Research in the Era of Gen AI

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Talk Title:
Research in the Era

Outline

- The essence, the requirements, and the goals of research
- Possible effects of Gen AI
- How should we use Gen AI

  Disclaimer: My focus is not on

  - tactical and practical considerations of how to use Gen AI, but on
  - strategic and ethical considerations of the use of Gen AI
- Richard Hamming on research
- Conclusions

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What is Research?

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In Search of Research?

- Observed Phenomena with no explanations
  - Puzzles and mysteries
- Lacunae in the known theory and/or practice
  - The need of a better understanding/method
  - Innovative ideas
- Innovative ideas waiting for new applications
  - Discovery of new puzzles, mysteries and/or lacunae

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The Essence of Research

- Is building a device, research?

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The Essence of Research

- Is building a new device, research?

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The Essence of Research

- Is building a device, research?
- Is writing a software, research?

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The Essence of Research

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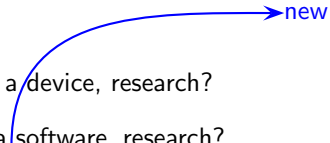

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The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?

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The Essence of Research

- Is building a device, research?
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The Essence of Research

- Is building a device, research?
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- Is proving a theorem, research?

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The Essence of Research

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Research could involve any of the above, or none of the above

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The Essence of Research

- Research is a game of innovative ideas that are significant

  Even an experimental research begins with an observation and speculation

- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

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Aesthetics

- Total is greater than the sum of the parts

  "Scientists study science not because it is useful, but because it is beautiful. Here I do not talk about the beauty of appearance or beauty of qualities ... Here I talk about that profound beauty which comes from a harmonious order of parts ..."

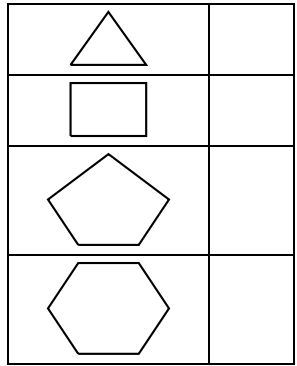
  – Henry Poincare

- Example : Painting

  Proportion of colours Vs. their arrangements

An Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?



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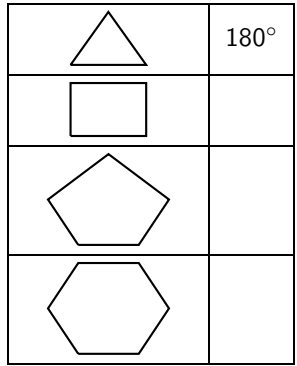

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An Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?

	180°
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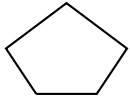	
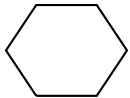	

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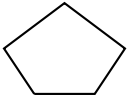
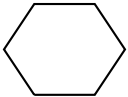
	540°
	

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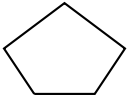
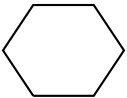
	540°
	720°

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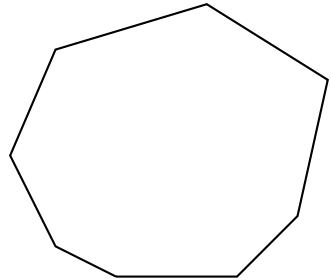
An Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?
  - Consider an n sided polygon



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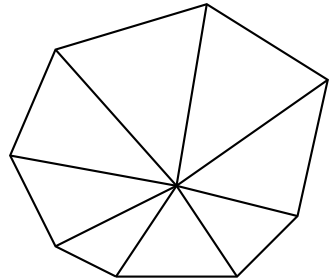
An Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?
  - Consider an n sided polygon
  - Choose an arbitrary inner point and connect it to all vertices



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An Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?
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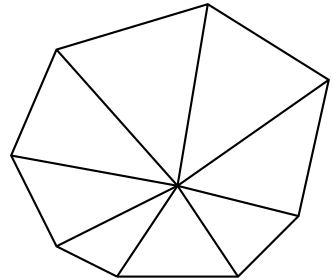

