Einstein-First: Modernising the School Curriculum

This document outlines the motivation for the Einstein-First Project, and the impressive results that led to new funding for the development of an Einsteinian curriculum across all years of school, the funds available, and a summary of the universities and partnerships involved in the project.

Background: paradigm changes: Over the past 2000 years our fundamental conceptions of the nature of the universe have undergone two major revolutions. For almost two millenia there had been a general consensus about the nature of the universe, based on the writings of Aristotle. *Common sense* for everyone was a universe consisting of a heavenly realm beyond the moon, that was permanent and unchanging, and a terrestrial realm, the Earth, the centre of the universe, characterized by completely different laws. This was Aristotelian physics. In a major revolution, Galileo, Newton and others replaced this picture with the world view we all learnt at school – a universe of absolute space and time, and absolute laws such as the law of gravitation. This revolution was contentious and bitterly opposed.

Newtonian physics provided the framework that powered the industrial revolution and 300 years later, the Newtonian world view has become the *common sense* we all share. It is embedded in our school curriculum from the earliest years.

A century ago, Einstein led another revolution, in which the Newtonian common sense was overthrown. Einsteinian physics encompasses quantum physics based on Einstein's discovery that light comes as photons, and the theory of space, time, matter, energy and gravity that Einstein called his called General Theory of Relativity. Einsteinian physics has powered the modern technological revolution. It underpins almost all aspects of modern life, from communications technology, solar power, GPS navigators, digital screens, medical imaging, cancer treatments, drug developments, and the understanding of the universe as a whole.

At each revolution people said the new description was too difficult to understand, it did not make sense, and it was unnecessary because the old description provides an adequate description of the world as we experience it. Newton and Einstein shared significant doubts about the implications of their discoveries. Newton thought his concept of action at a distance "a great absurdity" and Einstein called the statistical nature of the quantum world "spooky" and said "God does not play dice"!

The fundamental truths behind each new paradigm are completely different and today there is a universal consensus amongst physicists that Einsteinian physics is our best understanding of the universe.

However most physicists and educators believed that Einsteinian physics was too difficult for young people to learn, and should be left until university. This meant that only a very small group of specialists have had the opportunity to learn Einsteinian physics. Everybody

else learns little more than school children learnt 100 years ago. Physics lecturers at university are renowned for the statement “forget what you learnt at school.”
Whether we care about the truth, or we care about educating people to be literate in our modern technological world, Einsteinian physics is fundamental. The table below shows the fundamental tension between Einsteinian physics and the physics we learn at school.

Schools Today	**Modern Understanding**
Rigid Euclidean space	Space flexible and curved
Time is absolute	Relative spacetime
Light is a wave, Bullets are particles	Everything combines waviness and bulletiness
Energy is massless	$E = mc^2$
Newtonian determinism	Quantum uncertainty
Gravity: instantaneous force	Gravity: spacetime curvature, speed c

A team of physicists and educators at UWA began to question the fundamentals of science teaching in schools in 2013. Pilot studies with Year 6 and Year 7 students quickly demonstrated that 11 and 12 year-old children relished learning Einsteinian concepts, and since that time numerous studies have proved that the concepts of Einsteinian physics are within the reach of children as young at 8 years old. A summary of the findings from our project is given below.

Outcomes from 7 years of testing, ages 8-16

1. Children accept Einsteinian concepts with ease
2. Children are aware that they learn ‘old stuff’ at school
3. Most children are aware of Einstein and want to learn Einsteinian concepts
4. Children are extremely motivated by the activity based Einsteinian curriculum.
5. Teachers enjoy teaching using our activity based learning, especially those with minimal physics background.
6. Evidence of gender levelling: girls improve more than boys.
7. Positive responses from teachers workshops and from parents.
8. Strong evidence that the core concepts are accepted by all students independent of aptitude.
9. Published histograms from multiple interventions demonstrate very impressive improvements in both attitude and understanding.
10. Long term retention demonstrated over 3 years.

Current Primary School curriculum: Analysis of the primary school curriculum shows the many ways in which the obsolete Newtonian description of reality is implicitly embedded in learning. Relatively simple modifications are needed at the primary school level to open children's minds to the new reality, thereby creating expectations of a progression of learning that will equip them with scientific literacy relevant to the modern world.
With each new paradigm has come new mathematics. Newtonian physics needed calculus. while Einsteinian physics needs curved space geometry, vector mathematics and statistics. All of these forms of mathematics are simple to introduce conceptually at an early age, through activities and games at the primary level as preparation for their development at high school. Note that we do not propose introducing any of the scary mathematics that is needed only for specialists at the tertiary level. We teach it using graphs, models and activities. We believe that the early introduction of statistical concepts including the gamblers fallacy, are very important, not only because quantum reality is fundamentally statistical, but also because of the negative social impact of gambling.

The discovery of Einsteinian physics involved huge struggles with ideas that have occurred over centuries. They have often been intertwined with social history, wars and revolutions. The human stories that intertwine science, mathematics and history can enrich all of education, especially at primary school, as discussed further below.

Einstein-First: The Einstein-First project was named to emphasise the importance of introducing the Einsteinian language of reality at the very beginning of education. The project came to be known internationally, leading to a Norwegian-funded international workshop at the Gravity Discovery Centre in 2016 and a German-funded international workshop in 2019. The 2016 workshop led to the creation of the Einsteinian Physics Education Research Collaboration with the goal of combining international resources to create an Einsteinian oriented curriculum for use in schools internationally. The new ARC Linkage project is an outcome of this collaboration.

