Teaching Critical Thinking in (Software) Engineering

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Ariane 5

On June 4, 1996, just 30 seconds after launch, the Ariane 5 rocket slowly began to disintegrate until it finally exploded.

OpenMind Knowledge community
https://www.bbvaopenmind.com/en/technology/innovation/the-5-most-infamous-software-bugs-in-history/

What was the cause?

Old code from Ariane 4. An integer overflow. In this case, an attempt was made to put a 64-bit number into a 16-bit space.

The consequences in the system

These variables, which vary in size in memory, triggered a series of errors that affected all onboard computers and hardware, crippling the entire ship and triggering its self-destruct sequence.

What is Critical Thinking?

- Three approaches to define:
  - Psychological
    - CT related to cognitive skills and understand CT as a process
  - Philosophical
    - Focus on outcome rather than on the process
  - Pedagogical
    - CT is linked to the concept of higher-order thinking from Bloom's taxonomy and located at the higher-order levels of analysis, synthesis, and evaluation

We rely on the psychological approach.

Definition: Critical Thinking

"Critical thinking... means making reasoned judgments" In essence, critical thinking is a disciplined manner of thought that a person uses to assess the validity of something (statements, news stories, arguments, research, etc.)

Beyer, B. K. (1995). Critical thinking. Bloomington, IN: Phi Delta Kappa Educational Foundation.

"Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action".

Scriven, M. & Paul, R. (1996). Defining critical thinking: A draft statement for the National Council for Excellence in Critical Thinking. [Online]. Available HTTP: https://www.criticalthinking.org/pages/defining-critical-thinking/766

Critical doesn‘t mean „finding fault“! Critical Thinking skills refer to higher order cognitive skills to differentiate them from lower order thinking skills.

Consequences of the lack of critical thinking skills in Software Engineering

- Poorly designed software
- Security vulnerabilities
- Inefficient development process
- Poor collaboration
- Lack of innovation

CT skills are essential for success in software engineering.

A lack of CT skills has serious consequences for software development projects.

Challenge

Critical thinking skills are essential in software development.
Can we teach students to think critically?
How to teach students to think critically?

People tend to solve routine problems with habitual solutions .
The problem solver has no conscious awareness of the process.

Critical thinking requires the conscious exertion of mental effort.

Critical thinking framework

- One of the transferable skills.
  - Used across domains of knowledge
- CT includes cognitive skills and dispositions.
  - Dispositions have a critical role for the CT

CT education should focus on the development of skills and dispositions!

Skills	Dispositions
Interpretation	Truth-seeking
Analysis	Open-mindedness
Inference	Analyticity
Evaluation	Systematicity
Explanation	Self- confidence
Self-regulation	Inquisitiveness
	Cognitive maturity

P. Facione, "Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction (The Delphi Report)," 1990.

How to address the development of these skills through education?

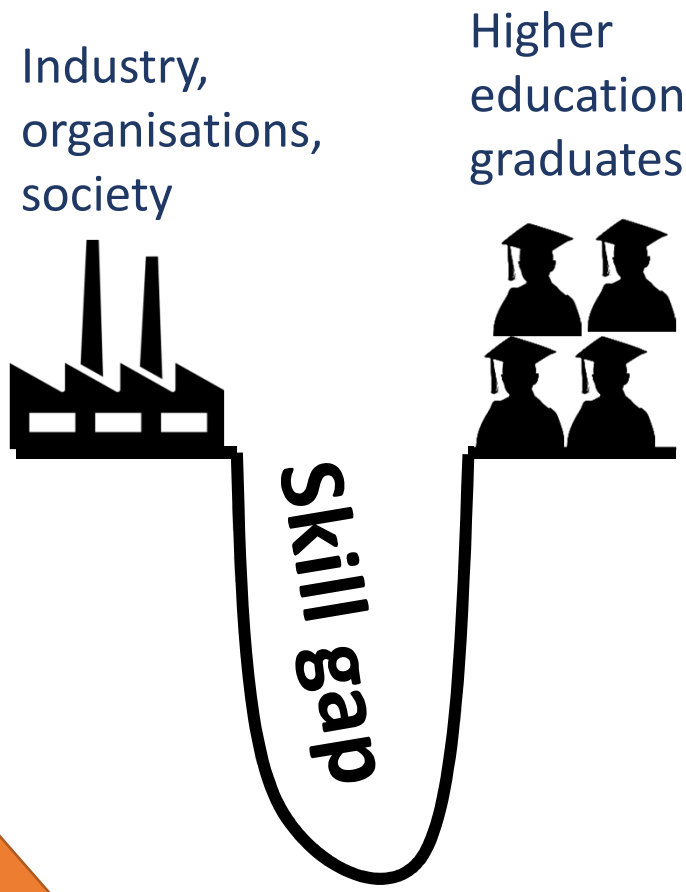
What skills are required in the future?

