Time for changing paradigms in science and in education

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General Relativity as a Challenge for Physics Education

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Organization of the presentation

- 1. Discussion of Paradigms
- 2. Changing Paradigms in Science
- 3. Changing Paradigms in Education
- 4.Published work on Einsteinian physics in schools and universities

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1. Paradigms

- Thomas Kuhn (1962). *The structure of scientific revolutions*.
- Challenged the current conception of science as a steady progression of the accumulation of new ideas.
- Science advances the most by occasional revolutionary explosions of new knowledge with the introduction of new ways of thinking – Kuhn called these paradigms.
- There are universally recognised scientific achievements that for a time provide model problems and solutions to a community of scientists leading to Paradigm Shifts

Paradigmatic Changes

- These paradigmatic changes do not happen overnight
- New ideas-models-theories only accepted **when based on reliable and valid and repeatable empirical data**
- Scientists find that new ideas-models-theories can **better explain** phenomena and **better predict** new and future phenomena
- Some scientists persist with ‘former’ ideas-models-theories but these scientist numbers lessen as time goes by.
- ‘Former’ ideas-models-theories become not acceptable by the majority of the scientific community

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2. Changes in thinking and researching in science become the new norm - Examples

- Ptolemaic Cosmology to Copernican Cosmology
- Aristotelian mechanics to classical mechanics
- Theory of spontaneous generation to theory of biogenesis
- Pangenesis to Mendelian inheritance
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- Maxwellian Electomagnetic to Einsteinian relativisitic worldview
- Newtonian physics to Einsteinian relativisitic worldview
- Classic mechanics at a micro level to Quantum mechanics

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Einstein's Annus Mirabilis –Four papers in 1905

- Particulate nature of light – 'quanta'
- Brownian motion
- Electrodynamics of moving bodies
- Mass –energy equivalence
- Four papers today recognized as tremendous achievements (Martin Hendrey 11.02.19).
- But at the time, they were not noticed by most physicists as being important.
- Many of those who did notice them rejected them outright.
- Some of this work—such as the theory of light quanta—remained controversial for years.

Some new ideas did not become the new norm - Cold fusion

- In 1989, Martin Fleischmann and Stanley Pons, then both at the University of Utah, made headlines around the world with their claim to have achieved fusion in a simple table top apparatus – a test tube - working at room temperature
- Other experimenters failed to replicate their work
- Most of the scientific community no longer considers cold fusion a real phenomenon
- Nevertheless, research continued for many years, especially in Japan
- A small vocal minority still believes in cold fusion (now privately funded)
- When experiments show a small fraction of excess heat in reactions, checking for experimental error is the next task!

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Some new ideas did not become the new norm - Lysenkoism

- Environmentally acquired inheritance – Lysenkoism – neo-Lamarkism
- 1940s-50s, pseudo-scientific concept based on Marxist-Leninist ideology
- Lysenko campaigned against Mendelian genetics – supported by Stalin
- Considered heritability of variation by mechanisms other than changes in DNA
- Repeated experiments in Cambridge could not be replicated
- Disastrous consequence for wheat yield during Stalin's time - belief that winter varieties of wheat could be transformed into a spring variety
- Negatively affected Soviet genetics, evolutionary and developmental biology - took a long time to recover
- Increasing interest in Russia to rehabilitate Lysenko's image

Ideas ahead of the Zeitgeist

- **Mendel's inherited characteristics** – laws of heredity
- Published "Experiments on Plant Hybridization" in the Proceedings of the Nature Research Society of Brünn (Brno, Czech) in 1866
- Sent to 40 leading biologists in Europe – most unread. One replied – he could not understand the mathematics. **Cited 3 times in 35 years**
- Englishman William Bateson translated Mendel's paper.
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- **Soldner (1801) – gravitational field acting on light rays** (Karl-Heinz Lotze, Monday 11.2.19)
- Treat light rays always as a heavy object being acted upon by gravity
- Light rays do not travel on a straight line but in a hyperbola
- Too early to be understood

Ideas ahead of the Zeitgeist

- From 1912 **Alfred Wagener proposed continental drift** arguing that all the continents were once joined together in a single landmass and had since drifted apart.
- But he had no mechanism to explain the phenomenon.
- By 1930 his theory had been rejected by most geologists, and it sank into obscurity for the next few decades, only to be resurrected as part of the theory of plate tectonics during the 1960s.

