Electronic Supplementary Material (ESI) for Chemistry Education Research and Practice.

Electronic Supplementary Material (ESI) for:

What's in a word? Student beliefs and understanding about green chemistry

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Course Demographics

Table 1. Fall 2018 and Fall 2019 demographic data for research population. Demographic and full class data provided for comparison. The study population for all semesters contained more female respondents than male respondents and the class population indicated that there might be a slight overrepresentation of female respondents. This is a well-known phenomenon as women often have higher response rates then men on surveys.[1,2]

	Study Population[3]						Course Population[4] Fall 2016	
	Fall 2019		Fall 2018		Fall 2016			
	N	%	N	%	N	%	N	%
Race/Ethnicity								
Asian	403	52.1	368	47.8	270	52.1	477	44.7
White	186	24.0	193	25.1	126	24.3	257	24.1
Hispanic, Latino or Spanish Origin	98	12.7	85	11.0	49	9.5	153	14.4
African American/Black	11	1.4	11	1.4	11	2.1	25	2.3
Pacific Islander	6	0.8	14	1.8	2	0.4	1	0.1
Native American/Alaska Native	4	0.5	14	1.8	1	0.2	3	0.3
International	64	8.3	78	10.1	44	8.5	100	9.4
Decline to State	2	0.3	7	0.9	15	2.9	50	4.7
Gender								
Female	512	66.1	507	65.8	323	62.4	628	58.9
Male	251	32.4	244	31.7	182	35.1	403	37.8
Non-binary	3	0.4	6	0.8	N/A	N/A	N/A	N/A
Not sure		0.0	2	0.3	3	0.6	N/A	N/A
Transgender	0	0.0	0	0.0	1	0.2	N/A	N/A
Decline to state	8	1.0	11	1.4	9	1.7	35	3.3
Total	**774**		**770**		**518**		**1066**	

[1] Underwood, D.; Kim, H.; Matier, M. To Mail or To Web: Comparisons of Survey Response Rates and Respondent Characteristics. AIR 2000 Annual Forum Paper; 2000.

[2] Sax, L. J.; Gilmartin, S. K.; Lee, J. J.; Hagedorn, L. S. Using Web Surveys to Reach Community College Students: An Analysis of Response Rates and Response Bias. Community Coll. J. Res. Pract. **2008**, 32 (9), 712–729. https://doi.org/10.1080/10668920802000423.

[3] Students who consented to be part of our research and provided demographic information

[4] Entire course population data were obtained from Berkeley Office of Planning and Analysis

Green Chemistry Understanding Construct

Previous work during the Fall 2016 semester led to the development of a construct map and a set of items to measure student understanding of green chemistry. This construct map and items were developed using a measurement model approach (Wilson, 2005). The 'four-building blocks' described by Wilson (2005) – construct, item responses, outcome space, and measurement model (Figure 1) – helped ensure the content validity of instrument and provides a pathway for instrument design and improvement. The design of the original instrument encompassed one (or one and half) iteration of this outlined process. The construct map and items were designed, item responses were obtained, the outcome space (scoring of items and mapping back to the construct map) was defined, and the Rasch partial credit measurement model was used to evaluate the construct. After going through one cycle of this process the results of the measurement model were used to redesign the construct and redefine the outcome space. The Rasch measurement model was once again used to evaluate and refine the redesigned construct. This produced a final construct map with three main levels of green chemistry understanding: *Intuiting*, *Applying*, and *Analyzing* (Figure 2).

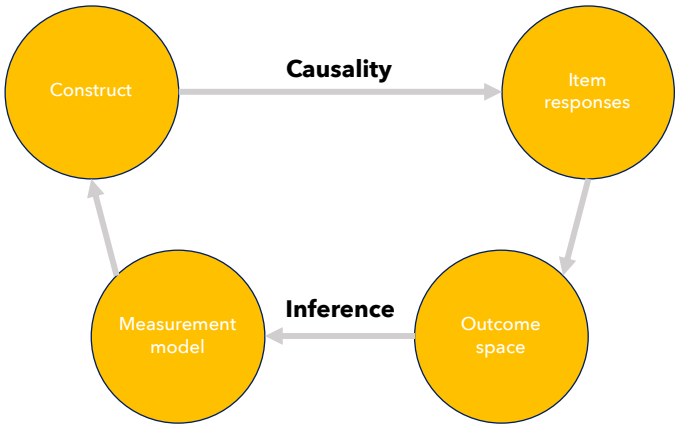


Figure 1. Iterative process of designing an instrument (Wilson, 2005)

Level 1: Intuiting

At this lowest level of green chemistry understanding, students have little to no understanding of green chemistry. If they do attempt to define green chemistry or use green-aligned language or terms, they rely on guesses/inferences and/or is supported with colloquial 'green' language and does not incorporate more specific normative knowledge of green chemistry. Often respondents specifically state (or choose the response that indicates) that they don't know what green chemistry or related terms/practices mean or how to apply them.

