

Supplemental Material

CBE—Life Sciences Education

Cole et al.

Experimental Card Sorting Task

Start of Block: Default Question Block

Q1 Thank you for participating in our research project on card sorting. Participation should take roughly 30-45 minutes. The first page of the survey has information about consent and data collection as well as space for you to enter demographic information for the project. The second page is the first card sorting task and the third and final page is the second card sorting task. Please complete all parts of the survey and card sorting tasks to the best of your abilities. If you have any questions about the project please email Dr. Megan Cole at megan.f.cole@emory.edu if you are participating on behalf of Emory University or Dr. Colin Harrison at colin.harrison@biosci.gatech.edu on behalf of Georgia Tech.

Q40 What institution are you affiliated with?

- Emory University (1)
 - Georgia Tech (2)
-

Display This Question:

If What institution are you affiliated with? = Emory University

Q41 CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY Emory University & Georgia Institute of Technology Project Title: Developing a Biology Card Sorting Task Investigators: *Colin Harrison, PhD and Megan Cole, PhD* Protocol and Consent Title: *2/16/19v2* You are being asked to be a volunteer in a research

study. **Purpose:** The purpose of this study is to develop and utilize a card sorting task to analyze scientific thinking. We expect to enroll 10 biology experts and 10 biology novices in part 1 of the study. We expect to enroll 25 biology experts and 100 biology novices in part 2 of the study.

Exclusion/Inclusion Criteria: Participants in this study must volunteer. Candidates under the age of 18 are not allowed to participate.

Procedures: If you decide to take part in part 1 of the study you will complete 2 card sorting tasks and accompanying surveys. You will then participate in a focus group interview to give feedback on the card sorting task. If you decide to take part in part 2 of this study you will complete 2 card sorting tasks and accompanying surveys.

Risks or Discomforts: The only possible risk would be the release of participant identifiers to

demographic and science thinking information. The risk is minimal because all data for analysis will be de-identified prior to scoring for the study. All data will be stored on a password protected server that meets Emory University and Georgia Tech's standards for the storage of sensitive data (as addressed in the section on data).

Benefits: Participants may benefit from positive effects of thinking about their relationship to science and from value affirmation intervention effects.

Compensation to You: There will be no compensation associated with completing this task.

Storing and Sharing Information: Your participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the researcher and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way to identify you. Any future research must be approved by an ethics committee before being undertaken.

Confidentiality: The following procedures will be followed to keep your personal information confidential in this study: Your identity will be kept in strict confidentiality and the data gathered from your surveys will be used specifically for research purposes. Your survey will be stored in locked files and the electronic data associated with them will be stored in a password protected directory accessible only by the trained personnel involved in this study. To protect your identity, we will give you a unique code which will consist of letters and numbers and another code will be given after survey results are entered into the electronic database. This will allow the data to be collected and handled in an anonymous format. The results obtained from the surveys will be published in scientific journals without any information that can be traceable to you and data may be used for future research purposes. The project's research records may be reviewed by departments at Emory University and Georgia Institute of Technology responsible for regulatory and research oversight. The Emory University and Georgia Institute of Technology IRB and the Office of Human Research Protections may look over study records during required reviews. Your privacy will be protected to the extent allowed required by law.

Costs to You: There are no costs to you for being in this study.

Questions about the Study: If you have any questions about this research project, you can contact Dr. Megan Cole at mfc@emory.edu (404) 727-4210 or Dr. Colin Harrison at colin.harrison@biosci.gatech.edu (404) 385-6517.

Questions about Your Rights as a Research Participant: Your participation in this study is voluntary. You do not have to be in this study if you don't want to be. You have the right to change your mind and leave the study at any time without giving any reason and without penalty. Any new information that may make you change your mind about being in this study will be given to you. You will be given a copy of this consent form to keep. You do not waive any of your legal rights by signing this consent form.

