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Scientific Phone Apps
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The world of biomedical apps: their uses, limitations, and potential

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Abstract

Many significant biomedical discoveries of old were made in the private property of famous scientists e.g. Leeuwenhoek and Archimedes. Today, discoveries are made in brightly-lit, hi-tech, ergonomic buildings that house research institutes. While such development is advantageous in many aspects, the spatial restriction of research into well-organized structures may delay and limit the spontaneity necessary for discoveries. The smartphone and peripheral mobile devices have the potential to not only increase the productivity and mobility of biomedical research, but also restore some freedom from spatial constraints. One possible way this can occur is the development of a mobile biomedical lab that allows researchers to carry out core research processes 'on-the-go' without being spatially restrained within a building or availability of equipment. For this exciting prospect, we surveyed the Google and Apple app stores, discussing the limitations and the potential of this area. Based on the developments, it appears to be just a matter of time before the majority of biomedical labs processes and equipment become mobile, centred on the smartphone and peripheral devices.

Keywords: Smartphone, Mobile lab, Biomedical research, Spatial mobility

Introduction

Many significant scientific discoveries of the past were made in spatial freedom of the discoverers, often in the very homes of the scientists themselves or unusual places such as in a bath tub. In the biomedical field, the discovery of animacules by the "Father of Microbiology" - Antonie van Leeuwenhoek occurred in his draper shop. Today, biomedical research is typically done in brightly-lit, hi-tech, ergonomic buildings that house expensive laboratory equipment. While such structures have clear benefits in providing systematic progress and ease of operation, the spatial localization has a small con. No longer can the brilliant thinker, kept awake by great ideas, simply get up from bed and proceed to the basement lab to test something. Unless the scientist lives near the lab or never leaves the lab, the bathtub "Eureka" moment of Archimedes (as legends go) must be delayed for him to run to the lab and run experiments using some expensive equipment. To an extent, the quote "structures become shackles" from Christopher Nolan's 2012 Batman movie "The Dark Knight Rises" holds some truth in this context.

Nonetheless, recent developments in mobile devices may be a solution to restoring the much needed spontaneity and also boost productivity and convenience.

Smartphones have revolutionised the world we live in. With global smartphone number predicted to exceed 6.1 billion by 2020 (Lunden, 2015), the number of apps are also burgeoning. In the area of biomedical research, mobile apps promise to increase the productivity and mobility of biomedical research as a truly mobile biomedical lab (Sim et al., 2015).

The nature of modern biomedical research incurs high costs. From expensive specialized equipment and consumables, there are other considerations involving rental, safety, and specialized infrastructure (e.g. for tissue culture). On top of the equipment, computers are required to control these devices and facilitate data analysis (e.g. flow cytometry). This necessary pairing of computer and equipment further constrains the researcher to a specific location within the lab. In this aspect, mobile apps and peripheral devices that displace computers or other equipment can aid to mobilize research processes, contributing to significant

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Table 1 Examples of biomedical apps classified under "Sequence analysis and alignment"

App name	OS	Description	App type	Hardware
ALS Online	Android	Align DNA sequences	Native (Comp Lab)	None
DNA analyser	Android	Analyses DNA or RNA sequence and GC content	Native (Comp Lab)	None
DNA2App - Sequence analyzer	Android	Analyses nucleic acid sequences	Native (Expt Lab)	None
DNAApp: DNA sequence analyzer	Android & iOS	Open and analyze DNA sequencing files (ab1)	Native (Expt Lab)	None
DNA & Co	Android	Transcript and translate DNA sequences to RNA and protein sequence	Native (Comp Lab)	None
DNA Easy	Android	Reverse complement of DNA	Native (Comp Lab)	None
DNA Shot	Android	Identify and displays DNA sequences from pictures	Hybrid (Expt Lab)	Camera
DNA to RNA	iOS	Converts DNA sequence into mRNA vice versa	Native (Comp Lab)	None
DPSAT	Android	Analyze nucleotide and protein sequences	Native (Comp Lab)	None
Gene Aligner	Android	Perform pairwise gene global and local alignments, and generate dot plots for the alignment	Native (Expt Lab)	None
Genetic Code	Android	Translate nucleotide codons	Native (Comp Lab)	None
SimAlign	Android	Align sequences of genes and proteins	Native (Expt Lab)	None
Pairwise Protein Aligner	Android	Generates pair wise protein global and local alignment. A dot plot for the alignment can also be created	Native (Comp Lab)	None
Genome	iOS	Sequence instantly and transcribe sample sequences	Hybrid (Comp Lab)	None

