Learning to think critically in and about engineering:
A liberative perspective

Lionel M. Claris and Donna M. Riley

Overview

• What is critical thinking?
• What can we learn from developmental and social theory to foster students' critical thinking?
• Integrative approach that addresses critical thinking skills across multiple contexts and educational outcomes in engineering
• Results and discussion of our initial exploration of student work and assessment
What is critical thinking: Conventional Wisdom
(Paul and Elder)

• Power / Knowledge (Foucault)
  - Truth is produced by “multiple forms of constraint,” and “induces regular effects of power.”

• The condition of the question (Derrida)
  - What assumptions about the Other precede the question?

• Critical and reflexive relationality (Haraway)
  - Given these power dynamics, how can we examine ourselves and our disciplines in relation to the world?

Social Theory
Developmental Theory
(King & Kitchener, 1994)

- Critical thinking critique:
  - Logical thinking skills approach
  - Problem solving process approach (well-structured problems)
  - Both ignore epistemic assumptions (authority-based, disallow uncertainty, rely on scientific method)
- Reflective Judgment Model:
  - Seven progressive sets of epistemic assumptions
  - Students gradually learn to hold epistemic assumptions that allow for true reflective thinking
    - Absolutism to Relativism: College students typically abandon “ignorant certainty” for “intelligent confusion” (Kroll, 1992)
    - Post-college emergence beyond relativism - comparison, evaluation, synthesis of contradictory information
    - Students operate in a range of stages at any given time

Thinking critically in vs. about engineering

- Critical thinking in engineering
  - Considering and articulating assumptions in problem solving
  - Selecting appropriate hypotheses/methods for experiments
  - Considering multiple perspectives in an ethics case study
  - Assessing social impacts of technology
  - Structuring open-ended design problems*

- Critical thinking about engineering
  - For whom and by whom is engineering done?
  - Who decides what is and is not engineering?
  - Who benefits and who loses from engineering?
  - How do social, political, cultural and economic pressures impact design choices?

- While the latter is traditionally seen as the domain of the social sciences and humanities, we believe it is essential for the kind of self-examination that leads to true critical thinking
Our Approach

- **Goal:** Address critical thinking across multiple contexts and educational outcomes
- **Liberative Pedagogy (Freire, hooks)** - importance of self-knowledge, reflection, relationships, questions
- **Meet students where they are, model a range of stages**
- **Background:** First year Intro Design and Mass & Energy Balances:
  - Narrative reflections on definition of/relationship to engineering
  - Readings/reflections on social/political contexts of engineering
  - Ethics case analyses focused on multiple perspectives, judgment
  - Closed and open-ended problem solving
  - Information literacy
  - Use of Felder and Rousseau thought questions
  - Reflections on learning styles, limiting beliefs, problem solving process, and team dynamics

Student work and assessment in Engineering Thermodynamics

- **Critical Thinking-related Coursework:**
  - Liberative Pedagogy reading and essay
  - Foucault reading and essay (truth and power)
  - Regular reflections via blog (on course content, student learning)
  - Critiques of content in and out of class (test question)
  - Use of history to demonstrate intellectual humility
  - Relationship of thermodynamics to life
  - Closed- and open-ended problem solving
  - Ethics case analyses

- **Assessment measures**
  - Focus groups
  - Student feedback
Student interpretations of Foucault reflect stages of intellectual development

- Most understood truth - power relationship, provided examples (Galileo, WMD justification for Iraq War)
- A few misunderstood Foucault to say “knowledge is power” (Bacon) - unidirectional or linear relationship
  - “we all know that people with more knowledge have more chance to be powerful than others…”
- A few misunderstood Foucault to say science is pure/ not subject to power (Althusser)
  - “I believe the truths in science are more real than the truths in society.”
  - “The only acceptable way to question truth is through scientific discourse.”
- A few misunderstood Foucault to say “truth is relative”
  - “As physics tell us, everything is relative. When there is just a truth, just a statement, it is neither good nor bad because there is no other truth by which to compare.”

Critical questions emerged from Foucault and Pedagogy reflections

- Questioning the textbook, syllabus, engineering education
  - “It is interesting that many of the laws of thermodynamics we simply accept as truths because they are printed in our textbooks and we assume that if they are in the textbook they must be truths.”
  - “The choice of concepts [we learn] has power not only over individual students, but also over the people whose lives our engineering will influence.”
  - “I think that even as engineering students, this idea of truth coming from an institution affects the way some of us do problems. Many times we are not confident in our answers if we cannot compare with the book, teacher, or TA.”
  - “This course is taught in such a way that students must be active participants in their education. Instead of accepting the current truths, we must challenge and wrestle with them.”
The Why of “Why?”

