Info Card 1

Absolute Zero

Absolute zero (-273,15°C) is the lowest possible temperature in our universe.
All matter freezes, not even electrons, protons or neutrons have any movement.

Many quantum applications (e.g. quantum computers) can only be operated at temperatures close to absolute zero. This, however, requires complex and expensive equipment.

Info Card 2

Entanglement

Entanglement means that a system as a whole can be in a well-defined state, even though the individual subsystems cannot be distinctly described. This can have intriguing consequences: although the result of a measurement of any sub-system is completely random, all of the results are interdependent.

It is as if two dice, when thrown, always mysteriously land the same way up.

Info Card 3

Quantum Simulations

Quantum physics has enabled us to better understand the properties of numerous materials such as semiconductors, for example. For some materials, however, computer simulations of their properties are too complex for our current computers.

Researchers are now able to use simple quantum systems, such as clouds of cold atoms, to simulate larger solid-state objects.

Info Card 4

Quantum Technologies 1.0

Many everyday applications are based on quantum physical phenomena. These include lasers, solar cells, transistors, MRI imaging technology, LED lighting and GPS navigation.

All of these technologies have become ingrained in modern day life and are part of the so-called first quantum revolution.

Info Card 5

Decoherence

Quantum objects have strange properties, but why can we not observe these in everyday life? Why is it possible, for example, for an electron to be in two places at once, but not for a cat? The answer to this is known as decoherence.

In large objects such as a cat, the quantum particles constantly interact with each other. These interactions destroy any potential superposition states, and thus the cat remains in a single location.

Info Card 6

Tunnelling effect

Normally, an object can only overcome a barrier if it has enough energy to overcome the obstacle. Due to the phenomenon of superposition, however, a quantum particle always has a (slight) probability of already being on the other side. It is as if the particle had „tunnelled“ under the barrier.

Special microscopes use this effect to image and even manipulate individual atoms or molecules.

Info Card 7

Elementary Particles

Elementary particles are particles that are indivisible, according to current knowledge. They are the fundamental building blocks of the universe, and are thus of great interest to scientists.

Elementary particle research, however, is extremely expensive. The construction of a single particle accelerator (the LHC at the CERN research centre) cost about 4,5 billion euros, for example.

Info Card 8

Quantum Sensors

The development of highly sensitive quantum sensors will enable us to measure extremely small physical properties.

Researchers are currently developing ultra-sensitive scales, for example, which use carbon nanotubes to weigh individual atoms. A further project are sensors that can measure the miniscule magnetic fields generated by brain activity.

Info Card 9

Ground State

The lowest possible energy state of a quantum system is defined as the ground state. In this state, all particles are stable.

Ultimately, all particles in a system strive to occupy the ground state.

Info Card 10

Interference

When two waves meet, they can either intensify or mitigate each other. This is called interference. If you throw two stones into a lake, for example, you can observe how the circular wave patterns interfere with each other: peaks become higher, troughs lower, but if a peak hits a trough, they cancel each other.
This phenomenon can be observed with all kinds of waves such as sound, light or quantum particle waves.

Info Card 11

Laser

A laser generates monochromatic, coherent (in phase) light. In this process, photon hits an atom in an excited state, which then emits a further, identical photon. This is repeated numerous times, generating a large number of identical photons: thus, a laser beam is created.

Lasers have numerous applications, ranging from CDs and DVDs to distance measurements and even eye surgery procedures.

Info Card 12

Light

Light is a form of electromagnetic radiation with a wavelength of 400 to 800 nanometres. The precise wavelength determines the colour of the light. Other forms of radiation (e.g. microwaves, radio waves or ultraviolet light) can be regarded as light with colours that we cannot see.

When investigating light, researchers discovered that it is made up of tiny particles, subsequently called photons.
This was the advent of quantum mechanics.

Info Card 13

Photon

A photon is the smallest possible amount of light. It possesses a distinct amount of energy and thus a certain wavelength. As a quantum object, it has the properties of both a particle and a wave.

Single photons are used in so-called quantum encryption and quantum cryptography. In these technologies, they are fundamentally responsible for highly secure data transmissions.

Info Card 14

Polarisation

The direction of the oscillation of a wave perpendicular to its propagation is known as polarisation. If you move one end of a suspended rope up and down, a wave travels through the rope. The oscillation goes up and down, the polarisation of the wave is thus vertical.