Level 2: Applying

At this level, students can define and apply green chemistry using normative green chemistry knowledge and practices. At this level, students are familiar and comfortable with green chemistry, use green chemistry vocabulary correctly, and can provide clarifying statements and general applications of green chemistry principles. There can be a mix of specific and colloquial green language (e.g., *eco-friendly*, *sustainability*, *good for the environment*) but

specific green chemistry terms or examples are used to clarify/support these more general statements and/or provide clarifying explanations, examples, or applications.

Level 3: Analyzing
At this level, students can both define green chemistry/terms and apply that understanding to novel situations. Students understand that green chemistry should be used to analyze systems and understand the applications of green chemistry (e.g., develop sustainable processes, chemicals, chemistries, products). They can apply general knowledge to real or hypothetical problems or scenarios. Students can analyze/evaluate situations from a green chemistry perspective and can apply green chemistry principles correctly. They understand multiple metrics should be used to make decisions and that green chemistry deals with tradeoffs and optimizations. They also understand the likely contributors to the environmental footprint of a product from a systems thinking perspective.

Direction of increasing green chemistry understanding

Levels	Respondents	Responses to Items
Level 3: Analyzing Understands how to use green chemistry to analyze systems; understand green chemistry applications	3: Can analyze/evaluate situations from a green chemistry perspective; can apply green chemistry principles to new situations; understands the likely contributors to the environmental footprint of a product from a systems thinking perspective; understand multiple metrics should be used to make decisions	Uses green chemistry principles to evaluate systems; can use metrics for decision making analysis; evaluates systems based on performance, efficiency, minimized human health and environmental hazards; can analyze processes, chemicals, products; understands multiple metrics/principles should be used
Level 2: Applying Able to define and apply green chemistry	2: Familiar and comfortable with green chemistry; uses green chemistry vocabulary correctly; can provide clarifying statements and general applications of terms	Use green chemistry vocabulary; can provide examples of green chemistry and can explain the meaning and general use of green chemistry principles
Level 1: Intuiting Little to no understanding of green chemistry	1: Intuit a naïve meaning of green chemistry from name; students define green chemistry using colloquial terms	Responses indicate students have a vague idea about green chemistry; ideas do not align with normative green chemistry terms

Direction of decreasing green chemistry understanding

Figure 2. Construct map for green chemistry understanding in the general chemistry classroom

Description and Administration of Items

We had previously developed a construct map for green chemistry understanding (and a set of items to measure student understanding of green chemistry) using a measurement model approach (Wilson, 2005). The "four-building blocks" described by Wilson (2005) – construct, item responses, outcome space, and measurement model – helped ensure the content validity of instrument and provided a pathway for instrument design and improvement. The construct map and items were designed, item responses were obtained, the outcome space (scoring of items and mapping back to the construct map) was defined, and the Rasch partial credit measurement model was used to evaluate the construct. After going through one cycle of this process the results of the measurement model were used to redesign the construct and redefine the outcome space. The Rasch measurement model was once again used to evaluate and refine the redesigned construct. This produced a final construct map with three main levels of green chemistry understanding: *Intuiting*, *Applying*, and *Analyzing*. This construct map (and some of the associated items) were used to design and refine the current items and coding schemes used for this analysis to test respondents' abilities to define green chemistry, apply green chemistry concepts and metrics, and make green chemistry decisions.

All new items including the in-class green chemistry items and multiple choice items were presented to several chemistry and green chemistry experts (experienced instructors, professors) who were asked if the items aligned to the construct and allowed students to demonstrate essential green chemistry topics and skills. Items that did not meet these criteria were revised or removed. Additionally, the new items were presented to multiple research groups as well undergraduate and graduate researchers familiar with green chemistry (education) as well as green chemistry experts. These researchers provided information on item clarity, understandability, and enjoyability as well as alignment to the original construct.

Student survey items

After administering and analyzing the initial Fall 2018 free response items several common student ideas/themes emerged: chemical toxicity/safety, atom economy, renewability, natural products. Students often only mentioned these topics by name and did not elaborate on their meaning or application to the question at hand, which was not unexpected since students often included multiple green chemistry topics in their free responses and could not be expected to give detailed explanations/examples about each topic. However, we wanted to give students the opportunity to demonstrate their understanding of these topics, which led to the development of several fixed response items over the following two semesters. We were mindful of our research capacity after completing our Fall 2018 analysis (i.e., reliably coding free response items is very time consuming for large enrollment courses) and thus, chose to develop fixed response items instead of additional free response items.

