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Types of Reasoning

As mentioned elsewhere (in other documents distributed as part of IIE-2015), what is presented to students as knowledge in school and college textbooks and classrooms is expected to be forms of rational knowledge. This is distinct from traditional knowledge, religious knowledge, commonsense knowledge, dogma, opinion, and intuition.

*Rational knowledge* is a body of rationally justified *conclusions* that we judge to be true beyond reasonable doubt. To understand what rational knowledge is, then, we need to understand what rational justification is.

After briefly examining reasoning in Chapter 4 “Reasoning” (Learning Trigger 4 A1), we identified the components of rational justification as grounds, background assumptions, steps of reasoning, and conclusions, in Chapter 8 “Justifying” (Learning Trigger 6A1). Let us now look at reasoning in some more detail, and examine the different *types* of reasoning we use in the rational justification of conclusions, in mathematical, scientific, and humanistic inquiries.

1. Deductive vs. Inductive Reasoning

If someone told us that Zeno has a beak, we would conclude that Zeno is a bird. If someone told us that Xetus has four legs, we would conclude that Xetus is not a bird. What is the rational justification for these conclusions?

We may articulate the justification as:

**Example 1**

All living organisms that have beaks are birds. (what we know)
Zeno has a beak. (what we are told)
Hence, it is reasonable to conclude that Zeno is a bird.

**Example 2**

No bird has four legs. (= All organisms with four legs are non-birds.) (what we know)
Xetus has four legs. (what we are told)
Hence, it is reasonable to conclude that Xetus is not a bird.

The propositions, ‘all creatures that have beaks are birds,’ and ‘no bird has four legs,’ are grounds we are presenting to support our conclusions, as part of our rational justification. But suppose someone asks: “Why do you believe that all creatures with beaks are birds, and that no bird has four legs? What is the rational justification for these beliefs?”

Our response would be:
Example 3
We have examined a large sample of birds, and noted that every bird in our sample has a beak.
Hence, until we find evidence to the contrary, it is reasonable to conclude that all birds have beaks.

Example 4
We have examined a large sample of birds, and noted that not a single bird in our sample has four legs.
Hence, until we find evidence to the contrary, it is reasonable to conclude that no bird has four legs.

The reasoning in examples 1 and 2 illustrates what is called **deductive reasoning**, while the reasoning in examples 3 and 4 illustrates what is called **inductive reasoning**.

To get a handle on the difference between the two, notice that:
In 1 and 2, the reasoning begins with a generalization on a population (that of living organisms), and arrives at a conclusion on a particular sample in the population (Zeno in 1; Xetus in 2).

In 3 and 4, in contrast, the reasoning begins with a generalization on a sample of a population, and arrives at a conclusion on the population.

So we can view inductive reasoning as reasoning from sample to population. In the diagram below, the ellipse represents the population, and the circle inside it represents the sample.

**Inductive Reasoning**

We may now view the reasoning in the other direction, namely, reasoning from the population to the sample, as a case of deductive reasoning:

**Deductive reasoning**

Another way of characterizing the distinction would be: inductive reasoning is reasoning from the particular to the general; while deductive reasoning is reasoning from the general to the particular.

A word of caution. Reasoning from the general to the general, and from the particular to the particular, also come under deductive reasoning. Thus, the following examples are instances of deductive reasoning:
Example 5
All birds have beaks.
All birds have two legs.
Therefore it is reasonable to conclude that all birds have beaks and two legs.

Example 6
Plato is taller than Socrates.
Aristotle is taller than Plato.
Therefore it is reasonable to conclude that Aristotle is taller than Socrates.

The reasoning we use in making mathematical calculations and proving mathematical theorems is deductive reasoning. Mathematical inquiry does not permit any form of reasoning other than deductive reasoning. In contrast, the reasoning we use in scientific inquiry, to arrive at observational generalizations from a sample of data points, is inductive reasoning. Rational justification in scientific inquiry appeals to a wider range of reasoning than is permitted in rational justification in mathematical inquiry.

Exercise 1
Suppose we have the information that Simi is an adult human being. If someone asked us how many hearts Simi has, we would say, ‘One.’ What is the rational justification for this position? Would you use deductive reasoning or inductive reasoning for this?

Exercise 2
How would you rationally justify the claim that every adult human being has exactly one heart? Would you use inductive reasoning or deductive reasoning?

