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The evolution of Physics textbooks used in Ireland 1860-2022

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Abstract

This paper focuses on the evolution of Physics textbooks used in Ireland from 1860 to 2022, in addition to the Irish influence on early physics textbooks in the latter part of the 19th century. Both Physics and Physics education are continually evolving and so textbooks change in response to that and to the changing priorities of educators. Physics is both experimental and theoretical and the presentation of it has always been multimodal. Physics textbooks tend to include diagrams, demonstrations, experiments, the use of mathematics and derivations, historical references to people, and applications of Physics, among other features. Our research looks at these various characteristics to discern what has changed and what has not, over the course of time. Twenty-eight textbooks were examined in the course of this study. A Physics concept (refraction) and a Physics instrument (electroscope) were chosen for special attention, so that the findings would be firmly rooted in how Physics has been represented in textbooks rather than general textbook publishing trends. A specific analysis of four textbooks by the same two authors across three syllabi is also presented. Our findings show that a great deal has changed in the realm of Physics textbooks, and given that this is the case, it is remarkable how many things changed very little in 162 years.

Keywords: Physics, textbooks, experiments, demonstrations, diagrams, derivations, mathematics, applications, electroscope, refraction, teaching, learning.

1. Introduction

Physics school textbooks for the Irish curriculum have been in existence for over 160 years [1]. Prior to that it was still called Natural Philosophy and was for the most part a hobby for the rich. In the mid-1800s Physics was becoming a profession at which one could earn a living. The industrial revolution was in full flow and schools were becoming widespread. In 1831, the Board of National Education and the National School system was established using public money. A commissioner of national education was appointed whose task was to assist in funding primary school construction, teacher training, the producing of textbooks, and funding of teachers [2]. The government made strenuous efforts to introduce science as a new subject in schools in the 1850s [3]. Jenkins [4] notes that the process of understanding the history of science education in England is complex, which mirrors the Irish experience. Universities began setting entrance examinations which came to control what was being taught in schools, and so their syllabi influenced and shaped textbooks [5]. In this context the scope of Physics as a school subject was being defined for the first time and textbooks were being produced to serve the needs of teacher and student alike. Two Irish born educators, Lardner and Tyndall [1, 6-8], made a marked contribution at this developmental stage in their influence on early physics textbooks. Dionysius Lardner was born in Dublin and following years of lecturing in Trinity College Dublin and University College London, he focused on producing books on a wide variety of themes. In 1857, following many other successful publications, he produced a textbook titled "*Natural Philosophy for schools*" [9]. It appears to be one of the earliest texts to possess the modern subject core of mechanics, light, sound and electricity and magnetism. In contrast to Lardner's work, Tyndall's books [10-12] were not specifically written as textbooks, but nevertheless they served that purpose effectively. His notes were widely sought by students and teachers [10]. John Tyndall was born in Leighlinbridge in Co. Carlow in 1820 and worked as a surveyor in London before moving to Germany in 1848, where he completed a PhD under the supervision of Robert Bunsen [1]. He went on to become an experimental physicist and was appointed Professor of Natural Philosophy in 1853 at the Royal Institution (RI) in London. He was also an advocate for the accessibility of scientific education to all, giving 35 lectures and courses in workman's clubs and in several American cities between 1872 and 1873. Tyndall succeeded Michael Faraday in presenting the famous RI Christmas Lectures -- an exciting new way of presenting science to young people. He produced detailed notes in support of his lecture series and in time these came to be published as a new type of science book which were valued by teachers and students as useful resources [13]. These notes rendered the subject of Physics attractive for the first time, without conceding anything to scientific accuracy.

In the following years, textbooks by Wright [14], Ganot [15] and Stead [16] were used. Adolphe Ganot's textbooks, were written during the second half of the nineteenth century, and made a decisive contribution to Physics and its teaching internationally [1]. His authoritative work was translated from French into several languages. D.P. Newton observed [5] that later Physics textbooks drew directly from Ganot who exerted a prolonged influence, both directly and indirectly at least as late as the 1930s. Gilbert Stead was a British professor of Physics who worked at Guy's hospital and whose textbook Elementary Physics [16], and subsequent editions, was continuously in print, for over 50 years.

Compulsory attendance in primary schools was introduced in 1922, although very little Physics has ever been taught at this level. In 1924, the Intermediate Certificate and Leaving Certificate were introduced in secondary schools. Free second level education in Ireland was introduced in September 1967 and thus the age of leaving school increased [17]. This is widely seen as a milestone in Irish history. The first Physics textbooks for schools published in Ireland were by Maurice O'Brien [18-20] and appeared around 1960, and there has been a wide range of textbbooks published and used since then, owing to the increased demand from greater numbers of students staying in education. Prior to this, there was a heavy reliance on UK textbooks [21, 22]. Prior to the introduction of free secondary education, most secondary schools were *single sex* schools and physics was very often not available in female-only schools. Physics for many years was taken mostly by males interested in a career in medicine or engineering.

Table 1 details the textbooks examined as part of this research. It is worth noting that we wished to include one other text in this analysis [23], but were unable to trace a copy.

