natural insecticide. The inducible aspect of this biochemical decreases the amount of secondary metabolites that a plant must synthesize, thus conserving energy efficiently and <u>also makes evolution of the herbivores more difficult</u> (Mckey, 1974).</p>	<p>I’m not entirely clear what you are saying here</p>	<p>Lack of logic between facts listed in introduction [line 624-631] “there’s no coherency or, um, point... or, there’s not even, like, an internal logic or flow between them” Introduction is a list of facts – some true, some not [line 624, 634] “this introduction is, like, a list of facts which are mostly true, some of them are not true,” “like, I know these facts and I need to write a paper, and it has something to do with this topic, so I’m just going to list a bunch of facts that I know about this topic and that will be an introduction.</p>

<p>3. <i>These defensive tactics have seen offensive metabolism mechanisms on behalf of the insects.</i> Some insects, for example the tobacco hornworm <i>Manduca sexta</i>, have gained resistance to secondary compounds but have also been able to use the plant's defensive compounds for their own benefit (Morris,1983).</p>		<p>Can't work out the meaning of this sentence [sentence in italics, line 636] "I don't know what that sentence means" Points out more facts with a lack of logical structure [line 638] "So, more facts, also not presented in a very coherent logical structure"</p>
<p>4. The tobacco' hornworm <i>Manduca sexta</i> and the tobacco plant are a classic example of a plant-insect co-evolution relationship (Orians,2013). Tobacco plants contain alkaloid nicotine, a chemical toxic to some insects. Homworms have developed a mechanism to digest nicotine, and are even able to use in for their own defensive function, such as preventing spider attacks (Kumar et al. 2014). Recent studies indicate that the physiology in the digestive and nervous system allow the caterpillars to reduce their susceptibility of the nicotine, but the exact mechanism is yet to be identified (Kumar, Pandit, Steppuhn and Baldwin, 2014). It is important to note that the phenolic chemical, salicin, is not part of the tobacco hornworm's natural diet.</p>	<p>I like that you've taken a wide angle view to your experiment, and trying to set up the context. Remember that everything in your intro should be pointing toward your hypothesis.</p>	<p>Students approach to intro [line 644-650] "I sometimes think that my students think that an introduction is like a... grade school report." "so they just write everything about penguins and there's not purpose to it..." "any fact is equally good as any other fact in that assignment" "But they don't realize that the introduction for a lab report is different in that facts that you're giving me should be in service of the hypothesis and of the experiment that you're going to be doing."</p>
<p>5. An experiment was designed and performed in order to demonstrate the use of secondary chemicals, specifically nicotine (inducible) and salicin, and observe the resulting effects on the growth of tobacco hornworm <i>Manduca sexta</i>. Final caterpillar size has shown to be highly correlated with reproductive fitness, thus it has been determined that anything that limits growth also limits fitness (Reynolds,1986). Since nicotine is a source high in nitrogen and many insects have evolved to acquire mechanisms to metabolize alkaloids biochemicals, <i>it could be predicted that not only will the caterpillars be able to consume nicotine, but also they might become significantly bigger due to the high nitrogen content of the metabolite</i> (Wagner, 2012).</p>	<p>bigger than what? than caterpillars fed plain food? Keep in mind that there is no plain food treatment group in your experiment so you're not going to be able to make that comparison. Also, are you saying that you think caterpillars fed the nicotine diet will do better than control caterpillars?</p>	<p>Attempts to follow style by starting broad [line 658] "she did try to start with the broader context and then get to her experiment" Does not use language precisely [line 661-671] "It's not grammatically incorrect, but it's not correct. Like, she's not using language in a precise way" Confusion [line 669] "I just feel confused the whole time that I'm reading the paper when a person writes like this" *Interviewer cue* [line 672] "What do you think she's trying to say?" Attempts to decipher [line 673] "I think she's trying to say that the experiment was designed in order to observe the effect of different secondary chemicals on the caterpillars."</p>

