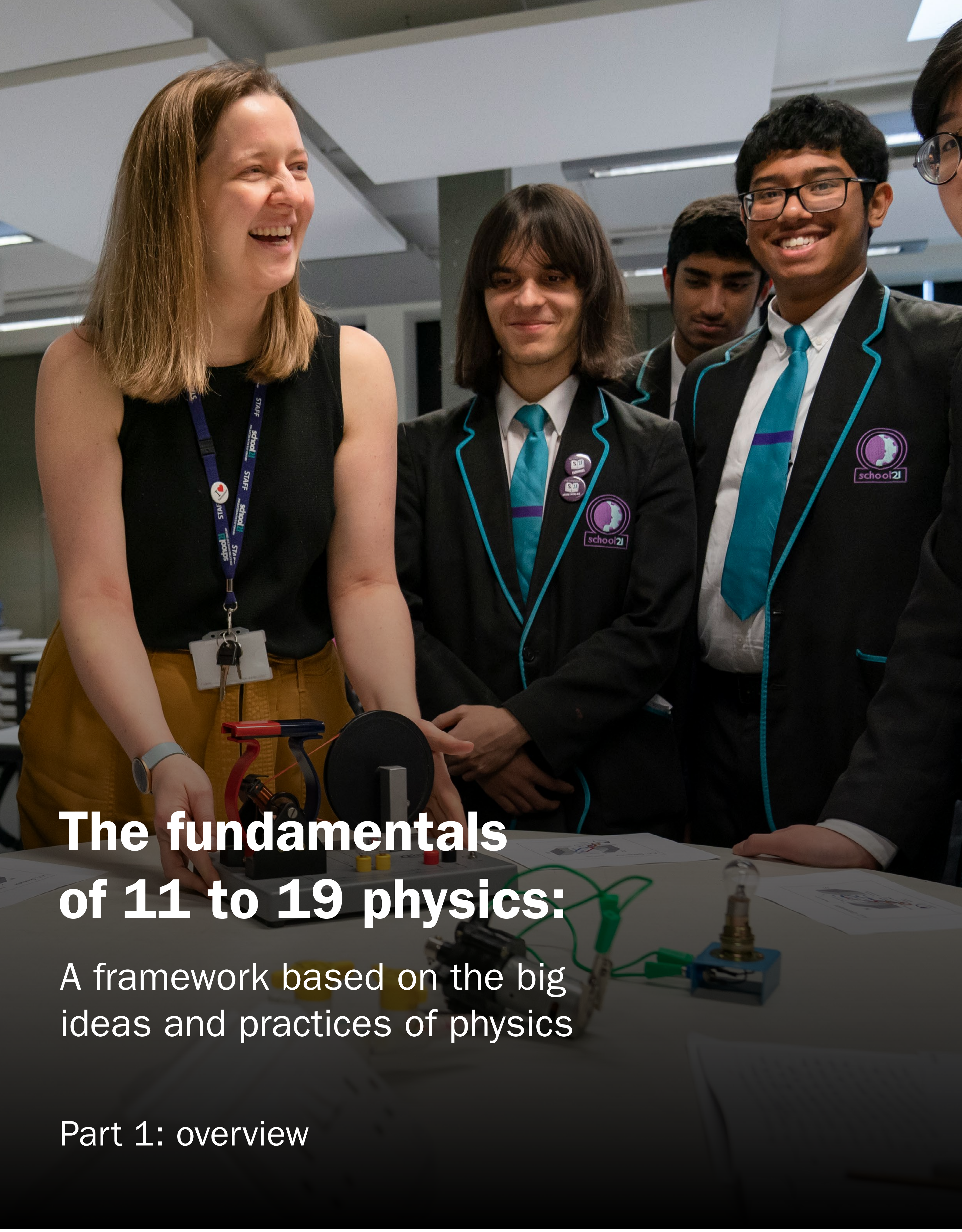

The fundamentals of 11 to 19 physics:

A framework based on the big ideas and practices of physics

Part 1: overview

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Foreword

Physics plays an essential role in our modern society and our future. It has great value to the individual, to societal wellbeing and to economic growth. Its ideas and explanations underpin much of our technology and are essential if we are to solve many of the big problems facing the world.

School and college physics curricula play an important part in preparing and equipping young people to take part in this world, not only as innovators and scientists but also as considerate and capable citizens. The curriculum also has a role in ensuring that all young people, especially those from currently under-represented groups, feel that physics can be for them.

They should be aware of the personal benefits of studying physics – to any level: that it provides them with capabilities that will serve them well in life and could well open up opportunities for many rewarding occupations.

Since the mid 2010s, the IOP, through its curriculum committee, has been working with experts to consider how a curriculum can be designed and structured to contribute effectively to those roles.

This document is the culmination of that work. The committee were keen for a physics curriculum to reintroduce some of the essence of the endeavour of physics into school curricula (see box 1). The curriculum should help establish the notion that physics is more than solely its established ideas and explanations, or substantive knowledge; it is also characterised by its practices and ways of thinking and reasoning.

Therefore, in this document, we put forward recommendations, design principles, and a framework to guide curriculum design based on a set of big ideas and the explicit delineation of those practices and ways of thinking in physics.

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About this document

This document is the first part of a two-part framework. It provides an overview of our recommendations and design principles and is suitable as an introduction to, and synopsis of, what we are proposing.

In Part 2, we develop the design principles and show how they will result in achieving the aims; and we provide some narrative background to the physics-related statements in this document. Part 2 will help those who want to get into the detail of curriculum design.

These documents do not, in themselves, represent a physics curriculum. Nor are they specific to any nation or jurisdiction. They are intended to inform, guide and support the development of curricula and schemes of work in any context. We hope that the documents – and, in particular, the design principles - will be used to start and inform discussions relating to curriculum design at national, school and department level.

Glossary of important terms in this document

We use a number of terms for the structural elements of a curriculum. This short glossary is intended to clarify how we use those terms in this document.

Enduring ideas: An overarching term for the knowledge and capabilities that last beyond an education in physics.

Substantive knowledge (of physics): The accepted accounts of what the world is made of and how things happen. For example, Newton's laws, the structure of the atom, and charge.