Exercise 3
Suppose you get the information that Synergy Stadium is circular in shape, and its diameter is 1000 meters. What is its area? Do you use deductive reasoning or inductive reasoning to arrive at your answer?

Notice that the conclusions in examples 3 and 4 have a caveat: they go with a willingness to correct the conclusions: “until we find evidence to the contrary.” Not all forms of inductive reasoning have this caveat; but some do. It is important to note that this is never used in deductive reasoning. In fact, the concept of ‘evidence’ does not play a role in deductive reasoning. We will return to some of these interesting features in later sections.

2. Deductive vs. Abductive Reasoning

Compare the reasoning in the following examples:

Example 7
Fire causes smoke.
There is fire on that mountain.
Therefore, it is reasonable to conclude that there is/will be smoke on that mountain.
**Example 8**

Fire causes smoke.
There is smoke on the mountain.
Therefore, until we find evidence to the contrary, or an alternative cause, it is reasonable to conclude that there is/was fire on the mountain.

Example 7 has two premises: a general proposition (“Fire causes smoke.”) and a particular one (“There is fire in the mountain.”). Along with the conclusion, it is a classic example of deductive reasoning.

Example 8 also has two premises: a general proposition (“Fire causes smoke.”) and a particular one (“There is fire in the mountain.”). But, while 7 infers effect (smoke) from cause (fire), 8 reverses this direction, and infers cause from effect. This is an instance of **abductive reasoning**.

Notice the caveat in example 8: “until we find evidence to the contrary, or an alternative cause.” Awareness of alternatives is a feature that distinguishes abduction, as well as speculative-deduction (to be discussed in the next section), from deduction.

The dialogue in the chapter “Justifying” (LT 6A1) between Zeno and Athena (reproduced below, with its parts marked) is an example of the use of abductive reasoning.

**Part 1**

Z: Hi Athena, I’ve just examined the body I told you about. This death was not an accident or a suicide: it was a murder.
A: What makes you say that, Zeno?
Z: There is no water in the lungs.
A: So?
Z: When a person dies by drowning, there is always water in the lungs, because of the victim’s gasping for air. Water doesn’t get into the lungs if the person is already dead. So it has to be that this person died first, and the body hit the water afterwards.
A: Makes sense. That rules out the suicide hypothesis. But...

**Part 2**

Z: But what?
A: It only means that he died first and hit the water later. He could have fallen into the well because he had a heart attack when standing at its edge. What makes you say that he was killed by someone? What evidence do you have?

**Part 3**

Z: Well, let us see. If you are right, this was an accidental death. If so, he must have been standing close to the edge of the well when he had the heart attack, and death must have been instantaneous.
A: That’s right.
Z: Hmmm, this is not impossible. But the probability is very low.
A: Oh! (About to say something, but Zeno interrupts.)
Z: Also during the postmortem, I found blue bruise marks around his neck, the kind that we find when a person is strangled.
A: Ah, I see now! If we assume that he was strangled, we have an explanation for the bruise marks.
Z: Exactly. And otherwise, there is no explanation. Bruises on the neck, absence of water in the lungs: they pretty much force us to conclude that he was murdered.

The conjecture (claim/conclusion/hypothesis) that Zeno seeks to prove (defend/argue for/provide evidence and reasoning for) is:

Conjecture: The death was the result of murder, not accident or suicide.

Zeno’s argument in part 1 is as follows:

Grounds:
General Theory: When a person dies by drowning, there is always water in the lungs, because of the victim’s gasping for air. Water doesn’t get into the lungs if the person is already dead.

Data point 1: There is no water in the lungs.

Explanation within the theory: If we assume that the person died first and then fell into the water, we can explain why there is no water in the lungs. However, if we assume that the death was due to drowning, our general theory predicts that there is water in the lungs. This prediction is false.

Conclusion: Hence, until we find evidence to the contrary or find an alternative explanation, it is reasonable to conclude that this person died first, and the body hit the water afterwards.

In part 2, Zeno’s argument rules out the conjecture that the person jumped into the water and died by drowning. It rules out both suicide and accidental death by drowning. But it does not rule out accidental sudden death, with the body then falling into the water.
Athena offers an alternative to Zeno’s explanation, suggesting that it could have been accidental death.

