Prevention of Potential Technological Disasters by Adopting an Innovative Pedagogical Strategy in Engineering Education and Professional Development

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Rationale

- Making mistakes is a natural part of every human activity
- Most of them are genuine but some are deliberate and made to mislead, manipulate, deceive, exploit, misguide, and misinform. For example, fake news, deceptive advertising, conspiracy theories and AI deep fakes.
- From the Age of Information to the Age of Misinformation
- The 21st century phenomenon – information disorder, weaponization of information, computational propaganda, troll armies, information arms race

Rationale

- Regardless of the nature of a mistake, an ability to recognise a mistake and avoid becoming the victim of it is a valuable skill and a key aspect of critical thinking.

- "Examining, questioning, evaluating, and challenging taken-for-granted assumptions about issues and practices" (New Zealand Ministry of Education).

- The word "critical" was used 60 times in the 67-page document *The New Zealand Curriculum.*

- Critical thinking is one of the top important skills according to the World Economic Forum

Future of Jobs, World Economic Forum (2016): Top 10 Skills in 2020

1. Complex Problem Solving
2. Critical Thinking
3. Creativity
4. People Management
5. Coordinating with Others
6. Emotional Intelligence
7. Judgment and Decision Making
8. Service Orientation
9. Negotiation
10. Cognitive Flexibility

WORLD ECONOMIC FORUM

Top 10 skills of 2025



Type of skill

- Problem-solving
- Self-management
- Working with people
- Technology use and development

Source: Future of Jobs Report 2020, World Economic Forum.

Examples: Politics

The Republican Party poster during an election campaign in the USA:

"317 million people in America and you spend $360 million on just introducing Obamacare?

Just give each citizen a million bucks!"

Parker, M. (2019). *Humble Pi: A Comedy of Maths Errors.*

Examples: Tax Department

IR 3 GUIDE INLAND REVENUE

Multiply Box 3 by 0.14 (1.4%). Print your answer in Box 4. This is your ACC earner premium. Print this amount at Box 11D of your return.

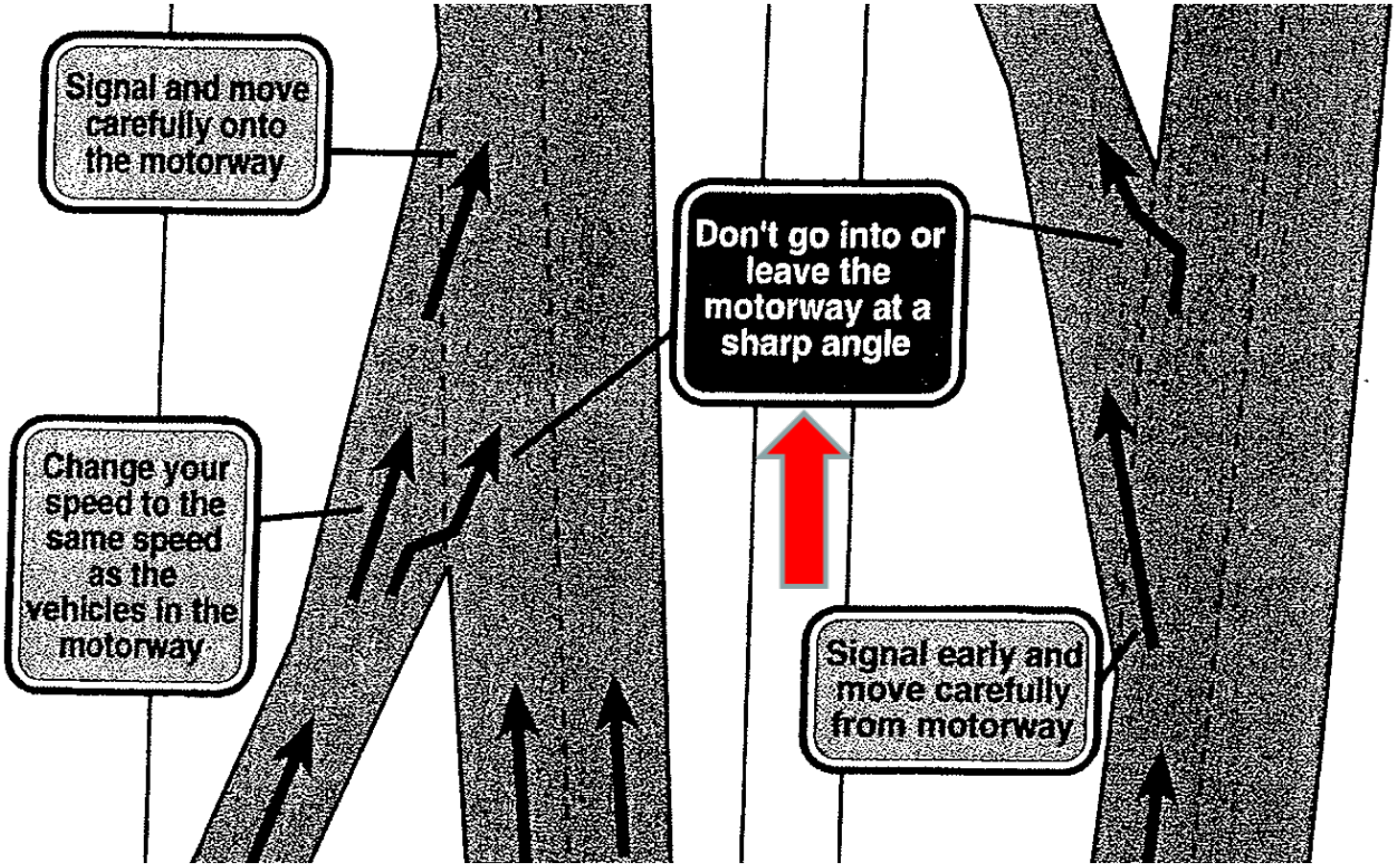
4 $ 346 .89

All other cases

In all other cases, your liable earnings amount is your other income. Print your other income in Box 37A of your return and calculate the earners' account levy—multiply Box 37A by 0.019 (0.19%). Print your answer in Box 37F. Now go to page 81 to calculate y[illegible] residual claims levy.