If you have any questions about your rights as a research participant, you may contact Ms. Melanie Clark, Georgia Institute of Technology Office of Research Integrity Assurance, at (404) 894-6942.

Display This Question:

If What institution are you affiliated with? = Georgia Tech

Q1 CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A RESEARCH STUDY Georgia Institute of Technology Project Title: Developing a Biology Card Sorting Task

Investigators: Colin Harrison, PhD and Megan Cole, PhD Protocol and Consent Title:

2/16/19v2 You are being asked to be a volunteer in a research study. **Purpose:** The purpose

of this study is to develop and utilize a card sorting task to analyze scientific thinking. We expect to enroll 10 biology experts and 10 biology novices in part 1 of the study. We expect to enroll 25 biology experts and 200 biology novices in part 2 of the study. **Exclusion/Inclusion Criteria:**

Participants in this study must volunteer. Candidates under the age of 18 are not allowed to participate. **Procedures:** If you decide to take part in part 1 of the study you will complete 2 card

sorting tasks and accompanying surveys. You will then participate in a focus group interview to give feedback on the card sorting task. If you decide to take part in part 2 of this study you will complete 2 card sorting tasks and accompanying surveys. **Risks or Discomforts:** The only

possible risk would be the release of participant identifiers to demographic and science thinking information. The risk is minimal because all data for analysis will be de-identified prior to scoring for the study. All data will be stored on a password protected server that meets Georgia Tech's standards for the storage of sensitive data (as addressed in the section on data). **Benefits:**

Participants may benefit from positive effects of thinking about their relationship to science and from value affirmation intervention effects. **Compensation to You:** If you are a student in BIOS 1107/1108/1207/1208 you will receive 1 point of extra credit for your participation in this project, students who do not participate in the study will be given the opportunity to complete an extra credit writing assignment. There will be no compensation associated with completing this task if you are not in one of the aforementioned courses. **Storing and Sharing Information:** Your

participation in this study is gratefully acknowledged. It is possible that your information/data will be enormously valuable for other research purposes. By signing below, you consent for your de-identified information/data to be stored by the researcher and to be shared with other researchers in future studies. If you agree to allow such future sharing and use, your identity will be completely separated from your information/data. Future researchers will not have a way

to identify you. Any future research must be approved by an ethics committee before being undertaken. **Confidentiality:** Your identity will be kept in strict confidentiality and the data gathered from your assessments will be used specifically for research purposes. Survey

completion is done in an anonymous fashion. You should be aware that the experiment is not being run from a https server of the kind typically used to handle credit card transactions, so there is a small possibility that responses could be viewed by unauthorized third parties such as

computer hackers. In general, the web page software will log as header lines the IP address of the machine you use to access this page, e.g., 102.403.506.807, but otherwise no other information will be stored unless you explicitly enter it. The results obtained from the surveys will

be published in scientific journals without any information that can be traceable to you and data may be used for future research purposes. The project's research records may be reviewed by departments at Georgia Institute of Technology responsible for regulatory and research

oversight. The Georgia Institute of Technology IRB and the Office of Human Research Protections may look over study records during required reviews. Note that Dr. Harrison will not

know whether you choose to participate in the study or not. We will comply with any applicable laws and regulations regarding confidentiality. **Costs to You:** There are no costs to you for being in this study. **Questions about the Study:** If you have any questions about this research project, you can contact Dr. Colin Harrison at colin.harrison@biosci.gatech.edu or (404) 385-6517. **Questions about Your Rights as a Research Participant:** Your participation in this study is voluntary. You do not have to be in this study if you don't want to be. You have the right to change your mind and leave the study at any time without giving any reason and without penalty. Any new information that may make you change your mind about being in this study will be given to you. You will be given a copy of this consent form to keep. You do not waive any of your legal rights by signing this consent form.

If you have any questions about your rights as a research participant, you may contact Ms. Melanie Clark, Georgia Institute of Technology Office of Research Integrity Assurance, at (404) 894-6942.

