Accelerators

Alexandra J. Boyd[1], Rebecca A. Harrop[2], Priya Patel[3], Anthony Valsamis[4], Timothy L. Vitale[5]
[1] Apex Friendship High School, Apex, NC, USA, ajboyd@wcpss.net
[2] Otumoetai College, Tauranga, New Zealand, rharrop@otc.school.nz
[3] The LIFE School, Horace Greeley High School, NY, USA, priyama8313@gmail.com
[4] Glenbrook North, Northbrook, USA, avalsamis@glenbrook225.org
[5] Clearview Regional High School, Mullica Hill, USA, vitaleti@clearviewregional.edu

Curriculum & classroom connections

Particle accelerators are an exciting concept to cover with secondary students when teaching physics, however, teachers are often constrained by time and topics the state or national curriculum mandate. Below are the standards from the United States of America, India, and New Zealand, which while they do not always clearly outline particle accelerators as part of the curriculum, there is scope to develop links within the current curricula. The final work completed by the authors, however, demonstrate that the concept of particle accelerators can, and should, be used to teach various topics in secondary physics classrooms.

Below are the topics that connect directly to particle accelerators:

- Accelerators
- Centripetal Force
- Cyclotron
- Electric Charge
- Electric Field and Potential
- Energy and Mass
- Energy in eV
- Fundamental Interactions
- Gravity
- Hydrogen Ionization
- Kinematics
- Large Hadron Collider
- Linear Accelerators
- Lorentz Force
- Magnetic Field
- Newton's Second Law
- Ohm's Law
- Optics
- Radiation
- Scientific Methods
- Special Relativity
- Standing Waves
- Superposition of Waves
- Thermal Physics
- Transverse Waves

India

In 29 states of India, each state has a state education board that has different syllabus and in state languages. The following is the Physics topics mandated by the Central Board for Secondary Education in the ninth and tenth grade classes.

Class 9th:

- Motion
- Forces and Laws of Motion
- Work and Energy
- Gravitation
- Sound

Class 10th:

- Light reflection & refraction
- Electricity
- Human eye and colorful world
- Magnetic effect of electric current
- Source of energy
- Management of Natural resources

New Zealand

There are links to the following standards of the New Zealand Curriculum Levels 5-8 of the Physical World, the Nature of Science, and National Certificate of Educational Achievement (NCEA) Level 2 and Level 3.

NCEA Level 2:

- 91168: Carry out a practical physics investigation that leads to a non-linear mathematical relationship
- 91169: Demonstrate understanding of physics relevant to a selected context
- 91170: Demonstrate understanding of waves
- 91171: Demonstrate understanding of mechanics
- 91172: Demonstrate understanding of atomic and nuclear physics
- 91173: Demonstrate understanding of electrical and electromagnetism .

NCEA Level 3:

- 91521: Carry out a practical investigation to test a physics theory relating two variables in a non-linear relationship
- 91522: Demonstrate understanding of the application of physics to a selected context.
- 91523: Demonstrate understanding of wave systems
- 91524: Demonstrate understanding of mechanical systems
- 91525: Demonstrate understanding of Modern Physics
- 91526: Demonstrate understanding of electrical systems.
- 91527: Use physics knowledge to develop an informed response to a socio-scientific issue.

United States of America *(Link to Standards)*

Each state has its own standards for Science, however the federal government developed the Next Generation Science Standards (NGSS) in an effort to improve science education nationwide. Nineteen states have adopted the NGSS, and over forty have shown interest in the standards, because they focus on teaching science through skills and cross-cutting concepts.

Below are the secondary standards that would directly connect to particle accelerators.

