SAND2010-5834C

Critical Thinking and The Scientific Method

Instructor:
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Critical Thinking & Scientific Method
(Main Teaching Points)

- Main Teaching Points
  1. Define Critical Thinking
  2. Principles of Critical Thinking
  3. Role of Critical Thinking in Problem Solving
  4. Scientific Method: Formalized Critical Thinking
  5. Critical Thinking Relation to System Thinking

Critical Thinking & Scientific Method
(Key Terms, Key Concepts, Desired Outcomes)

- Key Terms – Critical Thinking, Scientific Method, System Thinking
- Key Concepts – Critical Thinking, Scientific Method
- Desired Student Outcomes:
  1. Understand the Meaning of Critical Thinking and Its Principles
  2. Understand Role of Critical Thinking in Problem Solving
  3. Use Scientific Method to Formalize Consistent Application of Critical Thinking in Problem Solving
  4. Understand the Relationship Between Critical Thinking and System Thinking.

Critical Thinking & Scientific Method
(Assumptions and Prerequisites)

- This will be the first lecture on week 1
  - No previous GNEII lectures
- General requirements for admission into the GNEII program
  - Undergraduate degree in the physical or social sciences
  - Proficiency in English (reading, writing, conversation) - to pass a typical TOEFL: **Test** of **English** as a Foreign **Language** or equivalent

Introduction

- Three types of Thinkers (Ref. 1, Page 3)
  - Naïve Thinker
  - Selfish Critical Thinker
  - Fair-minded Critical thinker

Types of Thinkers

Naïve Thinker (Ref 1, page 6)

- Believes he/she does not need to think
- Believes most of what he/she hears
- Does not question the message
- Does not need/want to figure things out – just ask others
- Figuring things out is a lot of work / takes too much time for him/her
- Believes thinking gets one into trouble

Types of Thinkers

Selfish Critical Thinkers (Ref 1, page 5)

- Use thinking to get what they want
  - No consideration for how their actions might affect others
- Are good at thinking, but are selfish
- Think a lot!!
- Question only opposing views / ideas / beliefs
- Manipulate others
- Tell people what they want to hear – eve if it is not true

Types of Thinkers

Fair-minded Critical thinkers (Ref 1, page 4)

- Work to improve their thinking whenever they can
- They are generous
  - Willing to give up things to help other – when it makes sense to do so
- They think a lot!
- Want to understand what other people think
- Do not always believe what others say
  - Try question and understand other people's motives

Develop Intellectual Character (Ref. 1, page 7)

These traits define how Fair-minded Critical Thinkers live their lives
- **how they learn,**
- **how they communicate**
- **how they see the world**

Fair-minded Critical Thinkers Want to Develop An Intellectual Character

Become a Fair-minded Critical Thinker (Ref 1, page 8)

Intellectual Integrity

- Act toward others the way you want others act towards you
- Respect Others
- Do not expect others to act better than you do

Become a Fair-minded Critical Thinker (Ref 1, page 8)

Intellectual Independence

- Do your own thinking
- Figure out things yourself
- Be a good listener
- Use intellectual standards to decide what to believe
  - Accuracy
  - Relevance
  - Significance
  - Fairness

Become a Fair-minded Critical Thinker (Ref 1, page 8)

Intellectual Perseverance

- Do not be a quitter
- Do not be afraid to work hard
- You can always improve on your thinking
- Keep learning

Become a Fair-minded Critical Thinker (Ref 1, page 8)

Intellectual Empathy

- Try to understand how others feel and think
- Try to see things from others' point of view
- Remember some things you are right about, and some things others are right about

Become a Fair-minded Critical Thinker (Ref 1, page 9)

Intellectual Humility

- Recognize that you don not know everything
- Thing are not true until you they are
- Always ask:
  - How Do I know this is true
  - Ask others, "How do you know that is true?"

