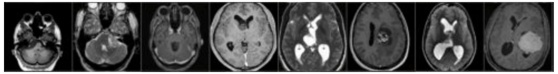
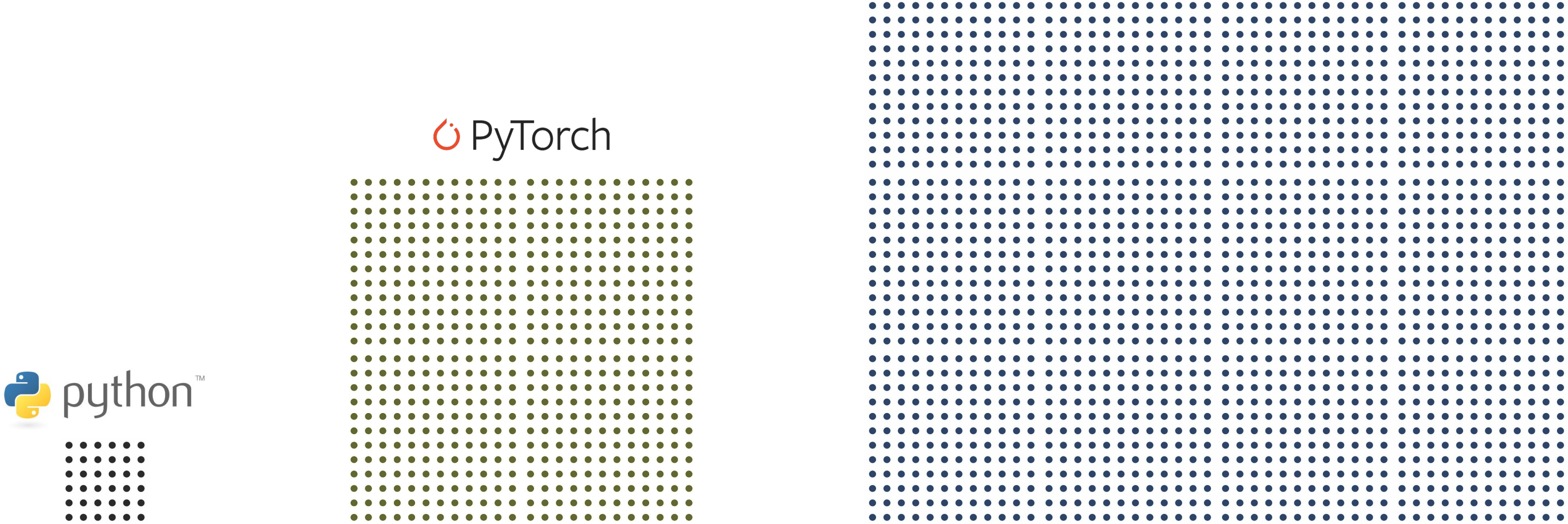
QML/QiML Technology for Medical Regulatory Agency Review

A Single Medical Model/Notebook





Some Classical Bits for
Python Notebook
Lowest RAM

More Classical Bits for
PyTorch Deep Learning
Medium RAM Requirements

Most Classical Bits for PennyLane Quantum-inspired Deep Learning
Example: 20 Qubits = $2^n = 2^{20}$ = 1.049 MBits minimum
Highest RAM Requirements for the Notebook

Figure 1: Single Model Classical Resource Approximations for Quantum-inspired Machine Learning Workflows, K. Kawchak [1,2,3,4,5]

Quantum Machine Learning (QML) is the integration of quantum algorithms within machine learning programs [6,7]
Quantum-inspired Machine Learning (QiML) is a practical form of QML processed with GPUs or CPUs

The Problem

1) ***1947 Bell Labs Memo: First Classical Binary Information Digit = "Bit"*** [8]
   a) Most basic unit of information in computing and digital communications
   b) Deep Learning platforms process a massive number of '0' or '1' Bits
   c) Despite ubiquity, Bits have not taken full advantage of quantum physics

2) ***Medical Machine and Deep Learning Applications***
   a) Limited scope of Deep Learning architectures (CNN, Transformer, etc.)
   b) Key improvement over time = Total number of trainable parameters
   c) Dropout and weight decay have helped, but still no quantum mechanics

3) ***Pure Classical Machine and Deep Learning Issues Remain***
   a) Can Transformers overtake CNNs in both patient safety and efficacy
   b) Will more parameters continue to process larger datasets better
   c) When will Natural Language Processing implement Quantum-inspired ML

CNN, Transformer

The Solution

1) *Quantum inspired Machine Learning (QiML) Workflows* [9]

a) Bits behaving according to quantum mechanics to make Qubits
b) Some Bits are for the notebook, and other Bits are for ML and QML
c) Qubits are free of quantum noise and compatible w/ ML Workflows Today

2) *Current Generation of Hybrid Algorithms*

a) A quantum algorithm and classical algorithm can be run on same device
b) Simulator advantages: Exact values returned, Pure states w/ ‘ket’ notation
c) Quantum circuit is linear component, Measurement is non-linear component

3) *Quantum Algorithm Concerns Similar to Classical*

a) QiML workflows will also need to address bias in datasets and data drift
b) Current: Multi-GPU QiML 30 qubit workflows, Circuit cutting for more qubits
c) Pending FDA verification and validation of QiML technology use-cases [10]

ML + QiML

The Market Opportunity

Medical Data and QML Projections

1) Global ML market growth from $17.1B to $90.1B in 2021 to 2026
   a) ML Compound Annual Growth Rate (CAGR) of 39.4% [11]
   b) Quantum Machine Learning 30% CAGR 2023-2030, $5B [12]

2) Healthcare Data accounts for 30% of World's Data Volume
   a) Growth: 36% CAGR through 2025: RBC Capital [13]

3) AI in Healthcare Market to Reach $428B by 2032
   a) Growth: 44.0% CAGR Over the Forecast 2023 to 2032 [14]

