# Supplemental Material

CBE—Life Sciences Education

Dewey *et al*.

Students' experiences and perceptions of the scientific research culture after participating in different Course-based Undergraduate Research Experience models (Dewey, Evers, & Schuchardt) - Supplemental Materials

| Table S1: Codebook for the Practices of Scientific Research | | |
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| Code | Definition | Example Quote |
| **P1** - Posing Questions, Hypotheses, and Predictions | Most scientific investigations start with a question being proposed or with the generation of a hypothesis. This leads to descriptions and explanations of how the natural world works that can be empirically tested. | "The biggest challenge was probably just coming up with the idea to begin with" |
| **P2** - Planning an investigation | Planning an investigation involves outlining a systematic approach that seeks to answer a question. This includes selecting procedures, establishing a timeline to carry out the experiment, and identifying variables and parameters. | "…you have to be so meticulous in your experimental design. You have to be so meticulous, and flawless, if you want to get, like, perfect results." |
| **P3** - Running an investigation | Investigations are conducted by working in the field or in the lab. This includes performing procedures/techniques and collecting data. | "…I'm a lot more comfortable going into the lab by myself without a lab partner, and doing what I have to get done, and, like, knowing how to do it." |
| **P4** - Data analysis | Because data patterns and trends are not always obvious, scientists use a range of tools (e.g., tabulation, statistical analysis) to classify and categorize their data. | "I also, surprisingly, found the data analysis at the end kind of fun." |
| **P5** - Evaluation and interpretation of data | Once scientists have analyzed their data, they must evaluate and intrepret its meaning. This involves critical thinking and distinguishing relevant data from "noise," as well as identifying sources of error in the investigations, calculating degree of certainty in the results, and interpreting representations of data. | "…as well as understanding the data that we got back from the [supercomputing] center and knowing exactly what we're looking at here" |

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| **P6** - Generating arguments, explanations, and conclusions | Scientists use their collected empirical evidence to construct arguments, explanations, and conclusions in order to propose new knowledge about the phenomena they are studying. | "We were able to draw, like, a pretty concise conclusion about our experiment, so, that's what I liked about it." |
| **P7** - Negotiation and debate | The process by which explanations are reached. Scientists should be able to: justify, evaluate, revisit, and rebut claims; discuss observations; listen to criticism; and engage in persuasion to resolve disagreements. | No example found |
| **P8** - Producing and using representations of phenomena | Scientists should be able to produce and utilize representations of phenomena that dare descriptive (rather than explanatory) such as graphs, tables, and images. | "But I learned a lot [about] how to actually graph and how to make things, like, easy to look at when you're graphing it, so, different ways to graph things" |
| **P9** - Developing and using models | Scientists use and construct models as helpful tools for explaining (rather than describing) ideas and relationships. These tools can include explanatory diagrams, drawings, physical replicas, mathematical models, analogies, and computer simulations. | "I thought it was cool that even though we were working with a small amount of bacterium, the implications of our results were actually interesting and relevant. Um, and it's not too hard to make a model like that." |
| **P10** - Applying and using computational approaches | Mathematical calculations, measurements, and power analyses are fundamental quantitative/computational approaches. They are used for a range of tasks such as constructing simulations, coding, statistically analyzing data, and recognizing, expressing, and applying quantitative relationships. | "I learned a lot of tools about, about coding that I never really thought that I would learn." |
| **P11** - Obtaining and Evaluating information | Scientists must be able to obtain, understand, and evaluate information. This involves finding relevant background information, understanding its content, and critiquing the work of others. | "For me, I think it's kind of like when you're looking at, you know, scientific journals and these studies. Now I understand a lot more of how it worked, what went into it. That's a big takeaway." |

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| **P12 -** Communication | Scientists must be able to communicate clearly and persuasively the ideas and methods they generate. This can take the form of writing a research paper, presenting a project, or offering updates on their work individually or in groups. | "I would say [I liked] feeling good about presenting the research we found, and also being able to communicate that with other people. Um, and also, we have a paper that goes along with it, so, just writing a scientific paper." |
| **P13 -** Teamwork | Scientists generally work in groups, rather than in isolation, when running investigations. They may have days alone in the lab or field, but they are always working with someone else in some way. | "Learning how to work together and communicate in order to get something accomplished was, I think that was one of the most important takeaways." |