savings not only in terms of equipment costs, but also reducing the rental space and equipment setup and delivery costs.

Such connectivity can be fulfilled utilizing the in-built wireless connectivity (WIFI, Bluetooth, NFC, Infrared, etc.) of the typical modern smartphone. These have already allowed add-on peripheral devices and sensors to further expand the reach of capabilities, e.g. thermostat sensors connected wirelessly can further open up capabilities of the smartphone. The prospect of wirelessly connected peripheral devices most certainly open up great potential in the displacement of lab equipment and improving the mobility of biomedical research. Given that the typical new smartphone is also generally under-exploited in its

Table 2 Examples of biomedical apps classified under "Structure builder and viewer "

App name	OS	Description	App type	Hardware
Atomdroid	Android	Include molecular viewer and builder functions for geometry optimization and Monte Carlo simulation for small molecules	Hybrid (Comp Lab)	None
iMolecule Builder	iOS	Support formats from PDB, Sybyl and Crystallographic information. Visualize and build 3D molecules from scratch	Native (Comp Lab)	None
iProtein	iOS	Provide access to PDB and Swiss- Prot, RefSeq, Ensembl, etc. Support accurate homology modeling by generating protein structural models	Hybrid (Comp Lab)	None
PocketMDS	iOS	Perform molecular dynamics simulation of Lennard-Jones fluids	Native (Comp Lab)	None
Yasara[a]	Android	Support graphics, molecular modeling and docking	Native (Comp Lab)	None
Molecular Dynamics	Android	Perform molecular dynamics simulation of particle motions and thermal changes of the molecular systems	Native (Comp Lab)	None
3D-Molecule View	Android	Built on top of jmol librabry and support multiple input formats to visualize 3D molecular structure	Native (Comp Lab)	None
Ball&Stick	iOS	Support visualization and local storage of input from PDB	Hybrid (Comp Lab)	None
Biochemistry Mnemonics	Android	Provide an interface of the Protein Data Bank to visualize or inspect protein structures in 3D or 2D.	Hybrid (Comp Lab)	None
iMolview Lite	Android & iOS	Browse and view 3D protein and DNA structures	Hybrid (Comp Lab)	None
NDKmol - molecular viewer	Android	View three dimensional structures of proteins, nucleic acids and small molecules	Native (Comp Lab)	None
PDB Xplorer	Android	Visualize 3D structures of proteins, nucleic acids and small molecules	Native (Comp Lab)	None
Pymol	iOS	Display proteins, nucleic acids, and other chemical structures, Support formats including pdb, sdf, mol2, pse, etc.	Native (Comp Lab)	None

[a]Krieger et al. Bioinformatics, 30(20), 2014 [doi: btu426]

Table 3 Examples of biomedical apps classified under "Equipment displacement"

App name	OS	Description	App type	Hardware
Colony Count	Android	Count bacterial colonies	Native (Expt Lab)	Camera
Colony Count BETA	Android	Count bacterial colonies and perform measurements of bacterial growth on agar plates.	Native (Expt Lab)	Camera
Colony Counter	iOS	Count bacterial colonies	Native (Expt Lab)	Camera
Fast Counter	iOS	Count bacterial colonies	Native (Expt Lab)	Camera
Promega Colony Counter	iOS	Count bacterial colonies; Manually mark additional colonies or remove false positives; Quadrant-zoom for easier adjustments.	Native (Expt Lab)	Camera
Gelapp: DNA&Prot Gel Analyzer	Android & iOS	Auto detection of bands and calculation of band sizes	Native (Expt Lab)	Camera

processing power and range of available sensors for research purposes, there is great promise for the future development in this area. It is only a matter of time before everyone owns core lab equipment in their smartphones to do research anytime and anyplace.