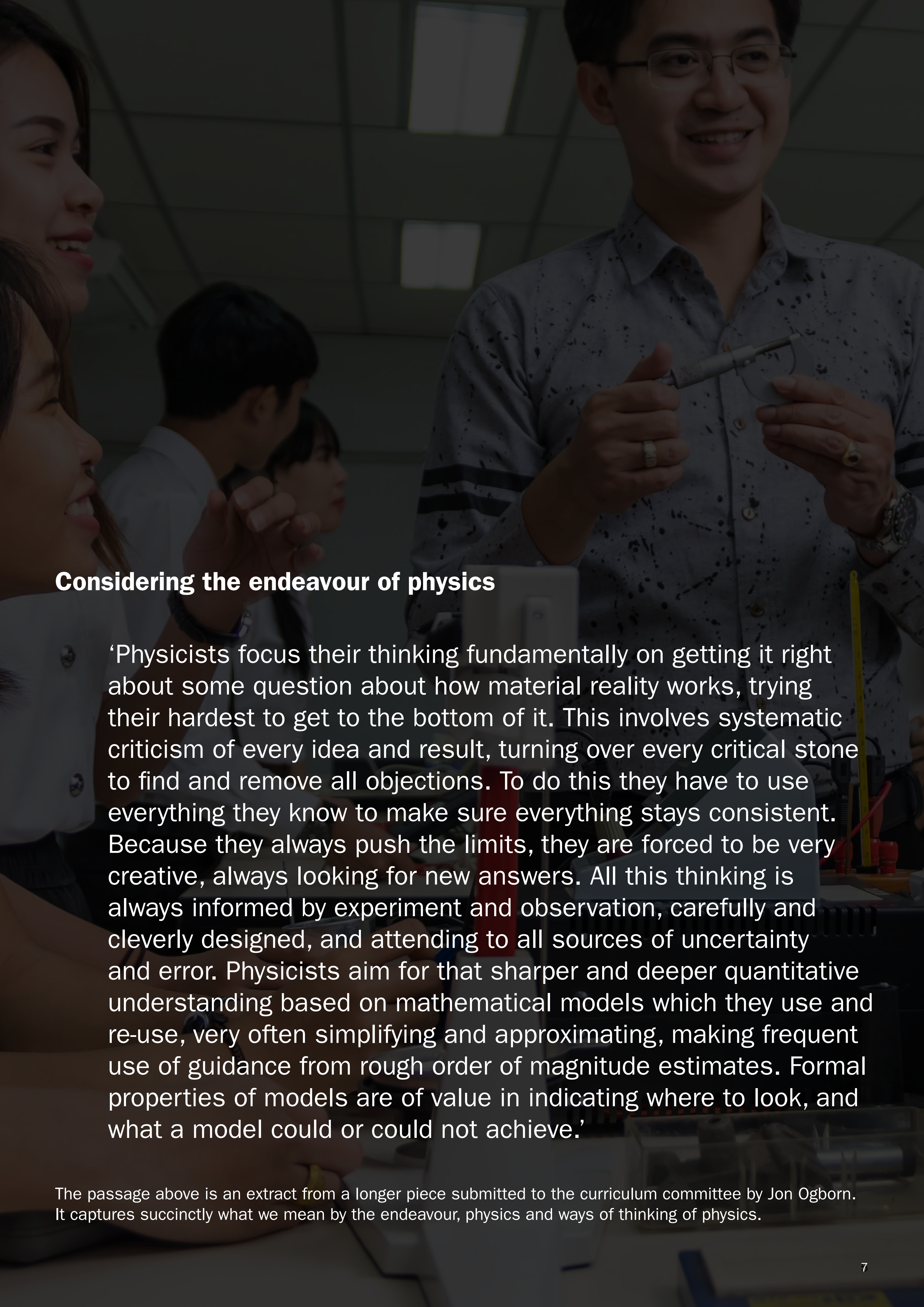
Big ideas: The set of ideas and explanation that represent the canon of physics, such as the particle model of matter, the laws of motion, and the idea of conservation. These are the ideas that we hope will endure in some form and can be recalled some time after studying physics. Some of these big ideas (such as conservation) are **cross-cutting** – they would be a part of physics no matter what; and others (the laws of motion and particles) are **domain-based** – we have chosen them as being representative of the canon of physics within the current domains of physics.

Practices and ways of thinking: These are the techniques that are employed by physicists to develop and modify the ideas and explanations of physics. They include **procedural knowledge** of physics and the sciences. However, whilst procedural knowledge currently dominates the practices of physics (and the sciences) at school, we are proposing going further. The practices should also include, for example, thinking with models, using reasoning to provide explanations, and employing mathematical techniques to make predictions and solve problems.

Procedural knowledge: This is knowledge of and capability in the steps of conducting an experiment or investigation in physics such as isolating phenomena, controlling variables and making careful measurements. Procedural knowledge is one aspect of the **practices and ways of thinking.**

Enduring impressions of physics: The lasting impressions of physics that students take away with them and hold a long time after they stop studying it. That is, the perception that they have of physics and physicists and the resulting relationship that they have with the discipline.

Applications: Knowledge of contexts in which physics has been developed and can be applied and knowledge of the occupations available to someone who follows a physics-related course.



Considering the endeavour of physics

> ‘Physicists focus their thinking fundamentally on getting it right about some question about how material reality works, trying their hardest to get to the bottom of it. This involves systematic criticism of every idea and result, turning over every critical stone to find and remove all objections. To do this they have to use everything they know to make sure everything stays consistent. Because they always push the limits, they are forced to be very creative, always looking for new answers. All this thinking is always informed by experiment and observation, carefully and cleverly designed, and attending to all sources of uncertainty and error. Physicists aim for that sharper and deeper quantitative understanding based on mathematical models which they use and re-use, very often simplifying and approximating, making frequent use of guidance from rough order of magnitude estimates. Formal properties of models are of value in indicating where to look, and what a model could or could not achieve.’

The passage above is an extract from a longer piece submitted to the curriculum committee by Jon Ogborn. It captures succinctly what we mean by the endeavour, physics and ways of thinking of physics.

Introduction

Studying physics should be fulfilling, enlightening and, as far as possible, representative of the endeavour of the discipline (see extract on page 7). It should highlight the interconnectedness of its ideas and students should be given a sense of wonder of the world and of the beauty of being able to describe and explain phenomena; and they should develop the tools to do so. Above all, they should be given every opportunity to leave their education in physics with a positive view of the discipline.

In this framework, we are proposing two shifts in emphasis in the way that physics is described and taught: the first is that the curriculum should be structured around a relatively small set of big ideas with space to explore these ideas in depth; and the second is that curricula should make explicit the practices and ways of thinking of physics. The intention is that teachers will help students to develop deep and lasting understanding of and about physics, as well as enduring capability in its powerful and prized ways of thinking.

Additionally, our design principles will help ensure that students leave their education in physics with a lasting, positive impression of the discipline, confidence in its ideas and explanations and the ability to distinguish a physics explanation from dubious, unscientific claims to which they are exposed.

