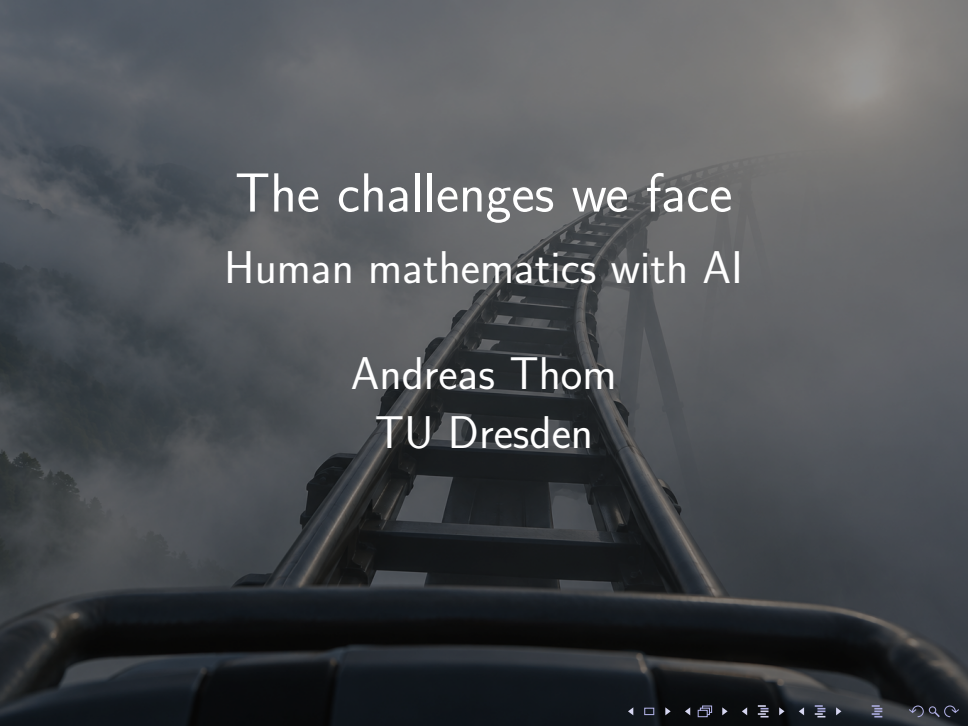




The challenges we face

Human mathematics with AI

Andreas Thom
TU Dresden

Contents

1. What is happening?
2. Holy s&\$t, what the f%c§ !!!
3. Why is OpenAI interested in doing this?
4. Can we afford to ignore that?
5. What needs to change? — Teaching and Research
6. How will the job market react?
7. What is still worth doing?
8. Where will it end?
9. Two alternatives
10. Taking responsibility for solutions

Questions during the talk

- ▶ Post your questions in Zoom Q&A at any time.
- ▶ Upvote questions you would like us to address.
- ▶ We will return to the questions at the end of the talk.

What is happening?

What is happening?

- ▶ The speed at which AI models generate mathematics and find answers to longstanding questions exceeds what humans were able to achieve.

What is happening?

- ▶ The speed at which AI models generate mathematics and find answers to longstanding questions exceeds what humans were able to achieve.
- ▶ Most colleagues needed a moment of shock or humiliation to realise the magnitude of the change we are facing.

What is happening?

- ▶ The speed at which AI models generate mathematics and find answers to longstanding questions exceeds what humans were able to achieve.
- ▶ Most colleagues needed a moment of shock or humiliation to realise the magnitude of the change we are facing.
- ▶ Our current task is, to a large extent, reduced to guidance and interpretation.

Holy s&\$t, what the f%cξ !!!

Holy s&\$t, what the f%cξ !!!

- ▶ For many, this is an existential crisis of identity.

Holy s&\$t, what the f%cξ !!!

- ▶ For many, this is an existential crisis of identity.
- ▶ Curiosity, excitement, sadness, grief, anger.

Holy s&\$t, what the f%cξ !!!

- ▶ For many, this is an existential crisis of identity.
- ▶ Curiosity, excitement, sadness, grief, anger.
- ▶ We see this in online discussions.