Q4 If you select yes below, it means you have read (or have had read to you) the information given in this consent form, and you would like to volunteer for the study.

- Yes, I consent to being in the study. (1)
- No I don't consent to being in the study. (2)

Skip To: End of Survey If If you select yes below, it means you have read (or have had read to you) the information given i... = No I don't consent to being in the study.

Q5 I agree that my de-identified information/data may be stored and shared for future, unspecified research.

- Yes (1)
 - No (2)
-

Q7 I am best described as

- An undergraduate student studying to earn a Bachelor of Arts (BA) or Bachelor of Science (BS) degree (1)
 - A graduate student studying to earn a Masters degree (2)
 - A graduate student studying to earn a Ph.D. degree (3)
 - A post-doctoral researcher (4)
 - A faculty member with a Ph.D. degree (5)
 - Other (please describe) (6)
-

Skip To: Q39 If I am best described as != An undergraduate student studying to earn a Bachelor of Arts (BA) or Bachelor of Science (BS) degree

Q8 I am majoring in:

- Biology (1)
 - Chemistry (2)
 - Biochemistry (3)
 - Other (please describe) (4)
-

Q9 Anticipated semester (Spring, Summer, Fall) and year of graduation.

Q10 Have you taken any Introductory Biology in college prior to this term?

- Yes (1)
- No (2)

Display This Question:

If Have you taken any Introductory Biology in college prior to this term? = Yes

Q11 If yes, at what institution?

Q12 Have you completed Introductory Biology in college prior to this term?

- Yes (1)
- No (2)

Display This Question:

If Have you completed Introductory Biology in college prior to this term? = Yes

Q13 If yes, at what institution?

Q14 Have you taken any college level biology courses while in college?

- Yes (1)
- No (2)

Display This Question:

If Have you taken any college level biology courses while in college? = Yes

Q15 If yes, please list the courses.

Q16 Did you receive a 4 or a 5 on the AP Bio Exam?

- Yes (1)
- No (2)
- Did not take AP Bio (3)

Q22 Have you worked in a research lab before?

- Yes (1)
- No (2)

Display This Question:

If Have you worked in a research lab before? = Yes

Q23 If yes, what did you study?

Q17 How old are you?

Q38 Select all degrees you have

- BA (1)
- BS (2)
- MS (3)
- PhD (4)
- Other (5) _____

Display This Question:

If I am best described as != An undergraduate student studying to earn a Bachelor of Arts (BA) or Bachelor of Science (BS) degree

Q39 What is your field of study?

Q18 What is your gender?

- Non-binary (1)
- Female (2)
- Male (3)
- Prefer not to say (4)
- Not listed/Other (5)

Q19 I most closely identify as (check all that apply, feel free to be more specific in associated text box)....

- African American (1) _____
- Asian (2) _____
- Hawaiian/Pacific Islander (3)

- Latinx/Chicano (4) _____
- Native American (5) _____
- White (6) _____
- Decline to state (7)
- Other (please specify) (8)

Q20 Have you done a card sorting exercise before?

- Yes (1)
- No (2)

Display This Question:

If Have you done a card sorting exercise before? = Yes

Q21 If yes, please describe when and where.

End of Block: Default Question Block

Start of Block: Block 1

Q24 Car Sorting Activity 1: Unframed Sort

On the following page you will be given a link to a card sorting activity with 16 biology scenarios. Each scenario is a separate card that can be dragged and dropped on screen to group together into your categories. Please do not rush, take the time to read each scenario carefully.

Considering what you know about science, sort these problems into groups that represent common underlying scientific principles. **Give each group of scenarios that you create a name that describes what this group represents for you.** Please note that a single scenario cannot be a member of more than one group. In the end, you must have fewer than 16 groups. There is no right or wrong way to group these problems!

Page Break

Q31 Record your start time for this sort here.

