The Embedded Development Tools You Did Not Have When Growing Up

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Adriana Becker-Gómez was born in Mexico City, Mexico. She received the B.S.E.E. degree from Universidad Iberoamericana, Mexico. She obtained the M.S. degree in Electrical Engineering from Texas A&M University, College Station, and her Ph.D. in Electrical Engineering from the University of Texas at Dallas. In 1992 she was a Lecturer and a Teaching Assistant at Universidad Iberoamericana. In 1990 she worked as a Research and Development Engineer and Project Leader for the Automotive Industry in the area of Embedded and Software Systems. She also worked as an Assistant to the Dean of the Graduate Studies of Engineering Division at Universidad Nacional Autonoma de Mexico, Mexico in 1995 .In 2000 she was a grader at Texas A&M University. In 2001 she interned in the Preamp R&D SP Group at Texas Instruments, Dallas, TX, and at Intersil Corporation, Dallas / Milpitas, as a Design Engineer, in the High Performance Analog Group in 2005. She worked at Intersil as a Senior Design Engineer in the Analog and Mixed Signal-Data Converters Group. In 2009 she joined Rochester Institute of Technology in Rochester, New York as an adjunct professor in ECT-ET Department. Currently she works as a lecturer in the Kate Gleason College of Engineering in the Computer Engineer Department. Her research interests are in the Design of Low Power Analog and Mixed Signal circuits, Data Converters, Sensors, Embedded Systems and Signal Processing.

Mr. Carmen A Bovalino III, Rochester Institute of Technology, Student

Carmen Bovalino is currently a fourth year Computer Engineering Technology student at Rochester Institute of Technology in Rochester, New York. He is a Dean's List student as well as in the Honors Program at RIT. His passion lies within software and embedded systems. Carmen is constantly coming up with new embedded side projects and keeping up to date on the newest technologies. He has been designing circuits and building prototypes since he was nine years old. His first software program was written when he was fifteen and has been selling worldwide ever since. Carmen is also very passionate about intelligent lighting and has been a Lighting Designer for eleven years. He has been the LD for countless productions ranging from theater to national rock concerts. Carmen has worked for Synaptics Incorporated and Toyota Motor Engineering & Manufacturing so far and cannot wait to start a career in embedded systems! He can be contacted at cab2753@rit.edu.

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Sajin George is doing his masters in Electrical Engineering at Rochester Institute of Technology(RIT). Working with his uncle at his repair shop, sajin was introduced to electronics at a very young age. He perused his Bachelors is Electronics and Communication at Karunya University, India after which he worked at Thinklabs Technosoultions Pvt. Ltd. at Indian Institute of Technology Bombay, India. At Thinklabs he was involved in Training and Design of Robotic and Embedded platforms for education and Robotics. After a year at Thinklabs he joined RIT for his masters and is now working with Prof.

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Abstract

In this paper we give a broad overview of the embedded tools that engineering technology students at the Rochester Institute of Technology (RIT) have been discovering and using for courses, laboratories, senior design and in their personal projects. By no means is this an extensive but a comprehensive list of embedded debugging tools used by students and faculty in our department. The important aspect is that in most of the cases, students have discovered these tools and integrated them into their toolboxes. Faculty and universities should also be on the lookout to integrate these tools into the curriculum by listening to students and their needs.

Introduction

A large number of current engineering and engineering technology instructors grew up in an era where embedded systems development was extremely expensive and inefficient. You were either working at a medium to large company which could afford tens of thousand dollars in equipment e.g. oscilloscopes, logic analyzers, emulators, compilers, assemblers, memory and microcontroller programmers or you had access to similar equipment available at the university. In the worst case you were in a small company where you were developing products and doing the best you could with very basic tools that did not allow thorough development or debugging.