Holy s&\$t, what the f%cξ !!!

- ▶ For many, this is an existential crisis of identity.
- ▶ Curiosity, excitement, sadness, grief, anger.
- ▶ We see this in online discussions.
- ▶ We need to find a way forward as a community and avoid fracturing over conflicting interests.

Breakout room 1

How do you feel about the current developments?

- ▶ Small groups, five minutes.
- ▶ Share time equally: just talking and listening, no questions.
- ▶ The breakout rooms will close automatically after five minutes.

5 stages of grief

5 stages of grief

The Five Stages Explained

- ▶ **Denial:** Feeling numb, acting as if nothing happened, or refusing to accept the reality of the loss to protect yourself from shock.

5 stages of grief

The Five Stages Explained

- ▶ **Denial:** Feeling numb, acting as if nothing happened, or refusing to accept the reality of the loss to protect yourself from shock.
- ▶ **Anger:** Feeling that the situation is unfair and directing frustration toward yourself, others, doctors, or a higher power.

5 stages of grief

The Five Stages Explained

- ▶ **Denial:** Feeling numb, acting as if nothing happened, or refusing to accept the reality of the loss to protect yourself from shock.
- ▶ **Anger:** Feeling that the situation is unfair and directing frustration toward yourself, others, doctors, or a higher power.
- ▶ **Bargaining:** Dwelling on “what if” scenarios and trying to make internal deals or negotiate a way to reverse the loss.

5 stages of grief

The Five Stages Explained

- ▶ **Denial:** Feeling numb, acting as if nothing happened, or refusing to accept the reality of the loss to protect yourself from shock.
- ▶ **Anger:** Feeling that the situation is unfair and directing frustration toward yourself, others, doctors, or a higher power.
- ▶ **Bargaining:** Dwelling on “what if” scenarios and trying to make internal deals or negotiate a way to reverse the loss.
- ▶ **Depression:** Experiencing deep sadness, a sense of hopelessness, and a feeling that life has lost its meaning.

5 stages of grief

The Five Stages Explained

- ▶ **Denial:** Feeling numb, acting as if nothing happened, or refusing to accept the reality of the loss to protect yourself from shock.
- ▶ **Anger:** Feeling that the situation is unfair and directing frustration toward yourself, others, doctors, or a higher power.
- ▶ **Bargaining:** Dwelling on “what if” scenarios and trying to make internal deals or negotiate a way to reverse the loss.
- ▶ **Depression:** Experiencing deep sadness, a sense of hopelessness, and a feeling that life has lost its meaning.
- ▶ **Acceptance:** Coming to terms with the reality of the loss and learning to live and move forward with it.

Why is OpenAI interested in doing this?

Why is OpenAI interested in doing this?

- ▶ The prestige of mathematics and OpenAI's ability to solve mathematical problems raise the value of the company.

Why is OpenAI interested in doing this?

- ▶ The prestige of mathematics and OpenAI's ability to solve mathematical problems raise the value of the company.
- ▶ Mathematical skills are crucial in many other areas.

Why is OpenAI interested in doing this?

- ▶ The prestige of mathematics and OpenAI's ability to solve mathematical problems raise the value of the company.
- ▶ Mathematical skills are crucial in many other areas.
- ▶ The task can be defined much more easily than in other areas.

Can we afford to ignore that?

Can we afford to ignore that?

- ▶ Mathematical research has cultural value, but for the most part it is useful training in problem solving.

Can we afford to ignore that?

- ▶ Mathematical research has cultural value, but for the most part it is useful training in problem solving.
- ▶ In the future, problem solving will be done with the help of AI whenever it helps.

Can we afford to ignore that?

- ▶ Mathematical research has cultural value, but for the most part it is useful training in problem solving.
- ▶ In the future, problem solving will be done with the help of AI whenever it helps.
- ▶ We should therefore train ourselves and our students to use AI whenever it helps.

Can we afford to ignore that?

- ▶ Mathematical research has cultural value, but for the most part it is useful training in problem solving.
- ▶ In the future, problem solving will be done with the help of AI whenever it helps.
- ▶ We should therefore train ourselves and our students to use AI whenever it helps.
- ▶ We have to be able to take responsibility for solutions we find, i.e. for our decisions.