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- Question: What is the sum of all internal angles of a polygon?
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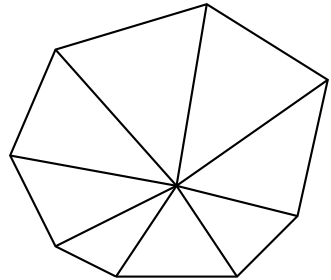
  - We have n triangles
  - Sum of all angles $= n \cdot 180°$



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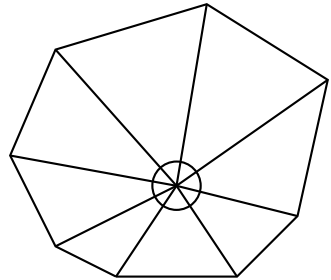
  - Exclude the sum of the angles incident on the chosen point



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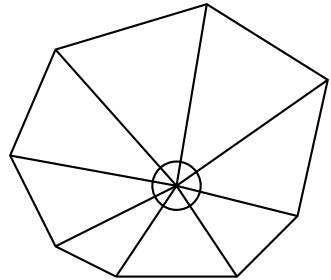

- Answer: $(n \cdot 180 - 360)°$

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Beauty of an Idea

- Ideas talk back to us

  When we fix one idea, it fixes some other ideas

- Beauty lies in creating simple ideas that
  - bring in unexpected implications
  - relate the seemingly unrelated things
  - illuminate and reveal much more than anticipated
- Beautiful ideas
  - explain more with less
  - are simple and general
- Total is greater than the sum of the parts

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On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation

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- Example: Divide 6 by 2

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  "Divide 6 into 2 parts and tell me the size of each part"

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- Example: Divide 6 by 2
  "Divide 6 into 2 parts and tell me the size of each part"
- Divide 6 by $\frac{1}{2}$
  "Divide 6 into half part and tell me the size"

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On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation
- Example: Divide 6 by 2

  "Divide 6 into 2 parts and tell me the size of each part"
- Divide 6 by $\frac{1}{2}$

  "Divide 6 into half part and tell me the size"
- More rigorous explanations:
  - *"Divide 6 into parts of size 2 and tell me the number of parts"*
  - *"Divide 6 into parts of size $\frac{1}{2}$ and tell me the number of parts"*

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The Process of Research

- Research is a game of innovative ideas that are significant
- Research is often a cycle of:
  Speculate, design, apply/perform experiment, observe, interpret, infer and repeat

  Repeat the following:

  Notice, imagine, generate ideas, evaluate them (discard most, retain the promising ones)

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Generating Ideas

Heuristics

Seeking duality. Observing similarity in apparently unrelated things

Seeking symmetry. Observing balance or patterned self-similarity

Generalization. Removing specificities to cover more situations

Refinement. Distilling to essence by removing irrelevant parts

Extensions. Trying to stretch an idea in all possible directions

Adaptation. Using an idea in an unrelated context

Facilitators

Curiosity

Experimentation

Observation

Discussion

Slow Hunch

Serendipity

Error

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Research and AI

Thinking Abilities Are Important

- Research makes researcher a much better learner
- Teaching is not restricted to conveying information

  Research is not restricted to solving a problem
- Teaching is a process of developing thinking

  "Sustained argumentation: the ability to construct and maintain a complex argument across an extended piece of discourse, distinguishing claims from evidence, handling counterarguments, and reaching a defensible conclusion."

  Research is a process of honing it further
- Both can be casualties of AI

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Playing the Game of Thinking

Generating the ideas requires

- intuition, lateral thinking, observing patterns, creativity, and imagination
- guesses based on gut feeling and hunches, without any explicit rules
- need not be explainable

Validating the ideas requires

- critical thinking, deductive reasoning, rational thinking
- systematic chain of inferences using explicit rules
- must be explainable

Gen AI uses contextual thinking based on probabilistic pattern matching based on observations in the training data

Can provide

- significant help in generating ideas
- partial help in validating them

Can construct enumerative proofs

- Knuth's recent experience

Relies on plausibility

- Everything that is plausible, need not be correct

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Kanheman on Types of Thinking