4) Global AI Medical Imaging: CAGR of 45.6% through 2027
   a) Global Radiomics Market Size: 16.2% CAGR through 2031 [15]

Product Development

NVIDIA	NVIDIA QCWARE	NVIDIA PENNYLANE NERSC Brookhaven National Laboratory	THE WALL STREET JOURNAL SANDBOXAQ
1) 4000+ V100 GPUs 960 A100 GPUs 2) 1200+ Compute nodes 3) Quantum state vector testing a range of circuits *Lubowe, T., Morino, S. 12/14/22* [16]	1) Quantum-inspired software platform accelerates large molecule simulation speed 2) NVIDIA GPUs to figure out a ‘big step change in performance’ *Lee, J. 4/17/23* [17]	1) Scaling up with GPUs and supercomputers 2) Accelerating 'Massive simulations of quantum systems' throughout 2023 *Stanwyck, S. 9/12/23* [18]	1) GPUs Transformed AI 2) Now GPUs For Quantum 3) ‘Quantum equations, quantum software on GPUs’ *Bousquette, I. 9/21/23* [19]
SANDBOXAQ UCSF sanofi AstraZeneca	acm Association for Computing Machinery	Bard	Bard
1) Cutting edge physics-based accuracy using massively parallel classical hardware 2) For breakthroughs in cancer, Alzheimer’s, Parkinson’s *SandboxAQ 6/22/23* [20]	1) A100 GPU Performance = Next Decades QPUs 10K error-corrected logical qubits, 10μs gate time 2) QPUs will be for big problems and small data amounts *Hoefler, T., Häner, T., Troyer, M. 5/23* [21]	1) QML has the potential to revolutionize many industries 2) QML can account for the complex interactions between genes *Google Bard 11/3/23* [22] [23]	1) QML algorithms can be used to simulate embedded systems with quantum mechanics 2) Can be useful for developing more efficient and reliable embedded systems *Google Bard 11/3/23* [24] [23]

Table 1: QiML Industry 1yr Product Development, K. Kawchak

Product Development

Journal	Authors	Date	Description	Medical Area	Results
BMC	Sengupta, K., et al.	2021 [25]	Quantum Algorithm	CT/Lungs/COVID-19	Accuracy + 2.9% vs. DNN
arXiv	Houssein, E., et al.	2021 [26]	Hybrid QCNNs	CT/Chest/COVID-19	Multi-class Accuracy 88.6%
bioRxiv	Yu, Z., et al.	2021 [27]	Quantum Classifiers	SARS CoV-2 Data	Efficient, Accurate Process
IEEE	Krunic, Z., et al.	2022 [28]	Quantum Kernels	Rheumatoid Arthritis	One of largest QML studies
medRxiv	Heidari, N., et al.	2021 [29]	Quantum Enhanced	Knee Osteoarthritis	Larger studies required
frontiers	Dong, Y., et al.	2023 [30]	Quantum Transfer	Knee Osteoarthritis	Accuracy + 1% vs. HQCNN
arXiv	Kim, Ryan	2023 [31]	Quantum CCNN	Alzheimer’s Disease	Accuracy + 5.9% vs. CNN
electronics	Shahwar, T., et al.	2022 [32]	Hybrid CQNNs	Alzheimer’s Disease	Acc + 1.8% vs. DemNet
mathematics	Alsharabi, N., et al.	2023 [33]	AlexNet-Quantum	Alzheimer, Parkinson’s	96% Alz, 97% Parkinson’s
AIP Publishing	Dong, Y. et al.	2023 [34]	Hybrid QCCNNs	4-Class Brain Tumor	Classification Acc 97.8%
TechRxiv	Konar, D. et al.	2023 [35]	3D-QNet Segment	Brain/Liver Tumor	Similar dice scores

