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Michele Mele, Gennaro Sicignano

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Saunderson's Tactile Table: the story of a pioneering educational device

Michele Mele
Department of Engineering, University of Sannio, Benevento
E-mail: mmele@unisannio.it

Gennaro Sicignano
SINAPSI Centre, University of Naples Federico II, Naples
E-mail: gennaro.sicignano@unina.it

Sommario: *Oggi le persone con patologie della vista possono contare su molte soluzioni tecnologiche, come display Braille e sintesi vocali, per avere accesso a contenuti matematici. Tuttavia, la storia della didattica della matematica per I non vedenti prese il via da una figura spesso sottovalutata e da una delle sue invenzioni, Nicholas Saunderson (1682-1739) e la sua tavola tattile per l'aritmetica. Progettata nel tardo XVII secolo, la tavola fu il primo strumento mai ideato per divulgare concetti matematici alle persone con patologie della vista; non fu soltanto un valido supporto per il suo inventore, ma ispirò anche la creazione di altri dispositivi ancora oggi in uso.*

Abstract: *Today people with low or no sight can rely on a number of different technological solutions for accessing mathematical contents, such as Braille displays and screen readers. However, the history of mathematical education for the blind actually started with an often underrated figure and one of his inventions, namely Nicholas Saunderson (1682-1739) and his table of palpable arithmetic. Designed in the late 17th century, it is the earliest tool to convey mathematical contents to students with low or no sight; it not only provided a much needed support for its creator, but also inspired other devices, some of which are still common nowadays.*

Introduction

According to the World Health Organization, about 3% of the world's population has some form of visual impairment; about three quarters of them are partially sighted, whilst some 25% of them are totally blind ([29]). Many students with low or no sight, particularly those from the countries in which schools for the blind are not considered a mere support, but an inevitable surrogate for standard school paths, cannot access quality mathematical education. Sadly, they often choose to exclude this subject from their school curricula, thus renouncing to the most complete instrument to analyse and understand our reality ([4], [6], [12], [20]).

In the vast majority of cases, they lament a lack of specific preparation from their teachers and the need for more adequate methods, texts, and materials. School books are generally designed for students with full vision, they are often based on a very visual approach and frequently refer to figures and graphs; so even the way teachers are used to convey mathematical concepts in the classrooms is often misleading, unclear and ambiguous to the students who can only rely on hearing ([5], [6], [24], [26]). Moreover, many of them completely ignore powerful and effective solutions, e. g. only 10% of teachers are aware of the problem of ambiguity in spoken mathematics and of the existence of MathSpeak ([14]). This is why, still in the 21^{st} century, the issue of accessible mathematics is central to the creation of a more inclusive environment and the individuation of, old and new, general and personalized, strategies to

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overcome visual impairment, particularly in the early school years, is a key point our education systems must focus on. No evolved society can afford to push aside this minority group, one of the most diversified, and to keep it away from mathematics and its sister subjects, e. g. physics, Information technology, economics, etc.

The difficulties faced by blind or visually impaired individuals in studying mathematics can be attributed to several aspects. First of all, mathematics relies on symbolism and on a representation that is primarily visual. The first steps to get acquainted with this subject in the early school years is basic arithmetic; so it is important to notice that the representation of numbers is essentially a coding of visual symbols. To get these contents accessible to the students with low or no sight, one must make sure they can navigate and manipulate these objects and the more intricate algebraic formulas, even in the more complex case of fractions, in which one can move in two different dimensions.

The learning of mathematics is strictly related to the ability to navigate and manipulate formulas and expressions, but it is clear that a blind or a visually impaired person cannot only rely on memorization to really succeed in this task. A significant point is that mathematics is intrinsically abstract; thus, by finding a vector of meaning different from the traditional and purely visual one, nothing prevents a blind or visually impaired person from grasping its concepts and applying them according to different needs, interests or inclinations, from simple everyday activities to study and research. The information vector, compared to the traditional written symbol, must possess an additional attribute: it should be accessible through the tactile channel while maintaining the characteristics of uniqueness, perceptibility, comprehensibility, and non-ambiguity found in the traditional visual symbol-based approach.