- Two basic systems in our brain
  - Impulsive, effortless, and fast, almost automatic, association of observation and conclusion
    - Called "System I" by Daniel Kanheman
    - Similar to Gen AI except that the connections are coloured by emotions
  - Effortful, reasoned, and usually slow deduction of conclusions from observations
    - Called "System II" by Daniel Kanheman
    - Deliberate thinking (required for critical thinking)
- By default, our brain works like a predicting machine (System I)
- With practice in a domain, System II thinking is replaced by System I thinking

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Thinking Out of the Box

- Research requires you to think out of the box
- For that you need to know what the box is
- Gen AI explores the box extremely well
  - The breadth of the contents of the box
  - The connections between the contents of the box
    By remixing the contents at a scale and speed far beyond human capacity
- Research changes the shape of the box
- Great research occasionally destroys the box

From Confusion to Conviction

Start

End

Ignorance

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From Confusion to Conviction

Start ● Growing Confusion ● End

Ignorance → **Uncertainty**

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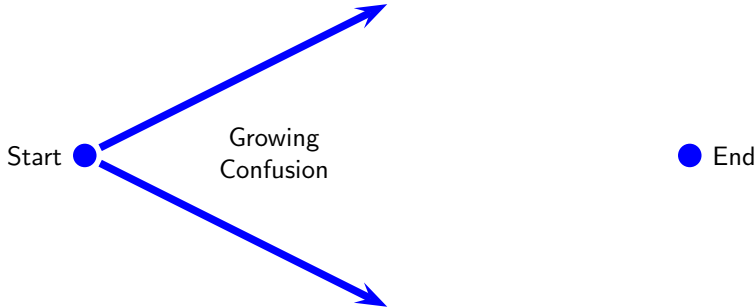
From Confusion to Conviction



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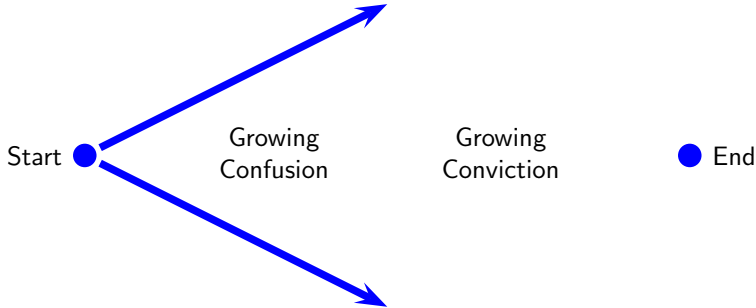

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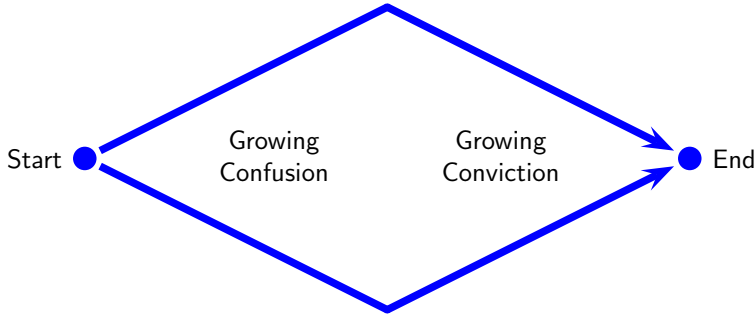

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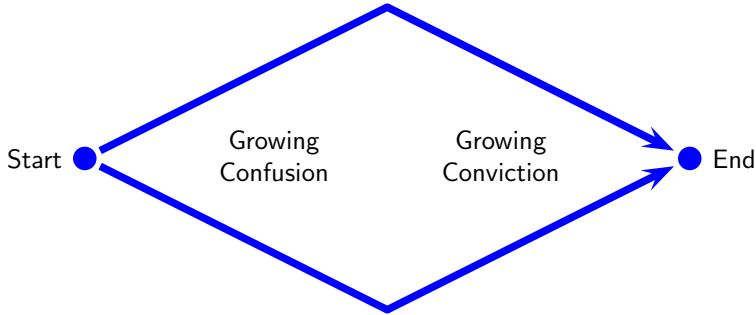