Review

To date, there are already reports of smartphones being used for spectrophotometry (https://publiclab.org/wiki/smartphone-spectrometer), enzyme-linked imunosorbent assays (Medgadget, 2015 & Berg et al., 2015, see http://www.medgadget.com/2015/02/elisa-immunoassay-disease-testing-on-your-smartphone.html) and more impressively as a potential mass spectrophotometer (Nemiroski et al., 2014). Similarly, there is already a number of mobile apps available for biomedical research. As of early 2016, a search using key words such as "bioinformatics","biomedical","biomolecular", "biotechnology", "DNA", "protein", "genomes", "colonies", and "genes" returned more than 486 hits in Apple App Store and 1536 hits in Google Play Store. Out of these apps, only about 65 of the search results were directly relevant to biomedical research. 23 were native apps used for lab processes and 42 were hybrid apps for repository information. Ranging from laboratory calculators ('An Array of genetic Tools from Gene Link,Inc' app) to viewing DNA and protein structures (e.g. NDKmol app), we found the apps generally fit into nine categories: analysis & alignment tools; structure builder & viewer; equipment displacement; peripheral device dependants; laboratory calculator; protocol assistant; database and others.

Sequence analysis & alignment (see Table 1)

Sequence analyzers allow handy and quick viewing of DNA or RNA or protein sequences on-the-go (e.g. DNA2App, see Sim et al., 2016). Some aid in opening sequencing files (e.g. DNAapp, see Nguyen, et al., 2014), bringing mobility to an analysis that was once limited to desktop/laptops. With these apps, pictures of sequences can also be processed (e.g. DNA Shot app) making impromptu lab analysis easier and more convenient than ever before, even without computers. With the sequences available, sequence alignment analyses are typically next used. However for such analysis, the small screen of portable devices often makes it challenging for viewing long sequences and perform other complex analysis. This limitation may in time be addressed by significant developments in the interface and design of smartphone technology, perhaps through gesture or eyeball tracking.

Molecular builder and protein structure viewers (Table 2)

One way to study a molecule is to investigate its structure and possible structural interactions. Apps in this category allow users to visualize protein structures, build customized molecules, and perform molecular dynamic simulations under various conditions (e.g. Atomdroid app).

Equipment displacement apps (Table 3)

Leveraging on the inbuilt sensors, apps in this category enable the smartphone to displace laboratory equipment that are often costly and bulky. Such equipment can range from colony counters to gel documentations systems.

Table 4 Examples of biomedical apps classified under "Peripheral device dependants"

App name	OS	Description	App type	Hardware
RadHalo	Android	Allows remote acess to Thermo Scientific Radiation detection products for configuration and management	Hybrid (Expt Lab)	Thermo Scientific Radiation Detection products
SpectBT - Spectrophotometer App	Android	Controls a Bluetooth based mobile Spectrophotometer, able to store and export multiple readings on to excel sheets	Native (Expt Lab)	APD Bluetooth based mobile Spectrophotometer
Thermo Scientific Centri-Vue	Android	Connects with Thermo Scientific sorvall LYNX superspeed centrifuge to provide remote excess to the centrifuge functions.	Hybrid (Expt Lab)	Camera; Thermo Scientific Sorvall LYNX superspeed centrifuge
VersaCool Mobile Communication	Android	Connects to VersaCool instruments and allows remote monitoring & control of functions Via the mobile device	Hybrid (Expt Lab)	VersaCool Refrigerated Bath Circulator

Table 5 Examples of biomedical apps classified under "Laboratory calculators"