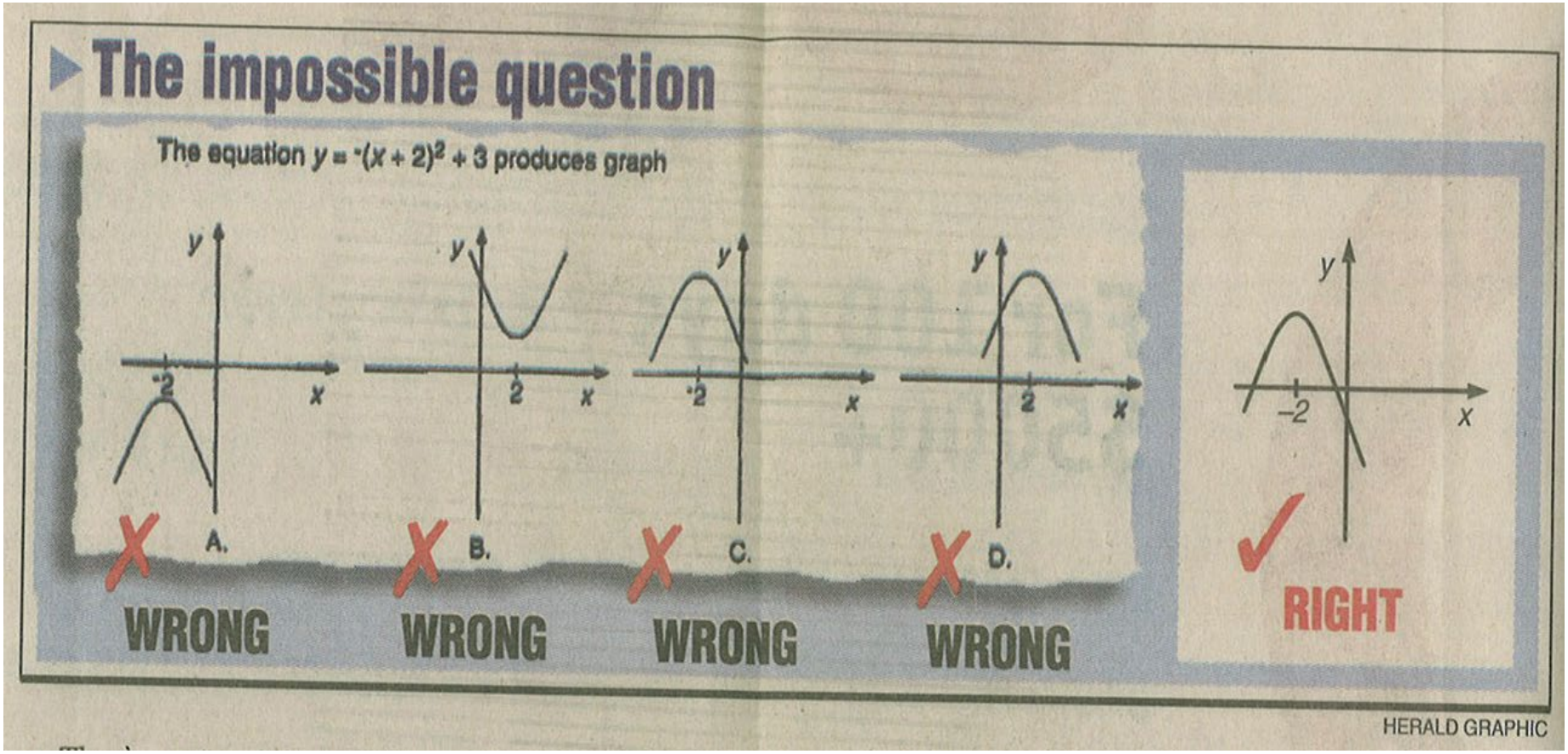
Examples: NZ Road Code

A sharp angle: geometric and metaphorical meanings



Examples: National Maths Exam

$$y = -(x + 2)^2 + 3$$



Examples: National Maths Exams

- There were 5 (!) mistakes in the New Zealand national school maths and stats exams in 2016

- The New Zealand Herald journalists reported that the students were ‘baffled’, ‘shocked’ and ‘confused’ by the mistakes

Examples: Media



А КАК У НИХ

Какую скидку можно получить на зарубежных курортах

Египет. Торговаться можно практически в любой торговой точке. Можно уходить и возвращаться. Главное - не жалеть времени, потому что торг тут - часть местного колорита. Цену можно снизить на 100%-150%.

Getting discount at holiday resorts

Egypt. You can bargain at any shop. It's a part of local culture and customs. You can reduce the price by 100%-150%.

Examples: Space Industry



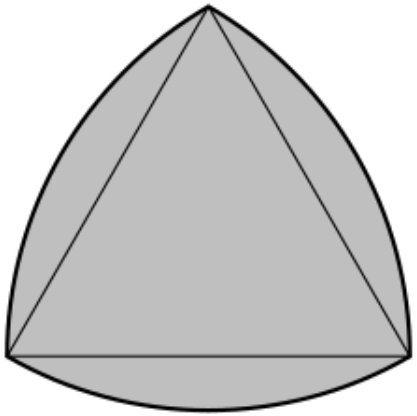
In January 1986, the Space Shuttle Challenger broke apart 73 seconds into its flight, killing all seven crew members aboard. The Challenger exploded because of a leak from one of the solid rocket boosters… But there was a second problem with the seals between the booster sections, a subtle mathematical effect...