- NGSS: HS-PS1 Matter and Its Interactions
- NGSS: HS-PS2 Motion and Stability: Forces and Interactions
- NGSS: HS-PS3 Energy
- NGSS: HS-PS4 Waves and Their Applications in Technologies for Information Transfer

Key ideas

The goal of this paper is to allow teachers to be able to teach typical classical physics concepts in terms of particle accelerators.This should also help teachers and students to develop their own understanding of particle accelerators without the need to create space within an already tight and varied curriculum. There are various resources available to teachers and students about accelerators. The authors of this paper heard the many teachers' concerns that there was not enough time to deliver authentic modern physics in their curriculum, or there was no opportunity within their current curriculum to include it. The authors believe this is a missed opportunity. Instead of teaching modern and nuclear physics at the end of the programme, there is scope to develop students' understanding of particle physics within the classical physics curricular. The intention of this paper is to demonstrate how to do this, within the scope of particle accelerators.

The authors also felt that it was beneficial for the student to understand why fundamental research is important. It is also vital that students comprehend how Scientists develop theories, models and create equipment to measure data to improve not only students' scientific literacy, but also their understanding of the complexity of Science and understanding of data. It is important for students to appreciate that creating new knowledge will lead to uses that Scientists, engineers, and designers could not have conceived with current knowledge. This is a necessity of any society that wants to learn more, do more, and create more than the generation before.

Potential student conceptions & challenges

Students generally come to class with a variety of knowledge: some have never heard of particle accelerators and others know a great deal about them. The authors have created a website that link some fundamental concepts of Physics to supply the reader with key information regarding how one could teach classical mechanics and incorporate particle accelerators within their standard lessons. The authors have addressed key ideas and are aware of other concepts that have not been included. The goal is not to have a complete picture of particle accelerators at all times, but to develop a model of how they work at a level that is appropriate for high school students. For example, while the LHC is not perfectly circular the authors use simplified circular motion concepts to build on understanding the LHC. Otherwise, the students would not be able to access the information very easily, and instead of exciting the student it might discourage them from investigating further. The key idea is to allow the student to access information and learn about particle accelerators in such a way as to allow the student to question their learning. This is then able to be easily accessed by many students at different levels.

Some conception challenges that frequently come up: Students struggle hugely with the idea of potential and electric and magnetic field theory. They want ideas to be concrete and correct. They struggle with the finite-life model aspect of Physics and that scientists do not know the answers, but can provide good explanations of what is happening with the knowledge they currently have available. The authors believe exposing students to this idea of uncertainty, inquiry, and the benefit of bringing fundamental research into the classroom is important to students conception and understanding of what Science is and what scientists do.

The authors discussed the point that students often ask “what’s the point”, and in some aspects this can be difficult for a teacher to find good examples or be able to demonstrate some way that an obscure point is used in today's world. For example; having an ability to discuss the LHC instead of cathode ray tubes would be one way to step up explanations and bring students up to face real world occurrences and cutting edge scientific research.

Helpful material and resources

Please refer to the Accelerator File, as that is the focus of this paper and the resource that the authors co-created.

Best practice examples

The way science is taught today has progressed in the past few decades. Instead of the traditional “chalk and talk” lecture-style lessons, many science teachers focus on executing lessons where students learn through the process of doing, inquiry, and projects. (Hodson, 2010)) In Capra’s 1982 study, he/she writes,

> “we are trying to apply the concepts of an outdated world view – the mechanistic world view of Cartesian-Newtonian science – to a reality that can no longer be understood in terms of these concepts. We live today in a globally interconnected world, in which biological, psychological, social, and environmental phenomena are all interdependent. To describe this world appropriately we need an ecological perspective which the Cartesian worldview does not offer” (pp. 15–16).

This quote exemplifies the need for teachers to not only focus on the theoretical knowledge but the practical application of the knowledge through interdisciplinary work and inquiry based lessons.

To optimize learning experiences, teachers should connect the content to the real world so that students are not left questioning the practical application of their learning. The process of creating lessons with theoretical knowledge connected to the practical application can be very difficult for a teacher, however when it is successfully done, the students and the world reap the rewards. It is important for students to see the practical application of the content they are learning through what has been identified as context-based learning. Research on context-based learning suggests that learning in this manner can increase student engagement, which is known to increase student achievement in any subject area. However, Whitelegg and Parry (1999) highlight the importance of first teaching theoretical knowledge and then applying it to the context or else the teachers run the risk of confusing and disengaging students.