Become a Fair-minded Critical Thinker (Ref 1, page 9)

Intellectual Courage

- Speak up for what you think is right
  - Use your best thinking to decide when is the right time to speak up
  - Always be respectful of others when you speak up, but
  - Do not be afraid to disagree
- Hold a belief but be willing to question it

Become a Fair-minded Critical Thinker (Ref 1, page 9)

Confidence in Reason

- When in disagreements, over come them by looking at the facts and evidence
- Work together to come to the most defendable conclusions
- Use information that is *accurate and relevant*
- *Look for the complexities in deep issues*
- *Trust evidence, facts and reasoning*

Become a Fair-minded Critical Thinker (Ref 1, page 9)

Fair-mindedness

- Think about everyone involved
- Do not put your desires about others'
- Be willing to give up things to help others
- Think before you act
- Do not act before you think

How to Be a Better Thinker (ref 1, page 10)

- Do not believe everything you hear or read
- Use intellectual standards to decide what to believe
- Intellectual Standards
  - Be Clear
  - Be accurate
  - Be relevant
  - Be logical
  - Be fair
  - Be reasonable

How to Be a Better Thinker (Ref 1, pages 10-11)

Be Clear: Understand:

- What you are saying
- What you are hearing
- What you are reading
- What you are seeing
- Tell other what you think they say – ask for confirmation

When not things are not clear, ask for:

- Examples
- Explanation in other words

How to Be a Better Thinker (Ref 1, page 12)

Be Accurate: Make sure it is true – it is not distorted

- Ask these questions to make sure you are accurate
  - How could we find out if this really true?
  - How can we check this?
  - How can we test this idea to see if it is true?
  - How do I know what I am saying is true?
  - How do I know what I read on the internet is true?
  - How do I know the information in this book is true?
  - How do I know what others say is true?
  - How can I find out for myself if something is true?

How to Be a Better Thinker (Ref 1, page 13)

Be Relevant: make sure you stay on track

- Something is relevant when it relates directly to:
  - The problem you are trying to solve
  - The question you are trying answer
  - Whatever you are talking about or writing about

How to Be a Better Thinker (Ref 1, page 13)

Be Relevant: make sure you stay on track

- Ask these questions when you not sure if something is relevant:
  - How does what you say relate to the problem?
  - How does this information relate to the question we are asking?
  - What will help us solve the problem?
  - How does what you say relate to what we are talking about?
  - How does this relate to our purpose?

How to Be a Better Thinker (Ref 1, page 14)

Be Logical: Make sure everything makes sense together

•Ask these question when not sure if something is logical

- Can you show me how it all fits together?
- How can I rewrite this paragraph so that the sentences all fit together?
- How did you come to your conclusion? Explain why this makes sense.
- An idea does not make sense. Should I follow it or should I reject it?

How to Be a Better Thinker (Ref 1, page 15)

Be Fair: Make sure you consider others

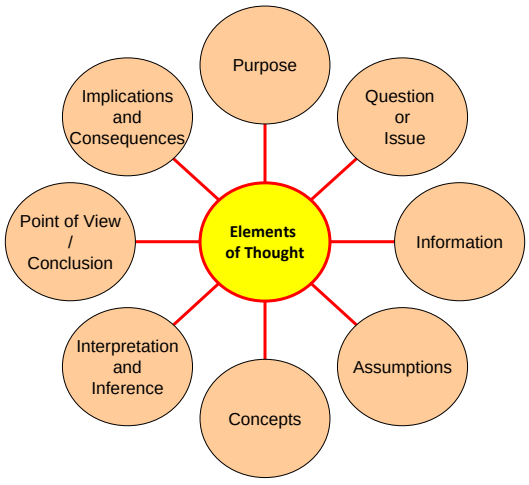
- Ask these question when you are not sure if you or someone else is being fair:
  - Am I being selfish?
  - Is someone else being selfish?
  - Am I considering the thinking of others?
  - Am I considering the feelings of others?
  - Are we being fair to everyone in this situation?

How to Be a Better Thinker (Ref 1, page 10)

Be Reasonable

- Ask this question:
  - Have thought through this problem and with an open mind?

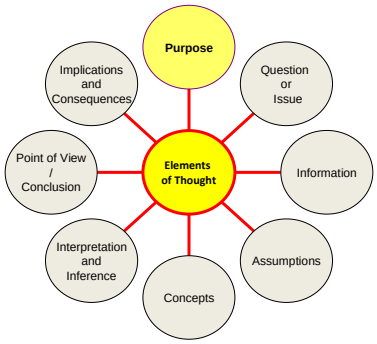
Elements (Parts) of Thinking (Thought System)



Elements (Parts) of Thinking (Thought System)

Think about PURPOSE
It is what we are trying to achieve or make happen

Typical questions to ask
1. What is the purpose of this lecture?
2. What is the purpose of GNEII?