What needs to change? — Teaching

What needs to change? — Teaching

- ▶ Integrate AI from the start.

What needs to change? — Teaching

- ▶ Integrate AI from the start.
- ▶ Identify which skills cannot be delegated to AI: understanding, evaluation, guidance.

What needs to change? — Teaching

- ▶ Integrate AI from the start.
- ▶ Identify which skills cannot be delegated to AI: understanding, evaluation, guidance.
- ▶ Develop those skills, perhaps with AI whenever it helps.

What needs to change? — Teaching

- ▶ Integrate AI from the start.
- ▶ Identify which skills cannot be delegated to AI: understanding, evaluation, guidance.
- ▶ Develop those skills, perhaps with AI whenever it helps.
- ▶ Change how we test those skills.

What needs to change? — Teaching

What needs to change? — Teaching

- ▶ Mathematical understanding goes beyond producing a correct proof.

What needs to change? — Teaching

- ▶ Mathematical understanding goes beyond producing a correct proof.
- ▶ Critical and logical thinking, mathematical language, and perseverance with abstract and complex ideas remain central goals of education.

What needs to change? — Teaching

- ▶ Mathematical understanding goes beyond producing a correct proof.
- ▶ Critical and logical thinking, mathematical language, and perseverance with abstract and complex ideas remain central goals of education.
- ▶ Students need to formulate meaningful questions and evaluate answers in context.

What needs to change? — Teaching

- ▶ Mathematical understanding goes beyond producing a correct proof.
- ▶ Critical and logical thinking, mathematical language, and perseverance with abstract and complex ideas remain central goals of education.
- ▶ Students need to formulate meaningful questions and evaluate answers in context.
- ▶ Protect learning phases without AI, where students must think, experiment, fail and understand for themselves.

What needs to change? — Teaching

- ▶ Mathematical understanding goes beyond producing a correct proof.
- ▶ Critical and logical thinking, mathematical language, and perseverance with abstract and complex ideas remain central goals of education.
- ▶ Students need to formulate meaningful questions and evaluate answers in context.
- ▶ Protect learning phases without AI, where students must think, experiment, fail and understand for themselves.
- ▶ Systematically test how these phases can be combined with thoughtful use of AI in teaching.

Breakout room 2

What is your experience with AI in teaching? Where do you see the risks and what are the advantages?

- ▶ Small groups, five minutes.
- ▶ Share time equally: describe your experience, then discuss.
- ▶ If you already have experience with AI in teaching, please start.
- ▶ The breakout rooms will close automatically after five minutes.

What needs to change? — Research

What needs to change? — Research

- ▶ We need to change the credit system.

What needs to change? — Research

- ▶ We need to change the credit system.
- ▶ Integrating AI-generated results into the mathematical landscape will become more important and should be rewarded.

What needs to change? — Research

- ▶ We need to change the credit system.
- ▶ Integrating AI-generated results into the mathematical landscape will become more important and should be rewarded.
- ▶ proof mining $\neq$ understanding $\neq$ endorsing

What needs to change? — Research

- ▶ We need to change the credit system.
- ▶ Integrating AI-generated results into the mathematical landscape will become more important and should be rewarded.
- ▶ proof mining $\neq$ understanding $\neq$ endorsing
- ▶ Building public alternatives to commercial model providers requires infrastructure, skilled staff and agent software.

What needs to change? — Research

What needs to change? — Research

Research infrastructure

- ▶ Distinguish routine assistance, autoformalisation and frontier proof discovery.

What needs to change? — Research

Research infrastructure

- ▶ Distinguish routine assistance, autoformalisation and frontier proof discovery.
- ▶ Build public capacity for coding, routine tasks and autoformalisation with open-weight models.

What needs to change? — Research

Research infrastructure

- ▶ Distinguish routine assistance, autoformalisation and frontier proof discovery.
- ▶ Build public capacity for coding, routine tasks and autoformalisation with open-weight models.
- ▶ Matching frontier proof discovery requires far greater resources and remains an uncertain goal.