Q40 You can access the scenarios and sort them into groups by accessing this link: https://www.flippity.net/ma.php?k=1prShfCC7euJK7WbkG3981enn09HnYUS7i_ImmThyuWM

Q25 Once you have created your groups please drag the relevant cards into your groups here. Cards are listed by letter associated with the card.

Gro up 1	Gro up 2	Gro up 3	Gro up 4	Gro up 5	Gro up 6	Gro up 7	Gro up 8	Gro up 9	Gro up 10	Gro up 11	Gro up 12	Gro up 13	Gro up 14	Gro up 15
A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)	A (1)
B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)	B (2)
C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)	C (3)
D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)	D (4)
E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)	E (5)
F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)	F (6)

Q32 Record your finish time for this sort here.

Q27 Please write your group numbers followed by the names you gave them here.

Q28 Describe why you grouped certain experimental scenarios together. Give an example of your reasoning.

Q29 How did you decide on the names of your groups?

End of Block: Block 1

Start of Block: Block 2

Q30 Card Sorting Activity 2: Framed Sort

On the next page you will be asked to perform another card sort with the same 16 biology scenarios. Please do not rush, take the time to read each scenario carefully. Considering what you know about science, sort these scenarios into the four groups listed below that represent common underlying scientific principles. Please note that a single scenario cannot be a member of more than one group. In the end, each scenario must be assigned to a group. There is no right or wrong way to group these scenarios!

Groups: Anecdotal/story Correlational/Observational Experimental/Manipulative Secondary/Meta-Analysis

Page Break

Q34 What time are you starting this sort?

Q41 You can access the scenarios and form groups by accessing this link: https://www.flippity.net/ma.php?k=1prShfCC7euJK7WbkG3981enn09HnYUS7i_ImmThyuWM

Q33 Please drag the relevant cards into groups here. Cards are listed by letter associated with the card.

Anecdotal/Story	Correlational/Observational	Experimental/Manipulative	Secondary/Meta-Analysis
_____ A (1)	_____ A (1)	_____ A (1)	_____ A (1)
_____ B (2)	_____ B (2)	_____ B (2)	_____ B (2)
_____ C (3)	_____ C (3)	_____ C (3)	_____ C (3)
_____ D (4)	_____ D (4)	_____ D (4)	_____ D (4)
_____ E (5)	_____ E (5)	_____ E (5)	_____ E (5)
_____ F (6)	_____ F (6)	_____ F (6)	_____ F (6)
_____ G (7)	_____ G (7)	_____ G (7)	_____ G (7)
_____ H (8)	_____ H (8)	_____ H (8)	_____ H (8)
_____ I (9)	_____ I (9)	_____ I (9)	_____ I (9)
_____ J (10)	_____ J (10)	_____ J (10)	_____ J (10)
_____ K (11)	_____ K (11)	_____ K (11)	_____ K (11)
_____ L (12)	_____ L (12)	_____ L (12)	_____ L (12)
_____ M (13)	_____ M (13)	_____ M (13)	_____ M (13)
_____ N (14)	_____ N (14)	_____ N (14)	_____ N (14)
_____ O (15)	_____ O (15)	_____ O (15)	_____ O (15)
_____ P (16)	_____ P (16)	_____ P (16)	_____ P (16)

Q35 What time are you finishing this sort?

Q36 Which if any of the scenarios was difficult to assign to one of the 4 categories and why?
Please list all that apply.

Q42 Now that you have completed 2 card-sorting activities, which group names do you prefer:
the group names that you created or the group names given to you by the researchers or
neither?

- Prefer the names I created (1)
- Prefer the names provided in the second sort (2)
- No preference (3)
- Unsure (4)
- Prefer not to answer (5)

Q37 Please explain your answer to the last question.

End of Block: Block 2

Task Cards

A

A new student in a fruit fly lab observes 50 flies each for 1 hour and records the time they spend in the air. They find that larger flies spend more time flying than smaller flies.