		<p>Figures out why Micky focuses on nitrogen [line 695] “(reading) ‘due to the high nitrogen content...’ Okay, this is why she was talking about nitrogen”</p>
<p>6. Salicin is included in the group of biochemicals with more variety and can be toxic to insects. This variety <u>would cause a barrier to evolution of insects to be able to survive the toxicity</u>. It could be postulated that the salicin would cause the caterpillars to not grow as large as the caterpillars on a nicotine diet. In conclusion, it is predicted that less growth will occur with the newly introduced chemical salicin, when compared with that of the natural diet, nicotine (inducible).</p>		<p>Not sure about meaning of sentence (underlined) [line 699] “I’m really still not really sure what that sentence means” Attempt to make sense of the sentence [lines 701-705] “If I had to guess what she was saying,” Reasonable hypothesis [line 706] “So that is a reasonable hypothesis” Hypothesis [in italics] is unreasonable [line 709] “The part that I found to be not reasonable was when she said it could be predicted that not only will the caterpillars be able to consume nicotine, but they might also become significantly bigger due to the high nitrogen content of the metabolite” Maybe confusing ability to metabolize with preference for given diet [line 718-724] “she’s confusing the ability to be okay with a chemically as actually liking it and choosing nicotine or preferring a nicotine diet over just a control diet.” Consider prediction made [lines 728-732] “She’s predicting... [she’s] not going to be able to make that comparison.”</p>

Appendix C. Excerpts from Nora’s lab report, Ed’s margin comments and interview comments. Line numbers refer to location of comment in the interview transcript and follow a chronological order.

Excerpt of marked report	Margin comments	Interview comments
<p>1. The effects of nutrients inefficiency caused by the existence of cellulose in diet on the growth of herbivores, <i>Manduca sexta</i>.</p>		<p>Idiosyncratic phrasing [line 484-486] “that’s pretty typical of the idiosyncrasy of her writing where I understand what she’s saying. It’s not how I would have phrased it and it’s not a particularly neat phrasing but it gets all the information across”</p>
<p>2. In this lab, we used <i>Manduca sexta</i>, commonly known as tobacco hornworms, used to be the object of the study. The larvae feed on the foliage of tobacco and related plants as the main resource of nutrients intake. <i>Manduca sexta</i> has relatively short life cycle, which can make the lab efficient and convenient. Also, the caterpillars’ size and fitness are highly depended on the diet for <i>Manduca sexta</i>, which can make the results physically easy to observe.</p>		<p>Information about <i>M. sexta</i> in wrong section [line 543-546] “now she actually gets into the <i>Manduca sexta</i>, which she should have done in the introduction but she’s putting the study system that should have been in the introduction in the methods and also putting the section that should be in the methods in the methods” Idiosyncratic phrasing [line 549-550] “well, they’re efficient and convenient for the lab, they don’t make the lab efficient, but I understand that’s just her phrasing” Student’s intended meaning comes through but requires some thinking [line 552-553] “Again, I understand what she’s saying, but it can be a bit of a puzzle”</p>
<p>3. Controlled and experimental diets were prepared from two pre-weighed beakers with different treatments in the hot bath: one contained mainly wheat germ without cellulose was the control diet, and one contained high concentration of cellulose instead of wheat germ. Other nutrients were maintained to be the same. Each treatment was poured into a labeled sterile petri dish separately, smoothed by the spatula, and set aside uncovered for an hour to cool down into solid. Meanwhile, 10 caterpillars of <i>Manduca</i></p>	<p>How much cellulose? Others need to know this to replicate your results. What growth stage were the caterpillars at?</p>	<p>Missing information about cellulose amounts [line 566-569] “she did not say how much cellulose, that one was high and one was not. In one containing wheat germ without cellulose was the control diet. In a high concentration of cellulose instead of wheat germ. Others, I point out, need to know the concentration you used if they’re going to test or replicate your results”</p>