Light, even down to individual photons, can be polarised. This effect is used un quantum cryptography, for example.

Info Card 15

Photoelectric Effect

If a solid object is exposed to light of a suitable wavelength, the photons are absorbed by the electrons within the object. This can cause the electrons to be dislodged from their atomic shells.

This property of light proves the existence of photons, as this effect is only dependent on the wavelength of the light.

Solar cells utilise this effect, as do photodiodes or CCD chips in digital cameras.

Info Card 16

Uncertainty Principle

It is not possible to know two complementary variables of a quantum particle such as position and velocity at the same time.
This phenomenon is known as Heisenberg's uncertainty principle.

The higher the precision of one variable, the lower the accuracy of the other. If, for example, the impulse of a particle is precisely known,
it is then not possible to determine its location.

Info Card 17

Quantisation

Quantisation is the property that the entire field of quantum mechanics is based on. Many values previously thought to be infinitely divisible, are, in fact, quantised. Light, for example, consists of individual photons, each of which has a certain amount of minimum energy.

Imagine a display screen: from a distance it is easy to imagine that you can zoom in as far as you like. Yet, when you get close enough, you recognise the individual pixels as the smallest possible sub-divisions of the image.

Info Card 18

Superposition

Superposition means that every quantum mechanical state of a system can be described as a number of overlapping individual states. When subjected to a measurement, the system is 'forced' to adopt one of the individual states. The nature of the superposition determines the probability of each individual state being adopted.

Info Card 19

Quantum Dots

Quantum dots are nanoparticles that emit and absorb specific wavelengths (colours) of light.
By altering the dimensions and the composition of a dot, it is possible to precisely control the specific wavelengths.

Quantum dots are used in computers, as markers in microscopy, or in LED televisions.

Info Card 20

Spin

The intrinsic angular momentum of a particle is known as its spin. In contrast to classical angular momentum, spin is not generated by the movement of matter on a circular orbit.

Instead, spin is a fundamental property of all particles. Some particles (fermions) have a spin value of ½, whilst others (bosons) have a value of 1.

Info Card 21

Superconductivity

At extremely low temperatures, the electrical resistance of a superconductor drops to zero. Electrical currents can thus flow through the superconductor completely loss-free.

This quantum effect is already used in magnetic resonance imaging or in particle accelerators.
Generating this effect at room temperature would have a number of advantages: more efficient power generation, stronger electric motors, grid losses reduced to an insignificant level.

Info Card 22

Qubit

Qubits (short for quantum bits) are the functional basis of a quantum computer. In a classical computer, the bits only have values of 0 and 1, whereas a qubit can have any value between 0 and 1, thanks to the phenomenon of superposition.

The enormous computing power of quantum computers is due to this property of qubits.

Info Card 23

Quantum Computers - Advantages

Based on qubits, the promise of quantum computers is enormous computational power. Many problems that cannot be computed by classical computers should be easy for quantum computers.

Whether route optimisation, simulations of novel medical drugs or highly precise climate models, quantum computers could potentially revolutionise many areas of our lives.

Info Card 24

Quantum Computers - Disadvantages

The enormous computing power of quantum computers could be used to easily decrypt our current data encryption methods. Our data would no longer be secure!

In addition, we still face a number of major technological hurdles: one difficulty is controlling the necessary qubits, which are also prone to errors. Also, many quantum computers are operated at extremely low temperatures, which is both challenging and expensive.

Issue Card 1

How long do we still need to wait? (1)

It sometimes takes decades to convert research results into viable, everyday products. Lasers are a prime example, with over 40 years between theoretical description and the development of a functional prototype.

What would have happened if we had given up hope long ago and, consequently, lasers had never been invented?

Issue Card 2

How long do we still need to wait? (2)

Some scientific predictions require years of research before they can be verified. 40 years passed between the theoretical prognosis of the Higgs boson and its discovery, for example.
What would have happened, if we had given up years ago and thus never discovered the Higgs boson?
This research also cost a lot of money and effort - could we have better used these resources to solve other immediate problems?

Issue Card 3

Vulnerable Cryptography

In principle, quantum physics provide theoretical protocols that are invulnerable to cyber-attacks.
And yet some scientists have managed to exploit weaknesses in their implementation to hack the quantum protocols and break the encryption. This raises the question of whether we should still rely on theoretical predictions despite the realities of human error in every technological endeavour?