| Table S2: Codebook for the Norms/Expectations of Scientific Research | | |
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| Code | Definition | Example |
| **NE1 -** Scientists aim to be objective | Scientists themselves work to be as objective in their work as possible by employing controls, asking for feedback, checking their biases when possible, and evaluating work based on merit rather than emotion. However, science is also a human endeavor, and as such is subjective to values and beliefs. | "One thing is like—don't be biased when we were doing statistical analysis because in our mind we really wanted it to be significant. But obviously, we can't force it." |
| **NE2 -** Science aims for integrity | Science is driven by the idea that there is a truth to be uncovered, and it should be presented with full integrity. Scientists should strive to achieve integrity in their work by presenting coherent and consistent work, exploring questions and ideas that have testability, using precision in their experiments, and being transparent and honest in all aspects of their work (such as keeping clear records and being honest when writing up/presenting their results). | "I think also, I've never kept a lab notebook in my life before. And that was a really big part of this course, that I think, was really underestimated…" |
| **NE3 -** Scientific work should be repeated | Repetition in scientific work, such as repeating experiments and running multiple trials, acts to reinforce the integrity of the work. Experiments should also be replicable in their entirety by outsiders. | "…and because of that, we actually had to redo our experiment to get three replicates for our final research paper." |
| **NE4 -** Scientific work is often peer reviewed | A major aspect of science is that any work/manuscript must be reviewed by peers so that multiple viewpoints are employed to make sure the work is robust and maintains its integrity. | "…when we were writing these, we'd been writing our paper in sections, and we would turn it in first as a peer eval, and then turn it in to the TA. And that was nice that you could get that peer eval and then give it to the TA so there's like, buffer, check points" |

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| **NE5** - Scientists must publish their work as a measure of success | In order for their work to be recognized and/or built upon by the scientific community, scientists strive to publish their work. | "And I think it has given me a newfound respect for scientific papers and just how difficult they are to get published…" |
| **NE6** - Science is often collaborative | Collaboration is a broader expectation of the scientific community at large; it involves cooperation among members, networking, and collaboration across disciplines and fields or companies relevant to the work. | "And just know how to ask for help too…being able to ask the TAs and listen to them and work with them." |
| **NE7** - Scientists should have freedom and independence | A major aspect of science is that it allows scientists to pursue topics of interest to them, providing them the freedom to choose their work and the independence to decide how to run their experiment on their own. However, context can greatly limit the reality of this expectation due to time constraints and materials. | "I was going to say, just like actually doing an experiment on your own and not being instructed on what you're doing is a big takeaway." |
| **NE8** - Scientists must be persistent and resilient | Science is not easy and often does not work on the first try. There will always be issues that scientists encounter when running their experiments, but it is a natural part of science that scientists understand how to overcome complications and learn from mistakes. | "Um, my takeaway would probably be that failing isn't always bad. It's still a result." |
| **NE9** - Scientists must be open to new ideas | Scientists must be willing to accept evidence that goes against what they believe to be true if the evidence is robust and strongly supported | "I mean, our result from this could be that *Pseudomonas* and *E. coli* can't coexist, even though I still believe they can." |

| Table S3: Codebook for the Values/Beliefs of Scientific Research | | |
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| Code | Definition | Example |
| **VB1** - Science is defined by the desire to discover new knowledge about the natural world | A driving force and fundamental aspect of science is the discovery of new information, even if it is something unexpected. | "I also just like seeing the results and seeing how all the work we put in kind of came out with an actual answer instead of just being - standing there with an I do not know still." |
| **VB2** - Science is defined by its requirement for empirical evidence | The discipline of science is founded on the need to obtain empirical evidence, whether through observation of the natural world or through experimental evidence. This value separates science from many other fields. | "A lot of our dilution plates weren't countable. So, we only had one replicate that we could actually count. So, all of these are single replicate figures... So, the most challenging [thing] is [that] we finished. And now, we have to redo it all." |
| **VB3** - Science is not all-knowing | As science is driven by empirical evidence, not all questions can be answered through scientific investigations. This is an inherant limitation and can cause uncertainty in the outcome of investigations. | No example found |
| **VB4** - Science is defined by the production of durable but tentative knowledge | Scientific claims change as new evidence is brought to bear on existing theories or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs. At the same time, scientists must rely on current scientific knowledge in order to expand it. | "But also, I think, just understanding and learning that science is a very fluid thing." |