The procedure for checking if a cross-section of a cylinder is still circular was to measure the diameter in three different places and make sure that all three were equal.

The NASA engineers used the wrong criterion of a constant diameter to identify a circular shape

Examples: Challenger Tragedy 1986

- The statement "A curve of a constant width is a circle" is false. For example, the famous Reuleaux triangle:



The Reuleaux triangle

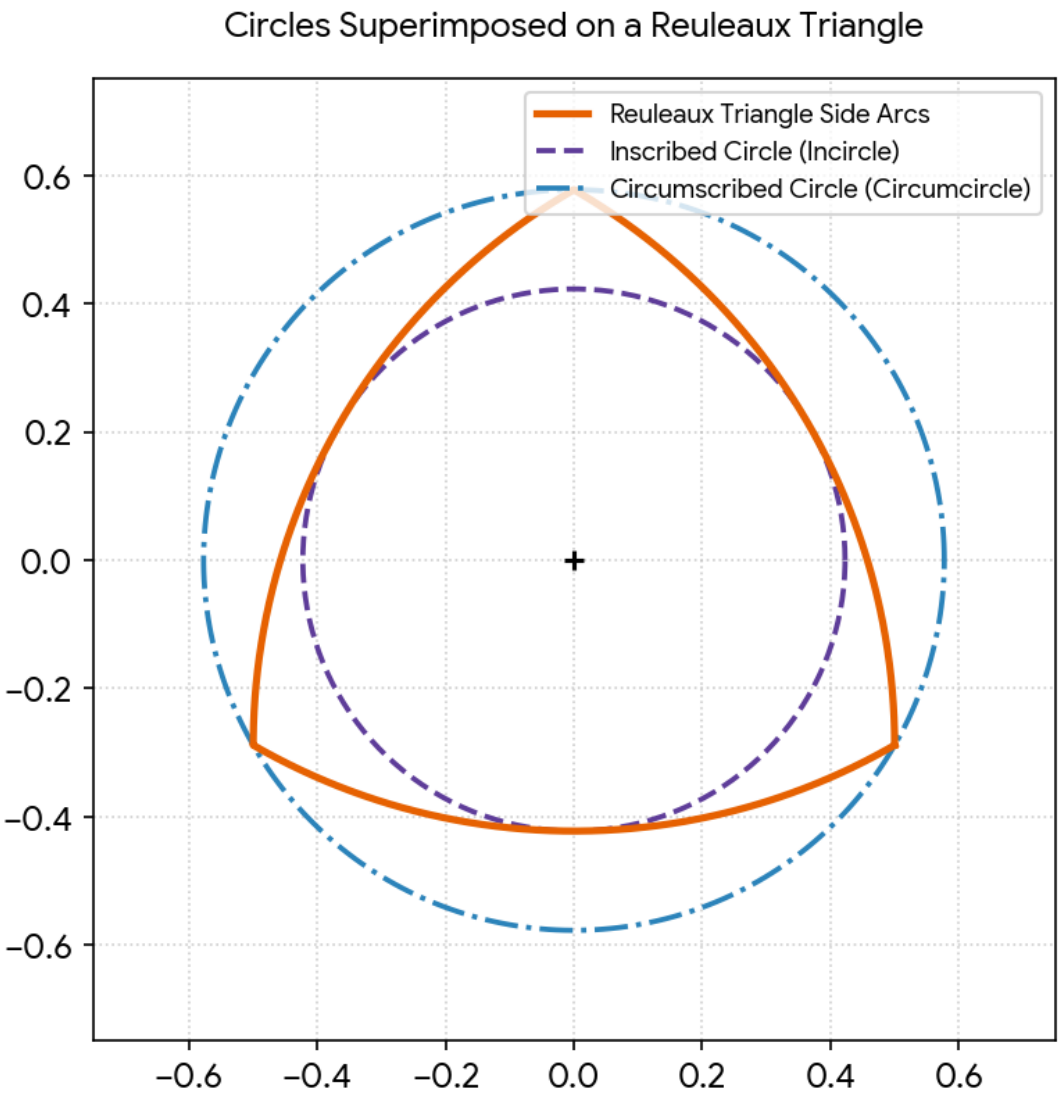


The UK 20p and 50p – equilateral curve heptagon

- That mathematical error contributed to the disaster as reported in Finding #5 of Chapter IV: The Cause of the Accident of the *Investigation Report*

https://www.nasa.gov/history/rogersrep/v1ch4.htm

Circles Superimposed on a Reuleaux Triangle



Examples: The “Fryscraper” 2013

The solar glare problem caused by a concave shape

of a 37-storey skyscraper

in London that focused light and raised the temperature at street level to 91^{o}C melting plastic car parts and even setting doormats on fire on some sunny days




MAGNIFYING

High Rhine Bridge between Germany and Switzerland 2003



The two teams used different reference points for sea level that resulted in a 27cm discrepancy. They knew about it from the start. However, to correct for it, someone added it instead of subtracting to produce a 54cm gap between the two halves. It was discovered just before the final sections were permanently joined. It resulted in a costly and embarrassing delay.