App name	OS	Description	App type	Hardware
An Array of genetic Tools from Gene Link,Inc	iOS	Provides calculators for laboratory protocols	Hybrid (Comp Lab)	None
BioChem Tools	Android	Provides calculations for laboratory protocols	Native (Expt Lab)	None
CloningBench	Android	Provides calculators to compute laboratory experiments etc. cloning	Native (Expt Lab)	None
Solution Calcutor	Android	Provides calculators to compute volumes etc. concentration	Hybrid (Comp Lab)	None
Promega	Android	Provides reference information, videos and calculators to compute laboratory experiments	Hybrid (Comp Lab)	None

Colony counters alleviate an otherwise laborious tedious manual counting process in applications ranging from determining transformation efficiencies (Chan et al., 2013) to determining microbial load in clinical samples and food samples. Colony counting apps provide an automated processing of agar plate images and count the detected colonies. Although the accuracy of the detection is often dampened by factors such as the camera itself, lighting, angle and presence of reflection spots, the incorporation of additional image processing algorithms might compensate for these factors. It is certainly expected that future colony apps will also distinguish colonies based on their morphology and perform microbiological analysis through comparisons with databases. With the smartphone camera, these apps can make colony counters widely available and mobile (bringing the counter to the plate rather than the plate to counter), as well as save space and equipment cost.

Table 6 Examples of biomedical apps classified under "Protocol assistant apps"

App name	OS	Description	App type	Hardware
Buffers	iOS	Design buffer solutions for pH control	Hybrid (Expt Lab)	None
DNA toolkit	Android	Analyze DNA sequences and display available restriction sites	Native (Comp Lab)	None
Fluorescence Spectraviewer	iOS	Plots and compares the compatibility of fluorophores	Hybrid (Comp Lab)	None
NEB Tools	iOS	Selects restriction enzymes based on recognition sequences, able to suggest buffer & reaction conditions	Hybrid (Comp Lab)	None

Another equipment displacement would be that of gel documentation systems for taking pictures of protein and agarose gels. For accurate determination of the DNA and protein band sizes in electrophoresis, distance measurements and graph plotting with comparison to the marker standards are necessary. Due to the tediousness of distance measurements, it is a more common practice to estimate the size based on quick comparisons with the marker standards. With advanced image processing algorithms and the smartphone camera, apps (e.g. Gelapp, see Sim et al., 2015) have been developed to make this process simpler and automated, decreasing reliance on human estimations, bulky gel documentation equipment, and doing away with laborious graph plotting. Although limited by the inability to emit UV or blue light necessary for DNA gels, handheld UV/blue light lamps can easily be used to solve this problem. With such apps, every smartphone owner can also own a portable gel documentation system, a boost towards quantitative biology and improved reporting of band sizes. With the smartphone gel analyzers, scientists no longer need to book or ensure the availability of machines for their gel analysis.

Peripheral device dependants (Table 4)

Apps such as RadHalo for radiation monitoring (see http://info3.thermoscientific.com/RadHalo?ca=radhalo) and Thermo Scientific Centri-Vue for centrifuges (Thermo Scientific, 2015) allow users to pair their smartphones with peripheral devices via Bluetooth for remote access. Apart from control, results can also be instantaneously viewed on the smartphone. This real-time connection enables close monitoring, minimizing reaction times. Other examples include the SpectBT- Spectrophotometer app that controls a portable Bluetooth-enabled Spectrophotometer. At present, apps in this category are rare due to many limitations. Firstly, they are often limited at times by the range of the connectivity (although some use internet connectivity), thus requiring close proximity of the devices during use. Secondly, the benefits are limited by the automation of the devices connected. Should the equipment itself require many manual steps (e.g. loading samples), off-site control is rendered meaningless. Lastly, these apps typically control only specific devices, requiring many apps to controls various devices. A universal remote controller may in time solve be made once standardized protocols are in place.