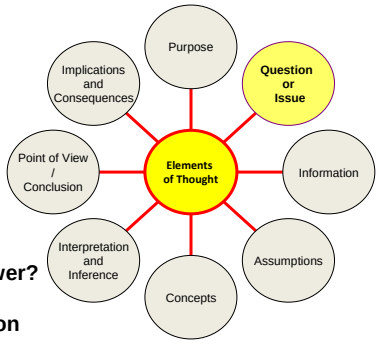


What is your purpose for enrolling in the GENII program?

Elements (Parts) of Thinking (Thought System)

Sate the QUESTION
- **Lays out the problem and helps us understand what we need to do to solve it**
- **Good thinkers state the question at issue as clearly as possible**

Typical questions to ask
- **What question are we trying to answer?**
- **Is our question clear?**
- **Should we asking a different question**



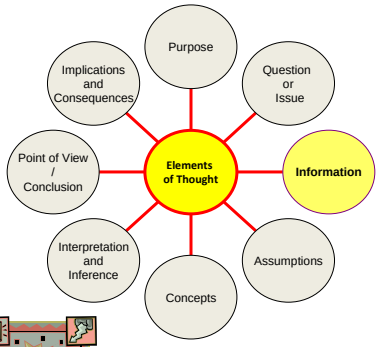
Elements (Parts) of Thinking (Thought System)

Gather the INFORMATION

- **The facts, evidence, or experiences we use to figure things out**
- **We get information from many sources – caution: lots of information is not accurate!**

Typical questions to ask

- **What information do we need to answer this question?**
- **Is this information relevant to our purpose?**
- **Is this information accurate?**



What information did you gather before enrolling in the GNEII Program?

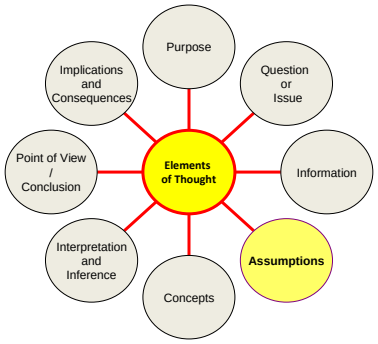
Elements (Parts) of Thinking (Thought System)

Question your ASSUMPTIONS

- **The beliefs we take for granted**
- **We usually do not question our assumptions, but we should**

Typical questions to ask

- **Are we assuming something that we should not?**
- **What assumptions lead us to this conclusion?**



What assumptions did you make when you decided to enroll in the GNEII Program?

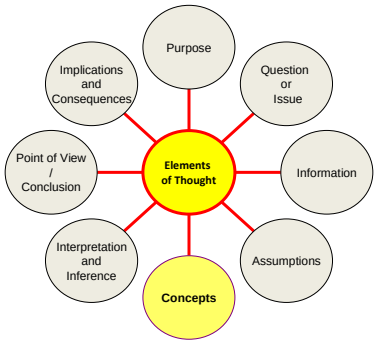
Elements (Parts) of Thinking (Thought System)

Clarify your ASSUMPTIONS

- **Ideas we use to understand what is going on and to figure out how to act in a situation**
- **Good thinkers are aware of the key ideas they are using in their thinking**
- **Examples: concept of "healthy foods" – fruits and vegetables**

Typical questions to ask

- **What idea comes into our minds when we hear the word 'school,' 'friend,' 'peace,' __?**



What is your concept of a "good training"?

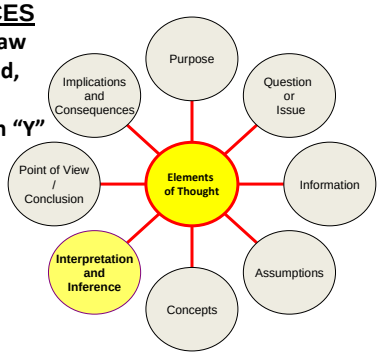
Elements (Parts) of Thinking (Thought System)

Check your INTERPRETATIONS/INFERENCES

- **These are extrapolations and extensions we draw based on our concepts – If someone is my friend, then I infer I can trust him/her**
- **Example: When our mind say If "x" is true, then "Y" is true – this is an inference.**

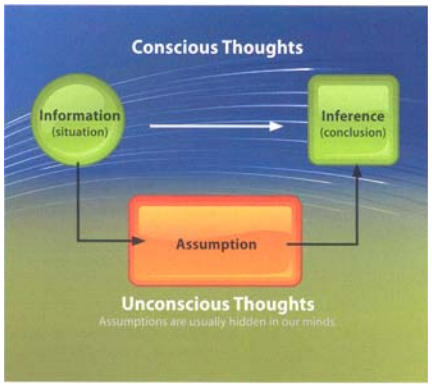
Typical questions to ask

- **Are there other inferences that we should consider?**
- **Is our inference logical?**