Table 1: Textbooks analysed in this research

Year	Title	Reference
1865	Natural Philosophy for Schools - Lardner	[9]
1871	Light and Electicity: Notes of two Courses of Lectures - Tyndall	[10]
1875	Sound – Tyndall	[12]
1876	Lessons in Electricity at the Royal Institution – Tyndall	[11]
1888	Sound, Light and Heat - Wright	[14]
1906	Elementary Treatise on Physics, Experimental and Applied – Ganot	[15]
1924	Elementary Physics – Stead	[16]
1962	Practical and Theoretical Physics: Light – O'Brien	[20]
1971	A modern course in Physics: Light and Sound – O'Donoghue	[24]
1971	A modern course in Physics: Electricity, Magnetism, Atomic Physics – O'Donoghue	[25]
1971	Physics – Br. D. C. Minogue	[26]
1972	Somerfields Physics Leaving Cert Course	[27]
1972	Physics Experiments for Leaving Cert – Henly	[28]
1981	Physics - a basic course – Casserly and Horgan	[29]
1984	Senior Physics – Porter	[30]
1984	Physics - Science of Action - O'Dowd	[31]
1984	New Syllabus Leaving Cert Physics –Collins	[32]
1984	Fundamental Physics – Casserly and Horgan	[33]
1987	Experimental Physics for LC – Travers	[34]
1990	Fundamental Physics (Revised) – Casserly and Horgan	[35]
2000	Physics Now! Casserly and Horgan	[36]
2000	Physics Today – Henly	[37]
2000	Real World Physics – O'Regan	[38]
2010	Investigating Physics – Kenny	[39]
2013	LC Physics FUSION – Carolan	[40]
2014	LC Physics Plus – Tierney	[41]

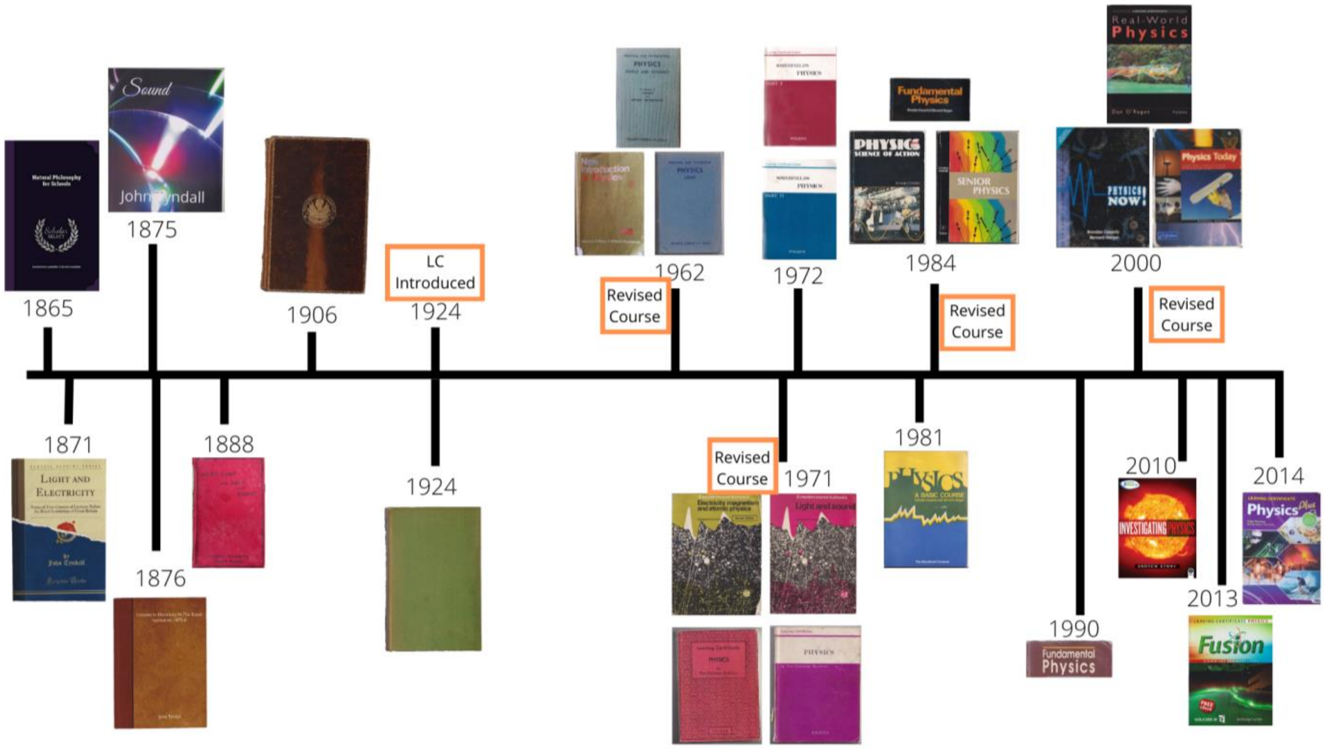

Figure 1: Timeline of books

Books from 1962 onwards were published for the Irish market. In recent decades, approximately 7000 students sit Physics in their Leaving Certificate exam and male students outnumber females by about three to one. There is essentially only one syllabus (available at higher or ordinary level) and so the production of Physics textbooks has been seen as a labour of love rather than offering a serious financial reward. It is noteworthy that the latest legislation governing school attendance in Ireland is the Education (Welfare) Act 2000. Under the Act, the minimum school leaving age is 16 years, or until students have completed three years of second-level education, whichever is the later.

The communication of Physics is highly multimodel [42]. It makes use of text, equations, diagrams, graphs and images [43]. This paper focuses on the transformation of Physics textbooks used in Ireland from 1860 to present day. It is interesting to note the similarities and differences in textbooks that arise from decade to decade. The evolution of Physics and the resulting evolution of Physics textbooks is presented in Section 2. In Section 3, the characteristics of textbooks, such as the use of mathematics and derivations, demonstrations, experiments, the use of diagrams, history and applications, and the represetnation of women are compared across textbooks. A specific analysis of four textbooks by the same two authors across three syllabi is presented in Section 4. In Section 5, two Physics topics were chosen for special attention, the electroscope and refraction, so that the findings would be firmly rooted in how Physics has been represented in textbooks in contrast to general textbook publishing trends.

2. The context: evolution of Physics and the evolution of textbooks

Evidence for the constantly changing context for Physics and the textbooks that serve the subject in Irish schools can be gauged from a number of examples. Thermionic valves had not been conceived of in the early years of textbooks by Lardner [9] and Tyndall [10-12] but throughout much of the 20th century valves had great significance for the heyday of radio and early television [25-27, 30-32], to fade into relative obscurity in modern school Physics textbooks [36-41]. Likewise, radioactivity was discovered in 1896 after Lardner and Tyndall had died. When it made its way into school textbooks [16, 25-27, 29-31] in the middle of the 20th century it was accompanied by experiments and demonstrations, which have since been reduced in significance because in Ireland, modern health and safety guidance has strongly discouraged schools from having any radioactive sources [44].