With the ever increasing technology where sensors are added into new smartphones all the time, this category of apps may decrease after soon increasing. It is certain that smartphone manufacturers would gradually

Table 7 Examples of biomedical apps classified under "Database"

App name	OS	Description	App type	Hardware
ATG Sequence Search	Android	Enables DNA and Protein sequence queries from National Center for Biotechnology Information (NCBI)	Hybrid (Comp Lab)	None
Atom 3D	Android	Provide access to the mnemonics database for filtering and editing mnemonics of particular subjects	Native (Comp Lab)	None
Harmonizome	Android	Integrate various databases & online resources	Hybrid (Comp Lab)	None
iOncology	Android	Provide access to database of enzymatic and cell-based data of several gene families	Hybrid (Comp Lab)	None
Mentha the interactome browser	Android	Analysis of selected proteins in the context of a network of interactions.	Hybrid (Comp Lab)	None
RCSB PDB Mobile[b]	Android & iOS	Provide access to RCSB PDB resources	Hybrid (Reference/ learning)	None
SimGene	Android	Provide up to date, cross reference and integrated genome browser information	Hybrid (Comp Lab)	None
PSICQUIC Client	Android	Provide access to the molecular interaction data repository	Hybrid (Comp Lab)	None
BioGPS	iOS	Browse gene information	Hybrid (Comp Lab and Reference/Learning)	None
FlyExpress[a]	iOS	Explore gene expression patterns from Fruit Fly embryogenesis	Hybrid (Comp Lab)	None
Yeast Genome	iOS	Browse genes and fundamental chromosomal features of *Saccharomyces cerevisae*	Hybrid (Comp Lab)	None
iSpartan	iOS	Provide atomic and molecular properties, NMR and infra spectra, molecular orbitals and electrostatic potential map Model 3D structure of small molecules and estimate energies for alternate conformers	Hybrid (Comp Lab and Reference/Learning)	None

[a]Quinn et al. Bioinformatics, 2014 [doi: btu596]
[b]Sudhir et al. Bioinformatics, 28(21), 2012 [doi: bts518]

incorporate popular peripheral sensors to enable direct measurements in the future.

Laboratory calculators (Table 5)

Chemical calculations ranging from determining and preparing concentrations of chemical solutions and samples (e.g. ELISA, PCR, etc.) are routine in labs. Apps in this category often do more than just calculate, but also facilitate these processes by providing formulas and references. However, most of them lack to include a history of the previous calculations and the incorporation of video tutorials to guide certain procedures. With good laboratory standard protocols shown in videos, such apps would be a reference point for complex procedures, probably aiding to standardize scientific protocols for process reproducibility.

Protocol assistant apps (Table 6)

There are complex processes in biomedical research that would benefit from memory assistance to recall details. Examples of such processes includes enzyme restriction sites and their incubation conditions which not only grow, but frequently require refreshing. To benefit such processes, apps (e.g. DNA2app, see Sim et al., 2016) allow users to analyse a sequence of interest, showing all possible restriction sites.

Table 8 Examples of biomedical apps classified under "Others"

App name	OS	Description	App type	Hardware
ForSight - Mutation Predictor	Android	Generates mutation rules from wild-type and mutant sequences to predict subsequent sequence based on the rule applied	Native (Expt Lab)	None
Mass Spectrometry Peaks	Android	Calculation of chemical formula from exact mass measured in mass spectrometry. Suited for instant identification of metabolites (small molecules) in non-targeted (open) metabolomics approaches	Native (Expt Lab)	None

Expt/Comp Lab = Experimental/Computational lab
Only apps from Google Play Store and Apple App Store are shown. "Expt" and "Comp" lab classifications based on their functions towards experimental lab processes. Classifications of native and hybrid apps are defined according to
Salesforce. (see https://developer.salesforce.com/page/Native,_HTML5,_or_Hybrid:_Understanding_Your_Mobile_Application_Development_Options).

Database (Table 7)

Apps in this category are the most common. They function to give users the convenience of access to pre-stored databases right on their smartphones. Some facilitate the communication of information to others However, only one of the apps (Atom 3D) we surveyed have the database locally stored in the phone. While this may take up valuable storage space, it allows the app to function without internet access. The feasibility of local storage is naturally determined by the size of the database, however, future apps may thus allow selective syncing of the database as a compromise between weaning off internet dependency and storage space usage.

Others (Table 8)

There are a few apps that did not fall into the previous categories but were clearly linked to biomedical research. These apps typically require specific keywords and they can range from generating mutations to aiding mass spectrometry peak analysis (see Table 8).