<p><i>sexta</i> were separately weighed and put into 10 plastic cups with labels of their treatment and number. After the diets in petri dishes cooled into solid, diets were cut into few pieces and put into the cups with the caterpillar in it depending on different treatments.</p>		<p>Missing information about growth instar [line 576] “She didn’t mention second instar of growth, so I pointed that out”</p>
<p>4. The results of the lab above indicates that the hypothesis, the growth of herbivores decreases as the amount of cellulose increases in the plant, is accepted. Caterpillars fed by diet with less cellulose had both means of Relative Growth Rate and % weight gain higher than the caterpillars fed by high cellulose diet did, which means that caterpillars with less cellulose intake grew better in terms of fitness and size than caterpillars with more cellulose intake. The performance of t-test of two means after 1 week reduced the possibility that the difference was caused by chance. Since the only difference between the controlled and experimental treatments was the absence or the existence of the cellulose in the diet, it can be said that the existence of cellulose in the diet affects herbivores’ growth and performance significantly. In other words, increasing the concentration of cellulose in plant itself can avoid much damage from the herbivores as one of the efficient plant defenses.</p>	<p>Possible sources of error?</p>	<p>Null hypothesis identified [line 616-617] “Your hypothesis, not the null hypothesis, but you made clear which hypothesis you were talking about, so fine” Size correlates with fitness [line 620-621] “In terms of size which correlates with fitness, but she mentioned that in her methods section when she was talking about why you use <i>Manduca sexta</i>” Misunderstanding of t-test or poor phrasing [623-628] “That, again, is something where I don’t know if she misunderstands the purpose of the t-test or just phrased it poorly. Because performing the t-test doesn’t reduce the possibility your results were caused by chance, it quantifies the possibility that your results were caused by chance. That’s an important distinction, but, you know... I don’t generally make line edits on [this student’s] paper because there would just be so many of them that I don’t think it would be useful” Understanding the meaning of what is written: either phrased poorly or poor understanding [line 629-636] “as long as I can understand what she’s saying, I generally just let it go. I think this would have been a good time to, actually, bring it to her attention, being, like, ‘make sure you know what you’re saying here, because what you’re saying is not correct and it may have not been what</p>

		<p>you meant – you may have meant the thing that is correct or you may not have, but I can't tell. So I should have called attention to that, I think, but I didn't because I'm not in the habit of making line edits on her papers. So I think maybe I'm not making like edits when they could really be useful on her papers.”</p> <p>Thinks caterpillars may eat more to compensate for low nutritional value [line 638-640]</p> <p>“I'm not so sure about that because it's also possible they'll eat more to compensate for the low nutritional value, as I think I mention in her summary”</p>
<p>5. As one of the defense mechanisms of the plant, cellulose is also a necessary structure of the plant: it exists in the plant even there isn't any external invasion. This indicates that like many other secondary chemicals, cellulose is also inducible. Further experiment can focus on different situations that might induce the increase or decrease of cellulose in the plant, and how does the plant “know” that it's under attack by external environment.</p>	<p>Really? Do plants produce more cellulose when attacked?</p> <p>Interesting ideas – give some more detail!</p>	<p>Knows Nora understands difference between secondary compounds and cellulose [642-645]</p> <p>“Good. I'm glad... it was clear before that she knew it wasn't like any other secondary compounds in here. She is, in fact, saying that its primary purpose in here is structural, so I'm glad that she understands that”</p> <p>Misunderstanding of ‘inducible’ [line 648-650]</p> <p>“Because I could tell here, that inducible did not mean what she thinks it meant. Because otherwise, she exactly contradicted her last sentence”</p> <p>Disagrees with idea that plants can regulate cellulose levels [654-659]</p> <p>“maybe she thinks plants can regulate their cellulose content, which I am pretty sure is not true. Um, but, doing this future direction would illustrate the fact that no, they don't dynamically alter their cellulose content, and I don't know for sure that they don't, but I don't think that they do, so I did not make a big deal out of this. And</p>

		I'm sure that somewhere in nature there's a plant that can alter its cellulose concentration of its tissues and, like, does so regularly,"
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