Fostering Critical Thinking Skills via Analysis of Primary Literature

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Image: Wikimedia Commons

The Thinker, A. Rodin

UCSD

Biological Sciences
where discovery comes to life
UC San Diego
Ability to Apply the Process of Science, the first of the six fundamental core competencies:

“posing problems, generating hypotheses, designing experiments, observing nature, testing hypotheses, interpreting and evaluating data, and determining how to follow up on the findings”
Who are our students?

- Contiguous Biology Master’s program – our own very recent undergraduates
- About 80% are in their first year of Master’s studies
- Perform lab research
- > 50% aspire to become physicians

This study:
- 10 weeks course
- 2 quarters
How do we define critical thinking?

Bloom’s taxonomy, Higher-Order Cognitive Skills (HOC’s):

- **Analysis**: interpreting data and drawing conclusions

- **Synthesis**: designing a controlled experiment

- **Evaluation**: evaluating author’s hypotheses or conclusions
Students self-evaluation of critical thinking: Analysis, beginning of the quarter

Analysis questions:
"Interpreting data in a paper in (or outside of) your area of research"
"Independently drawing conclusions from data presented in a paper in (or outside of) your area of research"
Students self-evaluation of critical thinking in context of primary research papers, beginning of quarter

**Synthesis:** "Proposing an experiment, with the appropriate controls, that would follow up on a paper in (or outside of) your area of research"
Students self-evaluation of critical thinking in context of primary research papers, beginning of quarter

Evaluation:
"Critically evaluating authors' conclusions in a paper in (or outside of) your area of research"
Structure of the course: 3 modules, centered around 4 research papers from different fields of biology

Meeting #1: Groups identify unfamiliar terminology and methods

Meeting #2: Groups explain terminology and methods to their peers

Meeting #3: Discussion of data. Each student presents one figure or panel

Meeting #4: Discussion of authors’ conclusions

Meeting #5: Groups present their follow-up experiments and evaluate experiments by others

Students submit description and analysis of three key experiments

Groups submit a written follow-up experiment + a schematic slide
Papers discussed

Paper 1: Problematic study design, unwarranted conclusions
Cell biology

Paper 2: Solid study design, justifies conclusions
Neurobiology

Papers 3 and 4: Investigations of the same phenomenon, reaching opposite conclusions
Molecular biology
Assessments

1) **Students’ self-evaluation** of critical thinking skills: anonymous surveys, pre- and post-quarter.

2) **Critical thinking test:**

   Data from two related biological experiments
   Graphs did not require specialized knowledge

**Parameters measured:**

- **Analysis**: analyze two graphs and draw conclusions based on both pieces of data
- **Evaluation**: evaluate hypotheses based on the first piece of data, then on both pieces of data
- **Synthesis**: propose a follow-up experiment
Administration, rating, and analysis of the pre/post critical thinking tests

- Two similar versions of the test (A and B), counter-balanced design:
  Half of the students: took A (pre-test) => B (post-test)
  Another half: B (pre-test) => A (post-test)

- Tests were evaluated by two (FA12) or three (WI13) expert raters blind to both students' identities and to pre/post status of the test.

- Inter-rater reliability was high for all relevant ratings (Cronbach’s alpha > 0.90).

- Mixed-design analysis of variance was used to compare end of the quarter to beginning of the quarter ratings
Increase in quantitative description of data

N = 42, Error bars: Standard error of the mean difference, P-value: 0.015
Changes in critical thinking, test analysis

N = 42, Error bars: Standard error of the mean difference, P-value for Synthesis: 0.0096
Students self-evaluation of critical thinking skills: Analysis

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**Synthesis:** "Proposing an experiment, with the appropriate controls, that would follow up on a paper in (or outside of) your area of research"
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**Evaluation:**
"Critically evaluating authors’ conclusions in a paper in (or outside of) your area of research"
What aspects of understanding and analyzing scientific papers do students find most challenging?

- Understanding unfamiliar techniques: Pre - 8, Post - 9
- Scientific language/writing style: Pre - 7, Post - 7
- Terminology (unfamiliar terminology): Pre - 6, Post - 2
- Drawing your own conclusions: Pre - 3, Post - 7
- Evaluating author's conclusions: Pre - 3, Post - 6
Changes in students’ perceptions about the challenges of analyzing scientific papers

Students responses

- Knowledge
- Comprehension
- Analysis
- Synthesis
- Evaluation

Pre
Post
Conclusions

Structured analysis of three scientific papers and design of follow-up experiments in groups results in:

- Increase in experimental design ability
- Increase in quantitative data description
- Increase in the perceived level of critical thinking skills
- No measurable objective increase in analysis, evaluation
- Changes in perception of what is challenging in analyzing scientific papers – possible shift to HOC’s
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