In part 3, Zeno responds by pointing out that the probability of the combination of circumstances (someone standing at the edge of a well, having a heart attack, dying, and then falling into the water) is extremely low. (The probability of each of these situations by itself is not low, and yet the combination has low probability. Why should this be so? We can understand this from probabilistic reasoning. [http://web.stanford.edu/~danlass/NASSLLI-coursenotes-combined.pdf ] )
Athena’s explanation cannot be ruled out just because it has lower probability than Zeno’s. To rule out this alternative, going beyond probabilities, Zeno draws attention to an additional data point in part 2:

Data point 2: The postmortem of the dead body revealed blue bruise marks around the neck, the kind that we find when a person is strangled.

General theory: Strangling a person to death leaves bruise marks on the neck.

Explanation within the theory: If we assume that the deceased was strangled to death, our general theory correctly predicts the presence of bruise marks, and hence explains the observed bruise marks on the neck. In contrast, if we
assume that the person died first and then fell into the water, the bruise marks have no explanation.

Conclusion: Hence, until we find evidence to the contrary, or find an alternative explanation, it is reasonable to conclude that the person was strangled.

Zeno’s summing up based on the combination of data points is:

If we assume that the person was strangled to death and then thrown in water, our general theories of strangling, and of death by drowning, correctly explain the two data points: presence of bruise marks on the neck, and absence of water in the lungs. In the absence of counterevidence and an alternative explanation, we must conclude that the person was murder by strangling.

When an anthropologist argues for the existence of trade between two regions on the basis of the observation that coins from region A are found in excavations of region B, she is using abduction. When a doctor interprets the symptoms of a patient as being caused by the medical condition that she conjectures, she is using abduction.

### Exercise 4

Here is a story:

Halfway through the typing of this document on types of reasoning, KP decided to make some onion chutney for breakfast. He put some chopped and sautéed onions in the blender, along with green chillies and ginger, and turned the blender switch. But the blender didn’t turn on. Why didn’t it turn on?

His first inference was that the blender wasn’t plugged in properly, so he fiddled with the plug, and concluded this was not the case. His next inference was that the blender must have turned itself off because the sautéed onions were hot. So he pressed the reset button, expecting the blender to start. That blender has the habit of turning itself off when overheated. But pressing the reset button at the bottom of the blender didn’t work, so this inference was also abandoned.

The third inference was that perhaps the blender and the microwave had been simultaneously turned on, blowing the fuse. KP checked the switch, and found the fuse to be fine. So this inference was also rejected.

The only remaining inference was that there was no power supply, and that the computer and the lights were working on the inverter. KP left the kitchen and went back to his writing.

Five minutes later, he heard the blender buzzing! He inferred that the electricity was back, and that Tara must have started the blender. But when he looked, he found Tara in her room at her computer. There was no one in the kitchen. The only inference left was that KPM must have left the blender switch on, and when the electricity came back, it must have started on its own.

**TASK:** Using the Zeno-Athena case as a model, provide an analysis of the different parts of reasoning in the above story.
3. Abductive vs. Speculative-Deductive Reasoning

In deductive reasoning, we take the grounds (statements of a theory — axioms, definitions, laws, etc., or generalizations) and derive their logical consequences. The grounds are not viewed as evidence. The concept of evidence does not play a role in deductive reasoning.

In inductive reasoning and in abductive reasoning, in contrast, the grounds we appeal to do constitute evidence. We may say that these are forms of evidence-based reasoning. The crucial feature that distinguishes abduction from induction is the concept of alternative conclusions, and the need to choose between competing alternatives. Because of this feature, abduction often calls for rational debates, unlike deduction and induction.

Another form of evidence-based reasoning that involves choosing between competing conclusions is speculative-deductive reasoning. The central difference between abductive reasoning and speculative-deductive reasoning is:

- In abduction, we argue for an interpretation or explanation of an observation (data point) on the basis of a pre-existing theory that we have accepted.
- In speculative-deduction, the theory itself is put on trial: we need to argue for it.

Suppose, in a laboratory, we see a ten-foot high cylindrical glass container. At the bottom of the container is a feather, and an iron ball. Someone turns the container upside down, and we observe that the feather and the ball fall downwards at the same rate, and hit the bottom at the same time. Had we dropped the feather and the iron ball in the room outside the container, the feather would have come down much slower. Why did it come down at the same rate as the iron ball?

To come up with an explanation, we assume that inside the glass container is a vacuum. In the absence of air resistance, we predict that the feather and the iron ball would come down at the same rate.