Table 2: QiML Medical Data Product Development, K. Kawchak

Product Development

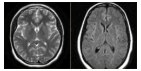
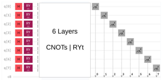
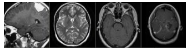
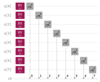
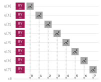
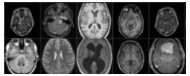
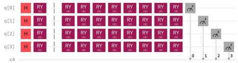
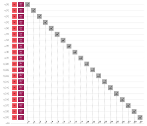
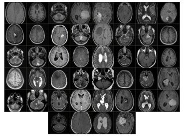
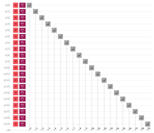
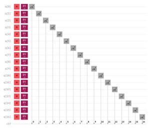
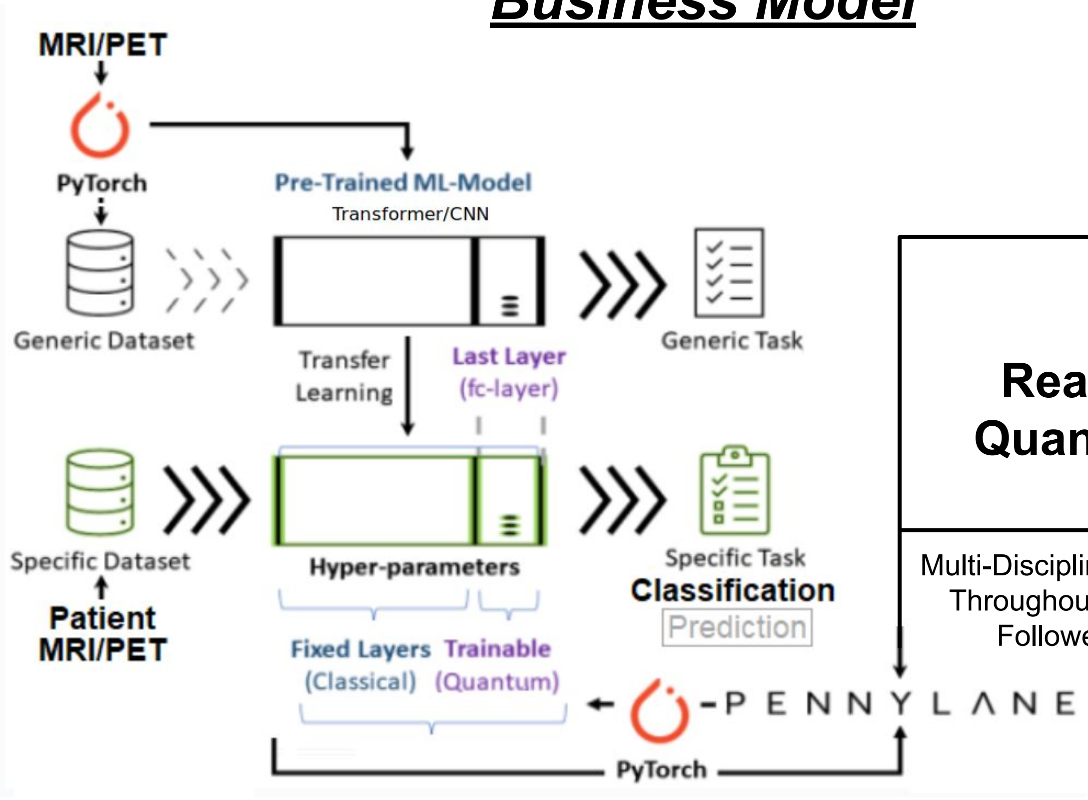
Brain Tumor Dataset	Quantum Algorithm	Model Results	Quantum Algorithm	Model Results
 2 Class 796 Images	 HRYeRYt(1) Trainable	Val Accuracy: 97.7% 1) Pre-Train RN50 2) No Train RN50 3) Train Quantum 10/16/23 [36a] [36] [37]	 HRYe(CNOTsRYt)(6) Trainable	Val Accuracy: 99.0% 1) Pre-Train RN18 2) No Train RN18 3) Train Quantum 5/5/23 [38] [39] [40]
 4 Class 1572 Images	 RYe Embedding	Val Accuracy: 61.1% 1) Pre-Train RN18 2) No Train RN18 3) No Train Quantum 5/10/23 [41] [42] [43]	 RYe Embedding	Val Accuracy: 88.1% 1) Pre-Train RN18 2) No Train RN18 3) No Train Quantum 5/16/23 [44] [45] [46]
 10 Class 3507 Images	 HRYeRYt(8) Trainable	Val Accuracy: 41.6% 1) Pre-Train RN50 2) No Train RN50 3) Train Quantum 8 Layers = Best, 1-10 studied Best Val % vs. 2, 44 Class 9/26/23 [47] [48] [49]	 HRYe Embedding	Val Accuracy: 85.8% 1) Pre-Train RN18 2) No Train RN18 3) No Train Quantum +11.1% vs. No QC -8.6% vs. Train RN18 No QC 5/27/23 [50] [51] [52]
 44 Class 4478 Images	 HRYe Embedding	Val Accuracy: 64.0% 1) Pre-Train RN18 2) No Train RN18 3) No Train Quantum +4.6% vs. No QC -21.5% vs. Train RN No QC -19.2% vs. Train ViT No QC 6/22/23 [53] [54] [55]	 HRYe Embedding	QTL CPU Efficiency: 9.92 TL CPU Efficiency: 19.50 1) Pre-Train RN50 2) No Train RN50 3) No Train Quantum 44 Classes. GPUs and TPUs not optimized for QTL model 8/9/23 [56] [57] [58] [59]

Table 3: QiML Brain MR Images Product Development, K. Kawchak

Business Model



Low Cost
Readily Available
Quantum Simulator

Multi-Disciplinary Expertise to be Leveraged Throughout the Total Product Life Cycle Followed by Impact Assessment

Figure 2: Example QiML Business Model, Modified from Subbiah, G., et al. [60]

1) QML/QiML Updates to Existing PyTorch Machine Learning Workflows
   a) PennyLane TorchLayer converts a QNode to a Torch layer [61] [62]
   b) Qiskit TorchConnector connects a Quantum Network to PyTorch [63] [64]

Technology

Quantum Processing Units

Limited Availability

Quantum ML

*Est. Forecast +5 Years **

Available Since +4 Years [65] [66]

CPUs or GPUs

Readily Available

Partial Error Mitigation

No Quantum Error

Forward Accumulation

Parameter Shift
Finite Differences

Output: Probabilistic

Not Exact Answers
Many Shots Required

Reverse Accumulation

Backpropagation
Adjoint Differentiation

Output: Exact

Exact Answers For
Circuit Evaluations

Density Matrices

Not Pure States
Interior of Bloch Sphere

No QML Workflows

No Exact, Continuous
Parameter Updates

Library:
PennyLane

Pure Quantum States

Preferred Ket Notation
Exterior of Bloch Sphere

QiML Workflows

Classical data generating
Classical processing

** Forecast: Readily Available, Error Corrected Quantum Computer with Accurate and Efficient QML Workflows. Significant Engineering of Hybrid ML may be needed.*

Next Step: 'Simulator' Specific Quantum Circuit Architecture
Required: Significantly better performance vs. Classical ML
Need: New Utilities not available w/ Classical ML processing

Figure 3: QML/QiML Technology, K. Kawchak

Technology

Device
Single CPU

python™

Variable [PENNYLANE

Classical
Notebook
+
Classical ML
Quantum ML

1) Speed: CPU Processing: **Low**
2) Parameters based on Low RAM: **Low**
3) Probable Benefit > Risk: **Medium**

Figure 3: Example QML/QiML Single Device Technology, K. Kawchak

Device 1+2
CPU/GPU

python™

Variable [PENNYLANE

NVIDIA

Notebook
Classical DL

+

Device 3
Multi GPU

python™

Variable [PENNYLANE

NVIDIA

Simulators
+ Quantum DL

1) Speed: Multi-GPU Processing **Medium-High**
2) Parameters based on Medium-High RAM: **Medium-High**
3) Probable Benefit > Probable Risk: **Medium-High**