Initially, five multiple choice (*select all that apply*) items were piloted during the posttest survey in the Spring 2019 semester. Students were asked to leave feedback on the multiple

choice items at the end of the survey and were encouraged to contact the lead researcher if they had any specific concerns or questions about the survey. Based on student responses, exit survey information, and expert feedback four multiple choice items were selected for the Fall 2019 semester. Think-aloud interviews were conducted with two additional lower division students for these selected items to check response process clarity as a part of the item design process (Wilson, 2005). After reviewing the resulting student responses from Fall 2019 with additional researchers, one multiple choice item was dropped from the final analysis due to expert confusion over the item prompt and choices. Thus, three multiple choice items were used for the final analysis.

Green Chemistry Assessment Tools

In-Class Green Chemistry Quiz

[Pretest Instructions]
This quiz should be completed individually with no outside help. We are interested in what you know about green chemistry before completing this laboratory course.

We are using these questions to gauge your current understanding of green chemistry. You are not expected to be a green chemistry expert! If you do not know the answer, please write '*I don't know, but my best guess is…*'. **The assignment will be graded based solely on effort.**

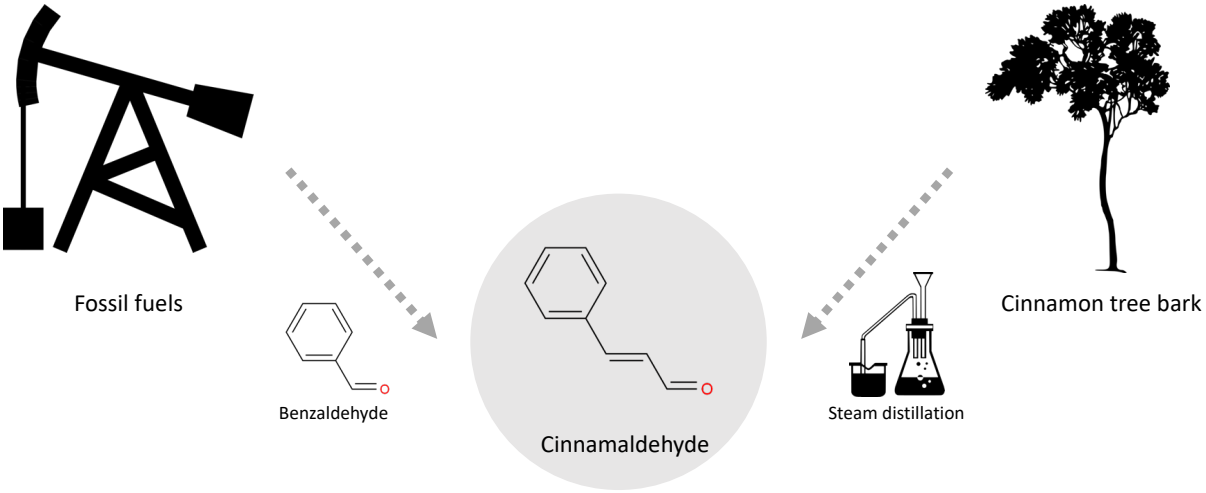
[Posttest Instructions]
Congratulations on completing your final laboratory experiment of the semester! Now that you're near the end of this course we'd like to once again ask you two green chemistry questions. These are the same questions you completed at the start of the semester; we plan on using both sets of quizzes to see how your green chemistry understanding shifted after completing this laboratory course.

This quiz will be graded based on effort; **please be as specific and detailed as possible with your answers to demonstrate the full range of your green chemistry understanding**. We truly appreciate your responses and read every single one of them. Good luck with the end of the semester and your future classes!

1. In my own words, green chemistry means:

The fall season typically brings an increased demand for pumpkin spice flavored… everything! For large scale production it's hard to get consistent flavors using natural spices. It's much easier to use synthesized flavor molecules like eugenol for clove, zingiberene for ginger, and cinnamaldehyde for cinnamon.

2. There are several different ways of making cinnamaldehyde, two of which are shown below:



From a green chemistry perspective, why would one method be preferable to the other? **Be as specific as possible.**

If you do not know the answer, please write '*I don't know, but my best guess is…*'.

Coding Schemes for Green Chemistry Quiz

Table 2. Coding scheme for **green chemistry definition** item administered on the in-class green chemistry quiz (Fall 2018, Fall 2019). This coding scheme was developed for a previous dataset for the exact same item (Fall 2016, Chapter 2).