Audiences

Our hope is that this framework will contribute positively to the deliberations of policy-makers and designers of national curricula. However, we also hope that it will be of interest to, amongst others, those developing teaching schemes in schools and colleges, physics teachers, physics teacher educators, examiners and content writers. Many of the ideas in the document could be used to shape schemes of work for existing specifications and curricula.

Executive summary

Our main recommendation is that a physics curriculum should be designed using the four design principles described in section 2. In brief, they call for curricula to be built on explicit statements of some big ideas of physics, its practices and ways of thinking, and the characteristics of the discipline. The amount of content should be realistic and allow space in the curriculum to explore the big ideas deeply and to develop capability in the practices and ways of thinking. This space will also allow teachers to illustrate the applications of physics and provide local and personal contexts. The curriculum should ensure that physics discoveries can be framed in the historical context of the time that they were made.

Students' experience of physics should be as authentic as possible: they should have frequent opportunities to carry out practical work and investigations, they should use mathematical analyses, and they should have frequent opportunities to experience and use the ways of thinking and reasoning of physics.

1. Purposes and aims of school level physics

A physics curriculum should provide teachers with a structure and the tools to allow them to develop enduring knowledge and capability that is of value to all students – whatever their background and whatever their future choices.

1.1 Purposes

Studying physics at school should provide all students with:

- Knowledge and capability that is of lasting value to them and to society by:
    - giving them a sound basis to understand everyday phenomena and scientific issues in the public domain,
    - providing the foundations for further study and training in physics, engineering and physics-related technical pathways.
- An enduring, positive engagement with the discipline of physics and an appreciation of its personal and social value.

1.2. Aims

In order to address those purposes, the aims of a physics curriculum are to develop:

a. Deep knowledge and understanding of some big ideas of physics.
b. Lasting capability in the practices and ways of thinking of physics.
c. Knowledge that established physics ideas are extremely reliable but open to challenge.
d. Ability to carefully assess information and scientific claims and make informed decisions on global issues such as climate change.
e. Curiosity and a sense of wonder at the world and a desire to understand and explain how things happen.
f. Recognition of the applicability of physics, its contribution to society and the opportunities it offers.
g. A deep-rooted belief that physics is inclusive and that they can take part.

Aims a to d relate to the first purpose of developing knowledge and capability that is of lasting value; aims e to g relate to the second purpose of engendering a positive enduring engagement with physics. These links are picked up in figure 2 on page 17.

We discuss these purposes and aims in more detail in section 6 in part 2 of this framework.

A physics curriculum that meets the needs of all students

Given that, in many jurisdictions, physics is a core subject to 16, the curriculum to that point must develop knowledge, understanding and capabilities that are of enduring value to *all* students. It must work for both those who will choose a physics-related route from 16 and those who will opt for other subjects (who make up by far the majority). We believe that the proposals outlined in this document achieve that dual aim and discuss this further in **section 3.3.**

2. Our design principles

In order to achieve the purposes and aims, we have developed the four design principles which are summarised below. They are discussed in more detail in section 7 in part 2 of this framework.

A curriculum should make explicit the following:

A. The big ideas of physics
Substantive knowledge should be expressed as a small set of big ideas taken from the canon of physics to develop a deep, lasting knowledge and understanding of those ideas.

B. The practices and ways of thinking of physics
The practices and ways of thinking of physics should be made explicit in order that they are taught in an organised way so as to develop lasting capability in them and to show students how they provide the warrant for accepting the substantive claims that physics makes, giving them confidence in its ideas, theories and explanations.

C. Characteristics of the endeavour of physics
The characteristics of physics should be described to help guide curriculum developers and teachers to provide a faithful representation of the discipline of physics within the school context and, as much as possible, develop a lasting positive impression of it.

D. Applications and contexts
Examples of major applications of physics should be provided and there should be space in the curriculum for teachers to give local and familiar examples to motivate students, make them feel included, and to show links with engineering and other scientific disciplines. Physics discoveries should be framed in a way that recognises the global historical context of the times.

2.1. Amount of content

It is undoubtedly the case that a physics curriculum has to include some substantive physics content. However, physics is as much about what students can do as what they know. Therefore, the amount of content should be chosen so as to be both manageable and to allow space for:

- Deep exploration of the big ideas.
- Specific consideration and development of the practices and ways of thinking of physics.
- The inclusion of frequent and meaningful practical activities.
- The inclusion of contexts and applications to supplement and bring to life aspects of the big ideas.

2.2. More on the big ideas

The big ideas will be described under two headings:

a. **Cross-cutting big ideas** that appear across many areas of physics and characterise the discipline, such as conservation, equilibrium and causation. These ideas pervade all levels of physics and are likely to always be a part of the discipline even if some explanations change.
b. **Domain-based big ideas** taken from the canon of physics. Given that a school curriculum cannot cover all ideas of physics, these are important explanations, laws and theories that have been chosen as representative of the substantive knowledge of physics, and directly applicable to everyday situations. We have identified 11 such ideas.

Age-related foci of domain-based big ideas

For each domain-based big idea, there is likely to be an age-specific focus. For example, there is a big idea that we think that matter is made of particles. We would hope that someone who has studied physics to age 16 would be able to recall – and possibly discuss – particles and matter sometime later. However, if they continue with physics to age 18, they ought to take this model further. For example, they could go on to make numerical predictions about the gas laws based on the kinetic theory of gases. The age-related foci will ensure a consistency of approach and are intended to provide continuity and progression within each big idea. The suggested foci are shown in appendix 1.

2.3. Practical work

Physics is an empirical discipline and learning physics should be both practical and thoughtful. The curriculum should ensure and encourage frequent opportunities for students to carry out meaningful practical work; and to follow this up with discussion and analysis that link the practical activities to physics explanations.

2.4. Preparation for further study and training

Post-16 technical routes

Education to 16 should help students to make a choice about whether to follow a technical route from age 16, and should prepare them for doing so. Physics teaching and the physics curriculum can contribute to this preparation in two ways. First, they can highlight and draw out the range of occupations in physics-related, and other, enterprises and how those occupations require and build on ideas from physics or contribute to innovation in the world of physics. Secondly, through frequent use of practical work, students can develop their ability to accurately take measurements, assemble apparatus, and develop their manipulative and technical skills.

Post-16 physics curriculum and engineering

It is important to note that, as well as those who progress to undergraduate physics degrees, a large proportion of students who take post-16 physics qualifications go on to study or train in engineering. Therefore, the substantive content knowledge of post-16 physics programmes must lay the groundwork for both physics and many engineering degrees. However, the ways of thinking in physics and engineering can be different. Therefore, it is essential that any post-16 programme of study also gives students access to considering problems in an engineering way – either as part of a physics qualification or as part of a portfolio of qualifications. It is not for this document to describe what it means to think like an engineer. However, we recommend that engineering experts are consulted in the design of post-16 programmes.