This explanation appeals to a combination of the theories of motion, gravity, and air resistance. What we are defending here is the assumption that inside the particular container we observe is a vacuum. To derive an explanation from this, our assumption has to be placed in the context of the theories of gravity, motion and air resistance. Hence, the rational justification of the claim that there is vacuum in the container involves using abductive reasoning.

Suppose someone were to challenge the theories themselves: Why should we accept the claim that every body in the universe attracts every other body with a force that is proportional to the products of their masses and inversely proportional to the square of the distance between the two bodies? Why should we believe that when a force acts on a body, it moves in the direction of the force? Why should we believe that a moving body will continue moving in a straight line unless a force acts on it to change its direction?

These questions call for a rational justification of the theories themselves, for which we use speculative-deductive reasoning.
In mathematical inquiry, theorems are rationally justified conjectures. Mathematical theories cannot be proved to be true. They do need to be useful, interesting, insightful, elegant etc., but those who construct mathematical theories are not required to provide rational arguments to establish their truth value. In contrast, we expect scientific theories to be rationally justified.

Of the different kinds of justifying knowledge claims, justifying theoretical concepts and theoretical propositions in scientific inquiry is the hardest for many. This makes it also hard to get a critical understanding of theoretical concepts and propositions.

A reason for this difficulty is the ‘commonsense’ conception of ‘knowledge’ built into for our textbooks and class sessions, where ‘knowledge’ is typically viewed as a set of facts or pieces of information. If we take what is presented in a textbook as a set of facts, then all that textbooks need to do is transmit the facts to the students, with the teacher as a mediator between the textbook and the students. In contrast, the concept of ‘knowledge’ in academic research/inquiry is as a body of rationally justified conclusions beyond reasonable doubt. Once we make the shift from facts to rationally justified conclusions, the obvious question to ask of each concept and knowledge proposition in textbooks is: What is the rational justification for this concept/proposition?

To answer this question, we need an appreciation of the types of propositions and concepts that constitute academic knowledge. Textbook propositions can be of six types:

A. Axioms and definitions: As with mathematical axioms and definitions, we don’t claim them to be true of false. They do not need to be rationally justified. But they are still ‘rational’ in the sense that they are subject to the foundational principle of rationality that prohibits logical contradictions. The choice between alternative definitions of the same concept within the same theory might call for rational justification, though, as with the definition of a straight line within Euclidean geometry.

B. Propositions that we take as theorems in a given theory (i.e., the logical consequences of the propositions of the theory): In scientific inquiry, these are called predictions. To show that a given proposition is a theorem/prediction of the theory, we deduce it from the propositions of the theory using deductive reasoning.

C. Theoretical laws (propositions that go into composing a theoretical model) and theoretical concepts: In a scientific theory, the laws seek to explain a set of observational generalizations, and the concepts go into the statement of these propositions. We justify scientific theories by showing that the theory we are defending is the best explanation for a set of observational generalizations. This in essence is speculative-deductive reasoning: we justify the laws by showing that they are crucial for the theory, and the concepts by showing that they are needed for formulating theoretical laws.

D. Propositions that we take as observational generalizations (observational laws), and the observational concepts that go into the formulation of these laws: In scientific inquiry, to show that a proposition is a ‘true’ observational generalization, we use inductive reasoning. And we justify observational concepts by showing that they are needed for the formulation of those generalizations.
E. Observational reports (data points, whose credibility needs to be checked): We cannot provide rational justification for observational reports, but if the person who doubts the observational report is at the observational site, (s)he would be in a position to confirm or disconfirm the report.

F. Interpretations or explanations of observational reports within a given theory. We use abductive reasoning to justify these.

How do we justify theories? How do we argue that the theory we wish to defend should be accepted as ‘knowledge’ in the scientific community?

As an illustration, let us take the following theoretical propositions of the theory of magnetism that textbooks expect sixth grade children to accept as ‘knowledge’.

1) Theoretical laws
   a) Every magnet has two poles located at its two ends.
   b) The two poles of a magnet are opposite.
   c) Given any two magnets M1 and M2, each pole of M1 is similar to one of the poles of M2, and opposite of the other pole of M2.
   d) Similar poles repel each other.
   e) Opposite poles attract each other.
   f) The force of attraction is directed towards the attracting body, but the force of repulsion is directed away from the repelling body.
   g) When a force of attraction acts on a body, the body moves in a straight line in the direction of the force.