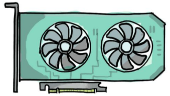
Figure 4: Example QML/QiML Multi-Device Technology, K. Kawchak

Technology

1) ***Key: How much quantum physics helps bits process big datasets***
   a) Emphasis needs to be placed on new algorithm architectures
   b) Inference will be slower than today's classical methods
   c) Qubit is most compatible, qutrit and ququart for other use cases

2) ***Quantum Simulator Benchmarking 25 Qubit Graph Embedding*** [67] [68] [69]
   a) A100 lightning.gpu = 20 second model total runtime
   b) Speed: 37x default.qubit, 16x qulacs.simulator, 10x qiskit.aer
   c) 8x cirq.qsim, 7x lightning.qubit, 1.2x V100 lightning.gpu See also [70] [71]

3) ***'Gate-based' algorithm architecture can require many resources***
   a) Issues mapping high-level algorithms to low-level gate-based
   b) Not all quantum gates are universal, and may not be sufficient OpenAI [72]

Technology

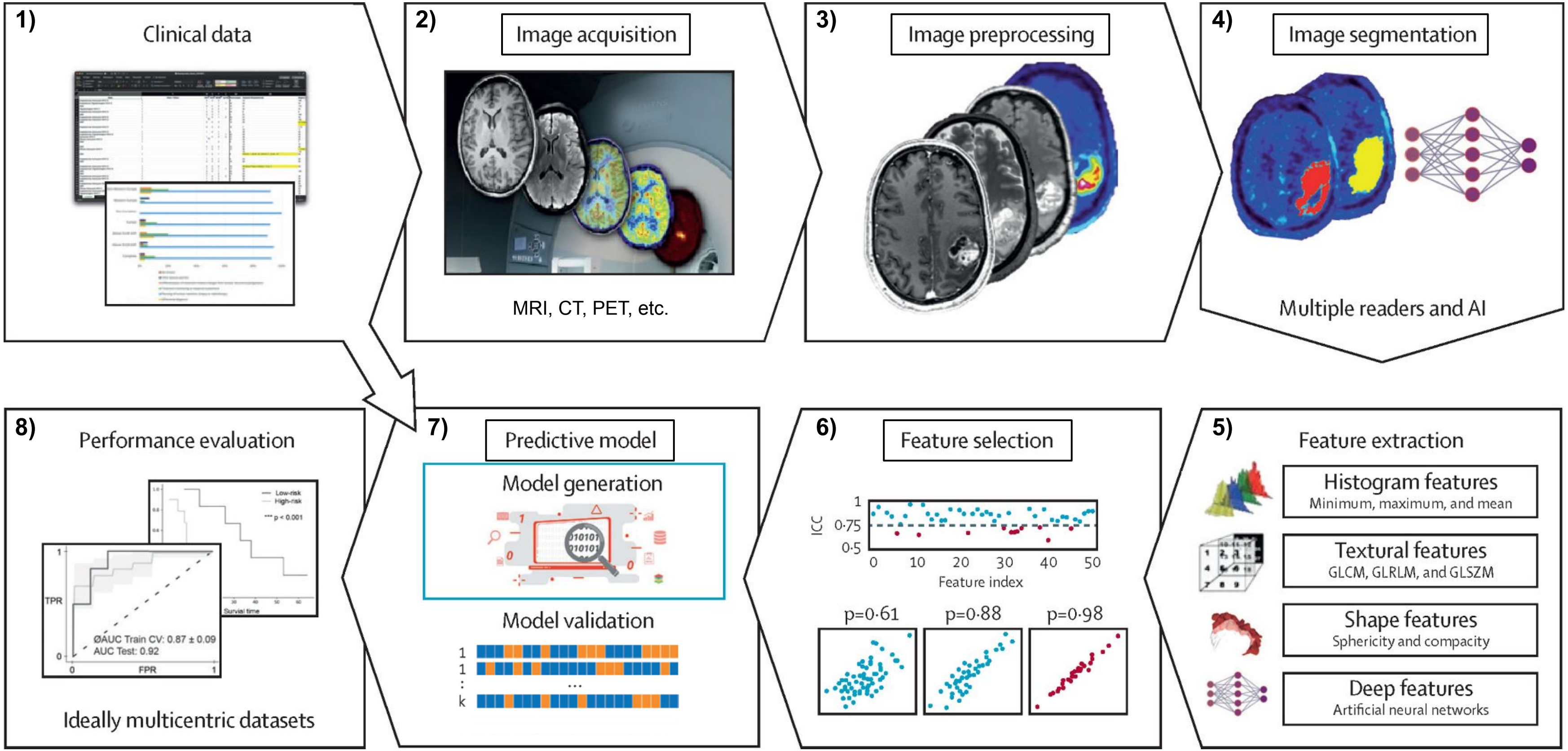


Figure 5: Potential Radiomics QML/QiML Workflow or Hybrid Algorithms Technology
Image modified from Lohmann, P., et al., The Lancet Digital Health [73]

Competition

NLP

Purely Classical

D-Wave
The Quantum Computing Company™

IONQ

rigetti

1) ***Purely Classical Deep Learning Developers Continue Innovation***
   a) New architectures will likely continue to improve or change
   b) Increasing number of parameters for harder to solve problems
   c) Have Organizational excellence, don't need QML/QiML expertise

2) ***Quantum computers will likely solve large problems + small data***
   a) Multi-Billion Dollar valuations will continue to attract attention
   b) Quantum noise, lack of efficient QML methods will likely prevail
   c) Quantum hardware firms also utilize quantum simulators for clients [74] [75]

