LUDDY FACULTY FELLOWSHIP APPLICATION DRAFT

Dan-Adrian German, September 27, 2020

MEASURING THE EFFECT OF COMPUTATIONAL-THINKING ACTIVITIES ON LEARNING IN AN INTRODUCTORY QUANTUM MECHANICS COURSE

Despite over one hundred years of history, the how of quantum mechanics remains a mystery. Some argue that the revolution in quantum computing will only happen when we understand the inner workings of quantum mechanics: how exactly is quantum information processed by Nature? Our belief is that the relationship is, in fact, more reciprocal and that, for example, the use of quantum computation activities in an introductory quantum mechanics course can, in fact, significantly accelerate the learning.

There is a plenty of research on active learning techniques in Physics, from the work of David Hestenes, Malcom Wells and Eric Mazur in the early 90s (that emphasized a learner-sighted perspective) to the more recent frameworks of Maker-Centered Learning and Agency by Design. Computational thinking in introductory physics classes has been, and continues[1] to be studied, but never before was this relationship investigated in the specific area of quantum mechanics—and that, of course, because it simply hasn't been possible, at least not to the extent that it can be done today.

Today quantum computers exist, access to them via the cloud is affordable, university- and industry-developed education is increasing, and government funding was approved to further research and focus on needed workforce development. Today many practical quantum computation concepts can be taught hands-on in the CS classroom (via either one of the many existing simulators or actual quantum computing platforms accessible in the cloud) to computer science undergraduates. We have shown this first-hand in our SIGCSE 2020 pre-symposium event—a very successful tutorial and workshop at the same time.

Although today's quantum computers are noisy, intermediate-scale devices, the theory behind them is solid. And it is not just the remarkable success in explaining all the known phenomena that makes quantum mechanics a fascinating subject. What is truly amazing is that, even today, a mere knowledge of the basic postulates can lead to startling new ideas and devices[2]. Therefore it becomes possible to convey

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[1] Computational thinking (CT) is still a relatively new term in the lexicon of learning objectives and science standards. The term was popularized in an essay by Wing, who said that "along to reading, writing and arithmetic, computational thinking should be added to every child's analytical ability". Agreeing with this premise, in 2013 the authors of the Next Generation Science Standards (NGSS) included "mathematical and computational thinking" as one of eight essential science and engineering practices that K-12 teachers should strive to develop in their students. There is not yet widespread agreement on the precise definition or implementation of CT, and efforts to assess CT are still maturing, even as more states adopt K-12 computer science standards.

[2] For example, just the knowledge of the principle of complementarity can lead to perfectly secure communication systems, or the understanding of a beam splitter for a single photon can lead to a highly counterintuitive communication protocol with no particle present in the transmission channel, or the resource of quantum entanglement can lead to novel quantum computing algorithms.

not only the foundations of quantum mechanics but also some mind-boggling applications, with just elementary knowledge of basic physics and mathematics.

Recent, accelerated breakthroughs in the field have led to a documented lack of talent in the quantum industry. High school programs have traditionally stayed away from quantum physics, but that is quickly changing. Inspired by the many recent educational initiatives worldwide and the increased expertise on campus we propose the development of a dual purpose MOOC on the Quantum, both for outreach (to HS students and teachers alike) and as a potential entry point to our new one year intensive MS degree in QIS. This project will have impacts with respect to technology transfer, education, and outreach.

Learning sequence is comprised of four introductory modules:

1. Introduction to Quantum Mechanics, Platforms and Materials
2. Introduction to Quantum Sensing and Metrology
3. Introduction to Quantum Communications and Quantum Networks
4. Practical Quantum Computing

The recommended time to create a MOOC on the EdX platform is 6-8 months. Before we start we need to assemble a team of teaching assistants, teaching fellows or undergraduate volunteers to help with creating the course (and maybe administer a pilot). We will also need volunteers to help moderate discussion forums and with debugging and testing the courseware. Occasional access to campus resources, such as video specialists or instructional designers, is also likely, and therefore foreseeable.

Development Plan		Budget Considerations	
Sep-Dec, 2020	Recruit Teaching Fellows	Teaching Fellows (4)	$8,000
Jan-May, 2021	Create Course Content	Focus Group (20)	$4,000
May-Jun, 2021	Prepare Course for Delivery	TAs for the Pilot	$2,400
June-July, 2021	Run Course Pilot	Travel (4 students)	$4,400

An online course alternates short videos with exercises, and benefits from a modular structure. The course will be designed as an overall experience. We have already carefully planned our course goals. Course content will be developed in EdX Studio. Courses delivered via the EdX platform have built in analytics. Opportunities for blended learning are significant, in the sense that once the course is ready students can take it whether they're on campus or off-campus (possibly overseas).

Each module will have a pre- and post-test to assess learning for each individual. Item response theory is useful in both the development and evaluation of assessments and in computing standardized measures of student performance. In item response theory, individual parameters (difficulty, discrimination) for each item or question are fit by item response models. These parameters provide a means for evaluating a test and offer a better measure of student skill than a raw test score. A standard test of general knowledge in quantum mechanics (a baseline test) will be used to compare (via item response theory) our focus group, at the end of the QC-based MOOC, with two separate control groups (students in traditional QM classes) and to that end we are partnering with Rose-Hulman (Prof. Mariij Syed) and the IU Physics REU site (Prof. John Carini).