- Sound subject-specific disciplinary skills
- Software development Practice

Transferable skills

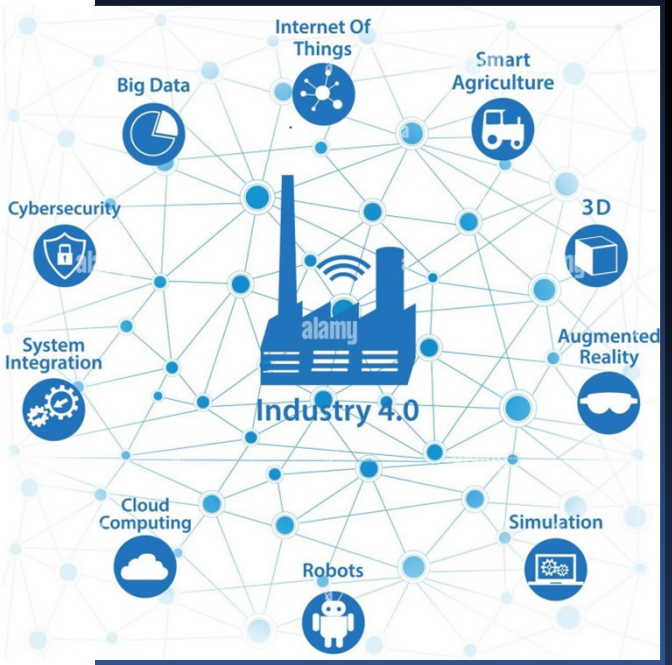
- Critical thinking
- Leadership
- Problem-solving
- Communication skills
- Collaboration in team
- Interdisciplinary thinking
- Creativity/Innovation ...

Transferable skills are strongly intertwined.



Professional focus of software engineers

- Future tasks of software engineers:
  - You plan, design, develop, manage, and apply digital solutions for organisational digitalization/digital transformation.
  - You advance Industry 4.0 & 5.0
  - You collaborate with the professionals from different disciplines inside and outside your organisation