The Ask

1) ***Quantum inspired Machine Learning (QML/QiML) Discussion Paper*** [76]
   a) QML/QiML Software Validation guidance for efficacy determination
   b) Premarket Submission for QiML Software framework
   c) Collaborative Communities as Human-AI Team for Earlier disease detection

2) ***Collaborative Communities in QML/QiML*** [77]
   a) Clinical Decision Support Software for QiML, Breakthrough Device potential
   b) QiML Mobile Medical App (MMA) guidance w/ new Algorithm Change Protocol
   c) QML/QiML AI Radiology Workshop, anticipated ‘intended use’ changes

3) ***Patient Engagement Advisory Committee Meeting*** [78]
   a) Pre-Cert Working QiML Model, Substantially Equivalent Predicate Device
   b) Pilot with real-world evidence generation program, Algorithm robustness
   c) GMLP, Transparency. Users Provided with clear, essential information [79]

Thank You

PENNYLANE Qiskit PyTorch

1) ***Xanadu PennyLane Quantum Machine Learning Researchers***
   a) 25+ Quantum Machine Learning Demos [80]
   b) Xanadu Discussion Forum w/ Experts, Xanadu Slack [81] [82]

2) ***IBM Qiskit Quantum Computing Researchers***
   a) 10+ Quantum Machine Learning Tutorials [83]
   b) Large Qiskit Slack Channel, Weekly Qiskit Discussions [84] [85]

3) ***PyTorch: QiML/ML Compatibility w/ Key Quantum Libraries***

4) ***Medical and Quantum Colleagues: LinkedIn Polls*** [86] [87] [88]

<table>
<tr><th>#</th><th>Works Cited Discussion #108 Thursday November 9th, 2023 ChemicalQDevice CEO Kevin Kawchak</th></tr>
<tr><td>1</td><td>Brain Tumor MRI images 44 classes. (2023c, February 12). Kaggle. https://www.kaggle.com/datasets/fernando2rad/brain-tumor-mri-images-44c?select=Germinoma+T2</td></tr>
<tr><td>2</td><td>Mari, A. (2021c, January 28). Quantum transfer learning. PennyLane Demos. https://pennylane.ai/qml/demos/tutorial_quantum_transfer_learning/</td></tr>
<tr><td>3</td><td>PyTorch. (n.d.). https://pytorch.org/hub/pytorch_vision_resnet/</td></tr>
<tr><td>4</td><td>Kevinkawchak. (n.d.-s). Medical-Quantum-Machine-Learning/R&D at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/R%26D</td></tr>
<tr><td>5</td><td>Kevinkawchak. (n.d.-q). Medical-Quantum-Machine-Learning/Code/PennyLane at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane</td></tr>
<tr><td>6</td><td>Wikipedia contributors. (2023e, November 4). Quantum machine learning. Wikipedia. https://en.wikipedia.org/wiki/Quantum_machine_learning</td></tr>
<tr><td>7</td><td>Dots square icon vector image. (n.d.). VectorStock. https://www.vectorstock.com/royalty-free-vector/dots-square-icon-vector-11344821</td></tr>
<tr><td>8</td><td>Wikipedia contributors. (2023e, October 18). Bit. Wikipedia. https://en.wikipedia.org/wiki/Bit</td></tr>
<tr><td>9</td><td>Quantum-Inspired Machine Learning: a Survey. https://arxiv.org/pdf/2308.11269.pdf</td></tr>
<tr><td>10</td><td>MIT OpenCourseWare. (2020b, October 22). 22. Regulation of Machine Learning / Artificial Intelligence in the US [Video]. YouTube. https://www.youtube.com/watch?v=k95abdkdCPk</td></tr>
<tr><td>11</td><td>Publishing, B. (2022, February 2). Machine Learning Market Size, Share and Growth Analysis Report. BCC Research LLC. https://www.bccresearch.com/market-research/information-technology/machine-learning-global-markets.html#:~:text=The%20global%20market%20for%20machine,the%20period%20of%202021%2D2026.</td></tr>
<tr><td>12</td><td>Virtue Market Research,https://virtuemarketresearch.com/. (n.d.-c). Quantum Machine Learning Market | Size, share, growth | 2023 – 2030. Virtue Market Research. https://virtuemarketresearch.com/report/quantum-machine-learning-market</td></tr>
<tr><td>13</td><td>RBC Capital Markets | Navigating the changing Face of healthcare episode. (n.d.-b). https://www.rbccm.com/en/gib/healthcare/episode/the_healthcare_data_explosion</td></tr>