Today's technology has changed and emulation and debugging capabilities are now embedded into embedded $5 platforms (e.g. Texas Instruments (TI) Launchpad). Personal oscilloscopes, logic analyzers, protocol analyzers are now in the range of $50-$500, they can be used on a computer, tablet or smart phone. Students and institutions can now afford to have access to these embedded tools that were not available five years ago.

On the other hand, several years ago Radio Frequency (RF) design was considered a dark art. To be able to incorporate wireless communications in embedded systems typically added hundreds of dollars to the price tag of already expensive systems. Today the concept of Internet of Things (IoT) is an everyday task and if your embedded device does not have connectivity to the internet, smartphone or tablet it is in serious risk of not being adopted by consumers. The current plethora of applications and libraries available for embedded systems make it possible to have systems connected through a mesh of wired and wireless networks that display real time data and control devices through the internet. Most of the communications with RF technologies in embedded systems is by means of serial communication protocols.

The smartphone is becoming a development platform that students can use to interface and control devices. In the most recent IEEE spectrum the article "Generation Smartphone"[9] gives us a glimpse of what students will be designing in the future and how the interconnected society will look. Tablets are headed the same way and we will see a really wide variety of devices controlled and interfaced to these. Several universities have already identified the need for students to have access to these types of embedded tools in order to reduce access to crowded labs or for homework assignments [4, 7].

This paper presents some embedded tools that have already been integrated into the engineering technology program at RIT as well as some other tools that the students and faculty have discovered and are using to develop their projects and applications. Of course this is not a comprehensive list, but rather our personal exposure to these *embedded tools you as an educator did not have when you grew up*.

The work is going to be divided into several sections. The next section contains the common features that these tools have; there are some tools that have each end every one of these features, while others just have a subset. We will not provide a thorough cross matching of all these features and the reader is welcomed to find more information at the respective websites. We would also present a Q&A responded by students and faculty using these tools, each interviewee responds to a set of directed questions in an attempt to give a fair unbiased view of the embedded tool. In some cases personal comments are added to make the contribution more complete. It is important to denote that some of these tools have only being used by the interviewee and have not yet adopted to be integrated into courses. The interesting aspect is how students are bringing these tools to help them be more productive in the laboratory.

We first divide the embedded tool features into two large domains, Analog and Digital.

Analog

Analog embedded tools contain two mayor features, signal measurement and signal generation. In reality all signals are generated and measured using digital devices, but the sampling frequency allows performing analysis as if they were continuous signals.

<u>Oscilloscope</u>
The first instrument that will be described will be the oscilloscope. This is one of the basic measurement tools that are the foundation in the analysis of electronic systems and students are introduced to its use in their freshmen year. To have a portable oscilloscope is a great feature.

<u>Function Generator</u>
A function generator is the instrument that generates a series of periodic waveforms as well as it can have modulation capabilities or work as a random noise generator. Sometimes the function generators can be preloaded with designed signals which are commonly known as arbitrary waveform generator. To have one especially to be used as input to filters is really nice.

<u>Power Supply</u>
Modern embedded systems work with different voltages in order to save power. Traditional voltages are +5V and +3.3V, but there are some designs that could require negative voltages as well as supplementary positive voltages. In addition to be programmable in voltage, it should have current sourcing capabilities. If the embedded tool is powered by USB, then it is already limited to 500 mA, otherwise if the tool is powered externally more current can be provided. We would need more current to drive motors, LEDs, etc.

<u>Reference Voltages</u>
While a power supply can be used as a reference voltage, a power supply can be subject to ripple voltage due to constant current handling capabilities, as well as switching noise due to the

instantaneous current demand of digital systems. In addition a power supply may be sensitive to temperature. It is very common especially in systems that require Analog to Digital and Digital to Analog conversions (A/D and D/A) to use a bandgap reference voltage which is a very reliable temperature independent voltage reference. Again, this is a nice feature to have.

Number of channels
To measure analog signals from one to four channels are common, since the signals are relatively complex and high in bandwidth. Two channels is the standard on an oscilloscope.