2.5. Global and historical contexts

Curriculum content, examples and perspectives should recognise that the development of physics relied on ideas and thinking from many people and varied groups globally. Children should be offered a chance to learn about historic contributions to the sciences from around the world, as well as the cutting-edge contemporary research produced by diverse teams of scientists.

Teachers should also be encouraged to discuss the context of the times in which discoveries were made and accredited within western science. They can explain how many of those discoveries drew on earlier work in other parts of the world and how, during the period of growth of western science, different groups, cultures and nations were more or less able to participate in research, resource scientific activity, or claim credit and ownership for ideas.

3. Explicit statements within the design principles

Table 1 below lists a summary set of statements under headings for each of the design principles. A full narrative description of each of these is given in section 8 in part 2 of this framework. It is worth noting that we would not expect the statements in sections C and D of table 1 to be assessed formally in the current system. Indeed, the suggestion that students should rote learn declarative statements *about* physics would go against the spirit of our proposals. They should acquire this impression through the way that physics is represented and the ways in which they are encouraged to take part.

Table 1. Summary of big ideas, practices, characteristics and knowledge of applicability. See also appendix 3 in Part 2.

Lasting knowledge and capability from physics

A. Big ideas

Students should develop a lasting and deep knowledge and understanding of the following big ideas:

i. Cross-cutting

1. Reducibility: explaining phenomena by identifying the constituents of a system and considering the mechanisms and processes that describe their behaviour.
2. Equilibrium occurs when two or more external influences are in balance (statically or dynamically).
3. Change is caused by a difference (in pressure, concentration, electric potential, temperature, etc).
4. Conservation: The idea that the amount of some quantities (e.g. mass, energy, electric charge, and momentum) are the same after an event as they were before; and this provides physicists with extremely powerful analytical tools.

ii. Domain-based

5. All matter is made of very small particles and this helps us to explain many behaviours of matter.
6. Atoms are not indivisible – they have their own internal structure.
7. Objects interact with each other (by contact or at a distance) – giving rise to pairs of forces
8. All matter emits radiation in a spectrum of electromagnetic waves.
9. The Earth and planets orbit the Sun, one of billions of stars in our galaxy, which is one of billions of galaxies in the Universe.
10. An object will continue moving without a net force acting on it: it has inertia.
11. Charge is a fundamental property of matter and this helps us to understand electrical properties and effects.
12. Fields are regions in which an object may experience a force.
13. Electricity and magnetism are two facets of a single phenomenon: electromagnetism.
14. There are two ways to change the energy stored in a system: by working on it or heating it.
15. Dissipation: every event results in greater disorder if we take everything that is involved into account.

B. Practices and ways of thinking

Students should develop, by experience, a lasting capability in the following practices and ways of thinking:

16. **Procedural knowledge:** proposing and testing explanations of phenomena; making measurements and observations and verifying explanations of phenomena through experiments
17. **Attitudes of physics:** thinking critically, working collaboratively, seeking deep understanding and consistency in explanations, setting aside preconceptions, and facility with scientific language.
18. **Thinking and reasoning techniques:** to solve problems and refine explanations using critique and logic.
19. **Models and systems:** defining systems and using models to think with and to make predictions
20. **Quantities and relationships:** using relationships that recur across physics.
21. **Numerical and mathematical techniques:** using numerical and mathematical techniques to analyse situations quickly and make predictions.

Enduring impressions of physics

C. Characteristics of the endeavour of physics

Physics and its practices should be experienced and presented in a way that develops an enduring impression that the ideas, explanations and theories of physics are:

a. **Fundamental and universal**
Physicists aim to provide explanations and theories that go beyond the superficial and can be used as widely as possible; in all situations: the laws of physics apply across the universe – from the very large to the very small.

b. **Reducible**
Phenomena are often explained by reducing a system to its constituent parts and considering the behaviours existing those parts using a small number of existing ideas.

c. **Synthesised and consistent**
Physicists use ideas from across physics to develop new explanations; these must be rigorously consistent within themselves and with all other areas of accepted physics.

d. **Empirical and based on measurements**
Physics is based on evidence rather than intuition or belief. Physicists generally go beyond observing phenomena qualitatively; they define measurable quantities and make measurements of them in carefully designed experiments.

e. **Reasoned and logical**
Physicists use reasoning (deductive, inductive and statistical) to analyse data and develop convincing explanations that are consistent with the evidence.

f. **Based on systems**
Physicists define systems (collections of objects that interact) that are of interest and simplify them to their core elements.

g. **Modelled**
Physicists develop models to help account for the observed behaviours of objects and systems.

h. **Mathematical and predictive**
The defined quantities enable physicists to develop verifiable quantitative relationships.

i. **Severely tested and reliable**
Physics models are used to make precise numerical predictions that can be tested – enabling a model to be rejected or supported. The accepted theories, laws and models of physics have survived severe and repeated testing.

j. **Open to revision**
Although reliable, physics explanations are always open to revision and improvement if there is evidence that brings them into question.

k. **Collaborative and global**
Physicists often work in teams across the world; our system of measurement enables ease of communication between communities of science practitioners.

D. Applicability and context

The substantive knowledge should be set in context to provide lasting knowledge that:

l. Physics ideas can be applied and add value in other domains of study that are both within the sciences and outside them.

m. Physics ideas are important when considering society's big questions and tackling its big challenges, such as climate change.

n. Physics ideas enable engineers to improve our comfort and wellbeing by designing solutions to defined problems.

o. Studying physics is preparation for many important, productive and rewarding occupations.