Issue Card 4

Great Potential

Although most quantum technologies are still in their infancy, the envisaged applications seem very promising in a number of fields. Thomas J. Watson, former chairman of IBM, is reported to have said in 1943 that there will be “a world market for maybe five computers”.
I retrospect this statement was, of course, completely wrong!
But is it even possible to assess the potential impact of new technologies at our current point in history?

Issue Card 5

Will we have a new Quantum Theory?

In the history of science, it has often happened that a newer theory has replaced an older one, heliocentrism replaced geocentrism, the theory of evolution replace catastrophism. No one can be certain that this will not happen in the field of quantum physics.
But how relevant is this question, as the current theory already allows us to make precise predictions and develop new technologies?

Issue Card 6

What do we measure?

When we conduct a measurement of a quantum system, we alter its properties. The wave function collapses and we observe a single, well-defined parameter.

But if our simple presence as an observer has such an influence on a quantum system, how can we actually know for certain anything about the system?

Issue Card 7

Intuition

We often have the feeling, that quantum physics is extremely hard to comprehend, thus leading to confusion and misunderstandings. Is this really the case, compared to other fields such as astronomy or chemistry? Or is this simply due to our inability to intuitively grasp the basic concepts of quantum theory?

Why is it, that the apparent randomness of quantum physics is more incomprehensible than the invisible existence of gravity?

Issue Card 8

We have more important problems

Science and technology have significantly improved our quality of life and will continue to do so. Research, however, often takes a long time to deliver on potential promises. In the meantime, there are many current problems and challenges that require solutions.

Would it not be better to focus on tackling social problems, unemployment or climate change here and now? Or can science and technology help us with these problems?

Issue Card 9

Basic or Applied Research?

It is not easy to predict when we as a society will be able to use a new technology. In fusion energy research, for example, new challenges keep appearing, causing significant delays to any plans for fusion power plants. On the other hand, some applications such as lasers, for example, originated from scientific curiosity without any consideration of practical uses.

With this in mind, how can we make any decision on which fields of research might deliver the greatest benefits?

Issue Card 10

Fake News

It is important for people to be informed in regard to scientific developments, so that they can critically assess articles and posts in newspapers, adverts or social networks. This helps prevent being fooled by fake news. Too often, however, information is spread by unreliable pseudo-scientific sources.

How should we deal with such dubious information and the opinions it creates?

Issue Card 11

Can we Predict the Future?

In the 1960s, most depictions of a 21st century future showed skies full of flying cars. Today, our expectations of the future have significantly different.

Does it make sense to listen to people who make promises that their field or research will bring us the technology of the future?

Is it even possible to make solid, reliable predictions in regard to science and technology?

Issue Card 12

Return on Investments

Basic research requires scientific resources, but does not directly produce any commercial or industrial applications.
Without basic research, on the other hand, it is almost impossible to achieve a degree of technological understanding and competency required to ensure economic prosperity.

How can we escape this vicious circle?

Issue Card 13

Public or Private Research Funding

Many people are of the opinion that knowledge should freely belong to all of humanity. On the other hand, many applications are developed by companies. These often invest large amount of money into research, with the goal being to make large profits from the resulting products. This obviously leads to a privatisation of knowledge.

How might it be possible to reconcile public and private research interests?

Issue Card 14

Applications of Basic Research

Sometimes, useful applications are created as a sort of side effect in in research fields that were not expected to produce immediate technological implementations. Some examples of this are the internet (from nuclear research) or satellite based navigation (based on the theory of relativity). Should we continue to invest in basic research in order to profit from unexpectedly developed applications? Or is the increase in basic knowledge sufficient to justify the costs?

Issue Card 15

More than one Universe?

How should we interpret quantum physics? The most common and oldest approach is the Copenhagen interpretation (1925-1927).

There are also other alternative descriptions, such as the many-worlds interpretation (~ 1960). This asserts that all possible outcomes of a quantum measurement are realised in parallel universes, of which we can only observe a single one. However, we do not yet know how to experimentally test this interpretation.

Issue Card 16

Military Applications

It is not just the civilian field that has high hopes in the promises of quantum technology. In the military sector, there are also numerous possible applications: secure communication, optimised submarine navigation, or quantum computer war simulations. These technologies have the potential to radically change our current geopolitical structures. Is this development a threat, or will this make our world a safer place?