Mercury was extensively used across the Physics curriculum for many years, in thermometers and barometers, and verification of Boyle's law using a mercury manometer and in many electrical experiments like the Faraday motor, demonstrating the Lorentz force, or Barlow's wheel. However, the toxic nature of mercury is nowadays better understood, and so modern textbooks feature alternative equipment and alternative methods for many experiments. The development of lasers has allowed cheaper and easier options than vapour lamps and spectrometers for determining the wavelength of visible light. These are but a few of the many examples of how Physics has adapted, and school Physics textbooks have evolved in response.

The socio-economic landscape has changed also. In earlier times only the teacher may have had a textbook whereas in the modern era students have their own individual copy of the book. Randal Henly, author of *Physics Today* [28, 37] recalls that there was no Irish-published Physics textbook in the 1950s when he was a schoolboy. The teacher provided notes to be copied into a science notebook. O'Brien's (1962) textbooks for Physics [19, 20] seem to be the first produced in Ireland since independence in 1922. Prior to that, Stead's Elementary Physics [16] was the standard that teachers worked from for nearly four decades. Before 1922, whatever textbooks were used in Britain were generally used in Ireland also. Ganot's Natural Philosophy (translated from French) was the officially recommended textbook for the Physics syllabus in Ireland, with page numbers 1878 – 1886 listed as specifically relevant [45].

Prior to 1970, only 10% of students pursued second level education to the age of 18, and the Irish educational system was greatly influenced by John Henry Newman; it valued the classics, with science very much on the margins. Since the introduction of State-funded secondary education, the vast majority of students continue in education to the age of 18 and have access to a broad curriculum. Nevertheless, Physics is not always available, and this has been a particular issue in girl-only schools [46]. Currently, Physics is an optional subject for the Leaving Certificate examination. The contemporary curriculum, a revised version of the syllabus introduced in 1984, has approximately 70% emphasis on pure science, with the remaining 30% focused on the applications of Physics [47]. In 2019, the total number of students undertaking the Physics examination was 7,942 [48] out of over 55,000.

Robin Miller identified that the school science curriculum has two distinct purposes: to develop the scientific understanding of all students as a preparation for active citizenship; and to provide the foundation for further study of science for those students who may wish to follow careers that require this [49]. These two purposes may lead to different criteria for selection of curriculum content, and to different emphases. The context of the syllabus naturally influences the textbooks of the day. The Intermediate Certificate and Leaving Certificate came into existence in 1924 with new syllabi that remained unchanged until 1942 [45]. In 1942 Pass and Honours Level Leaving Certificate courses came into existence for science subjects (Physics, Chemistry, Botany) as well as a new subject titled 'Physics and Chemistry' [45]. Less able students could study the 'pass' syllabus and more able students could study the more advanced 'honours' syllabus. Revised courses in Leaving Certificate Physics and in Leaving Certificate Chemistry came officially into operation in September 1962 and pupils were first examined on these courses in June 1964 [45]. The introduction of state-sponsored secondary education came into effect in Ireland in 1969. Subsequent Physics syllabus changes occurred in 1971, 1984 and in 2000.

Since the change in Physics syllabus in 1971, there has been healthy competition in the Physics textbook market. In 1971 there were three textbooks [26, 27, 29], the later revision in 1984 was accompanied by four new textbooks [30-33] and in 2000, four more books for a further syllabus revision [36-40]. Figure 2 illustrates the number of candidates taking Leaving Certificate Physics over the past twenty years, which gives an indication of the size of the market.

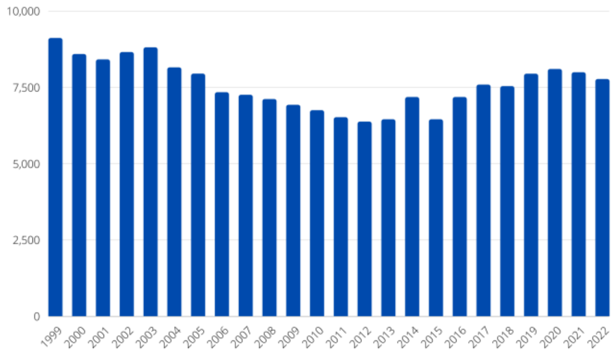

Figure 2: Number of candidates sitting Leaving Certificate Physics from 1999 to 2022 [50-53].

3. Characteristics of Textbooks

In 1983, Douglas Newton, a teacher and researcher in the UK, published his analysis of sixth form Physics textbooks from 1870 to 1980 [5]. Newton chose 14 textbooks for his detailed analysis and a further 21 texts covering narrower areas of Physics. This section will describe a similar analysis of textbooks used in Ireland over the last 160 years.

The significance of textbook characteristics depends of course on the use made of texts. The way in which texts have been used over the last one hundred years has varied. In earlier times in Ireland, a teacher might have had the only textbook in the room, from which he/she taught the students. Then in the early days of free education (1970s) every student had their own book and reading aloud from the book for most of the lesson was widespread. In some pockets of enlightenment, the philosophy of the Nuffield project [54] and its emphasis on active learning meant that the textbook was rarely used. In recent years with textbooks more attractive and impressive than ever, they are less used in classrooms (and more generally used as a reference by students at home), due to the trend towards increased use of computer presentations and other digital media by teachers.

3.1 Use of Mathematics

The work of Archimedes, Ptolemy and Euclid among others attest to the strong link between Physics and Mathematics from early times. Newton perhaps advanced the cause of Physics through Mathematics more substantially than anyone before him. The naming of his great work *Principia Mathematica Philosophiae Naturalis* may be seen as uniting Physics and mathematics [55]. Mathematical expressions help us by providing a numerical shorthand for making concise and precise statements, and mathematical operations are an invaluable aid to reasoning [56]. Mathematics provides a language of communication. Equations express relationships and enable us to calculate unknown quantities [57]. "*The miracle of the appropriateness of the language of mathematics for the formulation of the laws of Physics is a wonderful gift which we neither understand nor deserve*" (Wigner) [58].