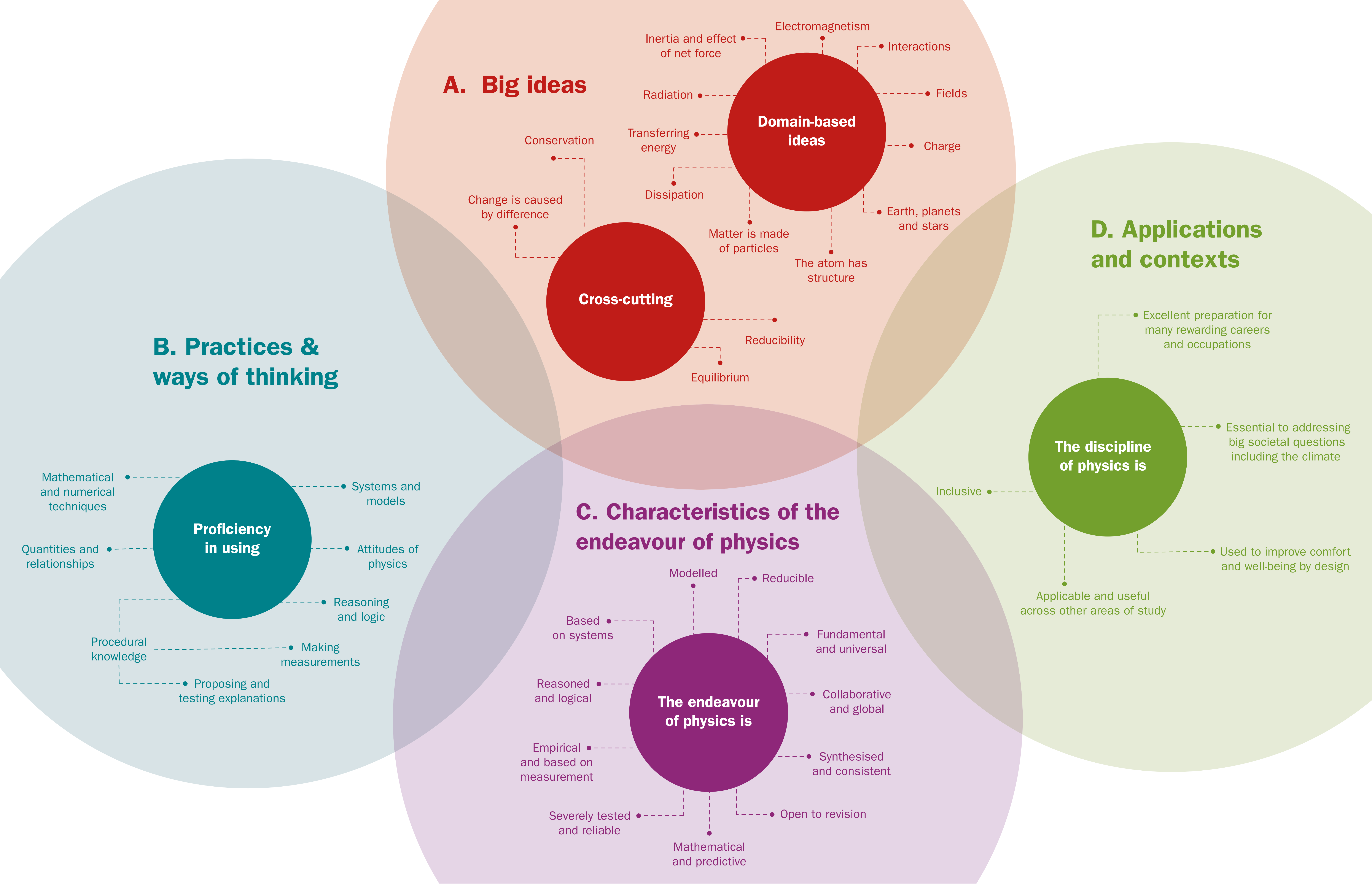


Figure 1: Map of big ideas, practices, characteristics and applications

4. How the design principles contribute to the aims of learning physics

4.1. From recommended to learned curriculum

Achieving the aims for a physics course relies on both the way that the curriculum is written and the way in which it is taught. We contend that the principled approach recommended in this document will enable curriculum designers to write curricula that will allow and support teaching that achieves the long-term aims outined at the start of this document. These steps are shown in figure 2; in effect, these documents provide the principles for a recommended curriculum that will be worked up into a written curriculum that is ready to teach; and will, we hope, provide enduring value to all students.

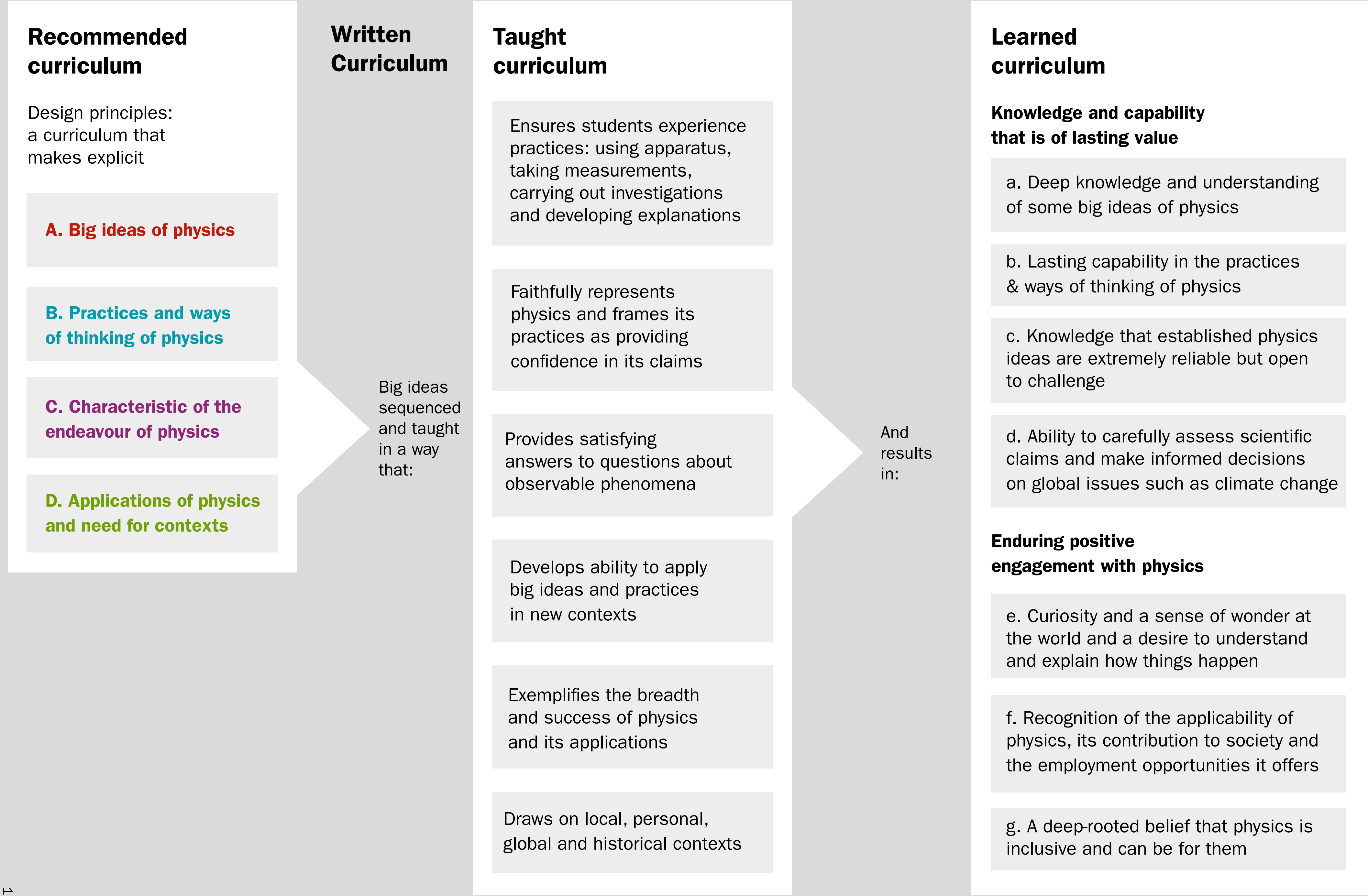
As we discuss in the next section, the sequence of the curriculum is most likely to be based on the substantive content – the big ideas. In that sense, the main structure of teaching schemes will likely follow similar sequences to those used previously.