3. Changing Paradigms in Education - Teacher-centred to Student-centred

- Lectures – dominant means of ‘gaining’ knowledge
- Teachers active – students passive
- Underlying theory for lectures – Behaviourism – B F Skinner
- Underlying a behaviourist approach to teaching is the belief that learning is governed by **invariant principles** and these principles are **independent of conscious control on the part of the learner**.
- Behaviourism is an empirically derived model or theory – modelled on scientific principles with data from animals and humans
- Human behaviour is predictable and controllable.
- Behaviourism stems from an objectivist epistemological position.

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Theory of Behaviourism

- Skinner's theory of learning – Behaviourism – provides underlying theoretical basis for development of **teaching machines**, **measurable learning objectives**, **computer-assisted instruction**, **multiple choice tests**
- Behaviourism's influence is still strong in corporate and military training, and in some areas of science, engineering, and medical training
- Behaviourism is useful for rote learning of facts or standard procedures such as multiplication tables, or for compliance with industrial or business standards or processes that are invariant and do not require individual judgement

Alternative Research Theories in Education

- Theorists like John Dewey, Jean Piaget, Carl Rogers, Jerome Bruner, Lev Vygotsky and others
- Each theorist has different underlying dimension but are similar in that students actively construct their own ideas
- Students learn and retain more information when they are actively involved in the learning process.
- Learning is most meaningful when topics are relevant to students' lives and interests
- Underlying theory of knowledge - Constructivism
- Constructivists emphasise importance of **consciousness**, **free will** and **social influences on learning**
- Strong challenges exist

Some new ideas did not become the new norm

- Open-ended inquiry learning – leave students to find out what they want to know.
- Programmed learning – based on Skinner's ideas

Paradigmatic Changes in Education

- These paradigmatic changes do not happen overnight
- New ideas-models-theories only accepted **when based on reliable and valid and repeatable empirical data**
- Accepted when educators, schools, universities find new ideas-models-theories can better improve student learning
- Some educators/lecturers persist with the ‘former’ ideas-models-theories but numbers lessen as time goes by.
- ‘Former’ ideas-models-theories are not accepted by the majority of educational community
- Compare to Slide 4 - same words

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Changing paradigms in science and in education

- Changing paradigms in teaching has the same underlying principles as changing paradigms in science
- Can look at this from a Kuhn or Lakatosian perspective

Comparison of Old and New Paradigms of Teaching

Entity	Old Paradigm	New Paradigm
Knowledge	Transfer	Construction
Students	Passive	Active
Faculty	Classify & Sort	Develop competencies
Context	Competition	Cooperation
Teaching	Expert can	Complexity of Teaching
Learning	Individual	Social process
Epistemology	Reductionist	Constructivist
Mode	Memorise	Relate

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Benefits of Student-centred learning

- Allows students to take responsibility for their own learning
- Can connect learning to students' own lives
- More opportunity for higher order thinking
- Increases student engagement
- Encourages innovation
- Enables alternative forms of assessment
- Challenges for appropriate "problems" with suitable assessment

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21st Century Skills – Now a part of science/ physics education

Skill	Skill
Critical thinking	Technology literacy
Creativity	Flexibility
Collaboration	Leadership
Communication	Initiative
Information literacy	Productivity
Media literacy	Social skills

Research findings that support the paradigm shift in teaching & learning

- Concept mapping
- Concept cartoons
- Group work
- Role playing
- Model-based learning
- Portfolios
- Cooperative learning - Jigsaw tasks
- Social-cultural aspects of content
- Socratic dialogue
- Flipped classroom
- Problem-based learning
- Project-based learning
- POGIL (particularly in chemistry classes)