Rene Descartes introduced the Cartesian Coordinate System that is named after him. It is the basis for drawing graphs which enable relationships between variables to be visualized. This mathematical skill is widely used throughout Physics and features often in Physics textbooks [56]. The swing of a pendulum does not appear to be mathematical beyond counting the number of oscillations and the time of swing. However, when Physics students take measurements and plot a graph and establish a relationship between the period and the length, the language of mathematics offers an elegant way to represent that relationship by:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where T is the period, l is the length of the pendulum and g is the acceleration due to gravity. The formula can be analysed and used in various ways that expand and deepen the understanding of the pendulum's motion. When the formula is studied, the absence of mass and the small angle approximation can be revealed.

Interestingly, Lardner's textbook [9] Tyndall's three longest tutorials [10, 12] represented experimental Physics with minimal reference to mathematics. Newton observed [5] that from 1900 onwards, Physics textbooks often began with a deductive, mathematical proof and ended with the physical law. The 1971 syllabus made few explicit references to mathematics beyond referring to *proof and use* of several formulae and calculations [22]. The use of mathematics in Physics textbooks for schools in Ireland perhaps reached a peak in the 1960s and 1970s before the Department of Education reduced the emphasis on Higher Level Mathematics which the Syllabus in 2000 says was not required [59]. Furthermore, it was stated that there was no requirement for the use of calculus techniques. Accordingly, Faraday's induced emf being represented elegantly by

$$\mathcal{E} = -\frac{d\phi}{dt}$$

and the law of radioactive decay by:

$$\frac{dN}{dt} = -\lambda \mathrm{N}$$

was often omitted, though school textbooks from earlier decades had included them. In this revised syllabus, the use of electronic calculators was not only permitted, but students were expected to have them [59]. Interestingly, despite this, in 2007 [60] found that there was a perception among Physics teachers and school principals that students believed Physics was a challenging and demanding subject due to the mathematical content.

Prior to 1971, textbooks throughout the 20th century [20, 24-27] included mathematical problems for students to do, and positioned them at the end of the chapter; these often referenced the examination from which they were taken [5]. The provision of worked examples was rare and it seemed that the presumption was that the teacher knew how they might be solved and could show the students if they needed help. Since 1971 a steady increase in the number of worked examples has scaffolded students to solve the exercises of mathematical problems with less dependence on teachers [36-41]. Most contemporary texts contain plenty of worked examples, which help students with questions requiring calculations. In *Real World Physics* [38], for example, chapters are subdivided into sections each of which includes solved problems and similar exercises for students to do.

3.2 Derivations

Derivations are important in Physics because they apply mathematics to an observation or experiment or formula to deduce new information. They produce the mathematical evidence that a law is true. The derivation of the formula for a simple pendulum serves as an example. Deriving an equation is important if students are to appreciate how laws and principles are developed [47]. Given that derivations involve the use of abstract mathematics, the extent to which textbooks included derivations has varied through the years. Some authors and syllabi have placed a strong emphasis on rigour and included many derivations and at other times textbooks have opted to state many results without including detail on their derivation lest the emphasis on mathematics deter students from studying Physics. The tradition of including derivations continued through the work of Wright [14] and the many editions of Stead [16] that were used from the 1920s through to the late 1950s. The derivation of the formula linking refractive index to the angle of minimum deviation by glass prisms that appeared in Ganot [15], carried through successive generations, as if it were a vital pillar of Physics [23-26, 32]. Integral calculus is used in a large number of derivations in [27]. However, the textbooks of the 1970s and 1980s placed a reduced emphasis on derivations in optics like that of the lens formula and the formula for apparent depth. O'Donoghue's derivation of a lens formula showed the extensive use of the geometry of Euclid [24]. These latter examples of derivations disappeared completely from the books published since 2000 [36-41] even though the results and associated experiments and problem solving all continued to be included. In Dan O'Regan's book [38] there are very few derivations of mathematical formulae throughout all topics. The publication of *Formulae and Tables* [61] has shifted the emphasis onto applying formula and away from deriving and proving maths results.

3.3 Demonstrations

Robert Hooke was an early proponent of demonstrations through his work at the Royal Society up until his death in 1703. These demonstrations were to a fee-paying audience and thus had to be clear, clean and easily visible [55]. Beginning around 1720, demonstrations of Newtonian Physics entered the classroom and from the 1750s onwards, electrical demonstrations became popular [55]. Tyndall appreciated the value of a demonstration and made a particular feature of them in his lectures, the notes of which at the time served as school textbooks. Tyndall invested a great deal of time in designing demonstrations for his lectures and he ensured that they had good visibility and audibility [62]. He even encouraged students to make their own electroscope and described how this might be done. Authors of textbooks throughtout the 1900s highlighted the importance and value of practical demonstrations in addition to the use of the textbook [16, 30, 47] and presented them in a manner of showing students what might happen. In the 2000 Syllabus, twenty-four mandatory experiments are listed, along with a list of activites that include demonstrations that it was hoped teachers would do in the classroom. More recently, Featonby [63] recommended a more inquiry-based learning approach to demonstrations whereby students might work in small groups and discuss possible outcomes of a given demonstration. Recent school textbooks have not yet adopted this approach. While the value of demonstrations is widely acknowledged, whether they are done is very much a matter that individual teachers decide when designing their lessons. The needs of the written examination, the availability of relevant equipment and the preparation time required, are all considerations that influence whether demonstrations are done or not.