However, the difference will be the way in which the substantive knowledge is represented and taught. As well as learning the substantive content, students will also acquire knowledge and capability, through experience and active participation, in the other aspects of physics. That is capability in its practices and ways of thinking, knowledge of the applications of physics, and a lasting awareness of the characteristics of the endeavour of physics.

This acquisition is facilitated by explicitly stating those additional capabilities and the features of the endeavour of physics acquisition (see table 1). The explicit statements of, for example, the practices and ways of thinking, will help curriculum designers and teachers to weave experiences of them into their teaching of the big ideas.

Importantly, by experiencing and using the practices and ways of thinking, students will not only develop lasting capability in them, they will develop the notion that physics ideas and explanations are securely based on observation and reasoning. In turn, we hope that such knowledge will give them enduring confidence in the ideas and explanations of physics.

The way in which the design principles can help achieve the aims of a course are discussed in more detail in section 7 in part 2 of this framework.



Recommended curriculum

Design principles:
a curriculum that
makes explicit

A. Big ideas of physics

B. Practices and ways of thinking of physics

C. Characteristic of the endeavour of physics

D. Applications of physics and need for contexts

Written Curriculum

Big ideas sequenced and taught in a way that:

Taught curriculum

Ensures students experience practices: using apparatus, taking measurements, carrying out investigations and developing explanations

Faithfully represents physics and frames its practices as providing confidence in its claims

Provides satisfying answers to questions about observable phenomena

Develops ability to apply big ideas and practices in new contexts

Exemplifies the breadth and success of physics and its applications

Draws on local, personal, global and historical contexts

And results in:

Learned curriculum

Knowledge and capability that is of lasting value

a. Deep knowledge and understanding of some big ideas of physics

b. Lasting capability in the practices & ways of thinking of physics

c. Knowledge that established physics ideas are extremely reliable but open to challenge

d. Ability to carefully assess scientific claims and make informed decisions on global issues such as climate change

Enduring positive engagement with physics

e. Curiosity and a sense of wonder at the world and a desire to understand and explain how things happen

f. Recognition of the applicability of physics, its contribution to society and the employment opportunities it offers

g. A deep-rooted belief that physics is inclusive and can be for them

Figure 2. Linking the design principles to the aims via the way in which the curriculum is taught based on big ideas

4.2. Evolution not revolution

It is not our expectation that curriculum structures or teaching sequences will have to be radically changed in order to teach physics as outlined by our design principles.

The sequences of topics may be similar to those currently in use with a change of emphasis to use each big idea to develop deeper and broader understanding of that idea and to develop the practices and lasting impressions that we are aiming for. Indeed, it would be possible to implement many of the proposals in this document onto existing specifications and existing schemes of work – with the proviso that this will require a reduction in the amount of content. This reduction is to provide space for teachers to develop lasting capability in the practices of physics and a deep and complete understanding of the big ideas.

To evolve existing curricula, we are proposing that the substantive knowledge – in the form of the big ideas – will continue to be the basis for the structure and sequence of what is taught. There are two reasons for this: substantive knowledge provides a structure on which to build a teaching sequence; and the other aspects cannot be taught or learned in isolation. They can only be developed through concrete examples of that substantive knowledge. That is, capability in the practices will be developed through experience and use when the substantive knowledge is taught.

For example, in a sequence on the first law of motion, students will observe and practise the thinking and reasoning that helps them internalise the notion that objects will keep moving without a force; they will also experience demonstrations, carry out experiments, and have opportunities to use the practices of physics to think through the implications of their observations and link them with physics explanations.

Similarly, students will get a sense of the utility, importance and opportunities that physics offers through contexts and examples of the application of its ideas and by finding out about people who work with physics and how it will provide solutions to global problems.