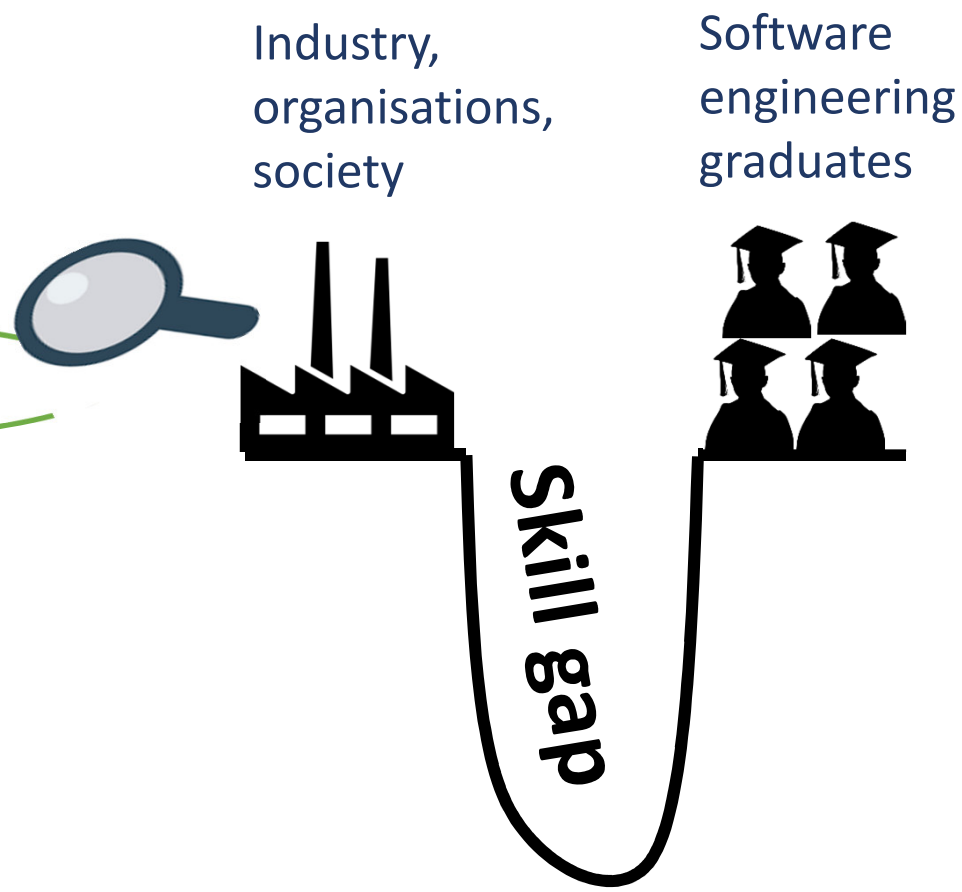
Motivation

What skills are missing?

- Sound subject-specific disciplinary skills
- Software development Practice

Transferable skills

- Critical thinking
- Interdisciplinary thinking
- Problem-solving
- Communication skills
- Collaboration in team
- Leadership
- Creativity/Innovation ...



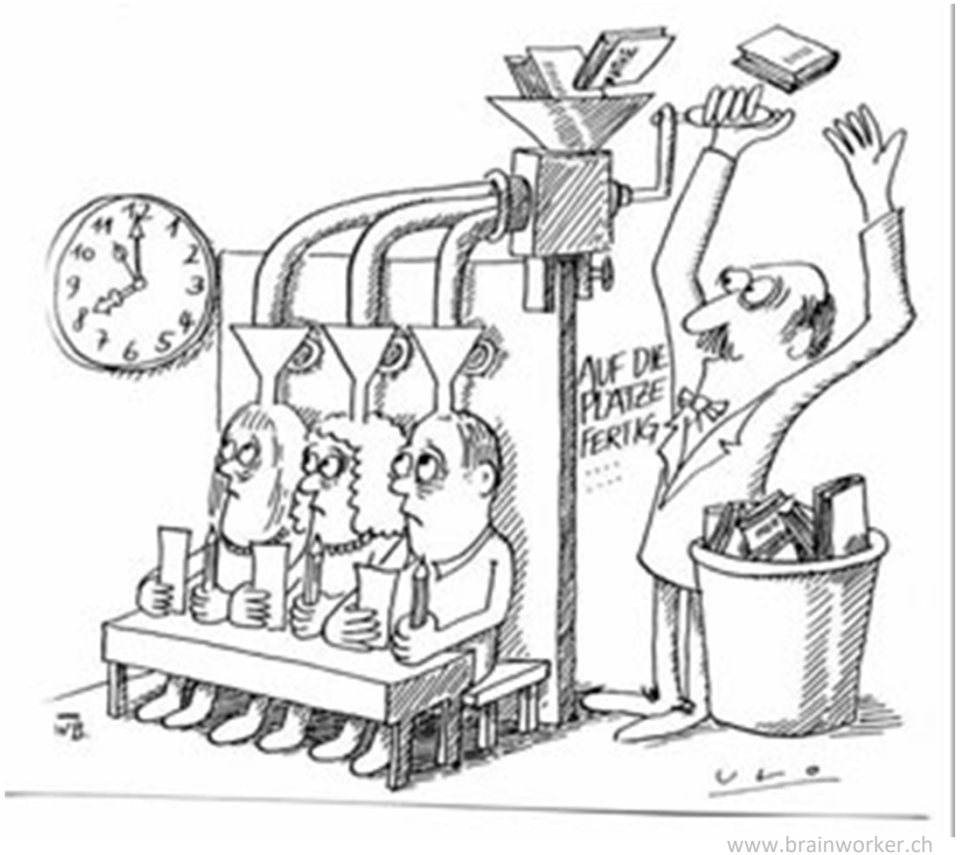
Critical Thinking in Software Engineering

- CT is an essential skill in software engineering as it helps developers to…
  - identify problems,
  - analyze situations,
  - create SW design/architecture and
  - make informed decisions.

We consider critical thinking as a thinking process.

A common teaching practice?

- Why do we teach?
- How do we teach?
- How do we address the development of critical thinking skills?
  (Skills + Dispositions)



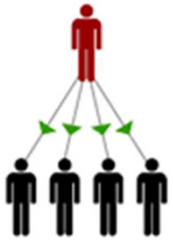
www.brainworker.ch

Goal for teaching: efficiency - maximum result in limited time + help learners to decide when critical thinking is not needed.