The ARC -funded project is limited because of funding constraints. It will support personnel to conduct teacher professional development and longitudinal trials over 3-4 years, one at primary level, one at secondary level, followed by a detailed review and assessment by curriculum experts. Even the two coordinators are restricted to 0.8 FTE by funding constraints. We are only able to conduct a limited number of trials.

Integrated mathematics, science and arts: At primary level we would like to support three strands: maths, physics and arts, to allow the Einsteinian ideas to be explored in parallel programs across mathematics, science, history, art and drama. By creating a linked mathematics, science and arts curriculum we would have much more integrated program free of the strict divisions in which often lead to disengagement in particular areas such as mathematics.

The Einstein-First project proposes that history should include the history of ideas and the history of science and mathematics. A few examples are given below. Each would be best supported by appropriate books, role plays, or art activities, and which could combine reading, mathematics, science, history, and art.

- The discovery of Australia by Captain Cook was a by-product of an expedition to determine the size of the solar system. This was the first step in measuring the distance to the stars and ultimately the size of the whole universe.
- The idea of measuring the shape of space starts with an experiment with sunlight on three distant mountain tops near Hannover in 1815, goes on to the heroic Wallal expedition in Western Australia in 1922, and ends with amazing images taken by the Hubble space telescope.
- The idea that time depends on height starts with Einstein's friend Schwarzschild solving Einstein's equations while serving on the Russian front in the first world war (1916), then a US rocket experiment called Gravity Probe A during the cold war, and a near fiasco when the US Navy forgot about Einstein during the planning of the GPS navigation system.
- The discovery of the number zero is entwined in the history of civilisations from Sumeria to Egypt and to India. When the idea reached Europe in the 16th century it inspired people like Shakespeare who wrote "Much Ado About Nothing".
- The discovery of the number Pi has been another extraordinary quest over at least 3000 years, that crosses civilisations from China to Greece, Persia to Arabia and Europe, and links with the search for extraterrestrial civilisations and yet only has a precise geometric value in flat space which does not exist!
- The discovery of radio that eventually brought us mobile phones is a history that combines science with business intrigue, international controversy, war, encryption and mass communication.
- The understanding of probability was driven by the invention of insurance. It affects everyone whether through consideration of risks in life, gambling and lotteries but it also underlies the theory of quantum physics. Maths, physics and social affairs are linked by this single concept.
- From zero to infinity. One cannot understand the universe without being able to grapple with huge and tiny numbers. The idea of zero discussed above, allowed us to envisage very large and the very small numbers, but also to imagine infinity. The history of numbers and the special role of infinity combines both the mathematics, the physics and the human history.

Teacher professional development: A key aspect of the implementation of an Einsteinian curriculum is teacher professional development. We plan to train teachers and have teachers present the Einsteinian curriculum supported by research staff in the first instance. In the long term we need to have suitable material and sufficient training that teachers develop sufficient confidence to be able to implement the proposed curriculum.

Engagement with education and curriculum authorities: We have engaged with curriculum authorities to ensure that the project is nationally reviewed by ACARA. We have also engaged with the Australian Academy of Sciences to ensure that Einstein-First is consistent with the Academy's Primary Connections education program. Our partners including AISWA, STAWA and DET are engaged and involved in the project planning.

Funds Currently Available

The currently awarded funding from the ARC with other funds from DET, and AISWA will allow us to support

a) Two x 0.8 FTE research associates: main role: trial designs, measurement of trial results, teacher PD designs and measurement
b) One PhD student. (Another is currently enrolled, several others are expected to receive PhD scholarships funded by universities.)
c) One 0.8FTE program delivery person with links to schools and the Gravity Discovery Centre, mainly focused on short interventions.
d) Limited funds for the creation of kits to support school programs.

Project Summary, Chief Investigators and Partners

The current Einstein-First Project arose as a result of an international workshop in November 2016, that was made possible by the collaboration between the Relequant project in Oslo, Norway, and the Einstein-First team in Western Australia. The workshop was held at the Gravity Discovery Centre near Perth. It brought participation from groups in Korea, Germany, Scotland and China. The participants formed the Einsteinian Physics Education Research (EPER) Collaboration. We formulated the plan for this project that was announced in March 2019.

Australian Research Council Summary

"Following a previous project that showed that it is possible and beneficial to teach the modern Einsteinian paradigm of space, time, matter, light and gravity to students as young as 8 years old, this project aims to test and evaluate a seamless progression of learning modern physics through primary and secondary school. It will sequence, integrate and test research-informed teaching and learning materials, and assessment instruments developed through a 7-nation collaboration. Research across 24 schools will be reviewed by a panel drawn from professional organisations and curriculum authorities, and learning resources will be widely disseminated, with view to worldwide introduction of Einsteinian science at school."

Chief Investigators:

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Partner Organisations:

1. Gravity Discovery Centre Foundation
2. WA Department of Education
3. Association of Independent Schools of WA

4. Science Teachers Association of WA
5. Mount Lawley Senior High School
6. University of Oslo, Norway
7. Seoul National University
8. University of Hildesheim
9. University of Glasgow
10. Beijing Normal University