Single or differential ended channels
An analog signal can be single ended which means that it carries a changing value on one wire while the other wire is used as reference. A differential signal has two signals of opposite values on each wire in addition to a reference wire. A differential signal is more immune to common noise since both signals are subtracted at the receiver. Since they had opposite signs the effect is to double the dynamic range of the signal while a common added noise affects both signals equally and after subtraction it is removed to a certain extent. Common electromechanical signal specifications are e.g. RS-232 (single ended); Inter Integrated Circuit (I2C) (single ended); Serial Peripheral Interface (SPI) (single ended); RS-422 and RS-485 (differential); USB (differential); Controller Area Network (CAN) (differential).

Digital

As mentioned previously, all the instruments analyzed in this paper are digital in nature, even if they perform analog functions. In difference to their analog counterparts, digital signals require multiple channels and traditionally are a multiple of bytes (e.g. 1, 2, 4, 8). Digital signals are have only two values thus no precision is required, just a threshold voltage, and in some cases hysteresis is required to make the signal more immune to noise.

Logic Analyzer
Digital signals have a meaning either by themselves or as a collection. In addition, the time relationship among all signals is a critical part of the analysis. This is where a large number of channels are very desirable. One of the most important characteristics of a logic analyzer is that trigger sequences can be programmed and the data before and after the event can be captured , decoded and displayed. Triggers can be as simple as a signal level or edge or as complex as represented by a finite state machine with a combination of values and edges. It is very common nowadays to use a logic analyzer to decode serial protocols; we will describe these in the next section.

Protocol Analyzer
Modern embedded systems are characterized by having available a large number of serial communication protocols some mentioned in the single ended/differential section such as I2C, SPI, and CAN.. A common misconception is that RS-232 is a protocol, while it is an electromechanical specification that can carry asynchronous and synchronous communications. RS-232 specifies that the signals transmitted and received will be positive and negative; in this case if we connect an embedded tool to negative voltages it could be damaged.

The most common serial protocols used in embedded devices are e.g. Universal asynchronous receiver and transmitter (UART) that carries from 5 to 8 bits information plus optional parity.

The time required to transmit a byte of information can be 10 or 11 bauds (baud=symbol/second) depending on the number of stop bits, speeds of 115,200 bauds are common nowadays; I2C is very common and is based traditionally on a configuration with one master and multiple slaves. Most of the time the communication is within the printed circuit board (PCB). There can be up to 128 slaves (there are extensions to the protocol) and the transmission is carried over 8 bit quantities, the maximum speed is around 400Kbits/sec; SPI is based on a shift register architecture where data is pushed into the register serially to write and at the same time is pushed out of the shift register to read, if we just want to read we send bogus data and if we just want to write we discard the output data, speed is common in the 1Mbit/sec and 2Mbits/sec, it can be daisy chained to cascade multiple devices, but the most common configuration is to have a chip select for each SPI device, it is not required to have powers of two multiple of bytes; CAN is very common in the automotive industry and surprisingly very popular with students who want to mess with their cars, it is a differential specification where the signal is unipolar (no negative voltages are required), high speeds in the range of Mbits/sec are possible and it is very robust to noise; USB is a very common differential interface, but the bandwidth required is larger than the available by most of the embedded tools presented here.

Pattern Generator
A pattern generator can load excitation signals to be fed to a digital system, the same way that a testbench generates excitation signals for a device under test (DUT). Some of the embedded tools allow signal pattern generation.

Devices

In order to be fair to all embedded platforms reviewed, the approach taken in this paper is that students and faculty that have acquired or used a particular embedded tool answered the same set of questions regarding that particular tool. The language used in the questions is informal to try to convey the experience of the student or faculty rather than a formal engineering evaluation of the tool. The questions are the following:

- Make and Model
- What were your original debugging requirements?
- What big piece of lab equipment it substitutes?
- How did you find about it?
- How have been using it? (look above in introduction)
- Price? Is it worth it?
- Would you recommend it to other students?
- Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?
- Cool things about it?
- Any other features not available at university's available equipment?
- Do you use it for School/Personal/Both use?