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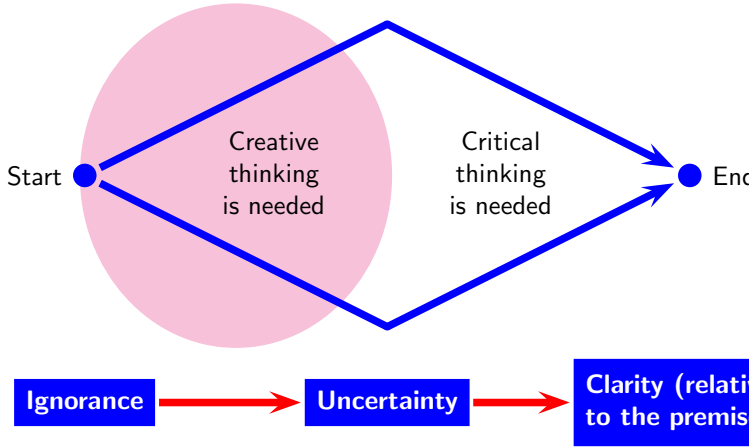

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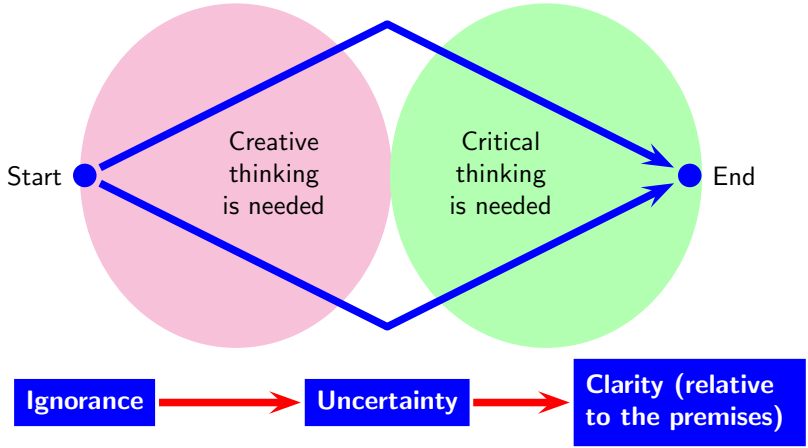

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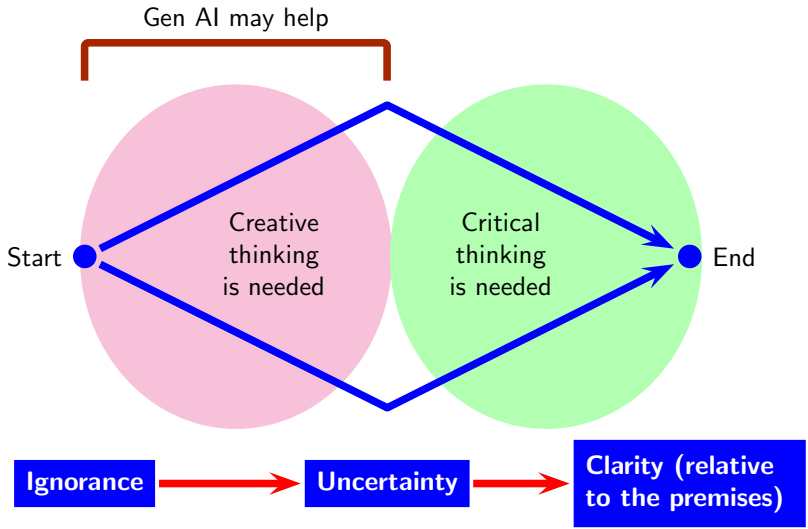

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Research is Gardening and Not Sculpting