Teaching to think critically

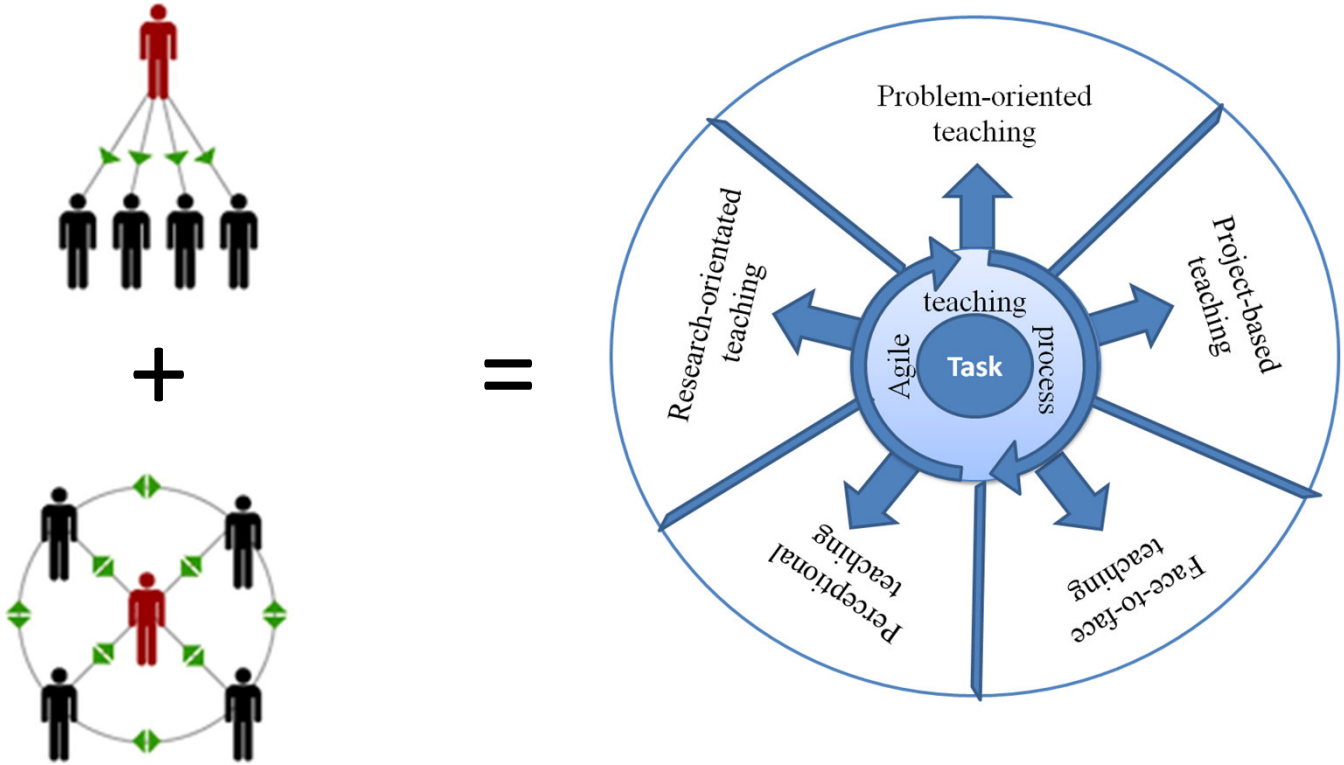
- Thinking is a part of a domain knowledge.
- Focus of teaching mainly on the disciplinary content instead of higher level cognitive skills (such as CT)
  - Not optimal for teaching thinking skills .
- Unique problems of teaching CT require pedagogical approach that focuses not on disciplinaty skills only
- Willingness vs. ability – no value of teaching if the willingness to use CT is lacking.