Issue Card 17

Vision: Quantum Batteries

Quantum batteries are quite different from conventional rechargeable batteries. Instead of simple chemical processes, quantum batteries use superposition and entanglement to greatly increase recharging and storage capabilities.
The research on this is still in an early stage, but if their full potential can be realised, quantum batteries could drastically change the way we store and use energy.

Issue Card 18

Vision: Quantum Navigation

Quantum navigation uses effects such as entanglement and superposition for highly precise, self-reliant navigation, especially in challenging environments or without reliance on GPS.

In the civil sector, this technology could potentially be used in deep-sea exploration, aviation or autonomous vehicles. In addition, the military is also very interested in this technology.

Issue Card 19

Vision:
Prosthesis Control by Quantum Sensors

Highly sensitive quantum sensors could be used to measure the electrical impulses of the human nervous system. These signals can then be used to control the actuators and motors in artificial limbs, enabling intuitive and trouble-free movement of prosthetics.
This would significantly increase the quality of life of amputees.

Issue Card 20

Vision:
Quantum Computer Drug Development

Quantum computers promise to be far superior in simulating molecules and their interactions than classical computers, enabling highly precise characterisations of molecular systems. This could greatly increase the rate of development of pharmaceutical drugs and therapies, as the necessary calculations would be conducted far quicker than possible today.

Issue Card 21

Vision:
Quantum Sensors for Cancer Detection

Quantum computers promise to improve the early detection of cancers. By using so-called hyper-polarisation in combination with nano-diamonds, it is possible to greatly increase the signal strength magnetic resonance imaging (MRI). The resulting high definition images enable doctors to detect cancer cells more precisely and at an earlier stage.

Issue Card 22

Vision:
Quantum Cryptography

Quantum cryptography utilises superposition and entanglement to transmit a so-called quantum key. This can then be used to encrypt and subsequently decrypt the main message. Any attempt to intercept the key inevitably alters it, immediately alerting the involved parties to the breach of security.

This property ensures that quantum cryptography is an extremely secure method for transmitting data.

Issue Card 23

Vision:
Computing highly complex problems

Quantum computers could be used in logistics and traffic planning to optimise routes and minimise transportation routes.
Current computers are quickly overloaded when subjected to large amounts of data combined with numerous variables.
Quantum computers, on the other hand, are able to compute all possible routes at the same time, and can quickly give an optimised result.

Issue Card 24

Vision:
Quantum Phase Imaging

The superposition and entanglement of photons can be used to generate highly precise and detailed images. Researchers hope to use this approach to glean information from wavelengths which cannot be resolved by classical means. This could be used to image concealed layers in paintings or to depict the inner structures of fossils, for example.

Story Card 1

Prof. David Doleman

I am a historian and a university lecturer. It is my conviction we, as a society, put too much pressure on scientists to apply their research to practical uses and products as quickly as possible.

History, however, teaches us that research requires time. The basic principle of lasers, for example, was published in 1917 by Albert Einstein in his paper on the Quantum Theory of Radiation.
Yet it was not until the 1960s that the first prototype was developed. And even then it took many more years for laser applications to achieve the widespread success they have today.

I think that we should not demand results so quickly. Instead, we should be patient and let scientists conduct their research without such constraints or pressure.

Story Card 2

Natalie Neuhaus

I teach physics at a secondary school. I am concerned about the apparent lack of scientific knowledge amongst the general population. Pseudoscientific fraud is constantly increasing, exploiting the ignorance of people by using falsified facts and technical terms to swindle them out of their money. No, there is no such thing as a miracle quantum therapy - science isn't magic.

This is why I encourage my pupils to understand scientific concepts and principles. This will enable them to be discerning and critically analytical in everyday life. But who are they going to believe more?

Story Card 3

Pavlos Papadopoulos

I'm a courier for a large parcel delivery service. Every day I have to visit a ton of different addresses. Often, I have to deliver too many parcels in a day, and then I have to work overtime. Often it seems that I drive up and down the same roads multiple times - it seems I could save a lot of time with better route planning.

Yesterday I heard on the radio that quantum computers are much better at calculating and planning such complex routes. My first thought was: I need one of those!

With a quantum computer in my pocket I could be home every evening in time for dinner and could spend more time with my two year old daughter. But unfortunately, it seems that quantum computers only exist in laboratories…

White Card

White Card

White Card

Story Card 4

Dr. Clara Caldini

I work at a quantum information research group at the Max-Planck-Institute for Quantum Optics. Apart from my scientific and technological research, I think it is important to inform the public on the impact that novel developments could potentially have on their lives.