- A sculptor begins with a complete plan and picture in mind

  After plannng, the main challenge is in correct execution
- Research involves active feedback by what is being built, leading to changing ideas and insights,
  - A gardener begins with
    seeds, soil, uncertainty, observation, pruning, adaptation,
  - The garden "talks back"
- Gen AI is at best an itelligent gardening assistant

  and never a gardner
  - It can suggest fertilizers, predict weather, identify diseases
  - It cannot decide what kind of garden is worth creating
    or how the best steps for reaching the final version of the garden

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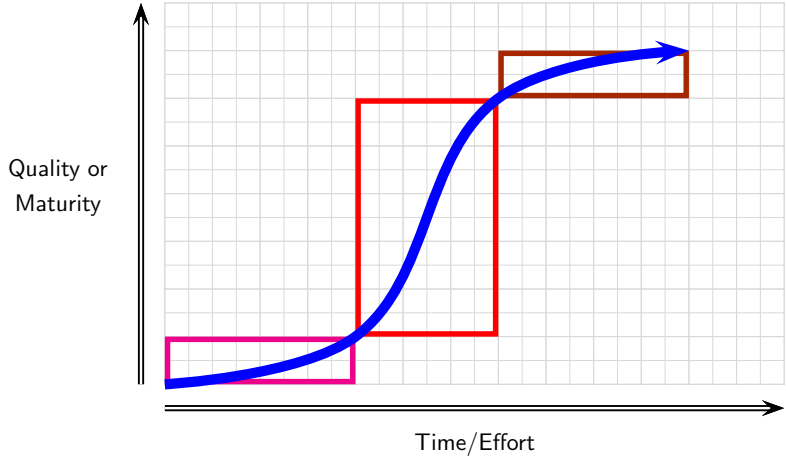
The "S" Curve of Research Life Cycle



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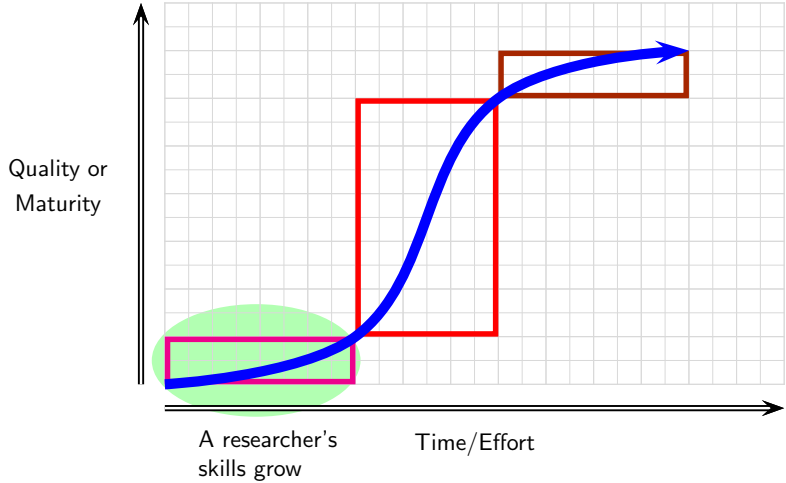

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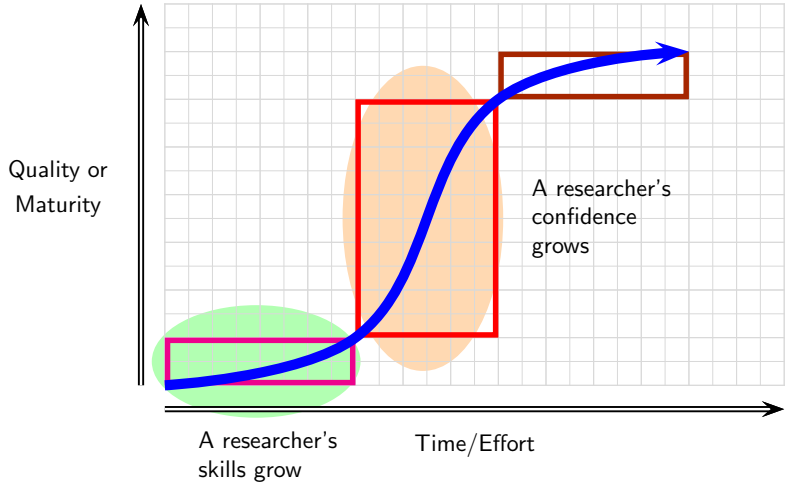