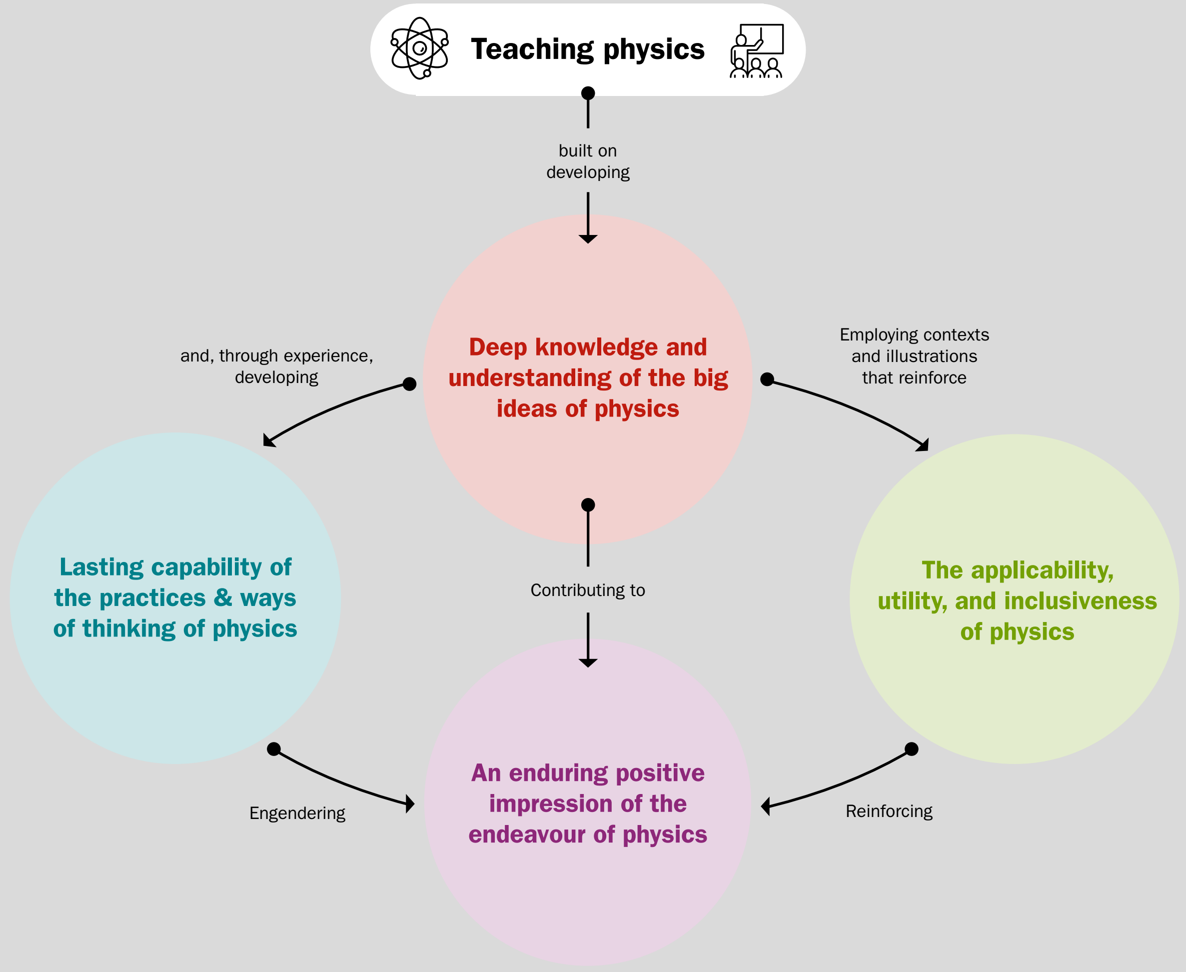


Figure 3. Teaching all four areas via a curriculum sequence

4.3. Meeting the needs of all students

In section 1, we highlighted that it is essential that a physics curriculum provides learning that is of lasting value to *all* students – not just the smaller group who continue with the discipline or in physics-related fields. We contend that the design principles in this document will support that requirement.

First, the explicit inclusion of the practices and ways of thinking will develop lasting proficiency in these transferrable capabilities; as well as being of value to those who continue with physics, such capability will also serve the larger group well. The practices and ways of thinking of physics will support them in all fields of study as well as in their daily lives as citizens – helping them to make reasoned decisions, critique assertions and take part in discussions on important public issues – whether or not they relate to the sciences. And capability in these transferrable skills is prized by employers – in many fields.

Secondly, the larger group will also benefit from the focus on big ideas: rather than having a fleeting, superficial grasp of a multitude of detailed facts, we can hope that they will have a lasting general understanding of some of the important ideas of physics. The hope is that, at the very least, they have a lasting grasp of the cultural significance of those ideas (from physics) and are able to identify and follow discussions relating to them a long time after they stopped studying physics.

Finally, the way in which physics ideas are developed and that students experience the practices and endeavour of physics, will help them to understand how it is that physicists have confidence in their ideas and explanations; and that those ideas and explanations are founded in a great deal of observation, thought and reason. We can hope that such understanding will help them to distinguish well-founded ideas and explanations from those that are unfounded, superficial or poorly thought through.

5. Recommended approaches to implementing curriculum change

The main aim of this document is to discuss the details of designing a physics curriculum. However, whilst it is slightly beyond the scope of this document, it is important that the curriculum and curriculum changes are implemented in a way that complement and support the design principles in this framework. We recommend that:

1. Physics should be taught and experienced in an inclusive way; as noted, the curriculum and teaching should frame the development of physics ideas within global and historical contexts; however, it is also essential that teaching approaches and the school environment are actively inclusive.

2. From the age of 14 (or before), physics should have its own identity with dedicated specialist teachers and identifiable timetable slots.

3. Both the design and the ongoing development of the physics curriculum should draw on expertise from outside (as well as within) awarding bodies, it should include curriculum experts, and it should seek and make use of evidence of what works.

4. Any reform to the physics curriculum should be backed up with sufficient funding to provide resources and professional learning and development opportunities for teachers and technicians.

5. Assessment schemes should be designed to encourage and support good practice in teaching and learning.

These recommended approaches are explored in more detail below.

5.1. Equity and inclusion in schools

Physics must be open to all. It offers young people the tools to solve complex problems and to understand the world around them. Also, it opens doors to a huge variety of rewarding and valuable careers. Physics itself benefits from the diverse thinking which comes from attracting people of all backgrounds into the field, and attracting more people will help tackle the physics skills shortage in the UK. However, currently some groups are under-represented – often because they feel excluded, because of outdated stereotypes about who can do physics or because they believe that physics is not for people like them. These under-represented groups include young women, some ethnic minorities, people from groups with lower socio-economic-status, and people with some disabilities. It is essential, therefore, that our physics curriculum and teaching support, include and encourage every student to see a place for themselves in physics.

Below are two ways in which curriculum designers, schools and teachers can ensure that all students feel included in physics and motivated to study it, whoever they are and wherever they come from.

i. Inclusive teaching approaches based on developing science capital

The Aspires programme has shown that an effective way to help young people – especially those in under-represented groups identify with physics is to provide contexts that are familiar to them and help to build their physics capital.

This can be achieved by teachers “building on their knowledge of students’ interests, aspirations, local communities and past experiences” and “using examples and settings that are familiar and local to students as ‘hooks’ into the science content.”

For the purposes of curriculum design, this means providing some example contexts and keeping space in the curriculum for teachers to provide their own contexts. The IOP has developed further **Top Tips for Inclusive Science Teaching** as part of its Limit Less campaign.

> “Personalising and localising is about making science content personally relevant to the everyday lives of students. This approach goes beyond contextusalising science - the key is to relate the content to examples and experiences from the students’ own lives.
>
> **Personalising and localising helps students see that their intersets, and attitudes and experiences at home and in the community relate to aspects of science. This helps them to realise that they have resources which are valued in science and enables the flame of engagement to burn more brightly.”**

This extract of the **Science Capital Teaching Approach** describes the value of using contexts. This document from the Aspires team also provides help on recognising and challenging everyday stereotypes in physics.

ii. A whole school approach to equity and inclusion

A whole school approach to equity and inclusion can help students from all backgrounds feel that physics (or any subject) can be for them. The whole school approach requires agreement, at a whole institution level, that there are no stereotypical expectations put on young people relating to their gender, background, sexual identity, disability, or ethnicity. Schools should be places where preconceptions can be, and are, challenged by everyone whenever they encounter them. This involves the whole school community (senior leaders, teacher, support staff, students, governors and parents) working together to create a plan to dismantle the barriers students face. and that everyone is empowered to challenge myths and stereotypes whenever they encounter them.