B

Scientists collect gut bacteria from monkeys who eat meat and from vegetarians. They compare the bacterial species present and the relative abundance of each in the meat-eater and vegetarian populations and find a few bacterial species that are largely specific to one group or the other.

C

A researcher gathers 100 published studies of sunlight exposure and depression and find that 85% of the studies found a significant correlation between low sunlight exposure and depression.

D

A scientist observes that a rose bush in the sun has more flowers than a rose bush in the shade. They decide that rose bushes need high levels of sunlight.

E

A friend has an area with red tulips and an area with blue tulips in their garden. They measure the day that each flower blooms one summer and find that the red tulips bloom on average 2 days before their blue tulips.

F

A doctor is interested in the effects of diet on health. They survey 2000 individuals in the United States and found that people who ate a fish-based diet had a 10% lower risk for heart disease.

G

A scientist has discovered a new mutation when looking for genes that control body size. They find that introducing this mutation into flies increases their weight by 20% on average.

H

A nanny takes a bacterial swab of the shiny kitchen counter in the home they work and sends it out for microbial analysis. The analysis shows a high level of staphylococcus bacteria, the child care provider concludes that staphylococcus likely causes the counter to be significantly shiny.

I

An insurance company gathers journal articles of studies on frequency of staph bacterial infections and hand-washing practices at hospitals. From the 143 studies they identified, 83% found a significantly lower bacterial infection frequency in hospitals with mandated hand washing.

J

A nurse observes three dead flies in a glass of vinegar in a patient's room. They conclude that a chemical in vinegar is toxic to fruit flies.

K

A doctor gives patients either placebo or a drug to inhibit testosterone hormone for 1 year. Rates of hair loss were reduced 25% in the treatment group.

L

A doctor studying memory loss wants to see the effects of ginko plant extract on memory. They enroll 100 patients to take ginko extract and 100 to take a placebo and find that patients taking ginko extract perform better on a memory test.

M

A health store owner interested in whether caloric restriction extends lifespan finds 25 published research studies on caloric restriction in fruit flies. They analyze results from all the studies and find an overall trend of increased lifespan with caloric restriction.

N

A student takes oral Echinacea pills for the 2 weeks leading up to final exams. They score 10% better in these final exams than in all their midterm exams and determine that Echinacea helps with memory.

O

A student gathers data from 28 studies on corn yields versus rainfall for areas with climates similar to their own. After analyzing the data, they found that corn yields were significantly higher in years with 50-75% increased rainfall over average but lower in years when rainfall increased by over 100%.

P

A student is studying soil bacterial composition on a farm and uses antibiotic spray to control harmful bacteria on one half of a field only. They measure the number of bacteria in the soil and find twice as many bacterial colonies on the plates growing swabs from the antibiotic-free side of the field.

Card predicted sorts

	Anecdotal	Observational	Experimental	Meta
Bacteria	H	B	P	I
Flies	J	E	G	M
Plants	D	A	L*	O
Humans	N	F	K	C

green - researcher
purple - healthcare
blue - layperson
yellow – student

*L included in both plant and human as feedback indicated that participants interpreted the study organism in two ways

