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Recollections and reflections relating to the educational potential of the Bush Differential Analyzer (d.a.)

This brief essay is intended to provide some background to what is essentially a new approach to the teaching of the calculus, notably differential equations, to engineering students. Traditionally, certainly in schools and institutes of higher education, the subject has been taught by mathematicians with minimal interest in real life applications. Consequently many students in the applied sciences have had difficulty in appreciating the tremendous relevance of the subject. They have been indoctrinated in the conceptual, albeit beautiful, language of mathematics without really understanding its power.

The ideas I shall portray were first outlined by Dr Vannevar Bush at MIT, who as early as 1931 suggested that the machine could be valuable in education as well as research. The important fact is that the machine can be regarded as a mechanical dynamic model of a system or process. In operation the behaviour of the system variables, (e.g. position, temperature, voltage, etc) under varying circumstances can actually be seen. And most importantly the relationships between them thereby providing insight and perspective. In other words the process of solving a differential equation can actually be observed. For the majority of students this must be much more desirable than the manipulation of mathematical symbols and procedures. I, personally, as described below, have experienced, on many occasions, the sheer excitement of watching the differential analyzer in action, Calculus in motion!

But I believe even more basically that the differential analyzer is today essentially an art form. It is a bridging technology. It epitomizes the fact that metaphor and model are conceptually equivalent.

My involvement began in October 1933 when I had the good fortune to meet Professor Douglas Hartree at the University of Manchester. I was in my final year as a student in the Honours School of Physics, Hartree was Professor of Applied Mathematics. What was, in retrospect, so significant about our meeting was the fact that Hartree had recently visited Dr. Bush at MIT with the express purpose of familiarizing himself with the differential analyzer. His enthusiasm was compelling, and he had already envisaged building a model of the machine using "Meccano" components. Would I be interested in such a project? At the time it was improbable that such an activity would enhance my aim to become a high school physics teacher, but within a minute or two I quickly changed my mind. Subsequently, Hartree became my teacher, mentor and lifelong friend.

The first integrator and the output table were operating by the end of 1933 and demonstrated the viability of Hartree's idea. Indeed the exponential curves resulting from the solution of $dx/dt = \pm kx$ were beyond expectations. We were encouraged to proceed and a 3-integrator model was operational in March 1934. Incidentally the only challenging problem was building the small torque amplifiers to ensure minimum "slip" between integrating wheel and disc.

The next few months were some of the most exciting of my life. The model was used to solve, albeit roughly, the Hartree self-consistent field equations, (approximations of Shrodinger's equation), for the atoms of Hydrogen and Chromium. We were thrilled with the results which were subsequently published. And most importantly gave the incentive for the building of the full-scale 8-integrator machine by Metropolitan-Vickers. The machine, an updated version of the original "Bush d.a." was installed in the basement of the Physical Laboratories at the University of Manchester. It was applied to solving a wide range of problems which in effect provided me with a Ph.D.!

In 1937, largely through the influence of Professor Lawrence Bragg (the youngest Nobel Prize winner) and Douglas Hartree, I obtained a fellowship to MIT which gave me the wonderful opportunity to work under Dr. Bush's leadership. During 1937-39, I was a member of the Bush Differential Analyzer team. The design of the machine (the so-called RDA) was well advanced in September 1937 when I arrived at MIT. It was undoubtedly the most advanced analog / digital computer ever built. It eventually incorporated 16 beautifully designed mechanical integrators (wheel/disc), 3 input function units, 2 output tables, an output printer and a complex digital switchboard for interconnecting individual components. My personal contribution related to the design and development of the function unit. As a matter of fact, I used the original d.a. to determine an effective method of converting digital (tabular) into analog (graphical) information.

I cannot stress too strongly the inspirational influence of Dr. Bush and his team; and their friendships as well. Indeed it is gratifying to record that my cordial relationship with 'Doc' Bush, Sam Caldwell, Claude Shannon and Jike Jaeger continued into the 1950's and beyond. Not surprisingly, my MIT experience gave me insights into the educational potential of the d.a. which I had not hitherto appreciated. If the present proposal materializes it will in a very real sense honor the pioneer, whose dreams of 45 years ago will be fulfilled. Notwithstanding the important contributions to civilian and military R and D during the 30's and 40's, I believe the ultimate success of the d.a. concept will be in education.

May I briefly outline the requirements. I suggest that introductory material should incorporate a documentary showing the operation of a full scale d.a. (perhaps the Manchester machine) and a model (Tim Robinson's model would be ideal). The development of software to simulate a 3-integrator d.a. with corresponding input and output facilities. Remote control (e.g. time scales, coefficients and initial conditions) of the virtual d.a. would be required.

The proposal has been discussed with many educators and professional engineers as well as a few social scientists. The response has been overwhelmingly enthusiastic. The following may be contacted:—

Jack Macdonald — formerly President, University of British Columbia and Professor of Higher Education, University of Toronto.

Peter Nikiforuk — formerly Dean of Engineering, University of Saskatchewan.

Ian Sharp — formerly President, "I.P. Sharp and Associates".

Jim Stoke — Consulting Engineer.

J. Rennie Whitehead — formerly Principal Science Advisor, Privy Council of Canada.

William Winegard — formerly President, University of Guelph.

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Arthur Porter

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