- Blog reflections: students evaluated on critical thinking.
  - Grades show improvement mitigated by end-of-semester crunch
- Were students motivated by strategic or deep learning?
  - “I understand that the Otto engine is more efficient than the Diesel engine when both are working at the same compression ratio but, then why is the diesel engine considered to be more efficient? ... why are they used in big 16 wheel trucks?”
  - "Why are there two different processes that... are used for the same general output? Is there a property in [diesel fuel] that regular gasoline does not have and thus it does not have the ability to ignite with air even under high temperature and pressure conditions? Or is there more to understanding the difference and why the two different processes were developed? Also, in terms of efficiency I know that the Diesel engine is more efficient, but in what way and why?"
- Important to examine student motivation, or in Derrida's terms, what precedes the question.
- Requires bringing blogs from the reflexive to the interpersonal, and into classroom relationships

Test question revealed critical thinking about entropy, textbook

- Students were asked to critique a textbook passage on entropy analogies - critical thinking, conceptual understanding of entropy, social implications of engineering
- Students were able to do this (median score = 10 / 10).
- Critiqued notion of high and low entropy learners:
  - "The use of entropy as a category that can potentially diminish people labeling them with the stigma of 'disorganized' is definitely a conflict between truth and power... Who determines that a person with memory [difficulties] has more entropy in her life than a person who stores information very easily?"
- Critiqued nationalism in notion of high and low entropy armies
  - "One army that consists of ten divisions is ten times more powerful than ten armies each consisting of a single division... The United States would not be such a powerful country if there were fifty independent countries in its place instead of a single country with fifty states." (Çengel & Boles)
Focus Groups

- 2005, 2006 classes (14 of 29, 6 of 12)
- How are you learning in this class?
  - What strategies for learning is your professor using to help you learn?
  - What strategies for learning are you using?
- How are the blogs helping you learn?
  - Have they changed how you see yourself in relation to engineering?
  - Have they introduced new thoughts?
- What is this class helping you learn to do?
  - How does it fit in with your overall goals?
  - What difference has what you are learning made in your lives?

Critical thinking came up frequently without prompting

- Intellectual Humility: “The class is helping me learn what I don’t know, which is disconcerting for many students, for me it’s sort of humbling, which is a good thing in my case.”
- Improved Problem Solving: “Before I would just dive into problems and try to solve them right away, whereas now before I even start I take a few minutes to look at the problem and just like really think about it. I ask myself about what I know about the problem. It is interesting to me because I have never done this before until this class - I try to see how it all relates together.”
- Interdisciplinary Framework: “Now I am more critical; about the problems we solve, about the issues we cover in class and the discussions we have there also... It was not just the sciences, the technology, and all the math behind it, it was also this other side that helped me develop these critical thinking skills.”
- Connection to Self-Directed Learning: “To me it was all about becoming an empowered learner and with that you learn how to ask questions that will enable you to learn more about thermo and take the class to the next level.”
Concerns

- Desire for certainty
  - “Something that she could do better would be to make it very clear what things you can assume for certain.”

- Time and effort
  - “We’re being tested on critical thinking that she really has not said ok well you have to take this whole idea and look at it this way. You can think it through but it takes so much longer…”

- Content/disciplinary anxiety
  - “If I wanted to be writing essays all the time, I would take an English class… I want more examples and not more essays to write.”
  - In-class dissent: “This [holding up essay] isn’t engineering, THIS [holding up problem set] is engineering!”

Summary and Conclusions

- Engineering educators should define critical thinking to include epistemic awareness, open-ended problem solving, and a critical view of ourselves and the field
- Student engagement with Foucault and pedagogy readings revealed various stages of intellectual development
- Students questioned content, learning process, engineering education, and demonstrated improved critical thinking “in” and “about” engineering, as measured by grades, self-reports, observations
- Critical thinking about engineering can provide a unifying framework bringing together critical thinking in various aspects of engineering
- The role of student motivation in critical thinking is central, requiring both reflection and relationship
Acknowledgments

• Ida Ngambeki, Geraldine Richards, Nathalie Flores for comments
• Participants in the August Liberative Pedagogies workshop at Smith College (Alex Keller, Lisa Armstrong, and Marguerite Harrison) for contributions on teaching Foucault.
• This material is based upon work supported by the National Science Foundation under Grant No. 0448240. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

http://thrall.org/criticalthinking/