What needs to change? — Research

Research infrastructure

- ▶ Distinguish routine assistance, autoformalisation and frontier proof discovery.
- ▶ Build public capacity for coding, routine tasks and autoformalisation with open-weight models.
- ▶ Matching frontier proof discovery requires far greater resources and remains an uncertain goal.
- ▶ Minimise exposure of sensitive data, audit services regularly and maintain public alternatives to commercial providers.

How will the job market react?

How will the job market react?

- ▶ An internal study at an unnamed software company suggests that AI makes programming work about three times as productive.

How will the job market react?

- ▶ An internal study at an unnamed software company suggests that AI makes programming work about three times as productive.
- ▶ Higher productivity could mean fewer people doing the same work, or more work becoming worthwhile.

How will the job market react?

- ▶ An internal study at an unnamed software company suggests that AI makes programming work about three times as productive.
- ▶ Higher productivity could mean fewer people doing the same work, or more work becoming worthwhile.
- ▶ It is unclear where the new equilibrium will settle.

What is still worth doing?

What is still worth doing?

- ▶ The pleasure of mathematics has always motivated me.

What is still worth doing?

- ▶ The pleasure of mathematics has always motivated me.
- ▶ It does not matter in the least to me that AI can do it, too.

What is still worth doing?

- ▶ The pleasure of mathematics has always motivated me.
- ▶ It does not matter in the least to me that AI can do it, too.
- ▶ My enjoyment of mathematics has not been affected.

What is still worth doing?

- ▶ The pleasure of mathematics has always motivated me.
- ▶ It does not matter in the least to me that AI can do it, too.
- ▶ My enjoyment of mathematics has not been affected.
- ▶ Human understanding and integration of AI results into the landscape remains an important task.

Do not be afraid!

Do not be afraid!

- ▶ I am not worried about mathematics students or mathematicians at any level.

Do not be afraid!

- ▶ I am not worried about mathematics students or mathematicians at any level.
- ▶ The skill set and tools might change.

Do not be afraid!

- ▶ I am not worried about mathematics students or mathematicians at any level.
- ▶ The skill set and tools might change.
- ▶ Resilience and perseverance, the readiness to accept endless frustration, curiosity and creativity will remain crucial qualities.

Do not be afraid!

- ▶ I am not worried about mathematics students or mathematicians at any level.
- ▶ The skill set and tools might change.
- ▶ Resilience and perseverance, the readiness to accept endless frustration, curiosity and creativity will remain crucial qualities.
- ▶ If Mathematics adapts, it is likely that we will still be needed for problem solving in a broad range of jobs.

Where will it end?

Where will it end?

- ▶ We do not know where this will end.

Where will it end?

- ▶ We do not know where this will end.
- ▶ We still need to decide now how to teach, give credit and work together.

Where will it end?

- ▶ We do not know where this will end.
- ▶ We still need to decide now how to teach, give credit and work together.
- ▶ We need to find a way forward as a community.

Where will it end?

- ▶ We do not know where this will end.
- ▶ We still need to decide now how to teach, give credit and work together.
- ▶ We need to find a way forward as a community.
- ▶ Mathematics is hit by this wave earlier than other parts of society. That gives some responsibility to act quickly and wisely.

Breakout room 3

Exchange your views on possible future scenarios.

- ▶ Small groups, five minutes.
- ▶ Share time equally: let everyone express their views.
- ▶ The breakout rooms will close automatically after five minutes.

Alternative 1: A new equilibrium

Alternative 1: A new equilibrium

- ▶ Let machines explore beyond today's mathematical frontier.

Alternative 1: A new equilibrium

- ▶ Let machines explore beyond today's mathematical frontier.
- ▶ Their capabilities, costs and finite resources will eventually limit further progress.

Alternative 1: A new equilibrium

- ▶ Let machines explore beyond today's mathematical frontier.
- ▶ Their capabilities, costs and finite resources will eventually limit further progress.
- ▶ A new equilibrium may emerge far beyond our present horizon.

Alternative 1: A new equilibrium

- ▶ Let machines explore beyond today's mathematical frontier.
- ▶ Their capabilities, costs and finite resources will eventually limit further progress.
- ▶ A new equilibrium may emerge far beyond our present horizon.
- ▶ Follow the machines to understand the mathematical landscape they have opened.