Code	Score	Definition	Common Themes	Examples	Notes
Research and Development (innovation)	0	Answer shows no evidence that green chemistry is a research process	1. Green chemistry is a field 2. Green chemistry is used, applied, practiced 3. Green chemistry is static 4. Finding reactions (static)	• *chemistry working towards environmental issues* • *Practicing chemistry in a way that is sustainable for the environment.* • *Using resources that are better for the environment.*	Innovations not just applications (e.g. practice of chemistry does not count for a point) Create new product [sustainable way] Note: using an application is not the same as innovation
	1	Answer indicates understanding of green chemistry as a research process	1. Experiment, research, process, field of study 2. Design, development, create, create product. mindfulness 3. Improve, evaluate alternatives, make alternative options, new technologies, make choices 4. Find ways, analyzes ways to have, figure out ways, seeks to 5. Creating/designing chemical experiments 6. Solving problems	• *Green chemistry is a form of chemistry where methods and substances are devised/ made to be better for the planet.* • *Chemistry that tries to make the chemicals in a way that they can broken down by the environment or at the very least will not contaminate the environment.* • *Green chemistry is the branch of chemistry focused on creating chemical solutions to sustainability and environmental problems we face, creating a "greener" society* • *Green Chem does this by finding new chemical reactions that produce the desired outcome or by optimizing an already used reaction to make it less..*	

Code	Score	Definition	Common Themes	Examples	Notes
Minimizing Hazards	0	No inclusion of minimizing hazards in answer	1. Atom economy 2. Waste	• *Chemistry that explores the properties of eco-friendly materials and seeks to apply them in daily life in a sustainable manner.* • *Green chemistry is the substudy of chemistry which focuses on efficient, environmentally friendly ways at generating a product.*	Minimizing 'hazardous waste' should be coded as ***Minimizing Hazards*** *OK if they don't actually say minimize*
	1	Answer includes explicit -mention of minimizing hazards	1. Safety, proper disposal or handling, PPE 2. Hazardous effect on environment 3. Hazardous/harmful materials (chemicals), harmful products 4. Hazardous waste 5. Nontoxic product 6. Pollution, contaminate the environment 7. Greenhouse gasses, carbon footprint 8. Chemical reactions that are safer 9. Minimize Chemical persistence	• *Chemistry that does not introduce or tries not to introduce too many hazardous materials to the environment* • *The practice of chemistry or usage of materials that minimize environmental impact/danger and/or are sustainable.* • *Refined chemistry that seeks to diminish the amount of hazardous byproducts of reactions.* • *Chemical processes that limit hazardous byproducts.*	
Minimizing Waste	0	No inclusion of minimizing waste in answer	1. Hazardous waste	• *Chemistry and engineering that discovers ways in which to minimize hazardous waste products*	Minimizing 'hazardous waste' should be coded as ***Minimizing Hazards*** Maximizing yield = minimizing waste *OK if they don't actually say minimize*
	1	Answer includes minimizing waste as a component of green chemistry	1. Eliminate waste, no chemical waste, no production of waste 2. Reduce/minimize waste/waste products 3. Environmental waste 4. Recycle waste 5. Minimizing byproducts	• *Chemistry that leads to less chemical waste and pollution resulting from chemical reactions to produce goods.* • *Sustainable design of chemical products that eliminate waste.*	

Code	Score	Definition	Common Themes	Examples	Notes
Energy	0	No mention of energy in answer	1. Resources 2. Efficient/efficiency 3. Eco-friendly	• *Using resources that are better for the environment.* • *Using chemistry in a way that is eco-friendly, or helpful to the environment.* • *Making chemistry more efficient*	Renewable resources are coded in ***Material Lifecycle***
	1	Answer includes energy component of green chemistry	1. Energy resources, energy consumption 2. Energy efficiency 3. Better/more efficient/eco-friendly fuels 4. catalyst	• *Taking the environment into consideration when doing chemistry: limiting waste, toxicity, energy…* • *production/use of chemicals that have little adverse effect on environment and made with high energy efficiency*	
Material Lifecycle	0	No indication of material lifecycle	1. Resources, replacements 2. Efficient/efficiency 3. Biodegradable 4. Sustainable	• *Finding suitable replacements for chemicals used in daily life* • *minimizing waste and byproducts when conducting experiments and trying to figure out the most efficient way to reach the end result.* • *Green Chemistry is trying to conserve materials in lab*	Efficient (lifecycle) = maximizing yield of a desired product while minimizing inputs Just saying "biodegradable" doesn't count
	1	Answer includes mention of material lifecycle	1. Biodegradable recycling, 2. Renewable resources, sourcing reactants 3. Conserving (resources), efficient/sustainable use of materials, broken down 4. Atom economy (efficient, high atom economy) 5. Maximizing output while reducing waste	• *The study of chemicals for use in "green" applications such as renewable energy, sustainability, and recycling.* • *Reusable materials and little waste* • *As little waste and as much product as possible* • *Products and reactants are used fully and completely*	

