Review of *Quantum Processes, Systems,& Information* by Benjamin Schumacher and Michael Westmoreland

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This book promotes information as the core concept underlying a proper appreciation of quantum theory. Given this, it is ironic that the authors' perpetuate, on page 2, one of the great myths in information transmission: that Paul Revere cried, on his midnight ride of 18th April 1775, "the British are coming!"[1] This historical slip aside, choosing such a dramatic illustration of the nature of information — a message (that the Regulars were staying put in Boston, that they were marching down the Neck, or that they were crossing the harbour by boat) that can be *encoded* into a *signal* (zero, one, or two lamps hung in a Boston church steeple), and that it can be *transformed* (into the thoughts and actions of Revere and others that night) – is an inspired start to an inspiring book.

Schumacher and Westmoreland are both eminent researchers in quantum information theory. The former has the distinction of having coined the term *qubit* [2] (only 15 years ago!) in the same paper that introduced quantum data compression. This book however is not a research monograph in quantum information. Rather it is, as the authors say, "designed to be both an undergraduate textbook on quantum mechanics

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[1] The American colonists at this time still considered *themselves* to be British. According to eyewitness accounts of the ride and Revere's own descriptions, his cry was "The Regulars are coming out." [1]

and an exploration of the physical meaning and significance of information." Having read the book, I have to agree with them that "attention to both subjects can lead to a deeper understanding of both." A bright undergraduate would get a tremendous grounding in modern quantum theory from reading this book, and solving the problems therein. So would many postgraduate students and academics wanting to get into the heart of quantum information research. Whether it can be easily used, in its entirety, as the basis for a first serious undergraduate course in quantum mechanics, remains to be tested.

The authors are well aware that working through the whole book would be a formidable task at an undergraduate level. For this reason, there is a clear delineation into three divisions. The first, which the authors call Part I (chapters 1-5), is the basic theory. As noted above, this begins with information, and only then moves on to quanta, qubits, and the formalism of finite Hilbert spaces. From the basic theory, the course could then take two possible directions: the "upper track" (the quantum information track) or the "lower track" (a more-or-less conventional quantum mechanics course). The authors divide the "upper track" into Part II (chapters 6-9) — the extension of the theory to entangled states, ebits, open systems and thermodynamics — and Part V (chapters 18-20) — advanced quantum information, including gates, data compression, and error correction. Similarly they divide the "lower track" into Part III (chapters 10-14) — the infinite dimensional systems that are traditionally introduced very early (i.e. wavefunctions), plus angular momentum, harmonic oscillators and identical particles — and Part IV (chapters 15-17) — stationary states, including the Hydrogen atom and perturbation theory.

Perhaps it is just because my undergraduate quantum mechanics education (which predated the quantum information revolution of the mid-90s) was firmly on the "lower track", but it seems to me that the level of mathematical sophistication and abstract thought required to tackle Part V was considerably above that of the rest of the book. While *coherent information* and the *quantum Fano inequality* are doubtless the most general way to approach quantum error correction (section 20.3), an undergraduate course instructor would probably have more success starting with the simple 3-qubit code, which is introduced (eventually) in section 20.4. Also, given how much of the material in this section is presented as the result of exercises, any instructor teaching from this part of the book would have to feel very confident in their own knowledge, and put in considerable preparation time.

For these reasons it would tempting for an instructor to skip Part V, or even the whole of the upper track. In this case, should they abandon *Quantum Processes, Systems,& Information* and use a conventional quantum mechanics textbook? Not at all. The introductory Part I will give students a profoundly different perspective from that usually presented, namely this: the property that sets quantum systems apart from classical systems is that they can carry a different sort of information. The concepts in Part I are introduced gently, and with physical examples. But still, in a relatively short space, the authors get to that beautiful (and uniquely "real-world") example of quantum information technology, quantum cryptography. The Hilbert space formalism, readily understandable for finite-dimensional systems, also forms the proper basis for understanding wavefunctions, so teaching the former first would hopefully help counter the pernicious idea promulgated in some undergraduate courses that quantum mechanics is all about waves in 3-dimensional space.

To give an example of the authors' pedagogical style, their first explanation (p. 36) of the difference between quantum and classical information is through this simple but

powerful metaphor: "The [spin-1/2] particle can carry a "secret message" encoded in its spin state. If we read the particle in the right way ... the message is revealed. But if we choose the wrong way ... then the message self-destructs." I do have some minor criticisms of the book. I am not in complete agreement with the authors' characterization of the EPR-Bohr debate (p. 132). The fact that $\mathrm{Tr}[\rho] = \mathrm{Tr}[\rho^2] = \mathrm{Tr}[\rho^3] = 1$ is a necessary and sufficient condition for a Hermitian operator ρ to represent a pure state is given only as Problem 8.2 (without a hint), and I could not find an index entry that would enable a reader to locate it. Similarly, there seems to be no index entry that would lead the reader to the section entitled **The Hamiltonian operator** (p. 102). But overwhelmingly I was impressed with the care the authors had taken to be consistent throughout, to painstakingly explain new concepts when they are introduced, and to present their perspective on quantum mechanics in a coherent and compelling way.

References

1. *Paul Revere's Three Accounts of His Famous Ride*, introduction by Edmund Morgan. (Massachusetts Historical Society, 1961).
2. B. Schumacher, "Quantum coding", Physical Review A **51** 2738-2747. (1995).