3.4 Experiments

Many earlier textbooks spoke strongly of the importance of ensuring that students perform experiments. Tyndall's lectures were profusely illustrated with experiments [13]. Wright made the point that the provision of numerical results should not take the place of measurements made by the student [14]. Typically, however, the textbooks did not specify the detail of how the experiments should be done. This is likely out of consideration of the fact that different schools would have had different equipment available, and would need to do the experiment by whatever means their equipment allowed. It may also have been to allow for teacher autonomy. Interestingly, an examiner's report in the 1880s stated disapprovingly that candidates had been prepared solely by reading books and had clearly never seen experiments performed [45]. To address this issue in the early 1900s, the number of schools possessing laboratories increased from 6 to 214 for a capital outlay of approximately £50,000 [45]. While the importance placed on experiments has remained [56], the emphasis on experiments changed from the 1970s onwards. Since then more detailed specific descriptions of experimental procedures were provided in textbooks which enabled students to be self-directed in experimental work. The 1971 syllabus made the point that there should be plentiful use of experiments and desmonstrations [22]. It further stated that experimental work should be integrated with the theoretical concepts as far as possible.

The methods of doing experiments have also changed over time due to the availability of new equipment (for example the use of lasers in optics experiments instead of a ray box using a filament bulb). New safety protocols in 2001 issued by the Minister for Education devoted an entire page to mercury in the classroom [64]. In 2002, the teacher guidelines [47] stated that in a school laboratory, it was appropriate to use mercury-in-glass thermometers as standard thermometers, since they are portable, react quickly, have a suitable range and can be clearly seen. However, by 2011 schools were advised not to use mercury. [65]. This effectively ended the use of the constant-volume gas thermometer and the Toricellian mercury barometer and other standard demonstrations. The 2002 teacher guidelines [47] stated that the careful use of ionising radiation was essential and that it was necessary to be aware when equipment might produce ionising radiation; attention was also drawn to the guidelines issued by the Radiological Protection Institute of Ireland. Then in 2013, schools were told to surrender all radioactive sources [66]. The RPII met with officials from the Department of Educations and Skills who agreed to fund a disposal programme for schools whereby sources were collected by a specialist firm and transported out of Ireland for reuse or recycling.

It is noteworthy that practical work, although emphasized in the syllabus, is not assessed other than by questions in a written examination [67]. Although assessment of practical work has been considered over the years it has so far not been implemented in Ireland.

More recently, Robin Millar [49] prefered not to use the term ‘experiment’ as this was often used to mean the testing of a prior hypothesis. Learning science at the school level is not the discovery or construction of ideas that are new and unknown. Rather it is making what others already know your own. This serves to highlight that the thinking behind best-practice pedagogy continues to evolve over time.

The recent European initiative “Science on Stage” [68] promotes excellence in science teaching and encourages science teachers to share best practice in science teaching. Its style complements Tyndall preference for using household items or commonly available materials.

Virtual laboratories like VPLab [69] and simulations like PhET [70] offer teachers and students attractive and interactive multimedia options for teaching and learning about Physics. These complement the traditional experiments described in textbooks. These and many other online resources may reduce the reliance on textbooks that was prevalent in the past.

3.5 Diagrams

The notebooks of Leonardo Da Vinci are a famous example of how science has for centuries relied on diagrams accompanying text-based explanations. School textbooks have followed in this tradition whether with hand-drawn sketches, black-and-white diagrams, or colour photographs. Often, the quality of the diagrams is a key indicator of the quality of the textbook. Lardner’s book contained many diagrams of machines in operation, that were evocative of the era, and these were explained in terms of principles of Physics. Diagrams in Tyndall's books were hand-drawn in black and white and labelled with letters that enabled the explanation in the text to refer to particular parts of the diagram [10-12]. The Christian Brothers used hand-drawn diagrams in their 1973 textbook [26]. Con O’Donoghue and Adrian Somerfield used black-and-white diagrams in their books in the 1979s [24, 27]. Books from 1984 onwards included some black and white images [30, 32], with just one coloured photo in Collins [32] showing spectra. Modern texts make extensive use of colour. All diagrams are digitally created (as opposed to hand-drawn) and are clearly labelled.

In his analysis of UK textbooks, Newton found that since the 1870s illustrations in texts were common and the picture density, that is, the number of illustrations per thousand words was found to increase linearly from about two per thousand words in the 1870s to three and a half per thousand words a century later [5]. This may reflect an increasing appreciation of the value of illustrations. He also found that in general, within a given text, an increase in simplification of representation and an increase in symbolic complexity went hand in hand.

The process of drawing a diagram is an important skill for students. It often assists in problem solving or contributes to clarity when explaining [71]. Research by Maries and Singh [72] on solving electrostatic problems by introductory Physics students, indicated that students who drew a productive diagram significantly outperformed students who did not. A Free Body Diagram (Figure 3) is often an important starting point for solving a problem [73]. It is commonly used in the study of mechanics and electrostatics. It is a vector diagram with the size and orientation of the arrow reflecting its magnitude and direction respectively. The diagram is a means of setting up equations which are then solved to yield an answer. Diagrams in other subjects rarely have such crucial importance. Ray-diagrams (Figure 4) are often used in the study of optics to describe the phenomena of total internal reflection and apparent depth and are seen throughout most texts studied in this research.

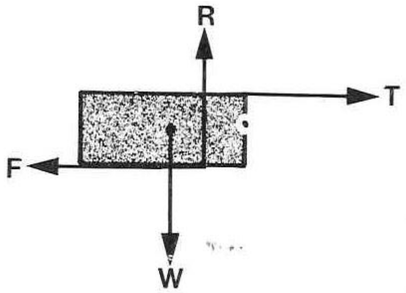

Figure 3: Free body diagram [30]

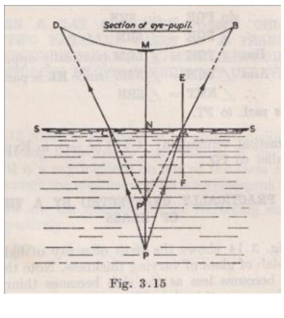

Figure 4: Ray diagram [20]

Bungum [43] reported on how images attract students in a sample of Norwegian Physics textbooks used at upper secondary school level, with the focus on how images invite students into the world of Physics. Bungum reports on the use of *canonical images* (images that form part of the canon of Physics education). Their presence will rarely be questioned, and the visual presentation is often also remarkably stable. Figure 5 shows an example of this stability in time. The image illustrates the repulsion between similarly charged rods. It is remarkable to observe how the entire geometry of the image, not only the content, is reproduced across centuries and publishers.