The mobile biomedical lab

The obvious lack of collaborations between app developers, hardware engineers and biomedical researchers is the main obstacle to the smartphone being exploited to mobilize core biomedical processes. The constraint of a small screen currently makes it difficult for complex analysis, but this may be addressed by the overall trend of increasing screen sizes in newer models of smartphones. The changes in mobile phones have come full circle. From going smaller to smaller in the 1990s, smartphone screens are now getting larger. It is foreseeable that the increasing size will be restricted by the market - no one wants to carry a 14 inch smartphone.

For this problem, there are already interesting solutions round the corner. Where there are problems, there is also innovation. One potential solution takes the form of a bracelet to project the smartphone screen onto the arm the user (http://www.entrepreneur.com/article/240580). Projected on other surfaces, the screen size can be enlarged as desired. This technology is particularly exciting as it also addresses the potential problem of contact contamination in a biomedical lab.

Conclusion

The overall potential of smartphones is gradually unlocked by apps and peripheral devices. There are some smartphone based devices that are not found in the app stores, but there is a clear displacement of lab equipment using mobile technology, such as in the areas of microplate reading (Berg et al., 2015; Christodouleas et al. 2015; Fu et al., 2016), live cell imaging (Walzik et al., 2015), microfluidics for cancer detection (Barbosa et al., 2015), food allergen detection (Coskun et al., 2013), and immunochromatgraphic detection of bacteria (Rajendran et al., 2014).Nonetheless, there are areas where no changes are expected; and this is the work of dangerous chemical and pathogens (e.g. Biohazard Class 3 work). With the requirement of specialized safety infrastructure, a significant revolutionary change would have to occur before technology can overcome this.

Regardless of drawbacks, there is much to look forward to. As technology advances, smartphones apps and devices will increase. Researchers should continuously tap on existing technology to heighten research efficiency and accuracy. The advent of the mobile biomedical lab may be just round the corner.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SKEG edited and directed the writing of the review. JK assisted with populating the table and providing draft versions.

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References

A Simple Bracelet Can Turn Your Arm Into an Interactive Smartphone Display. [Online[Available at http://www.entrepreneur.com/article/240580 . [Accessed 19 February 2016]

An Array of genetic Tools from Gene Link,Inc (2012)– Version: 1.2.1 in iTunes. [cited 2015]; from https://itunes.apple.com/us/app/array-genetic-tools-from-gene/id399712676?mt=8

Atomdroid (2012)– Version 1.5 in google play store. [cited 2015]; from: https://play.google.com/store/apps/details?id=org.atomdroid&hl=en

Barbosa AI, Gehlot P, Sidapra K, Edwards AD, Reis NM. Portable smartphone quantitation of prostate specific antigen (PSA) in a fluoropolymer microfluidic device. Biosens Bioelectron. 2015;70:5–14.

Berg B, Cortazar B, Tseng D, Ozkan H, Feng S, Wei Q, Chan, R.Y.L., Burbano, J., Farooqui, Q., Lewinski, M. and Di Carlo, D. Cellphone-based hand-held microplate reader for point-of-care testing of enzyme-linked immunosorbent assays. ACS Nano. 2015;9(8):7857–66.

Chan WT, Verma CS, Lane DP, Gan SKE. A comparison and optimization of methods and factors affecting the transformation of Escherichia coli. Biosci Rep. 2013;33(6):931–7. doi:10.1042/bsr20130098.

Christodouleas DC, Nemiroski A, Kumar AA, Whitesides GM. Broadly Available Imaging Devices Enable High-Quality Low-Cost Photometry. Anal Chem. 2015;87(18):9170–8.

Coskun AF, Wong J, Khodadadi D, Nagi R, Tey A, Ozcan A. A personalized food allergen testing platform on a cellphone. Lab Chip. 2013;13(4):636–40.