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Challenges to implementing a paradigm shift in physics education

- Lack of confidence in trying new methods
- Lack of confidence with the new content
- Fear not enough content coverage
- Fear that students can’t take control of their own learning
- Concern over pre-university examinations
- Loss of control over the class
- Lack of materials for the class
- Lack of background in the use of active learning approaches

4. Published work on Einsteinian physics in schools and universities

Research on Einsteinian physics in schools that was ahead of the Zeitgeist

- Haddad, W. D., & Pella, M. O. (1972): Relationship between mental maturity and level of understanding of concepts of relativity in Grades 4-8. *The Journal of Experimental Education, 41*(1), 22-32. (**4 citations**)
- Petri, J. & Niedderer, H. (1998). A learning pathway in high school level quantum atomic physics, International Journal of Science Education, 20(9), 1075-1088. (226 citations)
- Baldy, E. (2007). A new educational perspective for teaching gravity. International Journal of Science Education 29(14), 1767-1788 (**24 citations – 2 citations before 2013**)

Haddad & Pella (1972) Relationship between mental maturity and level of understanding of concepts of relativity in Grades 4-8

Grade	Classical Relativity	Special Relativity	General Relativity
4, 5, 6	K	K	K
7, 8	K C A	K C	K C
Note – K – Knowledge, C – Conceptual, A – Application (Bloom's Taxonomy)			

Study in private school in Beirut, Lebanon

Separate tests for 29 concepts

Equipment used

- Moving belt kit
- Wave propagation model
- Mini elevator
- Space-time continuum model

Elise Baldy "A New Educational Perspective for Teaching Gravity" IJSE, 29(14), 1767-1788

- Then at IUFM de Montpellier France
- Newton's theory taken out of French curriculum in 1998
- Einstein's more recent theory is acknowledged as a good approach for explaining the phenomenon of gravity.
- France's popular science magazines for youth consider GR accessible to adolescents.
- **Research used pillow analogy – similar to lycra sheets – non mathematical approach**
- Understanding that mass of celestial bodies deforms space–time, and this aspect alone, can be regarded as characteristic of the cognition of 15-year-old students.

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Research publications of Einsteinian physics being implemented in schools and universities

2012 - 2014

Blair, D. (2012).Testing the theory: taking Einstein to primary schools. *The Conversation* 9710

Blair, D. (2013). Gravity waves make young minds ripple. In Dayton, L. (Ed.), *The curious country: The role of science in Australian society* (p. 142). Canberra, ACT: ANU Press.

Blair, D, Ju, L, & Kaur, T. (2013). Einstein First, Newton Second: *World Conf on Science and Technology Education,* Borneo.

Zahn, C., & Kraus, U. (2014). Sector models: A toolkit for teaching general relativity: Curved spaces and space-times. *European Journal of Physics*, *35*, 055020

Henriksen, E. K., et al. (2014). Relativity, quantum physics and philosophy in the upper secondary curriculum: Challenges, opportunities and proposed approaches. *Physics Education*, *49*(6), 678–684.

Pitts, M., Venville, G., **Blair, D**., & Zadnik, M. (2014). An exploratory study to investigate the impact of an enrichment program on aspects of Einsteinian physics on Year 6 students. *Research in Science Education*, *44*(3), 363–388.

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Research publications of Einsteinian physics being implemented in schools and universities

2016

Stannard, W, **Blair D**, Zadnik M, & Kaur T.(2016). Why did the apple fall? *European Journal of Physics*, 38, 1.