Code	Score	Definition	Common Themes	Examples	Notes
12 principles	0	Does not mention 12 principles	1. Does not mention the 12 principles of green chemistry		
	1	Does mention 12 principles	2. Does mention the 12 principles of green chemistry		
Philosophy	0	No indication of systems approach	3. Not the same as research or innovation – systems thinking is viewing green chemistry as a complex interaction between different systems or processes		Indicates thinking across systems or processes, integration between different components Other categories rewards responses that are more specific and narrower responses
	1	Answer includes idea of integration or thinking across systems	1. Green chemistry is a philosophy of doing chemistry 2. Green chemistry is a version of doing chemistry 3. Movement of green chemistry 4. A way of doing chemistry (with green chemistry principles in mind) 5. Talk about green chemistry being a way to practice all chemistry. NOT just focused on how green chemistry is a branch of chemistry that can minimize damage to the environment and then go on to list principles of green chemistry.	• *Green chemistry is the integration of chemical techniques, principles, and concepts into a mindset of awareness of environmental and human health towards improving current chemical and industrial processes in order to achieve improved sustainability and environmental impact.* • *Green chemistry is still chemistry except it's chemistry with a better understanding and caution as to how experiments and certain methods can affect the environment. Green chemistry focuses on creating as little waste as possible, having a minimal effect towards the planet, and being more aware with the consequences from being environmentally ignorant in the lab.*	

Code	Score	Definition	Common Themes	Examples	Notes
Total reaction	0	Answer does not demonstrate that chemical reactions have multiple components	1. Does not indicate that chemistry/chemical reactions have multiple components	• *Products and reactants are used fully and completely*	Must have two of the three. Byproducts, waste, output, products all count as just the end.
	1	Answer includes multiple components of doing chemistry	1. Doing chemistry has multiple components (reaction, reactants, products) 2. Chemical reactions have different pieces, complex 3. Reaction process includes solvents, energy efficiency, safer reaction (i.e. For personnel) 4. Products can include, waste, byproducts, 5. Reactants – sourcing materials, safety of reactants	• *Make byproducts and processes more eco-friendly*	
Harm/good for Environment	0	Answer describes waste or hazards	1. Waste 2. Hazards (materials, compounds, waste, etc.)	• *Chemistry and engineering that discovers ways in which to minimize hazardous waste products* • *Chemistry that leads to less chemical waste and pollution resulting from chemical reactions to produce goods.*	Reduce or remediation of harm to the environment Positive impact on the environment Key word here is environment (something in relation to the environment)
	1	Answer describes negative or positive effect on the environment	1. Harm, impact on environnent, minimal affect on environnent 2. (Reduce) environmental footprint 3. Health of environment, improve environment 4. Environmentally friendly, sustainability, conscious, or responsible 5. Harm/good for earth/planet/world	• *Chemistry that minimizes harm to the environment(?)* • *Green Chemistry is the study of how alternative methods of instigating reactions and building devices can leave a lesser impact on the environment.* • *applying chemistry in the least harmful ways that affect the environment*	

Code	Score	Definition	Common Themes	Examples	Notes
Buzzwords only	0/1	Answer consists of green chemistry buzzwords only – or general statements - no explanation	1. Environmentally friendly/conscious/responsible 2. Sustainable/sustainability 3. Biodegradable 4. Pertaining to the environment 5. Eco-friendly, clean, good for the environment	• *Using chemistry to improve sustainability in daily activities* • *Chemistry that is good for the environment.* • *Chemistry in relation to the environment.*	*Efficiency* is interpreted depending on the content: sometimes it relates to energy (e.g. energy efficiency), sometimes it relates to material lifecycle (e.g. energy cost), sometimes it is coded as a buzzword (e.g. *Chemistry that helps make processes more efficient*). Do not check Buzzword if any of the content components or philosophy or total reaction etc. are checked. Harm/Good for environment and 12 principles may be checked with buzzwords only. Philosophy doesn't count for this category
Irrelevant	0/1	Irrelevant answer or no response	1. Healthy chemistry 2. Chemistry that is green 3. Good definition of some other aspect of chemistry	• *The chemistry of organic compounds* • *Learning about the plants and more biology type of studies involving chemicals*	

Table 3. Coding scheme for **two methods choice** item administered on the in-class green chemistry quiz (Fall 2019). The first draft of this coding scheme was developed from the administration of the initial version item during the Fall 2018 semester.