Alternative 1: A new equilibrium

- ▶ Let machines explore beyond today's mathematical frontier.
- ▶ Their capabilities, costs and finite resources will eventually limit further progress.
- ▶ A new equilibrium may emerge far beyond our present horizon.
- ▶ Follow the machines to understand the mathematical landscape they have opened.
- ▶ Work from that new frontier on problems, theories and conjectures.

Alternative 2: We are just too slow for anything anymore.

Alternative 2: We are just too slow for anything anymore.

- ▶ Finite machine capabilities may set limits, and exponential growth may eventually end.

Alternative 2: We are just too slow for anything anymore.

- ▶ Finite machine capabilities may set limits, and exponential growth may eventually end.
- ▶ Neither guarantees a pace of progress that humans can follow.

Alternative 2: We are just too slow for anything anymore.

- ▶ Finite machine capabilities may set limits, and exponential growth may eventually end.
- ▶ Neither guarantees a pace of progress that humans can follow.
- ▶ Machine progress may exceed what we can absorb per unit of time.

Alternative 2: We are just too slow for anything anymore.

- ▶ Finite machine capabilities may set limits, and exponential growth may eventually end.
- ▶ Neither guarantees a pace of progress that humans can follow.
- ▶ Machine progress may exceed what we can absorb per unit of time.
- ▶ We may constantly need to change our zoom factor to place new developments in context.

Alternative 2: We are just too slow for anything anymore.

- ▶ Finite machine capabilities may set limits, and exponential growth may eventually end.
- ▶ Neither guarantees a pace of progress that humans can follow.
- ▶ Machine progress may exceed what we can absorb per unit of time.
- ▶ We may constantly need to change our zoom factor to place new developments in context.
- ▶ This would differ fundamentally from classical human understanding of mathematics.

Taking responsibility for solutions

Taking responsibility for solutions

- ▶ What remains of human understanding is unclear. It has always involved subconscious processes beyond proof logic.

Taking responsibility for solutions

- ▶ What remains of human understanding is unclear. It has always involved subconscious processes beyond proof logic.
- ▶ If humans retain a role, we must solve problems and take responsibility for solutions.

Taking responsibility for solutions

- ▶ What remains of human understanding is unclear. It has always involved subconscious processes beyond proof logic.
- ▶ If humans retain a role, we must solve problems and take responsibility for solutions.
- ▶ I doubt society will fund mathematical culture in the long term unless it is also useful.

Taking responsibility for solutions

- ▶ What remains of human understanding is unclear. It has always involved subconscious processes beyond proof logic.
- ▶ If humans retain a role, we must solve problems and take responsibility for solutions.
- ▶ I doubt society will fund mathematical culture in the long term unless it is also useful.
- ▶ Identify which competences cannot be delegated to AI if we are to take responsibility for mathematical solutions.

Taking responsibility for solutions

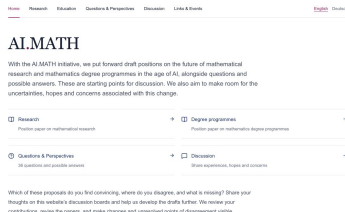
- ▶ What remains of human understanding is unclear. It has always involved subconscious processes beyond proof logic.
- ▶ If humans retain a role, we must solve problems and take responsibility for solutions.
- ▶ I doubt society will fund mathematical culture in the long term unless it is also useful.
- ▶ Identify which competences cannot be delegated to AI if we are to take responsibility for mathematical solutions.
- ▶ Focus education on those competences, using AI to help develop them.

- ▶ We currently have many questions and only a few answers.

- ▶ We currently have many questions and only a few answers.
- ▶ However, some thoughts seem worth sharing and discussing.

- ▶ We currently have many questions and only a few answers.
- ▶ However, some thoughts seem worth sharing and discussing.
- ▶ AI.MATH is a place where this discussion can take place.

<https://ai.math.ms/en/>



Discussion

- ▶ First: Q&A with everyone.
- ▶ Then: 15 minutes in medium size groups.