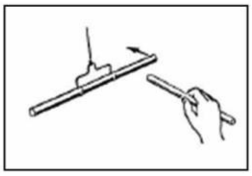

Figure 5: Repulsion of similarly charged rods [43]

3.6 Representation of Women

It is interesting to note that of all the textbooks that have been published for use on the Leaving Certificate syllabus, none have been authored by a female. A recent study of four Irish textbooks published since 2000 revealed that females are drastically under-represented, with women only accounting for between 13% and 28% of characters shown in images throughout [74]. Furthermore, only two female scientists are discussed compared to 91 references made to male scientists. In the textbooks analysed, frequent reference is made to male Irish scientist Robert Boyle. There is a notable absence of references to noteworthy female Irish scientists such as Sheila Tinney (a mathematician and theoretical physicist) [75], Dr Anne Kernan (involved in discovery of W and Z bosons in CERN) [76] and Dr Margaret Murnane (who designed the first laser that pulses in the range of femto-seconds) [77]. Interestingly, the preface of the very earliest textbook studied as part of this analysis includes the statemet “It may be hoped that this volume may be the means of extending instruction in the first notions of Physics into Ladies’ Schools” [9]. The Department of Education implemented a series of intervention projects in Physics from 1985 onwards towards improving the ratio of girls to boys sitting Leaving Certificate Physics [78] but although these have continued to the present day, only a quarter of those who sat Physics in the Leaving Certificate examination in 2019 were female [46]. The authors explored the representation of other minority groups (such as Black Irish and Asian Irish Physicists), and essentially found that they were not represented in these textbooks.

3.7 History and Applications

It has always seemed proper to acknowledge who it was that discovered something new. Throughout Physics textbooks names like Galileo and Newton are mentioned alongside their discoveries and this has often led to the inclusion of references to some of their other discoveries. This leads naturally to the possibility of a mini-biography and to some historical context being included. Teachers have often found that students take a measure of interest in a Physics concept when they know a little about the person behind it. Most Physics textbooks have historical references but to different extents.

Over the years, applications of Physics have gone in and out of fashion with examiners and textbooks have responded accordingly. Some purists might advocate for Physics courses being a quest for better understanding of the physical world and see applications as something for engineers, or an optional extra. Nevertheless, many would feel that being made aware of the usefulness of Physics concepts is motivational for students and gives a rounded appreciation of Physics. In some textbooks mention is made of applications as the concepts are explained and in other textbooks the applications are treated separately and more substantially.

4. A trio of textbooks by Casserly and Horgan

The case of Casserly and Horgan is interesting because they produced three different textbooks, in 1981 [29], 1984 [33] and 2000 [36] to meet the needs of three successive syllabi (Figure 6). Their books are characterized by having a very clear presentation style with diagrams that are realistic and yet readily reproducible by students in an examination. In each case they present the topic of Light ahead of Mechanics to allow the student’s mathematics to reach the standard required for dealing with the mechanics section. In 1981, *Physics – A Basic Course* [29] covered the course with the emphasis on simplification. It might nowadays be considered closer to a revision guide than a textbook. In line with the other textbooks of the period, calculus was used in several sections and in the topic of radioactivity, the half-life formula was deduced from a differential equation, representing the law of radioactive decay. Experiments were described and exercises included with some worked examples. There were very few historical references and little mention of practical applications.

Fundamental Physics [33] comprehensively covered the new syllabus with a dramatically enhanced presentation style. It had clarity and style despite not making use of colour or photographs, both of which were possible at the time. It placed a greater emphasis on experiments and included far more substantial exercises for students to do. Its layout is exceptionally clear and nearly 40 years later it has a freshness and appeal that more recent and more colourful books struggle to match. In 1990, *Fundamental Physics Revised Edition* [35] presented essentially the same material, but adopted a different page layout. At the end of each chapter short summaries and mini-biographies were included and some extra questions were added to the exercises.

Physics Now [36] responded to the significant focus of the new syllabus on Science, Technology and Society (STS). Accordingly, the relevance of Physics to the world around us is highlighted throughout. Many practical applications are explained and well illustrated. Short biographical pieces accompany many sections. Some photographs are included in the book and a modest amount of colour is used in a helpful manner. Overall, it is a little less mathematical in appearance (though the exercises offer plenty of opportunity). The experiments are set out more clearly with greater detail on the steps to be taken and some questions to encourage students to think about reasons for their actions and possible sources of error. Helpful summaries are included at the end of chapters.

Casserly and Horgan presented Physics very clearly and adapted well to changing times. Yet they were never market leaders in a competitive textbook market. The factors that influence choice of textbook are beyond the scope of this enquiry.

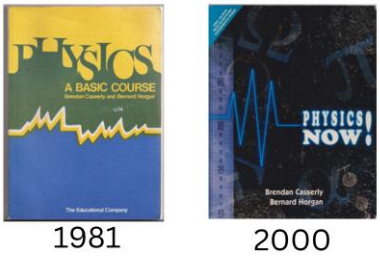

Figure 6: Textbooks by Casserly and Horgan

5. Case Studies

A Physics concept (refraction) and a Physics instrument (electroscope) were chosen for special attention, so that the findings would be firmly rooted in how Physics has been represented in textbooks rather than general textbook publishing trends.