Proposal

- To enhance students' critical thinking and prepare students for real life better it is proposed to include so-called provocative questions in teaching and assessment
- A provocative question is a question that is *deliberately* designed to mislead the solver
- It looks like a typical routine task, but it has a catch

Design of Provocative Questions

- Ask to do an impossible task, e.g.

- prove something that is not provable
- show the existence of something that doesn't exist
- apply a rule or formula or law that is inapplicable due to its conditions/constraints
- choose a correct answer in a multichoice format where all suggested answers are incorrect

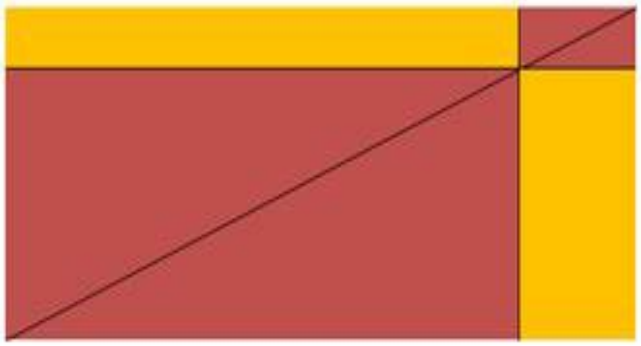
- Divert attention by providing non-essential information

Examples: Maths

1. Show that the area of the triangle with the sides 20 cm, 10 cm and 8 cm can be larger than 50 sq.cm

2. Explain why a longer number means a larger number

3. Prove that the orange rectangle on the right has a larger area than the orange rectangle on the left



Examples: Maths

4. Sketch a graph of a function that is differentiable on (a, b) and discontinuous at least at one point on (a, b)

5. Find the derivative of the function $y = \ln(\ln(\sin x))$

6. Find the following definite integral using the Newton-Leibniz formula: $\int_{-1}^{1} \frac{dx}{x}$.

Examples: Stats

7. Linda Problem. Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. Which alternative is more probable?

a) Linda is a bank teller.

b) Linda is a bank teller and is active in the feminist movement.

Daniel Kahneman (2011). *Thinking, Fast and Slow.*

Shocking Performance on Linda Problem

- "About 85% to 90% of undergraduates at several major American universities chose the second option, contrary to logic" (p. 158).

- "85% of doctoral students in the decision-science program at the Stanford Graduate School of Business, all of whom had taken several advanced courses in probability and statistics also incorrectly ranked "feminist bank teller" as more likely than "bank teller" (p. 159).

Daniel Kahneman (2011). *Thinking, Fast and Slow.*

Other Subjects: Physics

- What is the most famous quadratic equation in the theory of relativity?
- Many people would answer $E = mc^2$.
- The answer is incorrect: it is not a quadratic equation, as *c* is a constant, so it is a linear equation.

Other Subjects: Chemistry

- Why can't you obtain the reading of -1º C on a thermometer measuring ocean water temperature?

- The expected (wrong) answer is "Because water freezes at zero degree Celsius and at -1º C we have ice, not water".

- The correct answer is: "Yes, you can as ocean water freezes at around -2º C".

Other Subjects: Science

Which Statement is Correct?

- Shadow has mass
- Liquid has a definite shape
- Solid can be easily compressed
- Gas has a definite volume

- Expected (wrong) answers: one of them is correct
- Correct answer: All statements are wrong!

Other Subjects: Music

- You play the same piece of music twice and ask the question: What is the difference between those two pieces?
- Expected (wrong) answers: additional instrument(s); louder/softer parts; etc.
- Correct answer: No difference, they are the same

Other Subjects: Engineering

- Example 1. Give students a task to design a bridge with certain specifications (parameters, materials, location, etc.) that make the task impossible *without telling* them about it.

- Example 2. Give students a task to analyse a faulty electrical circuit diagram *without telling* them about the fault.

Why Provocations?

Develop a highly critical/skeptical mindset that would help with:

- Recognizing and avoiding mistakes
- Reducing susceptibility to misinformation
- Becoming better-informed citizens and decision makers
- Specifically for engineering students: preventing potential technological disasters



Assessment

Gradual inclusion of provocative questions:

- first use them for illustration purposes
- then include into formative assessment
- finally, into summative assessment

Assessment

The following optional warning might be added to the instruction page of the assessment:

"Some of the questions are typical routine questions and some are *deliberately* designed to mislead you. You should decide which is which and act accordingly".

Assessment

- Sometimes erroneous statements are being used in the assessment. However, normally they are clearly labelled as incorrect statements and the question asks students to correct them.

- For example, a question might ask to critique a misleading graph or disprove a wrong statement by a counterexample or identify a mistake in a sophism or verify whether the given statement is correct or incorrect and justify the answer.

Assessment

- But such questions contain prompts and hints indicating that something is wrong and this alerts students to think more carefully compared to solving a standard question.

- However, in real life there are often no prompts and hints about possible errors.

- Therefore, provocative questions go one step further towards enhancing critical thinking

Feedback on the Strategy of Using Provocative Questions

- Survey-1 of 82 school maths teachers

  Use in teaching – 96% in favour

  Use in assessment – 63% in favour

- Survey-2 of 8 university maths lecturers

  Use in teaching – 75% in favour

  Use in assessment – 38% in favour

Comparison: Teachers vs Lecturers

- Similar attitudes towards the use in teaching:
  the vast majority in favour

- Different reasons for not adopting in assessment:

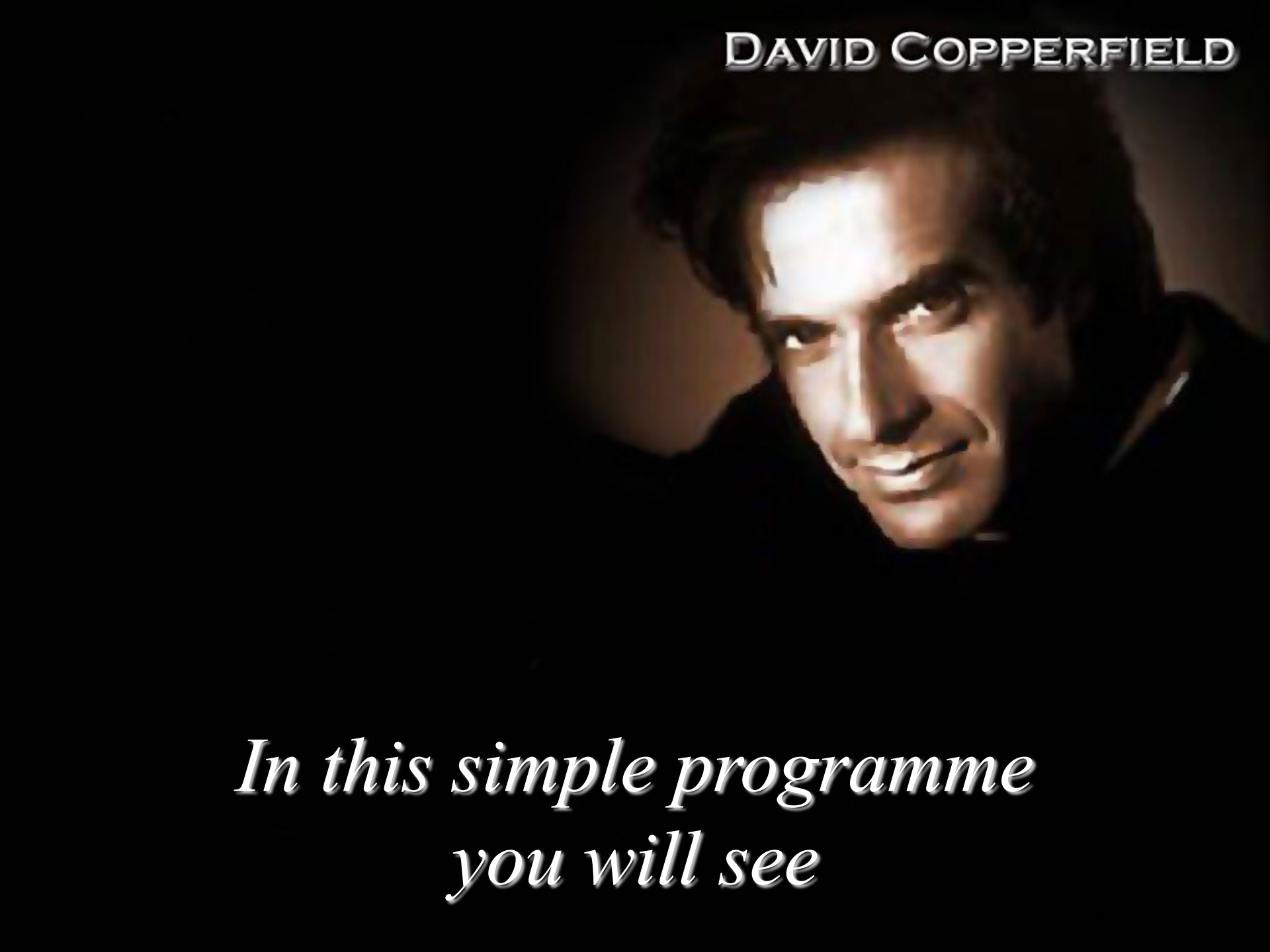
  - Teachers were concerned about students
    (unpreparedness, additional stress)