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| **VB5** - Curiosity, imagination, and creativity are important to science | The ability to devise creative investigatory methods and data reduction techniques, invent explanations, and generate new ideas is an important part of investigating questions. Scientists must use their imagination in order to conduct investigations. | "Uh, there was a lot of creativity…" |
| **VB6** - Science is defined by the use of a variety of methods | Scientists recognize that, as every investigation is different, there is no universal method for investigating a question. Scientists may observe, compare, measure, test, speculate, hypothesize, create ideas and conceptual tools, and construct theories and explanations. | "But, overall, I did like that experience because it was different from all the other biology courses I'd done as well. Biology is cool and I think doing it in different ways is very exciting." |
| **VB7** - Science is influenced by and contributes to society and culture | Science affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded (social fabric, power structures, politics, socioeconomic factors, culture, history, philosophy, religion). | "Um, I thought it was really cool, just like the applicability that this project had to humans, considering most of the people in my group were interested in healthcare." |
| **VB8** - Science builds on what has gone before | Many scientific investigations begin with finding a gap in current scientific knowledge. Scientists rely on previous knowledge and methods in order expand on or refine them. | "It seemed almost somewhat artificial to just kind of, think of something and then read the literature and basically just change up someone else's [work] a little, tiny bit." |

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| **VB9 -** Science is constructive and complex | Scientists establish scientific knowledge through models, theories, scientific texts, and persuasion in a constructive, complex process. | "I have just so much better understanding of how research like this is done now. I was always, you know, kind of baffled about how you can get such precise results from studies. I didn’t know the steps that went into DNA extraction, for example, and that was pretty fascinating. I just think that I have a greater respect for science and how it’s done." |

| Table S4: Percent of Responses coded as specific cultural aspects for each project area | | | | | |
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| Cultural Aspect | Project Area | | | | |
| | Bench-based | | | Average % bench-based | Computer-based |
| | Experimental Evolution (n=246) | Environmental Toxicology (n=219) | Microbiome (n=177) | | Computational Microbiology (n=143) |
| Pose Questions (P1) | 1% | 2% | 1% | 1% | 1% |
| Plan Investigations (P2) | 7% | 9% | 6% | 7% | 0% |
| Run Investigations (P3) | 22% | 19% | 18% | 20% | 3% |
| Analyze data (P4) | 1% | 1% | 1% | 1% | 6% |
| Evaluate and interpret data (P5) | 1% | 0% | 3% | 1% | 1% |
| Generate arguments, explanations, and conclusions (P6) | 0% | 0% | 1% | 0% | 0% |
| Negotiate and debate (P7) | 0% | 0% | 0% | 0% | 0% |
| Produce representations (P8) | 0% | 0% | 0% | 0% | 9% |
| Develop and use models (P9) | 0% | 0% | 0% | 0% | 0% |
| Computational thinking (P10) | 0% | 0% | 0% | 0% | 36% |
| Obtain and evaluate info (P11) | 2% | 3% | 1% | 2% | 1% |
| Communication (P12) | 7% | 4% | 4% | 5% | 5% |
| Teamwork (P13) | 11% | 16% | 10% | 12% | 12% |
| Objective (NE1) | 0% | 0% | 0% | 0% | 0% |

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| Integrity (NE2) | 1% | 1% | 1% | 1% | 1% |
| Repeat investigations (NE3) | 2% | 0% | 0% | 1% | 0% |
| Peer Review (NE4) | 0% | 1% | 1% | 1% | 1% |
| Publish as a measure of success (NE5) | 0% | 0% | 0% | 0% | 0% |
| Collaborative (NE6) | 2% | 0% | 2% | 1% | 0% |
| Freedom & Independence (NE7) | 22% | 15% | 28% | 22% | 9% |
| Persistence & Resilience (NE8) | 12% | 15% | 8% | 12% | 8% |
| Open to new ideas (NE9) | 2% | 2% | 1% | 2% | 0% |
| Discovery (VB1) | 4% | 2% | 6% | 4% | 1% |
| Empirical evidence (VB2) | 1% | 0% | 1% | 1% | 0% |
| Cannot answer all questions (VB3) | 0% | 0% | 0% | 0% | 0% |
| Durable but tentative (VB4) | 0% | 1% | 0% | 0% | 0% |
| Curiosity/ Imagination (VB5) | 0% | 2% | 1% | 1% | 0% |
| Variety of methods (VB6) | 0% | 0% | 0% | 0% | 1% |
| Influenced by/contributes to society (VB7) | 1% | 3% | 6% | 3% | 3% |
| Builds on what has gone before (VB8) | 0% | 0% | 1% | 0% | 1% |
| Constructive and complex (VB9) | 0% | 0% | 2% | 1% | 0% |