Conceptions of teaching



	Teacher-centred	Student-centred
Teacher	Transmission of content to students	Creation of a learning environment that helps students to learn
Students	(predominantly) passive-compliant acquisition of content	Active construction of knowledge Active learning – students are involved and engaged Students are responsible for their learning

Teacher-centred + Student-centred

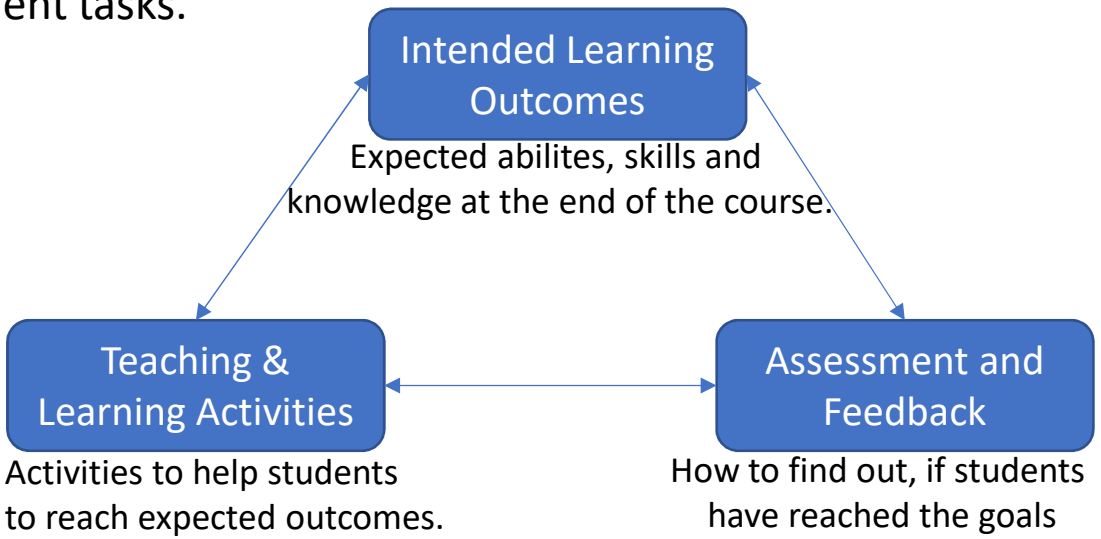


Task-centric holistic agile approach on teaching (T-CHAT)

Constructive Alignment

- **three** central facets of instructional design
  1. intended learning outcomes,
  2. learning activities, and
  3. assessment tasks.

- A high degree of coherence of these facets makes teaching effective and ensures learner-centred deep learning



From Biggs, J. B., & Tang, C. (2007). Teaching for quality learning at university: What the student does.

Intended learning outcomes

- Outcomes-driven and competency-based education
  - intended learning outcomes are formulated in the form of predetermined competencies, which can be both disciplinary and transferable (Schaeper, 2009)
- Description of outcomes from students perspective (what expected to learn?)
  - Overall objectives for a curriculum or module OR
  - specific objectives for individual teaching sessions.