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Specified Method	**Fossil Fuels**	Stated that fossil fuels would be the preferred method			*From a green chemistry perspective,* ***the best method of making cinnamaldehyde I guess would be through fossil fuels*** *because the cost of the product would be less and trees would not be needed to be cut down*
	Distillation / Tree Bark	Stated that tree bark would be the preferred method			*Using cinnamon tree bark and steam distillation is the best way.*
General: buzzwords		States very generic language that is relating to green chemistry principles, but with very little purpose or showing no deeper understanding	States very generic language that is relating to green chemistry principles, but with very little purpose or showing no deeper understanding	- green, sustainable -safer, environmentally friendly, eco-friendly, best for the environment - efficient -natural -Global Warming -pollution	*I would want to know which process is the most efficient while also causing the least amount of harm to the environment. For example, the process of using fossil fuels is bad for the environment, so I'd want to know if cinnamon tree bark with steam distillation would be better for the environment* *I would decide by assessing these reactions in the context of the 12 green chemistry principles. These 12 principles will inform me of the efficiency, toxicity, and environmental effects of the reaction (along with many other characteristics). This would then allow me to choose the best reaction.*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	**States Considerations**		
Renewability	**Unsupported**	Specifies that _____ in the reaction or process is renewable / non-renewable without explaining why or defining what renewable means OR Stating that one process is more renewable/non-renewable than the other without explaining why or defining what renewable means.	States that you should consider renewability in your reaction but does not explain what renewability means or why it is important.	- the reaction/process is renewable - you should consider renewable feedstocks in your reaction -fossil fuels are renewable	*… We would have to look at things like atom economy, renewability, safety, toxicity… If I were to choose, I'd choose the steam distillation because it's renewable, there's less energy consumption and it's non-hazardous for the environment.* *The best way would be via cinnamon tree barks as it is a renewable method.* *I would first see which source causes the most harm to the environment when depleted and whether is renewable*
	Supported	Specifies that something in the reaction or process is renewable (i.e., chooses fossil fuels or cinnamon tree bark) is renewable / non-renewable AND explaining why it is renewable. Demonstrates understanding of renewability and/or its importance.	States that you should consider renewability in your reaction and explains what renewability it or why it is important	- fossil fuels are non-renewable - tree bark is a renewable resource - Using renewable resources is important because ... *- depletion of fossil fuels in an issue*	*The method which uses renewable sources would be preferable. Methods that use fossil fuels are not eco-friendly because fossil fuels are not a renewable source. Tree bark is more renewable.* *I would make it using cinnamon tree bark because this resource can be easily replenished/regrown* *I would use the method with the cinnamon tree bark because it would be done using a renewable feedstock. Whereas the other method uses fossil fuels which are not renewable and are hence at the risk of depleting which is why it would not be sustainable (we are meeting the needs of the current generation by compromising the needs of the future generations*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	**States Considerations**		
Economic	**Unsupported**	Economic category is relating to monetary cost and/or the cost of production. This does not mean environmental cost. States that one reaction has a greater monetary cost or economic cost than the other without any explanation or evidence. Note: Making incorrect or far-fetched assumptions about the scenario will also be placed in this category	Economic category is relating to monetary cost and/or the cost of production. This does not mean environmental cost. States that one reaction has a greater monetary cost than the other without any evidence or support. Note: Making incorrect or far-fetched assumptions about the scenario will also be placed in this category	Do not code if: Reponses that consider time but don't relate it to cost; saying a method requires resources without any other statement tying it to economic cost	*I would decide to use the cinnamon tree bark because fossil fuels are potentially dangerous and **costly to the environment and the economy.*** *To decide which method is the best, look at the **cost of the reactants**...* *Efficiency -- Does it produce a lot of cinnamaldehyde with **little cost/resources?*** *Fossil fuels, the other method, is a nonrenewable source that negatively affects the environment through global warming*
	Supported	States that one reaction has a greater economic cost than the other with evidence or support as to how they came to that conclusion while explicitly defining what they mean by economic cost.	States that one should consider the economic implications of a process while specifying why it is important or what specific cost they are talking about (i.e., reactants, machinery, etc.) Provides methodology, baseline questions, or inquiries to how this economic cost can be measured. Must explicitly define what they mean by economic cost		*By getting [cinnamaldehyde] from fossil fuels, it would be synthetic and easier to obtain/use in cooking to keep the flavor consistent...getting it from steam distillation would be more timely and would not provide consistent flavoring.*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Energy	**Unsupported**	States that one reaction uses more energy than the other without evidence or explanation. Note: Incorrect or far-fetched assumptions about the two reactions regarding energy will be marked in this category	States that one should consider energy consumed in a process without specifying why it is important or what part of the processing they are talking about. Note: Incorrect or far-fetched assumptions about the two reactions regarding energy will be marked in this category	- consider energy consumption in the reaction - processes using fossil fuels uses more energy than distillation Don't code if: Reponses that say time but don't connect it to temperature and pressure; saying a method requires resources without any other statement tying it to energy	*We would look at the 12 chemistry principles and paying attention to human's and the environment's safety we would choose the one that is less hazardous. We would have to look at things like atom economy, renewability, safety, toxicity… If I were to choose, I'd choose the steam distillation because it's renewable,* ***there's less energy consumption*** *and it's non-hazardous for the environment.* *steam distillation saves more energy and does not pollute the earth more than fossil fuels which uses lots of energy and coal.*
	Supported	States that one reaction uses more energy than the other with evidence or support that this is true.	States that one should consider energy consumed in a process and specifying why it is important, or in what part of the processing it is important.	- fossil fuels take a lot of energy to process and refine for use	*However, using trees contribute to indirect land use and steam distillation does not occur at ambient temperature and pressure.*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Harmful Byproducts	Unsupported	States that one reaction has more/less harmful byproducts than the other without evidence or support that this is true. (i.e., did not specify the compound)	States that one should consider harmful byproducts produced in a process without specifying why it is important. Note: Making incorrect or far-fetched assumptions about harmful byproducts will be placed marked here	- fossil fuel method has more harmful byproducts than the distillation method -fossil fuels contribute to global warming Do not code if: responses that say they want to know the identity of the byproducts without associating it with hazard	*… it is more environmentally friendly and will **contribute less to pollution.*** *I'm **assuming** that it will create less toxic waste than fossil fuels* *Look at the **toxicity** of the byproducts and waste produced* *I would see the amount of waste produced by each method and if the waste is toxic or not. Toxic waste can be extremely harmful to the environment* *...using natural resources to prevent any hazardous waste*
	Supported	States that one reaction has more/less harmful byproducts than the other with evidence or support that this is true. For example, stating which compound is the harmful byproduct. - must state specific chemical compound	States that one should consider harmful byproducts produced in a process and specifying why it is important or insight in how to	-'fossil fuels product CO2 when burned which is harmful to the environment because of its contribution to global warming -steam distillation gives off water vapor which is not harmful to the environment -Polluting the atmosphere	*… I know that the use of **fossil fuels releases CO2 into the environment and is there bad for the environment**. Steam distillation seems less harmful.* *… **the intermediate for the fossil fuel pathway is a derivative of the very toxic benzene**.* *Look at the toxicity of the byproducts….check CO2 emissions for each method* *I would also want to know the toxicity of all products because humans consume this molecule and we don't want harmful effects*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Hazardous Reactants / Intermediates	**Unsupported**	States that one reaction has more/less hazardous reactants than the other without evidence or support that this is true. (i.e., did not specify the compound)	States that one should consider whether the reactants are hazardous without specifying why it is important or what it means for a reactant to be hazardous. Note: Making incorrect or far-fetched assumptions about harmful byproducts in the context of this question will be marked here	Do not code if: responses that say they want to know the identity of the reactants without associating it with hazard; saying a method requires resources without any other statement tying it to hazardous reagents	*Therefore, I would choose to use steam distillation of cinnamon tree bark since bark is a renewable, nontoxic resource.* *I would choose the 2nd method [tree bark] because of the use of natural and safe solvents* *Look at the toxicity of...the leftover reactants* *Cinnamon tree bark...because it uses the technique of steam distillation, which does less harm than adding chemicals such as benzaldehyde* *I want to know the safety of the materials used*
	Supported	States that one reaction uses more/less hazardous reactants than the other with evidence or support that this is true. For example, stating which compound is a hazardous reactant.	States that one should consider hazardous reactants used in a process and specifying why it is important or giving insight into how to define hazardous.	- steam distillation uses water which is a safe solvent	*Water is safe solvent* *Steam distillation most likely uses a safe solvent like water*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Less Waste/Waste Disposal	Unsupported	Waste is defined as having to do with material waste (as opposed to energy, time, etc.). States that one reaction has more/less waste than the other without evidence or support that this is true.	Waste is defined as having to do with material waste (as opposed to energy, time, etc.). States that one should consider waste without specifying why it is important. Note: Making incorrect or far-fetched assumptions about waste in the context of this problem will be marked here		*-fossil fuels are a limited resource* ***-Benzaldehyde is another added chemical which may leave waste when producing the product*** *…I would consider a number of factors like the 1) price, 2) release of toxic materials into the environment, 3) time, 4)* ***how much material is used/wasted.*** *1) Concentration -* ***which method consumes less resources****, 2) byproducts - which method produces the* ***least waste****/harmful material, 3) sustainability - are the raw materials renewable*
	Supported	States that one reaction uses more/less waste than the other with evidence or support that this is true. States that one reaction has more processible / less hazardous waste than the other.	States that one should consider waste produced and specifying why it is important or specifying what kind of waste.	- the distillation method has less waste because its raw material, tree bark, can be composted.	***The waste of distillation must be biodegradable.*** *There isn't much leftover chemicals, other than tree bark (biodegradable) and water* *The steam distillation with cinnamon tree bark would be the best since … the process to extract the chemical is not that energy intensive and doesn't require auxiliary components* I think the best method to use for making cinnamaldehyde would be the method that creates less trash and pollution to begin with this is important because it is easier to create less trash in the first place, then clean it up after