Difference between Inferences and Assumptions

- Assumptions are beliefs
  - Usually unquestioned and,
  - Not based on information
- Inferences are based on information
  - Even though they are interpreted from information
  - We use them to give meaning to the data / information



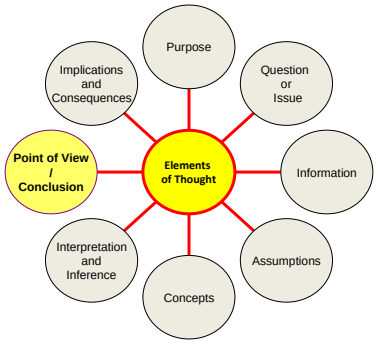
Elements (Parts) of Thinking (Thought System)

<u>Understand your POINT OF VIEW / CONCLUSION</u>

•We form our point of view or draw based on data using our inferences and interpretations
•There could be many different views and conclusions based on the same data / information

<u>Typical questions to ask</u>

- **To what extend do the data support our conclusions?**
- **Are our inferences consistent with each other?**

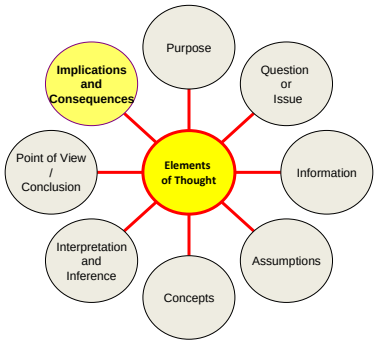


Elements (Parts) of Thinking (Thought System)

Think through IMPLICATIONS / CONSEQUENCES

•Our thinking or actions lead us to implications and consequences

•When we make promise we imply that we keep it



Typical questions to ask

- **What implications and consequences follow from our thought or action?**
- **If we accept a line of reasoning, what implications and consequences are likely ?**

What implications and consequences follow from your participation in the GNEII Program?

Discussion of your answers

- Read your answers to the questions
- Class discussions on the answers
  - All students to comment on the answers
  - Were the answers clear and relevant?
  - Did we exercise critical thinking?
  - How can we improve our thinking – become better thinkers?

Fair-minded Critical Thinking and System Solution Approach

- Most issues and problems we face today are very complex
  - involve multidisciplinary technical, social, economical, cultural, and political aspects
- We will use a System Solution Approach to address or solve these issues and problems
- Fair-minded Critical Thinking is an essential requirement of System Solution Approach

Critical Thinking and System Solution Approach

- We start with definition of “System”
- Introduce the traits / composition of a system
- Point to connections between Fair-minded Critical Thinking and traits / composition of a system

System Thinking (Ref 5)

What is a System?

According to *The Random House Dictionary of the English Language. 2nd ed. (New York: Random House, Inc., 1994):*

"A system is an assemblage or combination of elements or parts forming a complex or unitary whole, such as a river system or a transportation system;

- *any assemblage or set of correlated members, such as a system of currency;*

System Thinking (Ref 5)

What is a System?

According to *The Random House Dictionary of the English Language. 2nd ed. (New York: Random House, Inc., 1994):*

- *an ordered and comprehensive assemblage of facts, principles, or doctrines in a particular field of knowledge or thought, such as a system of philosophy;*
- *a coordinated body of methods or a complex scheme or plan of procedure, such as a system of organization and management;*
- *any regular or special method of plan of procedure, such as a system of marking, numbering, or measuring."*

System Thinking (Ref 5)

What is a System?

However; Not every set of items, facts, methods, or procedures is a system; For example:

A random group of items in a room would constitute a set with definite relationships between the items, but it would not qualify as a system because of the absence of unity, functional relationship, and useful purpose.

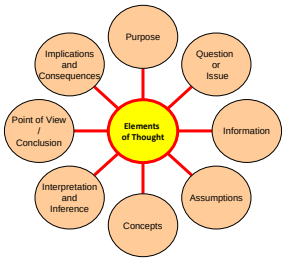
System Thinking (Ref. 5)

Systems are composed of components, attributes, and relationships. These are described as follows:

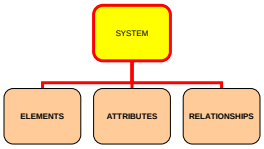
- ***Components:*** are the operating parts of a system consisting of input, process, and output. Each system component may assume a variety of values to describe a system state as set by some control action and one or more restrictions.
- ***Attributes:*** are the properties or discernible manifestations of the components of a system. These attributes characterize the system.
- ***Relationships:*** are the links between components and attributes.