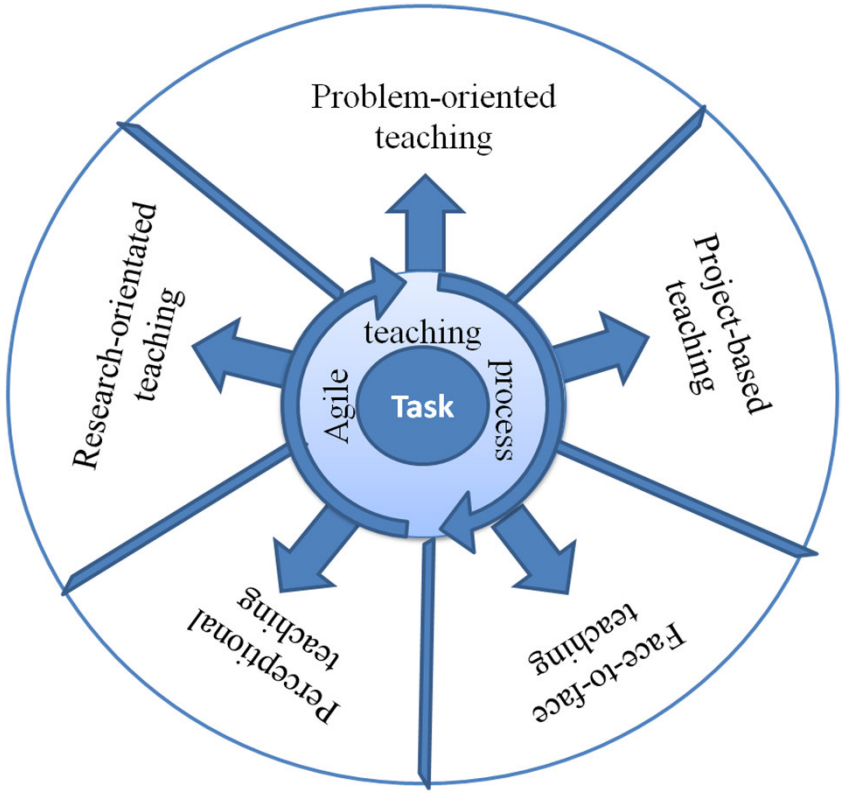
Instructional Design

Phase	Activities
Analyse	Analyse the requirements for the curricula. Define teaching strategy.
Design	Design the curricula using the selected instructional design model. Specify learning outcomes in the form of competencies. Introduce a learning scenario. Describe learning activities and assessment tasks.
Develop	Review and refine the curricula. Create the required resources and materials to support learning in the curricula. Prepare the curricula on Moodle.
Implement	Deliver the curricula.
Evaluate	Conduct pre-, middle-, and post-tests of students. Analyse the students' responses and present the results.

Branch & Kopcha, 2014

The Instructional Design

- Division of the subject matter into several blocks to teach:
  - Introduction of subject-specific concepts using the perceptional approach.
  - Processing of a task/problem by students (individually or in group).
  - Discussion of the problem-solving and thinking process and results using Socratic questioning and dialogue.
  - Introduction of general CT principles and aspects or reminder of them if they have already been introduced.



Critical Thinking Teaching Strategies

- **Immersion approach:** Integrates CT in subject-matter instruction. General CT principles are not made explicit. Course's content is important. Instruction is thought provoking. Sternberg, 1986; Ennis, 1989
- **Infusion approach:** CT is integrated in subject-matter instruction. General principles of CT are made explicit. Course's content is important.
- **Mix approach:** a hybrid between immersion and infusion approaches. Subject specific CT instruction + teaching of general principles of CT. CT is taught as an independent track within a specific subject. Content course.
- **General/ stand-alone approach:** CT abilities and dispositions are taught separately from the content. CT skills are best taught separately from subject matter content, although content may be included as part of the program.

Learning activities….

- .. are all what students do for their learning
- … need to be designed and planned carefully
- … focus on identifying and applying transferable thinking skills to prepare students for the unknown challenges of their future.
- Most critical components of the education to teach students:
  - the ability to think clearly and
  - the disposition to engage in the effortful process of thinking are the

How to teach critical thinking?

- **Explicitly address** the development of CT skills in the subject-specific modules.
  - Integrate teaching of these skills into subject-specific teaching.
  - Introduce general aspects of CT to students.

- A real-life **Task** is a central element of learning activities.
  It addresses the development of both subject-specific and transferable skills

- **Equal focus on teaching and learning**

Teacher-centred teaching

- Presentations of content and key concepts

Student-centred learning

- Group work
- Project-based learning
- Problem-based learning

Example 1: Interpretation

Skills
Interpretation
Analysis
Inference
Evaluation
Explanation
Self-regulation

- Description Facioni:
  - To comprehend and express the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, or criteria
- Questions Facioni:
  - What does this mean? What's happening? How should we understand that? What is the best way to classify this? In this context, what was intended by saying/doing that? How can we make sense out of this (experience, feeling, or statement)?
- Example scenario:
  - Create a class model for a given situation and justify why this model satisfies the given requirements.
  - Compare various solutions and value them.
  - Find alternative to your solution and value them.

Example 2: Analysis

Skills
Interpretation
Analysis
Inference
Evaluation
Explanation
Self-regulation

- Description Facioni :
  - To identify the intended & actual inferential relationships among statements, questions, concepts, descriptions, or other forms of representation intended to express belief, judgment, experiences, reasons, information, or opinions (P. Facione, 1990)
- Questions Facioni:
  - Tell us again your reasons for making that claim. What is your conclusion/What is it that you are claiming? Why do you think that? What are the arguments pro and con? What assumptions must we make to accept that conclusion? What is your basis for saying that? (P. Facione, 1990)
- Example scenario:
  - Given a solution to a problem. What are the advantages and disadvantages of the solution and why?
  - What aspects of the given problem might change in the future and how robust is the given solution to the changes?

Conclusion

- CT can be effectively thought – but it needs time to teach and to learn.
- Plan your curricula carefully.
- Use tasks to teach CT.
- Mix the teaching of CT and other transferable skills with the teaching of dicilinary knowledge
- CT dispositions play a crucial role in the teaching.
- Both disciplinary skills and transferable skills are needed – focus on both.

Thank you!
Questions?