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Sustainable Systems	**Unsupported**	States that one reaction has more/less processing damage than the other without evidence or support that this is true. - Very general, doesn't go into detail - Say something interesting but doesn't go into detail	States that one should consider processing damage without specifying why it is important or in what context they are talking about. - Very general, doesn't go into detail - Say something interesting but doesn't go into detail		***fossil fuels greatly negatively affect the environment**, whereas (I believe) **bark can be harvested with less overall harm to the environment**.* *I would believer the steam distillation from cinnamon tree bark would be the best method to use for making cinnamaldehyde. This is because it is **naturally derived in a way that isn't as bad for the environment.*** *Want to know how **disruptive the extraction of these resources will be to the surrounding environment and community***
	Supported	- Acknowledging that processing damage is a very complex system with lots of factors you need to weigh in and going into detail of why/how it is - Choose one method and goes in detail with how the processing damage specific to that method -Identifies who is being affected by the processing damage	- Acknowledging that processing damage is a very complex system with lots of factors you need to weigh in and going into detail of why/how it is - Choose one method and goes in detail with how the processing damage specific to that method -Mentions the impacts of sourcing precursors / reactants -Identifies who is being affected by the processing damage	-use of land resources -	*… **Are cinnamon trees endangered?** How much damage do fossil fuels have on the environment? **Will using cinnamon tree bark harm the tree itself or lower its lifespan?*** *The steam distillation would be ideal if the cinnamon **trees are not severely damaged as a result for the production.*** *1) which method is more hazardous to its surroundings. **2) is steam distillation more toxic to the environment than the extraction of fossil fuels? How much so? 3) does the extraction of cinnamon tree bark negatively impact the tree from which it came? I the tree still able to survive and thrive post extraction?***