As with any facet of science, there is a substantial amount of vocabulary associated with particle physics which needs to be articulated explicitly and in different modalities such as pictorially, kinesthetically, and in layman's terms. In 2017, scientists conducted a study to learn the best ways to teach particle physics to primary students in which they learned both primary and secondary school teachers should specifically define all words, especially words that are at times used interchangeably or may have multiple meanings. The scientists focused on words such as color charge and elementary particles It was found that when the teachers explicitly taught vocabulary through multiple modalities, even primary students could understand concepts in particle physics. *(Wiener, 2017)*

Although it is important to focus on the instructional strategies a teacher would employ, it is imperative to take a look at teacher training and professional development as a means to continue improving the quality of physics education. Historically, teacher training focused on teacher content knowledge (Shulman, 1986) however in the past few decades researchers have focused on what has been coined Pedagogical Content Knowledge (PCK) which is the marriage of pedagogical knowledge and content knowledge. Once a teacher has been effectively trained, they must continue to be supported so that they continue teaching and improving their practice.

To ensure teachers are able to continue their learning, it is imperative that outreach programmes like CERN's HST Programme continues. It is important that not only are a variety of teachers supported to participate in these programs but the resources that are created by institutes like CERN are continued to be made freely available. Opportunities similar to CERN's HST Programme include Perimeter Institute in Canada, The Institute of Physics (IoP) in the United Kingdom, and Fermilab in the United States of America. These facilities conduct research and provide outreach opportunities for teachers (and students).

It was interesting to note that in the United States of America, organisations such as Quarknet actively support teachers by linking up individuals with universities in order to improve the teachers knowledge and pedagogical approaches when teaching particle physics. The authors believe this to be an invaluable resource and would like to see more organisations making this initiative.

Goals

The authors believe this type of resource could lead to an ongoing project to expand the concept of connecting modern physics to classical physics. The website has been designed in such a way as to ensure key words that are commonly used in teaching are searchable. This pulls up a brief amount of information explaining how the classical mechanics terms are linked to the particle accelerator. There are data tables to allow teachers to form their own problems, and links to external sites to provide worked problems, background reading, or links to conceptual videos that relate to the key word. The authors felt it was important to create a resource that could be easily modified and wasn't a typical lesson plan where the authors explained how each concept should be taught. It is clear there are many pedagogical approaches to teaching physics and the authors felt this approach allowed teachers to find their own inspiration and use the links and resources to create their own lesson plans.

There is scope to develop this resource further. The centripetal force page on the website is a good example of the quality that was desired. Further development of the current key words would only enhance this resource. Moreover, additional concepts could be added including; particle detectors, and other aspects of accelerators, like; data storage, removal of noise, scientific methods, design, and findings could be added at a later date. They key idea of linking concepts together to form a coherent picture, and allowing teachers to access information from a classical sense was an important way of allowing teachers to expand their repertoire without going too far out of their comfort zone.

Moreover, additional accelerator concepts could be added including: data storage, removal of noise, scientific methods, design, and findings from future CERN research projects. A similar website could also be created with the focus of particle detectors to further supplement particle physics in a classical mechanics classroom.

Citations

Capra, F. (1982) The turning point: Science, society, and the rising culture. New York: Simon & Schuster.

Hennessy S (1993) Situated cognition and cognitive apprenticeship: implications for classroom learning Stud. Sci. Educ. 22 1–41

Hodson, D. (2010). Time for action: science education for an alternative future. *International Journal of Science Education*. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/09500690305021

Murphy P (1994) Gender differences in pupils' reactions to practical work Teaching Science ed R Levinson

Ramsey, G., Nemeth, M., & Haberkorn, D. (2013). Physics Pedagogy and Assessment in Secondary Schools in the U.S.

Whitelegg, E., & Parry, M. (1999). Real-life contexts for learning physics: meanings, issues and practice. *Physics Education*, *34*(2), 68–72.