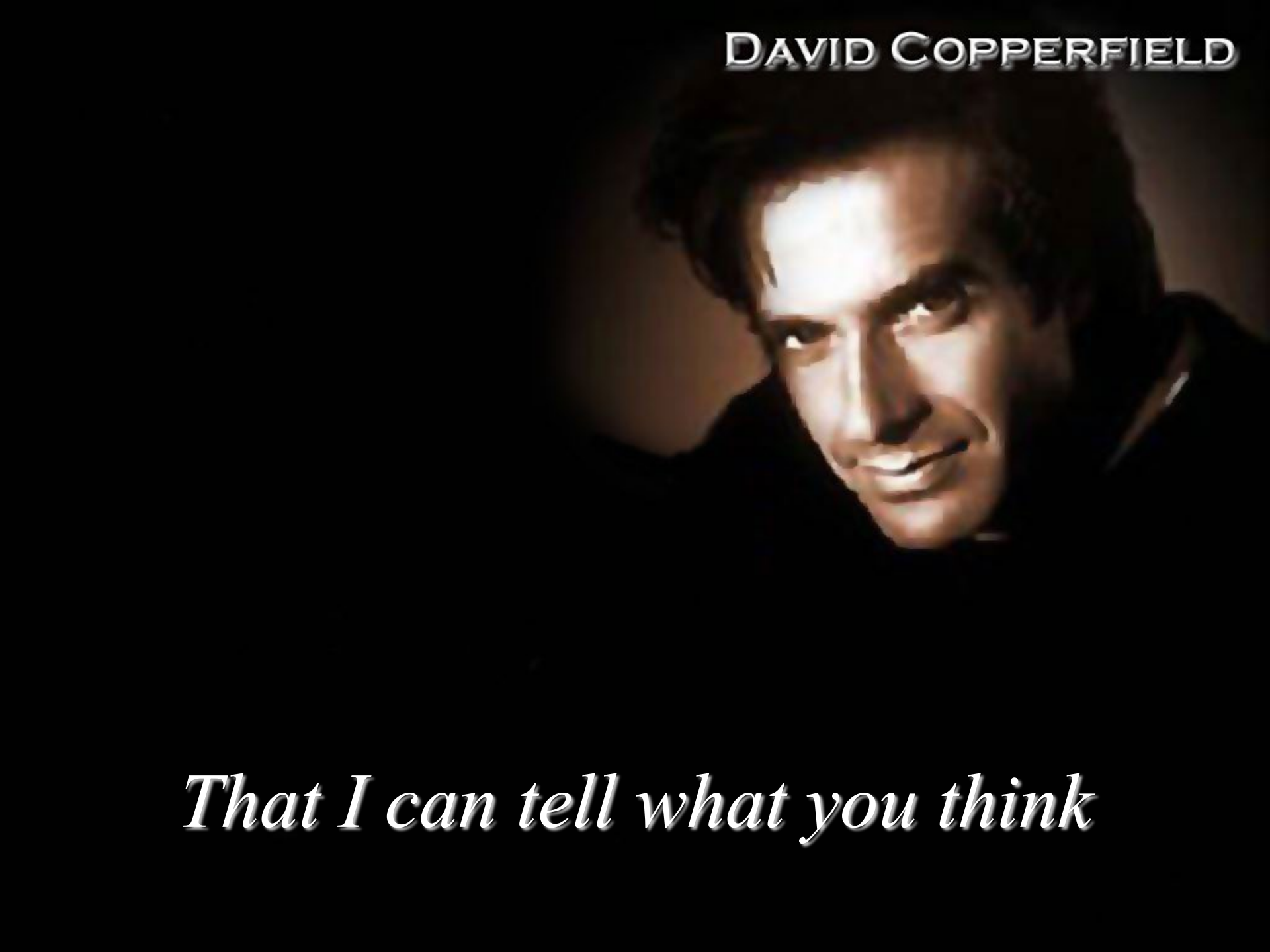
  - Lecturers were concerned about their own career
    (possible students' complains, lower pass rate)