		Coding Response Samples									
Participant Prompts	Group Names	1- bacterial influence on humans 2- plant data 3-mental strength experiments 4-lifestyle 5-flies 6- contamination	1. Doctor/student study 2. Sun/ soil 3. Bacteria 4. Flies	1: Flies 2: Flower 3: Placebo 4: Bacteria 5: Correlation 6: Other	1 - outlier, 2 - measurement over time, 3 - quantitative data supporting correlation, 4 - qualitative correlation, 5 - health-related, 6 - placebo control groups	Group 1: 2 groups w/conclusion, Group 2: trends, Group 3: percentages	Reduced group:1, increased group:2, correlation between data: 3, specificities: 4, significant differences: 5, simple conclusions between 2 test groups: 6, average conclusions: 7	1-Study analysis 2- Observational study 3- Experiment with placebo/control 4- Generalization based on observation	1.Neutral Reporting 2. Baseless assumptions 3. Meta-analyses	Group 1: Data Analysis Group 2: Experiment Group 3: Observation	Group 1: Observations Group 2: Experiments with manipulation Group 3: Review of many studies/big data analysis Group 4: Baseless conclusions from observations
	Grouping Explanation	Instances that used the same parent group for their independent variable, i.e. plants, bodily bacteria, and the human mind were grouped because they felt connected.	Based on common themes and words. There were two that mentioned bacteria, therefore did them together	I put experiments with the same subject together	Different aspects of creating and reporting studies that they share	I grouped scenarios based on how results were portrayed, so group 3 was all results that were given in percentages	I grouped certain experimental scenarios together based on similarities in trend (i.e. increasing decreasing, neither)	I grouped scenarios based on how similar their methods of experimentation/data gathering were. For example, J and H went together because in both scenarios one fact is used to generalize.	Group 1 contains experiments that had a limited focus and reported their results in a neutral fashion. Group 2 contains situations where an assumption was made based off of data or observations that do not necessarily support that assumption. Group 3 contains scenarios where many past studies were analyzed to come to a conclusion.	I grouped experimental scenarios together based on the methodology used in the scenario. For example, group 1 involved utilizing data from other studies or surveys, while group 2 involved manipulating variables.	All of the scenarios in group 3 involved the review of multiple studies, so it made sense to me to put it together. The rationale for the other groups are given in each group's name.
	Name Explanation	I used most concise and basic terms to easily communicate why I believe the instances could be grouped	Common themes	The word that best described all the scenarios	Description of the aspects	Based on how I grouped them	I summarized the data I categorized into a few words.	I tried to state what each group had in common.	I chose names that I felt most accurately and succinctly described the sorting criteria I used.	I decided on the names based on what I thought explained my groups best and most succinctly.	I decided on their names by stating what rationale I used to group each group together.
Novice Type Thinking	Subject of Card as Group Name	X	X	X							
	Field of Research	X			X						
	Who Conducted Research		X								
Developing Thinking	Multiple Surface Features Mentioned		X								
	Data Collection/Similar Data				X	X		X			
	Similar Type of Conclusion					X	X	X	X		
	Correlation/Causation			X	X		X				
Expert Type Thinking	Control Group			X	X			X			
	Given Group Names Similar to Own Grown Names							X	X	X	
	Experimental Design							X	X	X	
	Lack of Evidence								X	X	
Analysis	Past Study/Meta-Analysis							X	X	X	
	Category	Novice Only	Novice Only	Novice + Developing	Novice + Developing	Developing Only	Developing only	Developing + Expert	Developing + Expert	Expert Only	Expert Only
	Researcher Explanation	Used card subjects as group names (i.e. flies) and more broadly about field of research such as mental strength and contamination.	Used card subjects and researcher as group names indicating multiple surface features	Used card subjects as group names, also used placebo (control) and correlation as group names	In their group names they discuss a field of research (health), data/data collection (measurement over time, quantitative, qualitative), correlation, and controls	Group names based on conclusions they made. Other two groups that they made and their explanations made clear they were focusing on the data presented in a similar manner (i.e. percentages).	Group names discuss correlation as well as the conclusions reached and discussion of reasoning talks about both as well	Used group names similar to deep features for two groups and explained grouping based on experimental design. Also mention controls, conclusions, and one specific fact (data) in their explanation.	Grouped things together by what type of conclusions they came up with and specifically pointed out false-assumptions and meta-analysis.	Group names are similar to deep features (experimental, observational, secondary), they also talk about methodology of experiments and past studies.	Group names similar to deep features and all 4 present. Mentions reviewing completed studies and lack of evidence while the names bring in experimental design principles.