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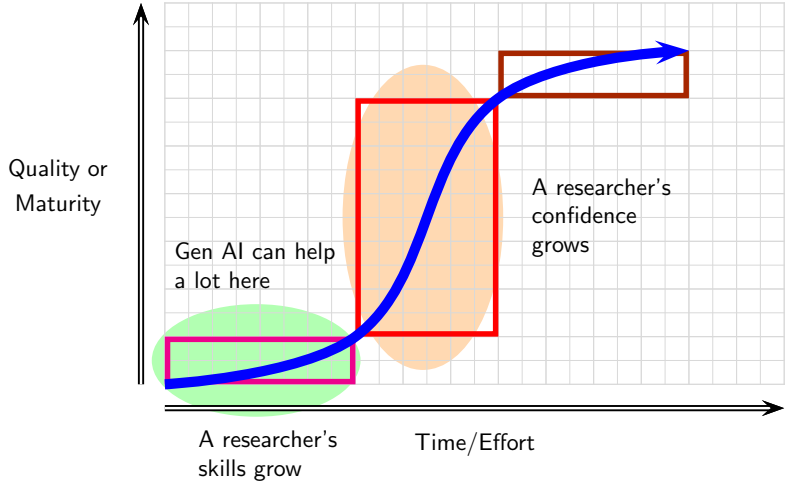

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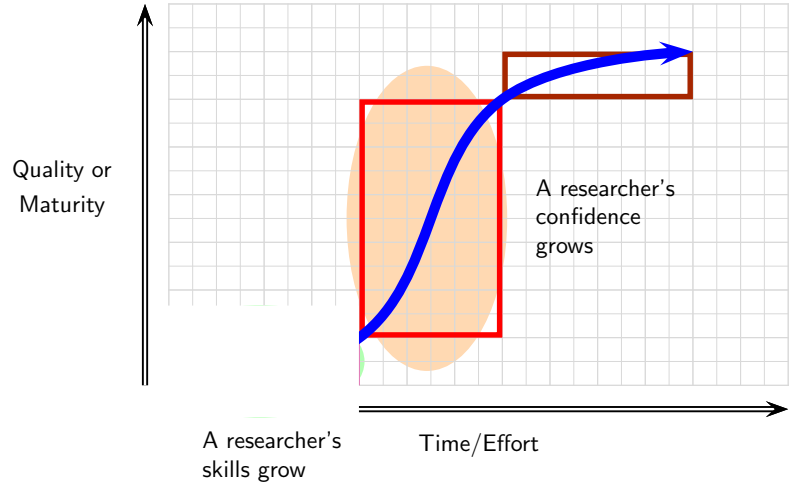

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What Happens to a Researcher's Skills?

- Twin goals of research
  - Solve a problem, a riddle
  - Enhance a researcher's skills to do better research
- If we focus too much on the former
  - Researchers will outsource their thinking instead of using Gen AI as a tool
  - Like muscle atrophy, we will have brain atrophy
  - Do we want to lose thinking skill?
- We already see attention span decreasing
- Students submit essays and programs that they do not understand

  They lose the ability to evaluate what Gen AI has given
- Where is the friction? There is no learning without friction.

  Kites rise against the wind and not along with it.

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Suppose Einstein had Chatgpt

- Would relativitiy have been discovered earlier? Possibly
- Would Einstein have been Eistein?