DNA Shot (2014) – Version 1.0 in google play store. [cited 2015]; https://play.google.com/store/apps/details?id=com.dnashot.v0

ELISA Immunoassay Disease Testing on Your Smartphone. (2015, February 04). Retrieved January 25, 2016, from http://www.medgadget.com/2015/02/elisa-immunoassay-disease-testing-on-your-smartphone.html

Fu Q, Wu Z, Li X, Yao C, Yu S, Xiao W, Tang, Y. Novel versatile smart phone based Microplate readers for on-site diagnoses. Biosens Bioelectron. 2016;81:524–31.

ForSight - Mutation Predictor (2015)– Version 1.0.1 in google play store. [cited 2015]; https://play.google.com/store/apps/details?id=com.ipaulpro.afilechooserexample&hl=en

GelApp DNA&Prot Gel Analyzer (2015)- Version 1.1.7 in Google Play Store. [cited 2015]; from: https://play.google.com/store/apps/details?id=com.bii.GelApp&hl=en.

Lunden, I, (2015) 6.1B Smartphone Users Globally By 2020, Overtaking Basic Fixed Phone Subscriptions, in Techcrunch

MyGels (2015)- - Version 1.1.1 in Apple App Store. [cited 2015]; from: https://itunes.apple.com/nz/app/mygels/id891708953?mt=8

Molecular Dynamics (2014)- - Version 1.2 Android Apps on Google Play. 2014; from: https://play.google.com/store/apps/details?id=com.mkulesh.mmd&hl=en.

NDKmol (2015) - molecular viewer– Version 0.95 in google play store. [cited 2015]; https://play.google.com/store/apps/details?id=jp.sfjp.webglmol.NDKmol&hl=en

Nemiroski A, Christodouleas DC, Hennek JW, Kumar AA, Maxwell EJ, Fernández-Abedul MT, Whitesides, G. M. Universal mobile electrochemical detector designed for use in resource-limited applications. Proc Natl Acad Sci. 2014;111(33):11984–9.
Nguyen P-V, Verma CS, Gan SK-E. DNAApp: a mobile application for sequencing data analysis. Bioinformatics. 2014;30(22):3270.
Public Lab Wiki documentation. (n.d.). Retrieved January 25, 2016, from https://publiclab.org/wiki/smartphone-spectrometer
RadHalo (2015)- – Version 1.0.0 in google play store. [cited 2015]; from: https://play.google.com/store/apps/details?id=com.thermofisher.mobile.android.btservicemodule.app&hl=en
Rajendran VK, Bakthavathsalam P, Ali BMJ. Smartphone based bacterial detection using biofunctionalized fluorescent nanoparticles. Microchim Acta. 2014;181(15–16):1815–21.
Sim JZ, Nguyen PV, Zang Y, Gan SKE. (2016) DNA2App: Mobile sequence analyzer. Scientific Phone Apps and Mobile Devices. Vol 2(2). doi:10.1186/s41070-016-0004-7.
Sim JZ, Nguyen PV, Lim PHJ, Su TTC, Gan SKE. (2015) The Rise of the Mobile Lab: the Use of Smartphone Apps for Biomedical Research. Asia Pacific Biotech News, Vol 19, 58 doi:10.1142/S021903031500021X.
SpectBT- Spectrophotometer App (2015)- – Version 1.0.3 in google play store. [cited 2015]; from: https://play.google.com/store/apps/details?id=com.apd.spectbt&hl=en
Smartphone Medical Apps to Turn Into Cancer-Detecting Tools. (2014, February 08). Retrieved January 25, 2016, from http://nuviun.com/content/smartphones
Thermo Scientific Centri-Vue (2015)- – Version 1.0.0 in google play store. [cited 2015]; from: https://play.google.com/store/apps/details?id=com.thermofisher.mobile.android.centrivue&hl=en
Walzik MP, Vollmar V, Lachnit T, Dietz H, Haug S, Bachmann H, Fath, M., Aschenbrenner, D., Mofrad, S.A., Friedrich, O. and Gilbert, D.F. A portable low-cost long-term live-cell imaging platform for biomedical research and education. Biosens Bioelectron. 2015;64:639–49.