<tr><td>14</td><td>Acumen Research and Consulting. (2023, October 10). AI in Healthcare Market is forecasted to Reach USD 427.5 Billion by 2032, growing at a CAGR of 44.0% Over the Forecast Period 2023 to 2032. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2023/10/10/2757664/0/en/AI-in-Healthcare-Market-is-forecasted-to-Reach-USD-427-5-Billion-by-2032-growing-at-a-CAGR-of-44-0-Over-the-Forecast-Period-2023-to-2032.html</td></tr>
<tr><td>15</td><td>Radiomics Market Size, scope, Growth and Trends Analysis. (n.d.-b). https://www.insightaceanalytic.com/report/radiomics-market/1711#:~:text=The%20Global%20Radiomics%20Market%20Size,forecast%20period%20for%202023%2D2031.</td></tr>
<tr><td>16</td><td>Best-in-Class Quantum Circuit Simulation at Scale with NVIDIA cuQuantum Appliance | NVIDIA Technical Blog. (2023c, July 5). NVIDIA Technical Blog. https://developer.nvidia.com/blog/best-in-class-quantum-circuit-simulation-at-scale-with-nvidia-cuquantum-appliance/</td></tr>
<tr><td>17</td><td>Lee, J. (2023, April 17). Waiting for quantum computers to arrive, software engineers get creative. Reuters. https://www.reuters.com/technology/waiting-quantum-computers-arrive-software-engineers-get-creative-2023-04-17/</td></tr>
<tr><td>18</td><td>Stanwyck, S. (2023g, September 12). Quantum Boost: CuQuantum, PennyLane Let simulations ride supercomputers | NVIDIA Blogs. NVIDIA Blog. https://blogs.nvidia.com/blog/2023/09/12/quantum-supercomputers-pennylane/</td></tr>
<tr><td>19</td><td>Bousquette, I. (2023f, September 21). GPUs Transformed AI. Now They're Here For Quantum. WSJ. https://www.wsj.com/articles/gpus-transformed-ai-now-theyre-here-for-quantum-b4ecbeeb</td></tr>
<tr><td>20</td><td>SandboxAQ announces Bio-Pharma Molecular Simulation Division to speed Life-Saving drugs to patients through AI and quantum solutions | SandboxAQ. (n.d.). https://www.sandboxaq.com/press/sandboxaq-announces-bio-pharma-molecular-simulation-division-to-speed-life-saving-drugs-to-patients-through-ai-and-quantum-solutions?utm_source=linkedin&utm_medium=organic_social&utm_campaign=pressrelease&utm_content=aqbiosim</td></tr>
<tr><td>21</td><td>Troyer, T. H. T. H. M. (2023b, May 1). Disentangling Hype from Practicality: On Realistically Achieving Quantum Advantage. May 2023 | Communications of the ACM. https://cacm.acm.org/magazines/2023/5/272276-disentangling-hype-from-practicality-on-realistically-achieving-quantum-advantage/fulltext</td></tr>
<tr><td>22</td><td>Before you continue. (n.d.). https://bard.google.com/share/6285d2244654</td></tr>
<tr><td>23</td><td>Bard: Over 2,277 Royalty-Free Licensable stock Vectors & Vector art | Shutterstock. (n.d.). Shutterstock. https://www.shutterstock.com/search/bard?image_type=vector</td></tr>
<tr><td>24</td><td>Before you continue. (n.d.-b). https://bard.google.com/share/df7eaa325c16</td></tr>
<tr><td>25</td><td>Sengupta, K., & Srivastava, P. R. (2021b). Quantum algorithm for quicker clinical prognostic analysis: an application and experimental study using CT scan images of COVID-19 patients. BMC Medical Informatics and Decision Making, 21(1). https://doi.org/10.1186/s12911-021-01588-6</td></tr>
<tr><td>26</td><td>HYBRID QUANTUM CONVOLUTIONAL NEURAL NETWORKS MODEL FOR COVID-19 PREDICTION USING CHEST X-RAY IMAGES. https://arxiv.org/pdf/2102.06535.pdf</td></tr>
<tr><td>27</td><td>Analyzing SARS CoV-2 Patient Data Using Quantum Supervised Machine Learning. https://www.biorxiv.org/content/10.1101/2021.10.26.466019v1.full.pdf</td></tr>
<tr><td>28</td><td>IEEE Xplore Full-Text PDF: (n.d.-c). https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9779984</td></tr>
<tr><td>29</td><td>A quantum-enhanced precision medicine application to support data-driven clinical decisions for the personalized treatment of advanced knee osteoarthritis: development and preliminary validation of precisionKNEE QNN. https://www.medrxiv.org/content/10.1101/2021.12.13.21267704v1.full.pdf</td></tr>
<tr><td>30</td><td>Yang, D., Che, X., Fu, Y., Liu, H., Zhang, Y., & Tu, Y. (2023c). Classification of knee osteoarthritis based on quantum-to-classical transfer learning. Frontiers in Physics, 11. https://doi.org/10.3389/fphy.2023.1212373</td></tr>
</table>