Critical Thinking versus System

- Thought and a typical System
- Commonalities
  - Elements
  - Attributes
  - Relationships
- More on Critical Thinking Relation to System Thinking Later in The Lecture



Thought System



A Typical System

Attributes of Elements of Thought

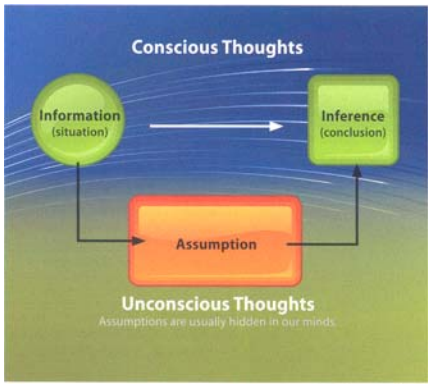
Element	Attributes
Purpose	• *Purpose is clearly stated* • *Objective is clearly stated* • *Focus is on the goal* • *Goal is realistic*
Question or Issue	• *Question is clearly stated* • *Question could be divided into sub-questions* • *Both facts and judgment may be required to solve the problem*

Attributes of Elements of Thought

Element	Attributes
Information	• *Information is based on accurate data* • *Information is relevant to the question /issue* • *Information is sufficient to reach a reasonable conclusion*
Assumptions	• *Assumptions clearly stated* • *Assumptions must be justified* • *Might be reasonably questioned* • *Impact the outcome*

Assumptions Impact the Outcome

- Assumptions are beliefs
- Clarify your assumptions
- Question your assumptions
- Justify your assumptions



Attributes of Elements of Thought

Element	Attributes
Concepts Theories	• *Guide the reasoning and solution development* • *Substantiate alternative solutions* • *Foundations on which solutions are built*
Interpretation Inferences	• *Bridge the data and information to solution* • *Must remain consistent through out the process* • *Could be numerous and varied*

Attributes of Elements of Thought

Element	Attributes
Conclusion Point of View	• *Must be supported by data and information* • *May have weakness (or weaknesses)*
Implications Consequences	• *All solutions and conclusions will have implications and consequences* • *Likely implications and consequences must be clearly stated*

Critical Thinking and a Typical System

- Relationships
  - Elements of Critical Thinking interact with each other
    - Change or perturbation of each element will change or perturb other elements and conclusions
  - Similarly, elements of a typical system interact with each other
    - Change or perturbation of each element will change or perturb other elements and the system outcome (output)

Connection of Fair-minded Critical Thinking to System Solution Approach

- System Solution Approach as applied to complex problems / issues require:
  - Intellectual Character
  - Intellectual Standards: Clear, accurate, logical, and fair thinking
  - Use of Scientific Method as tool for consistent application of Fair-minded Critical Thinking

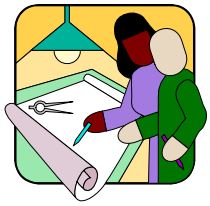
Critical Thinking and a Typical System

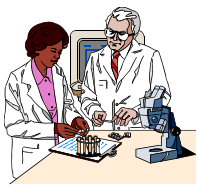
- Conclusion:
  - Critical Thinking is a trait of system thinking
  - Principles of Critical Thinking support a system solution approach
- Next: Scientific Method
  - A tool for implementation of Critical Thinking elements

Scientific Method

Q: What is Scientific Method?

A: A means or manner of procedure that scientists use to conduct their research and work. It is a systematic way of accomplishing goals of any research.

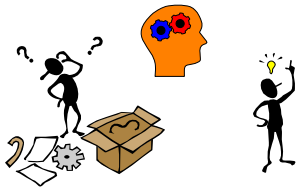




Scientific Method

Q: What is the Goal of a Research or Scientific Work?

A: Ask a question, find an answer and Compare the Answer to What Scientists Already Know About the World.



Q: Can this be applied to social or political "Sciences"?

Scientific Method

1. **Ask a question or state a problem.**
2. **Propose an "Educated " answer /opinion/ view for /on the question /issue/topic/ or solve the problem (Hypothesis).**
3. **Provide supporting arguments / evidence for your answer /opinion/ view AND those against ;**
   - **Provide arguments other views – why you disagree? Why they will not work? What are their risks / un-intended consequences?**
4. **Summarize your analyses/ results; and provide potential challenges with implementation/adoption of your answer /opinion/ view**
5. **Draw (make) Conclusions *(How does the conclusion compare to the hypothesis?).***

Scientific Method: How to Start?