In our student laboratory Photonlab we try to explain the basics of quantum technologies so that pupils and teachers understand them. Unfortunately, other scientists often dismiss or ridicule the importance of this work.

Story Card 5

Jun Jiang

I am the head of a global telecommunications company. Recently, I met some researchers at the Mobile World Congress who told me that quantum technologies could greatly improve the security of data transmissions. When I returned home, I told my engineers to look into how we could utilise quantum physics in our business.

Unfortunately, this could mean that my entire company needs restructuring.

Story Card 6

Franziska Friedrich

On one of my favourite YouTube channels, a young engineer explains how everyday technology works. Yesterday, for example, she showed that our mobile phones contain many transistors and other components made from semiconducting materials. Apparently, our whole digital society is based on these basic building blocks. Yet, without an understanding of the quantum properties of these materials, none of these applications would be possible.

I had no idea that I have quantum technology in my pocket!

White Card

White Card

White Card

Story Card 7

Alex Albrecht

Soon I will be taking my final school exams and then I will have to decide what to do with my life. I have always been fascinated by the natural sciences, but I can't decide which subject I want to focus on. Recently I read up on the recent advances in the field of quantum physics.

The whole field sounds very promising, and I am excited by the possibility to discover new things! It seems that scientists and researchers are our modern day explorers - but are there still enough new things to discover?

Story Card 8

Sahra Silva

I live in a small mountain village. That is why I buy almost everything that I need online. But there are many people in our village, like my grandma, who prefer to drive an hour to the nearest large town rather than enter their data into the internet, as they are afraid of hackers.

I know that I could be the victim of such an attack. But I am not too worried, as I recently read that scientists are developing an extremely secure encryption method based on the exotic properties of quantum physics.

How can I convince my grandma that such new technologies can make our data much safer and thus improve our lives?

Story Card 9

Dr. Minho Ma

In my job as a biochemistry researcher, I investigate new substances that potentially could be used as novel drugs. These could enable us to treat diseases, which so far have been incurable. The most challenging part of this development process is investigating the effects of these substances on living organisms.

Our simulation programmes for this could be greatly improved by using quantum computers. This in turn would drastically reduce the need for animal testing, significantly accelerating the development and introduction of new medical drugs.

I am thrilled by the possibilities of this new approach. But, in order to utilise the full potential of this method, the regulatory bodies will need to adapt and amend their drug approval processes.

White Card

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Yellow Card!

Guidelines

Use the yellow card to help the group stick to the guidelines.

Wave it if you feel a guideline is being broken or if you do not understand what is going on!

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Challenge Card

Explain briefly to your fellow players what you think could be the effect on future generations.

Challenge Card

Pick a Story Card and select one that is different from your own viewpoint.
Tell the group how you think your own views are similar and different to the character.

Challenge Card

Find out what the person on your right hand side feels on this subject.
Find an argument to support their opinion.

Challenge Card

Express any feelings on the subject that you have not yet expressed to the group.

Challenge Card

Pick a story card. As the character on your story card, present to the group your views on this topic.

Challenge Card

Can we justify spending money on this research given the inequalities in health care between Europe and developing countries?

Challenge Card

Are there any risks involved here? Think of a risk, tell the group, and ask two other players if they can think of another one.

Challenge Card

Imagine what your grandparents would say about this topic! Share it with the group.

Challenge Card

Does this have an impact on nature? Let the group know what you think.

Challenge Card

What do you think the media would make of all this?

Challenge Card

Find out what the person on your left hand side feels on this subject. Play devil's advocate (disagree with) their viewpoint.

Challenge Card

Tell the group who you think pays (in terms of resources, or consequences), and in what ways.

Challenge Card

Ask two other participants what their hopes and expectations are regarding this topic.

Challenge Card

What advantages would this technology bring for you personally?

Challenge Card

Is social media reporting on this technology?
If so, how trustworthy are the reports on it?
If not, why is there no discussion on this topic?

Policy Positions Quantum Technologies

1 - Rapid quantum tech expansion, minimum regulation

Promote rapid expansion of quantum technologies, with the minimum of regulation, to ensure its benefits are realised as quickly as possible.

2 - Proceed with quantum science but regulate

Allow scientific research and development in quantum technologies to proceed, setting new national and international regulations alongside the potential developments which emerge.