#	Works Cited Discussion #108 Thursday November 9th, 2023 ChemicalQDevice CEO Kevin Kawchak
31	Implementing a Hybrid Quantum-Classical Neural Network by Utilizing a Variational Quantum Circuit for Detection of Dementia. https://arxiv.org/pdf/2301.12505.pdf
32	Shahwar, T., Zafar, J., Almogren, A., Zafar, H., Rehman, A. U., Shafiq, M., & Hamam, H. (2022b). Automated detection of Alzheimer's via hybrid classical quantum neural networks. Electronics, 11(5), 721. https://doi.org/10.3390/electronics11050721
33	Alsharabi, N., Shahwar, T., Rehman, A. U., & Alharbi, Y. (2023b). Implementing magnetic resonance imaging brain disorder classification via ALEXNet–Quantum Learning. Mathematics, 11(2), 376. https://doi.org/10.3390/math11020376
34	Dong, Y., Fu, Y., Liu, H., Che, X., Sun, L., & Luo, Y. (2023b). An improved hybrid quantum-classical convolutional neural network for multi-class brain tumor MRI classification. Journal of Applied Physics, 133(6). https://doi.org/10.1063/5.0138021
35	3D Quantum-inspired Self-supervised Tensor Network for Volumetric Segmentation of Medical Images. https://www.techrxiv.org/articles/preprint/3D_Quantum-inspired_Self-supervised_Tensor_Network_for_Volumetric_Segmentation_of_Brain_MR_Images/12909860/4
36a/36	Mari, A. (2021d, January 28). Quantum transfer learning. PennyLane Demos. https://pennylane.ai/qml/demos/tutorial_quantum_transfer_learning/. Kevinkawchak. (n.d.-r). Medical-Quantum-Machine-Learning/Code/PennyLane/Algorithm, Learning Rate Studies at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Algorithm%2C%20Learning%20Rate%20Studies
37	Kevinkawchak. (n.d.-s). Medical-Quantum-Machine-Learning/Code/PennyLane/Algorithm, Learning Rate Studies/HRyERyT1/0.00052 lr Brain 30 epoch RN50 Batch 4 97.7% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Algorithm%2C%20Learning%20Rate%20Studies/HRyERyT1/0.00052%20lr%20Brain%2030%20epoch%20RN50%20Batch%204%2097.7%25%20kkawchak.ipynb
38	ChemicalQDevice - ChemicalQDevice May 2023 R&D update. (n.d.-c). https://www.chemicalqdevice.com/chemicalqdevice-may-2023-rd-update
39	Kevinkawchak. (n.d.-r). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class
40	Kevinkawchak. (n.d.-s). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class/02 Class 99.0% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class/02%20Class%2099.0%25%20kkawchak.ipynb
41	Kevinkawchak. (n.d.-v). Medical-Quantum-Machine-Learning/Code/PennyLane/Algorithm Prototypings I/Algorithm Prototypings I kkawchak.pdf at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Algorithm%20Prototypings%20I/Algorithm%20Prototypings%20I%20kkawchak.pdf
42	Kevinkawchak. (n.d.-v). Medical-Quantum-Machine-Learning/Code/PennyLane/Algorithm Prototypings I at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Algorithm%20Prototypings%20I
43	Kevinkawchak. (n.d.-w). Medical-Quantum-Machine-Learning/Code/PennyLane/Algorithm Prototypings I/05 NYNN 61.1% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Algorithm%20Prototypings%20I/05%20NYNN%2061.1%25%20kkawchak.ipynb
44	ChemicalQDevice - ChemicalQDevice June 2023 R&D update. (n.d.-c). https://www.chemicalqdevice.com/chemicalqdevice-june-2023-rd-update
45	Kevinkawchak. (n.d.-s). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class
46	Kevinkawchak. (n.d.-u). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class/04 Class 88.1% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class/04%20Class%2088.1%25%20kkawchak.ipynb
47	ChemicalQDevice - Quantum Parameter study for quantum inspired machine learning. (n.d.). https://www.chemicalqdevice.com/quantum-parameter-study-for-quantum-inspired-machine-learning
48	Kevinkawchak. (n.d.-ab). Medical-Quantum-Machine-Learning/Code/PennyLane/Quantum Parameters at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Quantum%20Parameters
49	Kevinkawchak. (n.d.-ac). Medical-Quantum-Machine-Learning/Code/PennyLane/Quantum Parameters/10 Class 8 Depth 41.6% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Quantum%20Parameters/10%20Class%208%20Depth%2041.6%25%20kkawchak.ipynb
50	ChemicalQDevice - ChemicalQDevice June 2023 R&D update. (n.d.-d). https://www.chemicalqdevice.com/chemicalqdevice-june-2023-rd-update
51	Kevinkawchak. (n.d.-t). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class
52	Kevinkawchak. (n.d.-w). Medical-Quantum-Machine-Learning/Code/PennyLane/2 Class 4 Class 10 Class/10 Class 85.8% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/2%20Class%204%20Class%2010%20Class/10%20Class%2085.8%25%20kkawchak.ipynb
53	ChemicalQDevice - 44 Class Classification Quantum TL vs. TL Transformer vs. 2 Classical TL. (n.d.). https://www.chemicalqdevice.com/44-class-classification-quantum-tl-vs-tl-transformer-vs-2-classical-tl
54	Kevinkawchak. (n.d.-ag). Medical-Quantum-Machine-Learning/Code/PennyLane/Quantum TL vs. 3 Models at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Quantum%20TL%20vs.%203%20Models
55	Kevinkawchak. (n.d.-ah). Medical-Quantum-Machine-Learning/Code/PennyLane/Quantum TL vs. 3 Models/QTL FE 44 Class 64.0% kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Quantum%20TL%20vs.%203%20Models/QTL%20FE%2044%20Class%2064.0%25%20kkawchak.ipynb
56	ChemicalQDevice - Time, Cost, Efficiency: RESNEt Quantum TL, TL Models. (n.d.). https://www.chemicalqdevice.com/time-cost-efficiency-resnet-quantum-tl-tl-models
57	Kevinkawchak. (n.d.-ai). Medical-Quantum-Machine-Learning/Code/PennyLane/Time Cost Efficiency at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Time%20Cost%20Efficiency
58	Kevinkawchak. (n.d.-aj). Medical-Quantum-Machine-Learning/Code/PennyLane/Time Cost Efficiency/QTL 44 Class CPU 9.92 Efficiency kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Time%20Cost%20Efficiency/QTL%2044%20Class%20CPU%209.92%20Efficiency%20kkawchak.ipynb
59	Kevinkawchak. (n.d.-ak). Medical-Quantum-Machine-Learning/Code/PennyLane/Time Cost Efficiency/TL 44 Class CPU 19.50 Efficiency kkawchak.ipynb at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/blob/main/Code/PennyLane/Time%20Cost%20Efficiency/TL%2044%20Class%20CPU%2019.50%20Efficiency%20kkawchak.ipynb
60	Quantum transfer learning for image classification. http://telkomnika.uad.ac.id/index.php/TELKOMNIKA/article/viewFile/24103/11559