Your professional feedback is much appreciated

Thank you
for your attention

Testing your focused attention

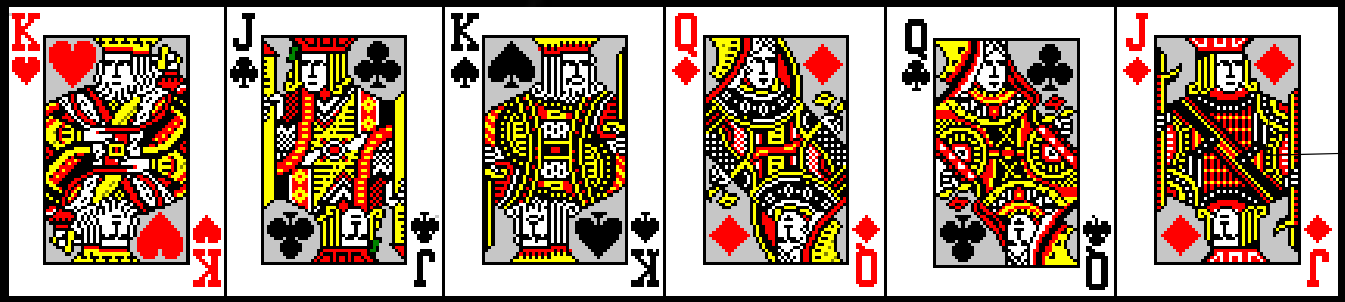

DAVID COPPERFIELD
In this simple programme
you will see

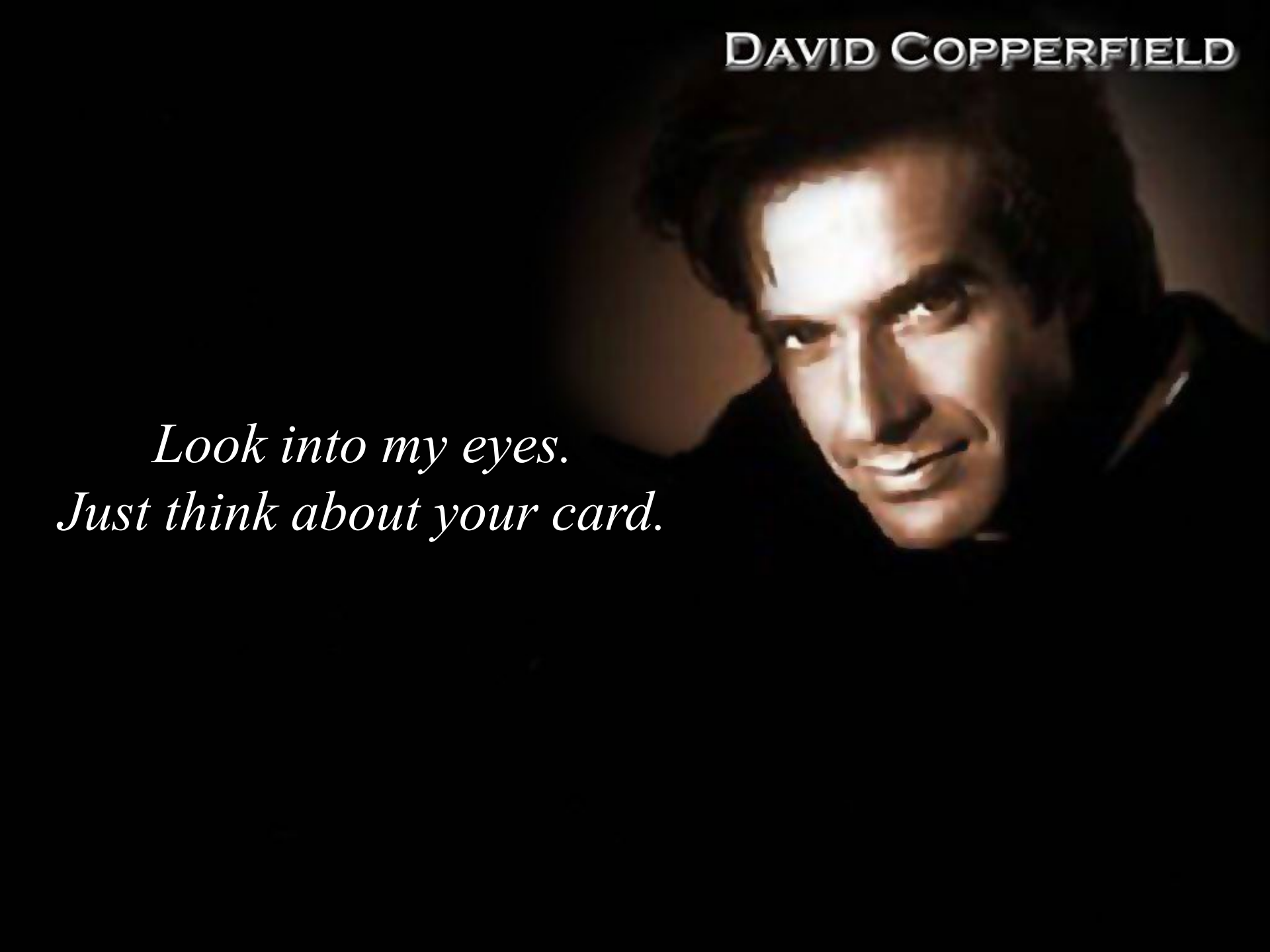

DAVID COPPERFIELD
That I can tell what you think

DAVID COPPERFIELD

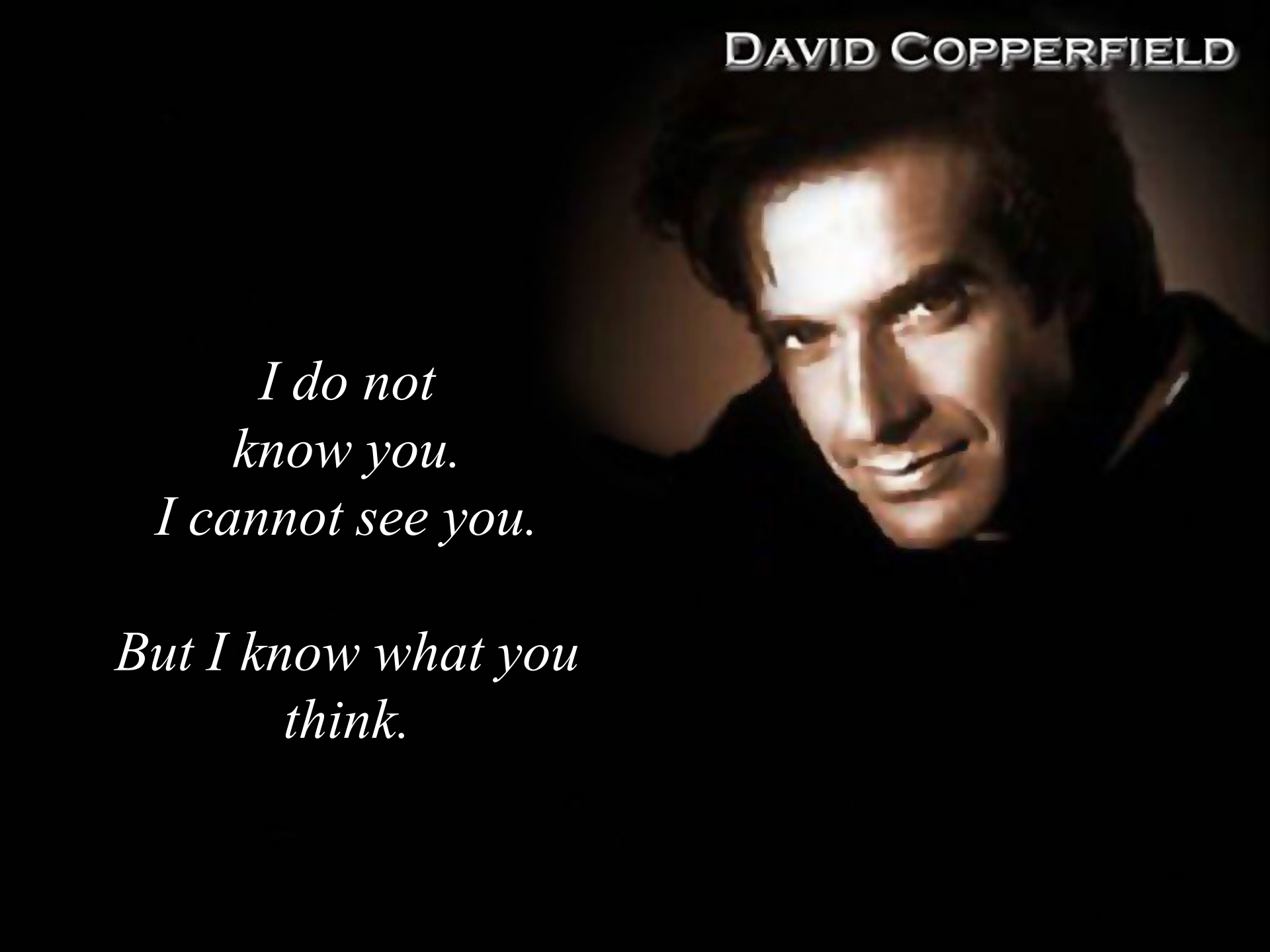


You can see 6 cards.
Think <u>one</u> of them.
Just think.
Think now.