3 - Regulated quantum science with public dialogue

As position 2, but opening public dialogue now on the directions of quantum research and applications.

4 - No quantum science unless specifically and publicly agreed

Allow only the quantum research and applications whose specific goals have been through an ongoing, widespread national and international public debate and dialogue.

5 - ______________________________

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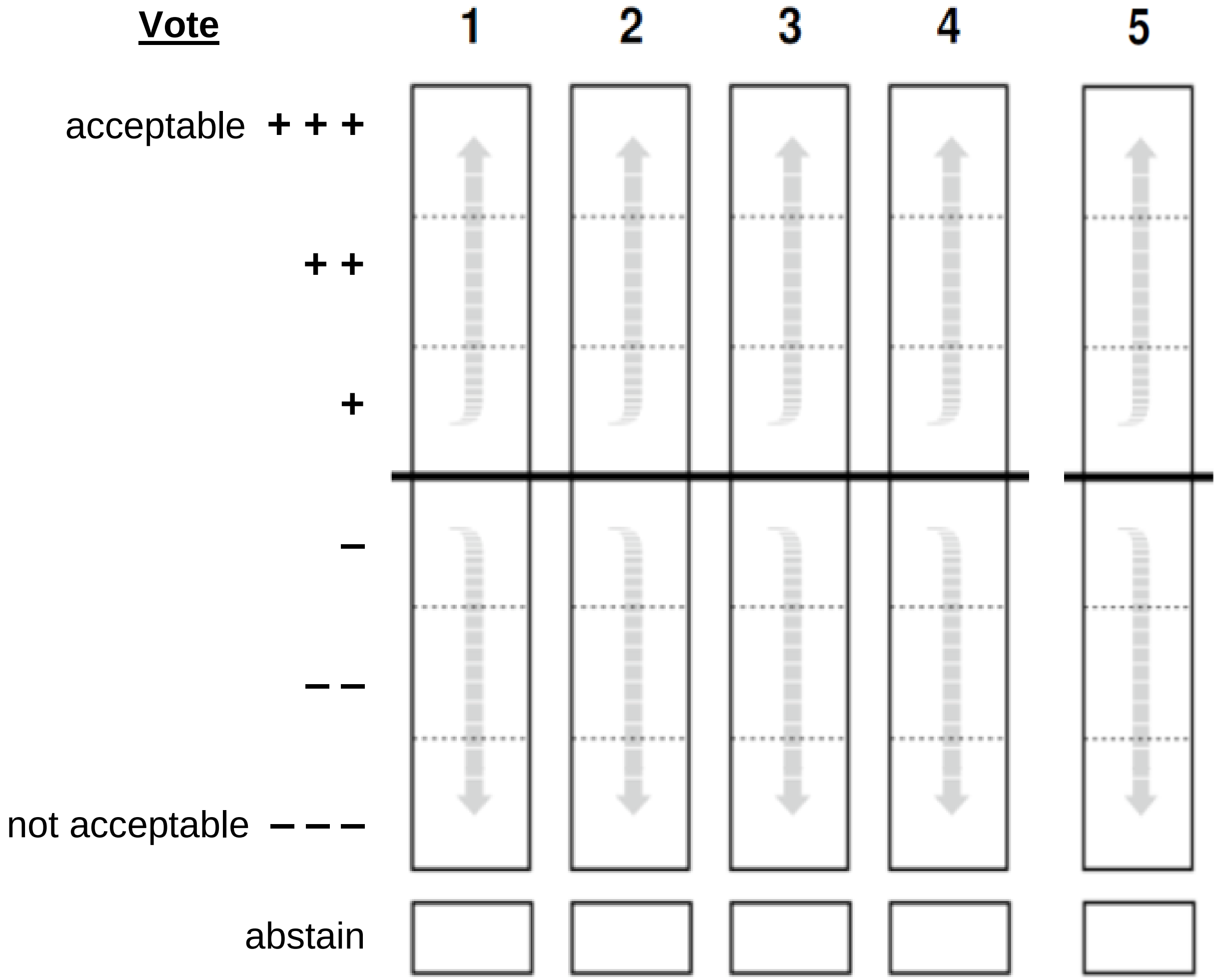

Name of cluster:

Which conclusions does this cluster lead you to?

Cards in this cluster:

Info Cards	Issue Cards	Story Cards	White Cards

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