#	Works Cited Discussion #108 Thursday November 9th, 2023 ChemicalQDevice CEO Kevin Kawchak
61	Qml.qnn.TorchLayer — PennyLane. (n.d.-c). https://docs.pennylane.ai/en/stable/code/api/pennylane.qnn.TorchLayer.html
62	Bromley, T. (2021b, January 28). Turning quantum nodes into Torch Layers. PennyLane Demos. https://pennylane.ai/qml/demos/tutorial_qnn_module_torch/
63	TorchConnector — Qiskit Machine Learning 0.6.1 documentation. (n.d.-b). https://qiskit.org/ecosystem/machine-learning/stubs/qiskit_machine_learning.connectors.TorchConnector.html
64	Torch Connector and Hybrid QNNs — Qiskit Machine Learning 0.6.1 documentation. (n.d.-c). https://qiskit.org/ecosystem/machine-learning/tutorials/05_torch_connector.html
65	Xanadu Releases PennyLane, the First Dedicated Machine Learning Software for Quantum Computers. https://www.prnewswire.com/news-releases/xanadu-releases-pennylane-the-first-dedicated-machine-learning-software-for-quantum-computers-300749107.html
66	Mari, A. (2021e, January 28). Quantum transfer learning. PennyLane Demos. https://pennylane.ai/qml/demos/tutorial_quantum_transfer_learning/
67	Schuld, M. (2023c, July 13). An equivariant graph embedding. PennyLane Demos. https://pennylane.ai/qml/demos/tutorial_equivariant_graph_embedding/
68	ChemicalQDevice - Benchmarking Quantum Machine Learning Devices. (n.d.). https://www.chemicalqdevice.com/benchmarking-quantum-machine-learning-devices
69	Kevinkawchak. (n.d.-ac). Medical-Quantum-Machine-Learning/Code/PennyLane/Benchmarking Devices at main · kevinkawchak/Medical-Quantum-Machine-Learning. GitHub. https://github.com/kevinkawchak/Medical-Quantum-Machine-Learning/tree/main/Code/PennyLane/Benchmarking%20Devices
70	Kordzanganeh, M., Buchberger, M., Kyriacou, B., Povolotskii, M., Fischer, W., Kurkin, A., Somogyi, W., Sagingalieva, A., Pflitsch, M., & Melnikov, A. A. (2023). Benchmarking simulated and physical quantum processing units using quantum and hybrid algorithms. Advanced Quantum Technologies, 6(8). https://doi.org/10.1002/qute.202300043
71	Lubinski, T. (2023, February 5). Optimization applications as Quantum Performance Benchmarks. arXiv.org. https://arxiv.org/abs/2302.02278
72	OpenAI. (n.d.-c). https://openai.com/
73	Radiomics in neuro-oncological clinical trials. https://www.thelancet.com/journals/landig/article/PIIS2589-7500%2822%2900144-3/fulltext
74	IonQ Newsroom and media resources. (n.d.). IonQ. https://ionq.com/posts/ionq-works-with-dell-technologies-to-deliver-hybrid-classical-quantum
75	Llc, R. &. C. (2023, November 1). Rigetti Computing awarded Innovate UK grant to enhance quantum machine learning methods for Anti-Money laundering detection. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2023/11/01/2771203/0/en/Rigetti-Computing-Awarded-Innovate-UK-Grant-to-Enhance-Quantum-Machine-Learning-Methods-for-Anti-Money-Laundering-Detection.html
76	Proposed Regulatory Framework for Modifications to Artificial Intelligence/Machine Learning (AI/ML)-Based Software as a Medical Device (SaMD) - Discussion Paper and Request for Feedback. https://www.fda.gov/files/medical%20devices/published/US-FDA-Artificial-Intelligence-and-Machine-Learning-Discussion-Paper.pdf
77	Center for Devices and Radiological Health. (2023a, June 23). Collaborative Communities: Addressing health care challenges together. U.S. Food And Drug Administration. https://www.fda.gov/about-fda/cdrh-strategic-priorities-and-updates/collaborative-communities-addressing-health-care-challenges-together
78	Center for Devices and Radiological Health. (2020, October 13). Patient Engagement Advisory Committee. U.S. Food And Drug Administration. https://www.fda.gov/advisory-committees/committees-and-meeting-materials/patient-engagement-advisory-committee
79	Stanford AIMI. (2022b, April 1). Zach Harned - FDA, AI/ML, and medical devices [Video]. YouTube. https://www.youtube.com/watch?v=zu9r2Zsto58
80	Quantum Machine Learning | PennyLane Demos. (n.d.-b). https://pennylane.ai/qml/demonstrations/quantum-machine-learning/
81	Xanadu Discussion Forum. (n.d.). Xanadu Discussion Forum. https://discuss.pennylane.ai/
82	Slack. (n.d.-b). Slack. https://xanadu.slack.com/
83	Machine Learning Tutorials — Qiskit Machine Learning 0.6.1 documentation. (n.d.-d). https://qiskit.org/ecosystem/machine-learning/tutorials/index.html
84	Slack. (n.d.-d). Slack. https://qiskit.slack.com/
85	Before you continue to YouTube. (n.d.). https://www.youtube.com/@qiskit/streams
86	Kawchak, K. (2023, November 8). Kevin Kawchak on LinkedIn: Please take time to complete the following survey. Thank you. https://www.linkedin.com/posts/kevin-kawchak-38b52a4a_please-take-time-to-complete-the-following-activity-7128064512703807491-XFdy?utm_source=share&utm_medium=member_desktop
87	Kawchak, K. (2023a, September 21). Kevin Kawchak on LinkedIn: A September 21, 2023 Wall Street Journal article featured a quote by Jack. . .. https://www.linkedin.com/posts/kevin-kawchak-38b52a4a_a-september-21-2023-wall-street-journal-activity-7110643147478589440-Driw?utm_source=share&utm_medium=member_desktop
88	Kawchak, K. (2023a, September 17). Kevin Kawchak on LinkedIn: Please take time to complete the following poll: https://www.linkedin.com/posts/kevin-kawchak-38b52a4a_please-take-time-to-complete-the-following-activity-7109086495457624064-lmxD?utm_source=share&utm_medium=member_desktop
89*	More QML/QiML: LANL 1 2 3 Embeddings 4 5 6 7 8 Contextuality and Inductive Bias 9 Single Qudit Multi-class Classification 10 Expressivity 11 Hilbert Space and Quantum Interference 12 Quantum Feature Extraction 13 Quantum Feature Selection 14 Quantum Variational Classifier 15
90*	More FDA AI/ML: Good Machine Learning Practice (GMLP) 1 Breakthrough Devices Program 2 Artificial Intelligence and Machine Learning (AI/ML)-Enabled Medical Devices 3 Fmr. FDA Commissioner Dr. Scott Gottlieb on the Opportunities for A.I. in Healthcare 4