5.1 The Electroscope: an instrument for demonstrating electrostatics

Electricity had a slow start. The ancient Greeks knew that when amber was rubbed with a cloth it attracted light objects. Two thousand years passed before Benjamin Franklin recognized the electrical nature of lightning in 1752. In the 1860s Lardner [9] and Tyndall [10] saw electrostatics as a curiosity that made for some interesting demonstrations. The gold leaves of electroscopes diverged as though by magic when certain objects were presented, and the electroscope was seen as useful for detecting the presence of charge and estimating how much. They described the structure of an electroscope — a feature that remained in textbooks all the way to the present day [15, 16, 26, 30-33, 37, 38]. They descibed how electroscopes may be deployed in testing materials to see if they conduct electricity or not — a feature that has remained in more recent textbooks [29-33]. They both focused on the differences between charging by conduction and by induction, again a feature that has remained in textbooks to the present day [11, 16, 23, 25, 42, 43, 49, 56]. Induction was seen as temporary by Lardner and Tyndall [9-11] if earthing is included in the process. Larnder talked of the gold leaves giving up their electricity when communicating with the ground [9]. Earthing was again mentioned by Ganot and Stead with the acknowledgement that the human body is a conductor [15, 16].

Both Lardner and Tyndall [9-11] talked of an object being electrified by friction rather than charged, although neither described what was going on in terms of positive and negative charges. The evolution in understanding of the structure of the atom has allowed for explanations in terms of the movement of positive and negative charges. Ganot [15] references this phenomenon when describing a lantern projection (rendering the leaves visible from a distance). He described the electroscope as being used for indicating differences of potential; a new way of descibing the behaviour, used later by several authors [29-33].

Stead [16] referred to the electroscope's use to detect beta and gamma rays from radioactive substances. This important application came too late for Lardner [9] and Tyndall [10, 11] and is rarely mentioned in the modern era.

For the first time in the 1970s, the use of an electroscope in Faraday's ice-pail experiment and its significance were explained [26]. This also appered later in the 1980s in [29, 31-33].

For the first time in the 1970s, emphasis was placed on how an increase in divergence of leaves in an Electroscope may be a useful indicator of the size of charge in a way that convergence is not [26]; a feature that continued into the books of the 1980s [29-33]. Uniquely, Somerfield [27] offered an explanation for the divering leaves in terms of potential gradient, and that positive charges want to move down the potential gradient and negative charges want to move up.

For the first time, in the 1970s, O'Donoghue [25] mentions that an Electroscope may be used to demonstrate *point action*. Step-by-step explanations in terms of the motion of charges under the influence of forces of attraction or repulsion are given for all. Specific mention of electrons moving is used in the explanations. It also mentions the use of a pear-shaped conductor for the first time, which is later mentioned by [29-33].

In 2000, Henly [37] and O'Regan [38] the addition of colour to the diagrams features for the first time and in 2014, Tierney [41] adds photographs in support of the colour diagrams. Carolan [40] shows the electroscope in use in conjunction with a Van de Graaff generator to show that charge resides on the outside of a hollow conductor and also accumulates at a point.

While the electroscope is most often represented as an instrument used to test for the presence of charge, the fact that ionising radiation discharges electroscopes proved of great practical benefit to Marie Curie. That this humble instrument could be of use in research that led to a Nobel prize might be expected to have received more attention than we found in the textbooks since that time.

Overall, the structure of this electrical device has changed little over time but the explanation for what is going on when the leaves diverge has varied considerably. While some prefer to explain its operation in terms of charge, others find an explanation in terms of electrostatic potential more satisfying. The emphasis given to charging by induction may puzzle many students, but teachers might feel that their wrestling with how and why charges move may benefit them in the study of current electricity. Its initial curiosity value in Victorian times has been supplanted by its value in laying a foundation for understanding modern electricity.

5.2 Refraction of light

Refraction of light has received significant attention in Physics textbooks throughout the years. The sources of light used have changed radically, from candles to filament bulbs and now lasers. In contrast, water and glass continue to remain popular as media. In most cases the laws of refraction are outlined and this introduces the term refractive index, n. Measurement of n then receives attention as do the concepts of *apparent depth* and *total internal reflection*. Refraction of light by prisms and lenses leads onwards to applications in many optical instruments. The same novel examples of refraction used in the 1860s (mirage, etc) continue to fascinate up to the present day.

Lardner [9] gave relatively little attention to the concept of refraction before progressing to look at lenses and instruments which use them, to which he gave plenty of attention. Tyndall [10] on the other hand dealt at length with refraction. He introduced refraction with light passing from air into water, a tradition continued by others[14-16, 31-33]. Quite elaborate apparatus was used to enable the change of direction of light to be observable. Diagrams of this apparatus paved the way for Tyndall's [10] explanation in which he patiently introduces the concept of the sine function from Trigonometry and the concept of mathematical ratios. Years later, Wright [14] and Ganot [15] describe variations of specialist apparatus for displaying the light changing direction and represented them in neat black and white ray diagrams. All three noted [10, 14, 15] that the ratio of the sines of the angles of incidence and refraction is constant for a particular pair of substances.

In the 1600s, Fermat proposed the principle of least time and the entire subject of geometrical optics is governed by the fact that light will choose the quickest route. [79] Lardner and Tyndall both referred to the fact that when light is refracted on its passage through successive media, it accomplishes its transit in the least time. Surprisingly, we found that this illuminating truth received little emphasis in most of the books since their time. Stead [16] outlines how the refraction of light may be accounted for by the fact that light travels more slowly in denser media. Thus Snell's law may be extended to say that the refractive index is equal to the ratio of the speeds in the two boundary media. Stead [16] outlines how the explanation of refraction by the wave theory of light ultimately closed the chapter on Newton's corpuscular theory. Textbooks for many decades followed Stead's approach and emphasized the historical wave-particle controversy of light.