Moreover, using only the auditory channel can lead to further problems because of the often underrated burden of ambiguity in spoken mathematics ([14]). This is why it is necessary to apply a coding system that is simultaneously simple to learn and use, and yet direct and effective, allowing to convey concepts through the tactile channel while respecting the aforementioned constraints. It is fascinating to notice that Nicholas Saunderson's approach in creating his tool perfectly fits these guidelines and effectively layed the groundwork for more modern systems, from the cubarithm to dactylorhythmic methods, a process that culminated in contemporary Braille displays, in the so-called 8-dots Braille and other tools based on the creation of some form of alternative coding.

The winding road to equitable and inclusive mathematical education might be still long to go, but the last decades have surely seen a progress, both with the introduction of new and more effective teaching methodologies and with the creation of advanced technologies ([2], [3], [5], [14], [15], [17], [24]]). It is worth noticing that some of these solutions are direct descendants of Saunderson's tactile table, this makes this pioneering device an important milestone for mathematical education and a good source of inspiration for modern researchers and practitioners. The figure of Nicholas Saunderson (1682-1739), a self-taught English mathematician who managed to obtain the most prestigious chair in the mathematical world, is indeed a key passage in the history of mathematical education of the blind; it also constitutes an unmistakable proof of the absurdity of the prejudice that still discourages many students with low or no sight from following a scientific career.

Biography of Nicholas Saunderson

Nicholas Saunderson was born in Thurlstone, a small village in South Yorkshire, and was baptized on 20 January 1682 ([25] [28]). His father John was an exciseman, a tax collector, for the British government and had a profound impact on his elder son's life. Young Nicholas contracted smallpox at the age of twelve months; at that time, the disease was one of the most common reasons of blindness and the child's eyes fell victim to this implacable burden ([25], [28]). However, an intuition by an otherwise historically irrelevant exciseman changed the course of science.

John used to take his son to Penistone, an ancient town a few miles from Thurlstone, and precisely to the graveyard that surrounds the medieval St. John the Baptist Church. From the age of two, young

FIGURA 1 – The portrait of Prof. Nicholas Saunderson by English artist John Vanderbank.

Nicholas Saunderson learned the alphabet thanks to the tactile exploration of the inscriptions on the monuments, showing incredible speed in the memorization process ([1] [25] [28]). This act of trust in the child's ability played a crucial role in the development of a rational understanding of disability, it swept away every form of pietism and self-commiseration in the youngster, paving the way for a bright future.

Nicholas Saunderson attended Penistone Free School, gaining a good knowledge of Greek and Latin classics, becoming fluent in French language and studying music on the flute with decent results ([25] [28]). Being totally blind, he needed someone to read texts for him; he had some important private teachers, including Dr. John Nettleton, an important medicine expert born in Halifax and based in Sheffield, and Richard West, Esquire of Underbank and member of the British parliament ([11] 13]).

During his youth, in particular during the 1690s, prior to his university years and claim to fame, he designed the first tool to transpose calculations in tactile form, a device that John Colson called "The palpable arithmetic" and that became also known as Saunderson's Tactile Table ([10] [25] [28]). Even if its inventor did not publicize it, this ingenious tool represented a milestone in the development of accessible ways to convey scientific culture and was the main source of inspiration for future attempts to make mathematics available through the sense of touch.

It was on the tactile table that Nicholas Saunderson performed intricate calculations, even to help his father in this latter's work, and it was on this device that he gained full mastery of some branches of mathematics, not only arithmetic, but also algebra and geometry. In fact, he also created a version of the tactile table to represent geometrical figures ([10] [28]), as explained in the next section. After a brief period of study at Attercliffe academy, an institution he abandoned because of its old-fashioned way to present mathematics and logics, Saunderson proceeded in his studies by himself, acquiring more knowledge through the readings of others, but developing his own style and taste , eventually becoming an enthusiast of Isaac Newton's work ([13]).

In 1707, he moved to Cambridge, where he wanted not to be a student, but to teach his beloved subject. The University of Cambridge showed great inclusion spirit, this historical institution did not concentrate on his blindness, but on his mathematical talent, and accepted Nicholas Saunderson in its ranks, allowing him to give lectures and to tutor students in mathematics and physics ([25] [28]). He was given access to the university library and an apartment at Christ's College. He became a member of the so-called Newtonian school of mathematics and Physics, together with renowned scientists such as Roger Coates, Robert Smith and William Whiston ([25] [28]).