"The greatest challenge to any thinker is stating the problem in a way that will allow a solution."

(Bertrand Russell)

- Clearly state the problem / or issues
- Is the problem solvable?
- Is the issue focused enough to allow a manageable system solution approach?

Scientific Method: How to Develop a Hypothesis?

- *Educate yourself on the topic by researching the existing information on the topic (develop a background);*
- *"Best Educated Guess", that is, a "Hypothesis", is developed based on this research on the subject;*

The key is to educate oneself before guessing!

Scientific Method: Test Your Hypothesis

- **Note**: Remember you are NOT trying to PROVE that your HYPOTHESIS is CORRECT; you are trying to find the real answer.
- Your research/experiment must be doable, relevant to your hypothesis, and repeatable.
- Clearly identify and examine the variables: 1) Independent Variables , and 2) Dependent Variables
- Clearly identify the data or information to be recorded before, during, and after your research/experiment. Record data AND observations.

Scientific Method: Analyze the Test Results

- Determine what the results of the experiment / research show:
  - Use Tables, Charts, and Graphs to organize and display the results.
  - Utilize any additional observations you made.
- Try to explain any discrepancies if possible. It is not unusual for the results of an experiment / research to raise additional questions, some of which can be answered by additional experimentation / research.

Scientific Method: Draw Conclusion

- **Reach a conclusion based on your data and analysis.**
- **Does the data support your hypothesis? If so, to what degree (give a brief sentence). If not, what does it show? Explain in one or two brief sentences.**

Scientific Method: Prepare Paper / Presentation

The presentation must have the following sections:

- State the question, the problem, or the issue.
- State your hypothesis and reasoning behind it,
  - Show the information you researched and used in developing your hypothesis
- Describe your experiment / research method and procedures / process
  - Critical requirement: Research and arguments MUST BE RELEVANT to the issues / topic / view / position
- Present a summary of your results (graphical, tabular)
  - Don't forget your observations
- State your conclusion (s) AND challenges / implications.

References

1. The Aspiring Thinker's Guide to Critical Thinking by Dr. Linda Elder and Dr. Richard Paul; The Foundation for Critical Thinking
2. The Thinker's Guide to Engineering Reasoning by Dr. Linda Elder, Dr. Robert Niewoehner, and Dr. Richard Paul, and ; The Foundation for Critical Thinking
3. The Miniature Guide to Critical Thinking, Concepts and Tools, by Dr. Linda Elder and Dr. Richard Paul; The Foundation for Critical Thinking
4. Critical Thinking, Tools for Taking Charge of Your Professional and Personal Life, by Dr. Linda Elder and Dr. Richard Paul; The Foundation for Critical Thinking
5. B. S. Blanchard and W. J. Fabrycky; "System Engineering and Analysis," Third Edition, 1998.

Supplement to Lecture

List of Required Texts

The following books and material will be the required:

1. The Aspiring Thinker's Guide to Critical Thinking by Dr. Linda Elder and Dr. Richard Paul; The Foundation for Critical Thinking
2. The Thinker's Guide to Engineering Reasoning by Dr. Linda Elder, Dr. Robert Niewoehner, and Dr. Richard Paul, and ; The Foundation for Critical Thinking
3. The Miniature Guide to Critical Thinking, Concepts and Tools, by Dr. Linda Elder and Dr. Richard Paul; The Foundation for Critical Thinking

Assignments, activities, exercises

- Some activities are listed in the note-pages below each slide. See for example the note-pages for slides on Elements (Parts) of Thinking (Thought System)
- Provide a copy of an article and a technical paper to the students, and
  - Have them evaluate and analyze them using the templates in the references – at the instructor's discretion and based on the students' interests and backgrounds

Assignments, activities, exercises

- Complete the following activities in reference 1.
  - Pages 30-31
  - Page 32 (PM activity)
  - Pages 34-35
  - Ask questions in class which target the Elements of Thinking (Page 43)
- From reference 2:
  - Reading assignment on Pages 16-17
  - Read the two stories on pages 39-40 and page 41
    - Discuss what parts of thinking were crucial in the success story and the missing ones in the failure example
    - Students must write a one-page summary of the discussions and submit it for grading