- We already
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Limitations of AI

- Converges on common patterns if prompted vaguely.
- Favors plausible over truly groundbreaking ideas.
  It cannot know what is groundbreaking.
- Lacks lived experience and intuition.
- Misses emotional, cultural, or organizational nuances.
- Cannot build trust on which institutional cooperation rests
- Cannot give a sense of taste and style
- Cannot constitute goals

The most transformative innovations often arise from

- observations in the real world,
- deep expertise, and
- a willingness to pursue an idea despite little evidence

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When Answers are Easy to Get, Questions Become More Important

- A good question expands the field of awareness.
- It reframes the problem.
- Value is created not by declaring what is known, but by directing attention to what remains unresolved.
- Valuable answers today are not necessarily those that appear complete and articulate, but those that reveal where we must keep looking.

Source: https://cacm.acm.org/opinion/as-answers-get-cheaper-questions-grow-dearer/

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Why Do We Need Care When We Use Gen AI?

- We need to get invested in research and Gen AI may rob us of the investment of our mind.
  - When an answer feels good enough, we tend to stop asking.
  - Plausibility becomes a stand-in for truth.
  - Fluency and presentation become markers of confidence.
- Gen AI subtly persuades you that there is no need for further inquiry.
- Gen AI often complete our thoughts and reinforce existing narratives.
- Good answers are not necessarily those that appear complete and articulate, but those that reveal where we must keep looking.
- Good answers revise beliefs, not just confirm them.

  Gen AI rarely challenges our beliefs.

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How Should we Use Gen AI in Research?

- We have to learn to use Gen AI as a tool
  - to discover information
  - to do low level tasks that need not count as useful skills
  - to complement our abilities and not replace our abilities
- We should retain the ability to accept or reject what Gen AI gives to us
- We should be careful about which skill can be considered irrelevant
  - Thinking skill should not become a casualty of Gen AI
  - The ability to think deeply and critically should not erode

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How Should we Use Gen AI in Research?

You provide

- Context
- Goals
- Constraints
- Deep domain knowledge
- Judgment
- Taste
- Decision-making

Use AI for

- Breadth of coverage
- Speed of comparing and contrasting ideas
- Diverse perspectives
- Interesting Analogies
- Idea generation
- Rapid iteration for refining ideas

The value of Gen AI is not simply in producing answers
It is in helping people explore a much larger landscape of possibilities
Increases the surface area of luck

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Richard Hamming on Research

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On the Role of Luck in Research

Pasteur: "Luck favours a prepared mind."

Hamming: "Our society frowns on people who set out to do really good work. You're not supposed to; luck is supposed to descend on you and you do great things by chance. Well, that's a kind of dumb thing to say.

I spoke earlier about planting acorns so that oaks will grow. You can't always know exactly where to be, but you can keep active in places where something might happen.

A prepared mind sooner or later finds something important and does it. So yes, it is luck. *The particular thing you do is luck, but that you do something is not.* "

Luck is when preparation meets opportunity

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Turning Difficulties into Opportunities in Research

Knowing right questions is the first step in knowing the answers

Hamming: "Often the great scientists, by turning the problem around a bit, changed a defect to an asset.

Hamming, you think the machines can do practically everything. Why can't you make them write programs?" What appeared at first to me as a defect forced me into automatic programming very early. What appears to be a fault, often, by a change of viewpoint, turns out to be one of the greatest assets you can have. "

Doing research is a test in which you are allowed to write your own question paper and then answer it

The Role of Consolidation through Hard Work in Research

- Research is 1% inspiration and 99% perspiration

  Newton: "If others would think as hard as I did, they would get similar results."

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- Continuous consolidation works like compound interest

  Hamming: "Given two people of approximately the same ability and one person who works ten percent more than the other, the latter will more than twice outproduce the former. The more you know, the more you learn; the more you learn, the more you can do; the more you can do, the more the opportunity . . ."