This latter was, at that time, Lucasian professor at Cambridge, the most prestigious academic role for a mathematician, but he was also a famous translator, astronomer, philosopher and theologian ([14]). He played a crucial role in the acceptance of Nicholas Saunderson at Cambridge and spent many hours reading for him. When Whiston was eventually removed from his chair following a scandal arising from some of his theological publications, Saunderson was designated as his natural successor ([21] [25] [27] [28]). After receiving a mandatory degree, in 1711 he was appointed as the new Lucasian professor of the University of Cambridge, a role he kept until his death on 19 April 1739 ([10] [25] [28]).

In 1714 he was nominated in the commission that had to indicate the winner of the prestigious Longitude Prize, a collective which also included great names such as Isaac Newton and Edmund Halley, and he became a member of the Royal Society of London in 1719 ([11] [13]). He published two posthumous books, both with a preface by mathematician John Colson, a close friend of Saunderson's and his successor on the Lucasian chair, in which he presented both original works, including a first formulation of the inverse of the Bayes formula, and elements of the Newtonian method of fluxions, infinite series, algebra, number theory and more [22] [23]). These publications were instrumental for the education of many scientists in the 18th century, including science and technology pioneers such as Henry Cavendish and John Harrison, and constituted part of the compulsory readings for every Cambridge fellow ([1]).

The Tactile Table

The idea of teaching to the blind and the visually impaired through the sense of touch had been already brought forward by some figures of the Renaissance era, including William Caxton and Gerolamo Cardano ([7] [13]). Nicholas Saunderson took the first steps towards this goal, at least as far as mathematics is concerned, with the creation of his famous tool. He devised the table of tactile arithmetic sometime during the 1690s, we don't have clear indications on an exact date for this event, but sources indicate that he rapidly became very efficient on this new instrument ([10] [28]).

The table was designed as follows. It was a wooden table with the shape of a square, similar to a chessboard, having dimensions of approximatively one foot and divided in 100 smaller squares (digit squares) by thin wooden stripes on one of its surfaces. Those lines were then recognizable under the fingertips and constituted the main structure of the tool. Each one of the digit squares had nine holes in it, arranged in a 3 for 3 grid, just like in the tic-tac-toe field ([10] [13]).

Saunderson's idea was basically to reproduce the decimal representation of numbers on the table's rows, putting, from right to left, the units, the tenths, the hundreds and so on, in the digit squares of a single row to code a number. Hence, he created a simple, unique and non-ambiguous way to code digits from 0 to 9 with the use of two sets of pins which differed only for the dimension of their heads, thus distinguishable by the sense of touch. The use of pins inserted into the holes allowed him to touch the table to read the numbers without altering the representation ([10]).

He represented 0 by a large headed pin in the middle hole of the 3 for 3 grid, i. e. in the central hole of the middle line, 1 by a small headed pin in the middle hole, 2 by a large headed pin in the middle hole and a small headed pin just above it, i. e. in the central hole of the upper line. All the other digits were coded starting from the representation of 2 and moving the small headed pin clockwise. For example, 3 was represented by a large headed one in the middle hole of the grid and one in the top right corner; whilst five was represented by a large headed one in the middle hole and a small headed one in the bottom right corner ([10] [25] [28]).