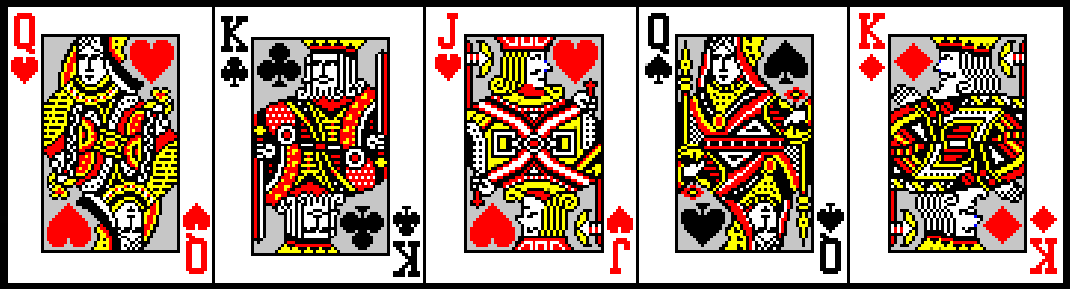
Look into my eyes.
Just think about your card.

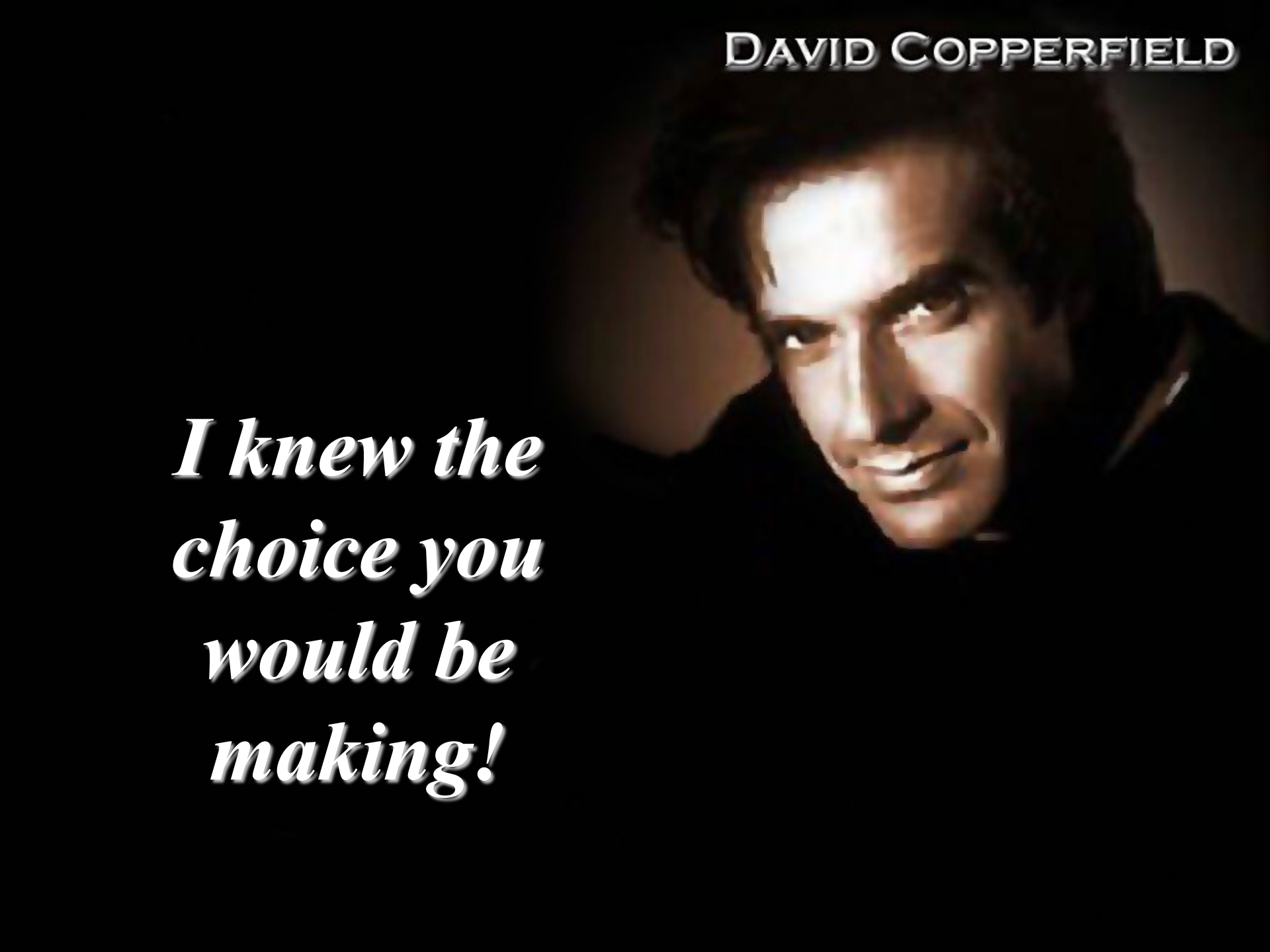

DAVID COPPERFIELD
I do not
know you.
I cannot see you.
But I know what you
think.

DAVID COPPERFIELD



Look,
I took
your card !!!




DAVID COPPERFIELD
I knew the choice you would be making!

???

Thank you
for your attention