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The Role of Consolidation through Hard Work in Research

$$1.01^{365} =$$

$$0.99^{365} =$$

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The Role of Consolidation through Hard Work in Research

$$1.01^{365} = 38.161$$

$$0.99^{365} =$$

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The Role of Consolidation through Hard Work in Research

$$1.01^{365} = 38.161$$

$$0.99^{365} = 00.025$$

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The Role of Consolidation through Hard Work in Research

- The physical time remains same but you are able to give deep attention with small conscious effort,

  "Getting into the zone" or "Getting into the flow"

- Consolidation through hard work helps you to reduce your conscious effort

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The Role of Consolidation through Hard Work in Research

- The difference between ordinary and extraordinary is that little extra
- One needs
  - The initiative to find that extra
    Must be smart and relevant extra, not arbitrary extra (use controlled imagination)
  - The patience and discipline to keep doing that extra again and again
- Initiative and discipline helps you get into the zone

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On the Role of Intelligence and Courage in Research

Hamming: "How about having lots of 'brains?' It sounds good. . . . But great work is something else than mere brains.

One of the characteristics you see, and many people have it including great scientists, is that usually when they were young they had independent thoughts and had the courage to pursue them.

Once you get your courage up and believe that you can do important problems, then you can. If you think you can't, almost surely you are not going to. . . . That is the characteristic of great scientists; they have courage. They will go forward under incredible circumstances; they think and continue to think. "

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On the Role of Drive and Commitment in Research

Hamming: "Well, one of the reasons is drive and commitment. The people who do great work with less ability but who are committed to it, get more done that those who have great skill and dabble in it, who work during the day and go home and do other things and come back and work the next day. They don't have the deep commitment that is apparently necessary for really first-class work. "

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On the Role of Commitment and Creativity in Research

Hamming: "If you are deeply immersed and committed to a topic, day after day after day, your subconscious has nothing to do but work on your problem. And so you wake up one morning, or on some afternoon, and there's the answer. For those who don't get committed to their current problem, the subconscious goofs off on other things and doesn't produce the big result.

So ... you don't let anything else get the center of your attention - you keep your thoughts on the problem. Keep your *subconscious starved so it has to work on your problem, so you can sleep peacefully and get the answer in the morning, free.* "

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On the Role of Uncertainty in Research

Hamming: "Most people like to believe something is or is not true. Great scientists tolerate ambiguity very well. They believe the theory enough to go ahead; they doubt it enough to notice the errors and faults so they can step forward and create the new replacement theory. If you believe too much you'll never notice the flaws; if you doubt too much you won't get started. It requires a lovely balance. But most great scientists are well aware of why their theories are true and they are also well aware of some slight misfits which don't quite fit and they don't forget it. "

On the Role of Ignorance and Doubt

Richard Feynman: "It is our responsibility as scientists, knowing the great progress and the great value of a satisfactory philosophy of ignorance, the great progress that is the fruit of freedom of thought, to proclaim the value of this freedom, to teach how doubt is not be feared but welcomed and discussed, and to demand this freedom as our duty to all coming generations. "

Three Requirements of Creativity

- Deep knowledge
  - Keep your antennas tuned
  - You never know when and where the signals come from
- Holding a problem in the background thinking for a long time without acting on it
- Dealing with loosely structured ideas and structuring them over time

Incremental Research Vs. Fundamental Research

Hamming: "Most great scientists know many important problems. They have something between 10 and 20 important problems for which they are looking for an attack. And when they see a new idea come up, one hears them say 'Well that bears on this problem.'

The great scientists, when an opportunity opens up, get after it and they pursue it. They drop all other things. They get rid of other things and they get after an idea because they had already thought the thing through. Their minds are prepared; they see the opportunity and they go after it. "

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Conclusions

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The Ten Commandments of Success in Research

1. Work on important problems

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The Ten Commandments of Success in Research

1. Work on important problems
2. Work on multiple problems

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The Ten Commandments of Success in Research

1. Work on important problems
2. Work on multiple problems
3. For each problem, identify where you are on the S curve

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The Ten Commandments of Success in Research

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3. For each problem, identify where you are on the S curve
4. Seek excellence and beauty in your work

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4. Seek excellence and beauty in your work
5. Get emotionally involved

   (with the process, not with the results. Judge your day by the seeds you sow and not by the harvest you reap)

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7. Work hard, work continuously

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9. Don't depend on luck

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10. Handle uncertainty and disappointments

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Also applicable to

- A practising engineer
- A student
- A teacher

. . . in all intellectual pursuits!

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Last But Not the Least

Thank You!