2) Theoretical concepts
   a) magnet (DEF.): an object that attracts iron, nickel, and cobalt
   b) force; attraction; repulsion; pole, similar and opposite poles

The observational generalizations the above theory is designed to express can be formulated as:

3) Observational generalizations
   a) Some objects (call them m-objects) have the trait of making objects of iron, nickel and cobalt move towards them.
   b) When two iron bars/needles are m-objects, one with its end marked as A and B, and the other with its ends marked as C and D, we find that
      i) A either attracts or repels C.
      ii) If A attracts C, then B repels C, and vice versa.
      iii) If A attracts C, then B attracts D and vice versa.
      iv) If suspended freely, one of the poles of an m-object is oriented towards the south, and the other towards the north.
Notice that in formulating (3a, b), we have not used any of the theoretical concepts in (2a, b). Formulating observational generalizations without using the constructs of the theory we wish to defend is a crucial part of the intellectual hygiene of rational inquiry.

To use (3) as the basis for an explanation-based argument for (1) and (2), we need to demonstrate that the propositions in (1) and (2) constitute the best explanation for the propositions in (3). Such a demonstration would consist of three steps:

- First, we show that the propositions (1) and (2) explain the propositions in (3). To do this, we show that the propositions in (3) are derivable through deductive reasoning from the propositions in (1) and (2). That is to say, we show that the statements in (3) are logical consequences (= predictions) of (1) and (2).
- Next, we show the reader/listener that (1) and (2) make no incorrect predictions.
- If (3) is deducible from (1)-(2), and (1)-(2) do not make any incorrect predictions, we consider alternative explanations show that (1)-(2) form the best explanation (that is, this explanation is superior to its competitors).

Here is an example of how we derive the predictions from theory:

**Derivation of (3a)**

A magnet is an object that attracts a piece of iron. \(\text{(by (2a))}\)

An iron paper clip is a piece of iron. \(\text{(What we know)}\)

The force of attraction on the paper clip is directed towards the magnet. \(\text{(by (1f))}\)

When a magnet exerts a force on a paper clip, the paper clip moves towards the magnet. \(\text{(by 7g)}\)

Given the above, it follows that when a paper clip is placed near a magnet, the paper clip would move towards the magnet. \(\text{((3a) derived)}\)

**Exercise 5**

Using the derivation of (3a) as a model, derive the observational generalizations in (3b).

In the case of (1)-(3), the second and third steps are straightforward: we know that (1)-(2) don’t make any incorrect predictions; and there are no alternative theories, hence this is the best theory we have.

We can now provide the justification for the theory as follows:

**Justification of the theory of magnetism**

The observational generalizations in (3a, b) call for explanation.

The theory in (1)-(2) correctly predicts the generalizations in (3), thereby explains them.

It does not make any incorrect predictions.

There are no competing theories to explain (3).

Hence, until we find evidence to the contrary, or an equally good alternative explanation, it is reasonable to conclude that the theory is true.

To illustrate the justification of a theoretical proposition within a theory, let us take (1d):
Justification of law (1d): Similar poles repel each other. The observational generalizations in (3a, b) call for explanation. The theory in (1)-(2) is the best explanation for (3a, b), and hence we must accept this theory as correct (argument given above). Since law (1d) is crucial for the theory, and we must accept the theory, we must accept (1d) as well. The same goes for the concept of magnet as defined in (2a):

Justification of law (2a):
The observational generalizations in (3a, b) call for explanation. The theory in (1)-(2) is the best explanation for (3a, b), and hence we must accept this theory as correct (argument given above). Since the concept of magnet as defined in (3a) is crucial for the theory, and we must accept the theory, we must accept (3a) as well.

Exercise 6

Using the argument for (2a) as a model, and the explanation of the yearly cycle of temperature on earth as the grounds (discussed in detail in LT4: "Explaining"), construct an argument in support of the theoretical proposition that the axis of the rotation of the earth is tilted to the plane of revolution around the sun.

One of the components of the deep understanding of a body of knowledge is the critical understanding of the concepts and propositions of that knowledge. Critical understanding of a concept or proposition is the understanding of the rational justification of the concept or proposition. This means that, to help students develop a deep understanding of a scientific theory, we need to help them to master speculative-deductive reasoning, understand the observational generalizations (evidence) on the basis of which the argument that is made, and understand how speculative-deductive reasoning is used to defend the concept/proposition on the basis of those generalizations.