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Yield		Mentions the yield of the process or a comparison of the number of reactants to the amount of product -this specifically refers to the amount of product in relation to the number of reactants		yield Notes: amount of product in relation to amount of resources, economic cost, or byproducts	
Amount of Material		States the physical amount or volume of reactant material (*without tying this amount to increased toxicity or any other consideration*) as a factor to consider or explains how one process may require the use/involvement of more reagents or material. Tying this physical amount to any other category, such as economic, less waste, toxicity, processing damage etc. results in the answer being coded toward those categories only.		number of reactants extra additional Notes: -saying a method requires resources without any other statement tying it to reactant material	*See...the number of reactants needed to perform the reaction(48)* *Steam distillation minimizes the use of external chemicals (45)* *Through steam distillation you are not using extra reagents....the [fossil fuels] reaction requires extra benzaldehyde to run (42)*
Atom Economy		Mentioned atom economy			*Also,* ***using a minimal number of resources to produce the end product - Atom Economy*** *- is important.* *…The* ***atom economy is important, to maximize efficiency.*** *Long-term effects should be considered as well. The amount of energy needed to move the reaction forward is also important so we can choose the more energy efficient option.*

Main Category	Sub-category	Definition		Common words/Phrases	Examples
		Chooses Method	States Considerations		
Incorrect assumptions about reactant (Benzaldehyde)		Specifically mentions use of the chemical benzaldehyde as a consideration against the fossil fuel method, or assumes benzaldehyde is harmful in their response. -Differs from amount of material in the response's direct characterization of benzaldehyde as negative -Claims synthesis with benzaldehyde is bad/unnatural compared to steam distillation		harmful benzaldehyde Notes: Neutral mentions of benzaldehyde, e.g., simply referring to the fossil fuel method as the benzaldehyde method, or mentioning benzaldehyde as an example of an additional reagent (coded into amount of material instead)	*...steam distillation is much **safer for humans** + the plane**t than the chemical benzaldehyde*** *We would rather perform natural processes such as steam distillation rather than artificial synthesis with benzaldehyde*
I don't know but my best guess is...		States I don't know but my best guess is... as part of their answer			
Off-topic					*The best way is probably extracting it from fossil fuels because it reduces pollution. If you extract cinnamaldehyde from cinnamon tree bark, you use a lot of land/water, which can affect wildlife. In addition, steam is utilized in the process, which could produce fossil fuels.*