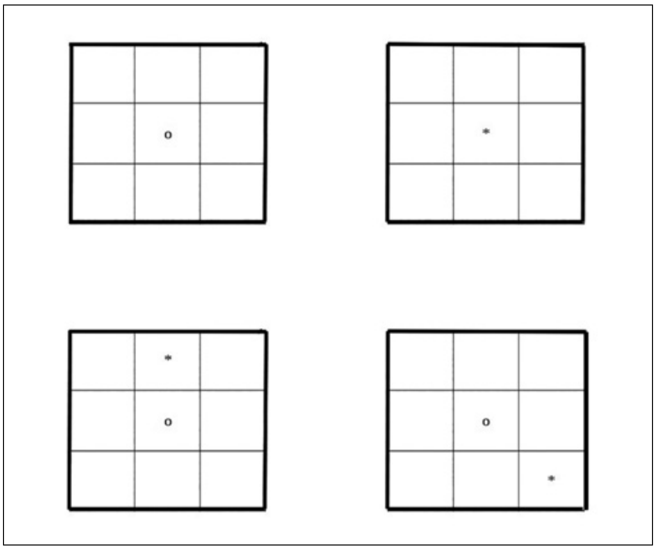

FIGURA 2 – The digit square coding of 0 (top left), 1 (top right), 2 (bottom left) and 5 (bottom right) A large headed pin is represented by a circle, whilst a small headed pin is represented by a star.

One could think that there is a more immediate way of coding digits, the one that represents 0 by an empty digit square, 1 by just one pin, 2 by two pins and so on. However, this method is not the most efficient when it comes to explore the table with the fingertips. For example, with this alternative method, the coding of 1.000.000 would include a long sequence of consecutive empty digit squares; this is time consuming and not very helpful for a blind person who needed to quickly explore rows from right to left, as it was required to execute basic operations and, most of all, to read the number at ease. This is probably the reason why the future Lucasian professor chose to use two sets of pins and adopted the coding method presented above.

Saunderson could perform complex computations on the tactile table, coding numbers on rows and lining up digits on columns. It is not clear if he also used to note operations on the table, sources do not explicitly answer this question, but he could have either use the most left column on the table, having already established a code to represent operations such as addition, multiplication and division, or just keep them in his mind. His memory and his dexterity on his own device were indeed remarkable; it has been reported that he could restart performing his intricate calculations on the tactile table with no hesitation or mistake, even after long pauses or being interrupted whilst at work ([11] [28]).

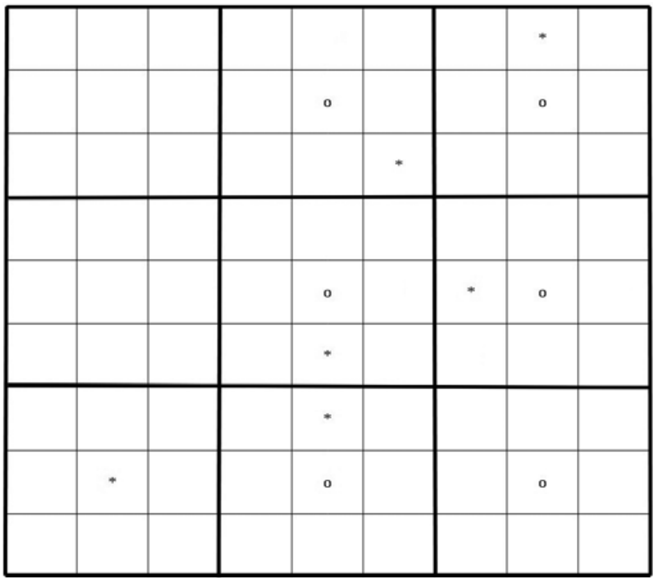

FIGURA 3 – In the corner created by the intersection of the top three rows and the most right three columns of Saunderson's tactile table, the operation $52 + 68 = 120$.

The creation of a tactile table for geometry is also attested during his youth. This latter tool was structured similarly to its equivalent for arithmetic, with holes arranged in a grid pattern that covered the whole table. However, in this case he used to represent geometrical figures inserting pins in the holes and tending thin silk threads through their heads to reproduce line and segments in a tactile way ([10] [13]).

Other devices descending from Saunderson's tactile table

For decades, Saunderson's tactile table has been the only way blind people could approach mathematics through the sense of touch. Its importance does not limit to the fact it was the first tool to convey mathematical contents to people with low or no sight, it also inspired other inventions with the same goal.

During the 1770s, Henry Moyes, a lecturer in chemistry at the University of Manchester, constructed a similar device, a sort of extension of Saunderson's tactile table that needed pins with three different kind of heads and a total of 576 squares arranged in a 24 for 24 grid. He also provided a coding for basic operations to be represented in the most left column of the device. Just like his illustrious predecessor, Moyes did not publicize his creation and kept it for his own use until 1788, when it was the subject of an entry in the British encyclopedia dedicated to the blind ([18]).