5.2. Timetabling

In some jurisdictions, the sciences are taught for a combined science qualification. It is often the case that students taking this combined science option are timetabled in a way that disadvantages their learning in each of the sciences. We are recommending that, at a minimum, even within combined science qualifications, biology, chemistry and physics should be given identifiable timetable slots and each one should have its own teacher – preferably one with specific expertise in that science discipline. Doing so will give all students most of the advantages that are currently enjoyed by those who study the sciences as separate qualifications.

5.3. Curriculum review and development

This document is not focusing on the details of appropriate mechanisms for the implementation of curriculum design or review. However, it is important to note that the curriculum is about more than solely a specification for assessment. It is also about considering how physics can be faithfully represented and taught in schools. Therefore, both a revision and the ongoing review of the curriculum requires expertise from outside awarding bodies (as well as from within them). That expertise should include experience and capability of both the discipline and in curriculum design.

There are a number of aspects of the curriculum that will benefit from such expertise. These include: representing the subject fairly and protecting its reputation; ensuring that the content is accurate; ensuring that the curriculum goes beyond what is assessed; ensuring that assessment drives good practice within the teaching and learning of the discipline; ensuring that the ideas and practices are developed in a spiral manner across different educational stages. It might be that ensuring compliance with these considerations can be best achieved through a curriculum body; however, that remains open for discussion.

5.4. Resources and training

Any curriculum change will only work if teachers and technicians are both committed to the change and given the expertise and tools to implement it. Whilst the design principles in this document do not require wholesale restructuring of the sequences of physics teaching, they do propose a different emphasis – particularly in developing the practices and ways of thinking of physics and in bringing contexts into their teaching. It is therefore essential that funding and time is made available for physics and science departments to take part in structured professional learning to consider these new ideas; and that they are provided with centrally produced resources about applications, occupations and contexts of physics to bring into their teaching.

5.5. Assessment and learning

Whilst this document is not directly about assessment, successful implementation will rely on assessment schemes that reinforce the aims and principles of the curriculum design. This is because the nature and style of assessment schemes and assessment items wash back into styles of teaching and the ways in which students are prepared for exams. In particular, care should be taken not to implement assessment schemes that drive undesirable behaviour. Achieving a positive influence on the ways that physics is taught and learned is likely to require a variety of different, and possibly new, types of assessment. For example, there might be questions that require students to demonstrate their ability to use reasoning techniques or to identify inconsistencies in an argument. In particular, the assessment of practical work should encourage frequent opportunities for students to carry out meaningful and varied practical activities throughout their time learning physics.

Appendices

Appendix 1. The age-related foci of each of the domain-based big ideas.

As discussed in section 2.2, it will be helpful to consider how far each big idea is developed in each age range.

Below are some illustratuions for potential age-related foci of each of the domain-based big ideas (from table 1 on page 13). These are listed by the age at which they would have been covered.

5. All matter is made of small particles and this helps us to explain many behaviours of matter.

By age 14: The particle model of matter can explain the properties and simple behaviour of solids, liquids and gases and changes of state.
By age 16: We live at the bottom of an ocean of air and, as in other fluids, it exerts a pressure in all directions.
By age 18: The kinetic theory of gases can predict and explain the behaviour of gases with changing temperature, pressure and volume.

6. Atoms are not indivisible – they have their own structure .

By age 16: Atoms are made of a nucleus (comprising protons and neutrons) and electrons.
By age 18: Quantum; behaviour at a sub-atomic level is determined by probability and predictions requiring large numbers of particles; we cannot make definite predictions about outcomes for individual entities.

7. Objects interact with each other (by contact or at a distance).

By age 14: Interactions between objects give rise to pairs of forces that can affect the shape or movement of a body.
By age 16: The symmetry of a pair of forces results in the momentum of a system being conserved.

8. All matter emits radiation in a spectrum of electromagnetic waves.

By age 14: All matter emits radiation in the electromagnetic spectrum. Electromagnetic waves can travel in a vacuum.
By age 16: Waves can carry information and can transfer energy without disrupting the medium that might carry them.
By age 18: Waves superpose, interfere, and diffract.

9. The Earth and planets orbit the Sun which is one of billions of stars in our galaxy.

By age 14: We can explain and predict the apparent motion of the Sun and Moon using a model of the Moon orbiting the Earth and the Earth orbiting the Sun.
By age 16: The Universe comprises galaxies of stars and we think it began with the Big Bang about 14 billion years ago.

10. An object will continue to move at a constant velocity unless an unbalanced force acts on it.

By age 14: A moving object does not need a force in order to keep moving; forces change motion rather than preserve it.
By age 16: Inertia is a measure of how difficult it is to change the velocity of an object. For a constant force, the acceleration is inversely proportional to the inertial mass.
By age 18: All motion is relative: the laws of physics do not change in a frame that is moving at a constant velocity.

11. Charge is a fundamental property of matter and this helps us to understand electrical properties and effects.

By age 14: Electrostatics: charged objects interact with each other; the interactions can be explained by thinking of two types of charge.
By age 16: Moving charges carry an electric current; we can predict the size of a current in a simple series circuit from its resistance and the potential difference of the power supply.
By age 18: Currents in more complex, parallel circuits, can be predicted using formulae and Kirchoff's laws.

12. Fields are regions in which an object can experience a force.

By age 14: Magnets interact with each other and magnetic materials; there is a magnetic field around a magnet.
By age 16: There is an interaction between masses called gravity which gives rise to a gravitational force acting on each of the masses; there is a uniform gravitational field near the surface of the Earth.
By age 18: There are four fundamental interactions; the field around point masses and charges varies as an inverse square of distance.

13. Electricity and magnetism are two facets of a single phenomenon: electromagnetism.

By age 16: There is a magnetic field around a current-carrying wire and it will interact with magnets or current-carrying wires.
By age 18: Moving a wire in a magnetic field will induce an EMF that will oppose the motion that produced it.

14. There are two ways to change the energy stored in a system: by working on it or by heating it.

By age 14: Levers and simple machines can multiply force or the distance moved but not both – they compensate for each other; the total mechanical work out cannot exceed the mechanical work put in.
By age 16: Temperature changes can be achieved by heating or working on objects; both heating and working are measured in joules.
By age 18: Momentum is always conserved in collisions; in elastic collisions kinetic energy is also conserved.

15. Dissipation: Every event results in greater disorder if we take everything that is involved into account.

By age 16: Dissipation: in most events, some energy is transferred to the surrounding raising its temperature by a very small amount. As such, it is stored in a way that is less useful than the original way in which it was stored.
By age 18: Dissipation is one example of the disorder of a system increasing over time in a way that cannot be reversed.

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