Krijtenburg-Lewerissa, K. Pol, H, Brinkman A,van Joolingen W. (2016) Insights into teaching quantum mechanics in secondary and lower undergraduate education**.** *Physics Review. Physics Education Research, 13*, 010109

Blair D (2016a). Gravitational waves discovered. *The Conversation* 54237 http://www.theconversation.edu.au

Blair D (2016b). When black holes meet. *The Conversation* 54236http://www.theconversation.edu.au

Blair D, **Hendry M, Henriksen E K** (2016)**.** Why don't we teach Einstein's theories in school? *The Conversation* 69991

Kapotis, E. & Kakanis, G. (2016). Einstein's elevator. The Physics Teacher, 54(7)

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Research publications of Einsteinian physics being implemented in schools and universities

- **2017**

- Kaur,T.**, Blair, D**., Moschilla, J., Stannard, W., & Zadnik, M. (2017a).Teaching Einsteinian Physics at schools: Part 1, models and analogies for relativity, *Physics Education*, 52, 065012.
- Kaur, T., **Blair**, D., Moschilla, J., and Zadnik, M. (2017b). Teaching Einsteinian Physics at schools: Part 2, models and analogies for quantum physics, *Physics Education*, 52**,** 065013.
- Kaur,T., **Blair, D.**, Moschilla, J., Stannard, W., & Zadnik, M. (2017c).Teaching Einsteinian Physics at schools: Part 3, review of research outcomes. Physics Education, 52 065014
- Kaur, T.**, Blair, D**., Burman, R., Stannard, W., **Treagust, D**., Venville, G., Zadnik, M., Mathews, W., & Perks, D. (2017d). Evaluation of 14 to 15 - Year - old students' understanding and attitude towards learning Einsteinian Physics. http://arxiv.org/abs/1712.02063
- Kaur, T., **Blair, D**., Choudhary, R., Dua, Y., Foppoli, A., **Treagust, D**., Venville, G., and Zadnik, M. (2017e). Gender response to Einsteinian physics interventions in schools. http://arxiv.org/abs/1712.06323

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Research publications of Einsteinian physics being implemented in schools and universities

- **2018**

- **Kersting, M., Henriksen, E.** K., Bøe, M. V., & Angell, C. (2018). General relativity in upper secondary school: design and evaluation of an online learning environment using the model of educational reconstruction. *Physical Review Physics Education Research*, *14*(1),
- **Kersting,** M. & Steier, R. (2018). Understanding curved spacetime: The role of the rubber sheet analogy in learning general relativity. Science & Education,
- **Choudhary, R**., Foppoli, A., Kaur, T., **Blair, D.**, Zadnik, M., & Meagher, R. (2018). Can short intervention focused on gravitational waves and quantum physics improve students' understanding and attitude?, https://arxiv.org/abs/1807.02995
- Foppoli, A., **Chaudhary, R**., Kaur, T., **Blair, D.**, Zadnik, M., & Moschilla, J. (2018). Public and teacher response to Einsteinian physics in schools. https://arxiv.org/abs/1806.10776.
- Bungum, B., Boe, MV. **Henriksen, EK.** (2108). Quantum talk: How small group discussions may enhance students' understanding quantum physics. Science Education, 102, 856-877
- **Zahn, C., & Kraus, U**. (2018). Geodesics. *European Journal of Physics*, *40*
- **Zahn, C., & Kraus, U**. (2018).Spacetime geodesics. *European Journal of Physics*, *40*
- Kaur, T., **Blair, D.**, Stannard, W., **Treagust, D.**, Venville, G., Zadnik, M., Mathews, W., & Perks, D (2018). Determining the intelligibility of einsteinian concepts with middle school students. Research in Science Education, https://doi.org/10.1007/s11165-018-9791-y

Science and Education

- Science certainly has paradigms shifts
- Education is pre-paradigmatic but also has shifts
- The previous paradigm can remain useful and important
- More recently, paradigm changes in education are becoming more evident with more agreement with the outcomes of empirical research supporting teaching and learning
- As shown there are growing research findings to support the effectiveness of teaching of GR in schools

Many more publications

Pössel, M. (2017). Relatively complicated? Using models to reach general relativity at different levels. Invited talk German Physical Society, Bremen

https://arxiv.org/abs/1812.11589

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Thank you!