Whilst working at the Yorkshire School for the Blind between 1836 and 1883, Reverend William Taylor developed his "ciphering tablet", now more widely known as the Taylor Slate [13]))]. It consisted of a rectangular aluminium typing frame, 432 octagonal cells are stamped on the top in a 18 for 24 grid, with a recessed compartment at one end for holding the extra type when the frame is in use. The top part is riveted and braised into the frame, a black treated canvas or paper is often located between the top part and the base to serve as a sound buffer. Just as in the Saunderson's table, the cells can be filled with polyhedral type pieceswith Braille inscriptions to represent digits and operations; these are generally of a bright yellow plastic, so to help visually impaired people who need a marked contrast of colours. The

Taylor slate is still in use in some countries, in particular it is quite common in English speaking States and southern Asia nations like India and Bangladesh ([9], [16], [19], [26]).

Another device designed for teaching mathematics to people with low or no sight is the cubarithm, also known as cubarithm slate or cubarithm board. It was invented in 1886 by Alphonse Oury, a blind piano maker and former student of the Institute National des Jeunes Aveugles of Paris, and consists of a board with square cells in which wooden or plastic cubes could be inserted. Each cube had Braille dots embossed on each face, so nineteen different symbols, digits and operations, could be represented. Numbers can be coded, just as in the case of Saunderson's tactile table, on the grid rows with digits lined up on columns ([3]). There are clear similarities between the Cubarithm and the Taylor slate: both rely on the juxtaposition of objects into cells; the cubarithm is easier to get familiar with, but Taylor's device has many more cells and allows more complex computations. The cubarithm is still today relevant to the early mathematical education of people with low or no sight and has been even the starting point for researches to create digital devices with the same goal ([3] [17]). Unlike the Taylor slate, probably for its simplicity and affordability, it is not only common in the English speaking world, but also in other countries such as France, Italy and Brazil ([8], [13]).

Despite their differences, the Taylor Slate, the cubarithm and Moyes' device are clearly direct descendants of Saunderson's tactile table; they were all designed to convey mathematical contents through the sense of touch and achieve this goal through a form of coding of numbers in cells and frames. Even the more recent 8-dots Braille method is an offspring of Saunderson's intuition, it clearly applies a form of alternative coding, different from the traditional and visual one, but it does not use the same cells pattern, allowing to embed formulas inside a written Braille text.

Conclusions

The life of Nicholas Saunderson is the proof that people with low or no sight can be extremely proficient in mathematics and that they can choose a scientific career; his achievements demonstrate the absurdity of stereotypes and mark a significant case of study in the history of mathematics. The tactile tables he invented are a remarkable result of his dauntless mind, a milestone in the development of the techniques to teach mathematics to blind and visually impaired people through the sense of touch.

Surprisingly, many games and devices to convey mathematical contents to children, especially in the English speaking world, were inspired by the Taylor slate and by Saunderson's tools; hence, in the last century, many people have first discovered the basic notions of quantity, shapes, numbers and operations through a device that, in its original form, was conceived specifically for people with low or no sight. This is the demonstration that inclusion processes not only improve the lives of individuals belonging to a minority groups, but the whole community benefits from their effects.

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Michele Mele

Laureatosi in Matematica presso l'Università degli Studi di Salerno, Michele Mele ha conseguito un dottorato di ricerca in Scienze Matematiche e Informatiche all'Università di Napoli 'Federico II'. Attualmente svolge attività di ricerca su problemi di Ottimizzazione Combinatoria e su temi di Didattica della Matematica presso il Dipartimento di Ingegneria dell'Università degli Studi del Sannio. Per i suoi risultati e la sua attività di divulgazione è stato insignito del titolo di Cavaliere dell'Ordine al Merito della Repubblica Italiana dal Presidente Sergio Mattarella.

Gennaro Sicignano

Gennaro Sicignano, ingegnere elettronico e dottore di ricerca in Metodologie di analisi e progettazione di sistemi per l'E-sanità, si occupa da più di 20 anni di accessibilità digitale e inclusione, in particolare in ambito universitario. Attualmente inquadrato nell'area delle Elevate Professionalità presso l'Università degli Studi di Napoli Federico II.