Physics offers a rich blend of experimental and theoretical approaches and this is especially evident in optics, and refraction of light serves as a good example of this. O'Brien [20] devotes 45 pages in Chapter 3 of his book to refraction of light with a strong emphasis on geometric proof of each variation of conditions. Refraction of light has offered students plenty of opportunity to use their skill in geometry, since Ganot showed how to derive a formula relating the refractive index of the glass of a triangular prism to both its refracting angle and the angle of minimum deviation. This derivation continued to be prominent in textbooks for nearly a century.

Textbooks in the 1970s [24, 26, 27] continued to use a lot of mathematics to derive some results and prove others. Exercises for students were included on a far greater scale than in books used in preceding years. Plenty of good black and white ray diagrams were also used.

Textbooks from 1984 to 2000 [30-33] had a reduced emphasis on mathematical derivation and proof, and less reliance on geometry. Derivation of the formula linking μ and the angle of minimum deviation of light by a prism was dropped. In this period there was an increased emphasis on experiment. An experiment to determine n for water by the method of apparent depth was added, as were experiments verifying Snell's law and measuring the focal length of a convex lens. Also included was mention of fibre optics and its applications. It is worthy of note that one of Tyndall's most celebrated demonstrations was that in which he guided a light beam through a falling stream of water. This demonstrated the phenomenon known as *total internal reflection* which was a curiosity then, but is very significant today because it forms the basis of all modern fibre-optic communication.

Textbooks from 2000 [36-41] to the present, have reduced further the emphasis on derivation and promoted the use of problem solving with formulae that are given. They have given greater attention to applications including details of the human eye and sight defects. Experiments involving refraction are descibed. Ray diagrams receive quite an amount of emphasis, but telescopes and microscopes, once popular, are no longer receiving attention.

Throughout the period covered by this research, many authors offer the following favourite examples of refraction: water always appears shallower than it is [10, 14, 15], a straight stick partly under water appears bent [10, 14-16, 26], a coin in a basin appearing when water is added [10, 14, 15, 33], the sun and stars are visible to us even when below the horizon [10, 15, 24], a star appears higher in the heavens that it really is and twinkling is caused by refraction [14, 15, 24], mirage in a desert [10, 14, 15, 30, 33, 37] which is in part due to continual refraction by the atmosphere, optical fibres [30, 32, 33, 37].

Typically, authors have used a similar sequence whereby they explain critical angle [10, 14, 15, 20, 24, 30, 32, 33, 37] and move on to total internal reflection [10, 14-16, 20, 24, 26, 30, 33, 37] and, onwards to glass prisms [10, 14, 15, 30], lenses [10, 14-16, 26, 30, 32, 33, 37] and the eye.

Conclusions

This research studied Physics textbooks used in an Irish context over the past 160 years and looked also at the influence of two Irish Physicists, Tyndall, and Lardner at a formative stage of Physics as a school subject. Given that Physics is both experimental and theoretical, it lends itself to multimodal forms of presentation. The special nature of Physics requires that diagrams are widely used to clarify the meaning of the text and that mathematics is extensively used to express relationships succinctly and to assist in logical deductions. Our research has shown that the use of diagrams has always played a significant role whether in clarifying the concepts described verbally or in conjunction with mathematics to establish results or solve problems. The number of diagrams has generally increased over time and the style of diagrams has been helped by advances in printing and the availability of colour. Digital photography has greatly enhanced the visual presentation of Physics.

Lardner's influence on later textbooks was particularly evident in relation to diagrams. His book was one of the earliest used in schools and he set a very high standard in terms of the number and quality of diagrams that were included. In general, most subsequent authors followed this approach. Tyndall placed great emphasis on the value of demonstrations in his teaching and this approach has been adopted in most textbooks since his time which describe how various physics ideas may be demonstrated.

We found that diagrams have been widely and abundantly used in most textbooks to enhance the communication where the visual representation complements the written word. However, where mathematics was used in problem solving or for derivations, diagrams often played a crucial part (not just a complementary role).

We found that while mathematics is a valuable tool in physics and an elegant language of expression it has been viewed by some as an impediment to some students' engagement with physics particularly if they were not well-versed with mathematical language. Accordingly, it was little used by Tyndall, but usage increased for many decades and has reduced in recent times to make physics more inclusive for all. The use of mathematics has expanded in terms of *worked examples* and exercises. A strong emphasis was found on experiment and demonstration throughout, but formerly with minimal detail, then latterly with a blend of scaffolded learning and investigative perspective.

Historical references and applications have varied over time, influenced by the perspective of authors and by the emphasis inherent in the syllabus of the day (and trends in the associated examinations).

The concept of refraction and the basic nature of the instrument known as an electroscope have remained remarkably stable components of physics textbooks throughout the period studied. Since neither is a pillar on which the subject is supported, it may seem surprising that they are present throughout when so many other ideas have come and gone or waned in importance. The evolution in understanding of Physics led to different approaches being taken in the explanations provided and in the array of applications described. It was notable in both cases that the canon of examples shows a great deal of consistency over time. We found little evidence that Fermat's elegant principle of *least time* found the emphasis it deserved in the treatment of refraction. The benefit to the later study of electricity, of exploring why the gold leaves of an electroscope diverge was not revealed to students in the textbooks we examined.

Overall, there seemed to be a shift towards making textbooks more effective and attractive as resources for self-directed learning by students rather than as an aid to teachers in giving instruction. Although many attractive variations in pedagogical style have emerged in recent times, textbooks are likely to fulfil an important (even if diminished) role in the years ahead. Suggestions for teachers on what to look for when choosing a new textbook include clarity of presentation, quality of diagrams, appropriateness of use of mathematics, suitability of exercises and worked examples, degree of detail of experiments, the relevance of the applications, the inclusion of attractive demonstrations and historical asides, and attention to gender balance and inclusively. These suggestions would also be useful to potential future authors of Physics textbooks. Physics needs the perspective of female authors which has not yet happened in Ireland. Future authors also ought to decide on whether their book would be primarily a teaching tool or a resource for students for self-directed learning. Finally, this paper highlights the clear benefit in retaining vintage textbooks as a useful resource for teaching and learning.

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