The list of evaluated devices is the following in no particular order:

- Digilent – Electronics Explorer board[2]
- Digilent – Analog Discovery[2]
- Saleae –Logic 16[5]

- Oscium – iMSO-104[8]
- Oscium – LogiScope[6]
- Seeed Studio - DSO Quad[3]
- Dangerous Prototypes – Bus Pirate [1]
- XMEGA Xprotolab[10]

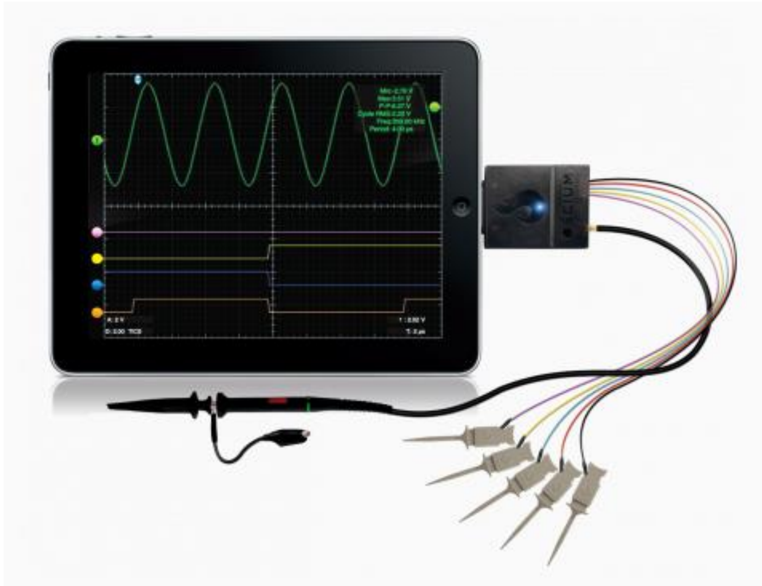
User	Computer Engineering Technology faculty
Make and Model	Digilent – Electronics Explorer Board
What were your original debugging requirements?	We have been looking for equipment that could replace aging instruments in the lab as well as some equipment that students can buy or rent to be used in different courses. The requirements are analog and digital signal analysis and generation. Especially serial protocols used widely in embedded systems courses and logic analyzer capabilities.
What big piece of lab equipment it substitutes?	Oscilloscope, logic analyzer, power supply, function generator, multimeter and frequency counter. This has all features listed.
How did you find about it?	During ASEE conference in 2010 I was given one after participating in a workshop.
How have been using it?	For everything, lab demonstration, lab debug, senior designs, independent projects, the whole spectrum.
Price? Is it worth it?	Academic price $399. I think it may not be economically feasible for students to buy, but the department can buy them and lease to students as being done with other boards at a similar price.
Would you recommend it to other students?	This is the mother of all low cost, portable embedded tools, it has all the features required and more.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	It is a complement in some cases and in some others it brings modern features not available in the equipment we already have. If we update all lab equipment with state of the art mixed signal oscilloscopes (MSO), then it may just be a complement, but as of today it may be more productive. The bandwidth and sample frequency on commercial MSOs is a big difference.
Cool things about it?	Everything, it is a really amazing piece of equipment for the price.
Any other features not available at university's available equipment?	As mentioned before, it brings serial protocol decoding which we currently do not have. Students can save waveforms to complement their reports.
Do you use it for School/Personal/Both use?	I use it for preparing laboratory experiments in my office or at home. I personally lend it to students for debugging whenever they need it. I also use it for industrial projects and research.

User	Computer Engineering Technology Student
Make and Model	Digilent - Analog Discovery
What were your original debugging requirements?	I needed an oscilloscope which was portable to debug embedded systems at home and at school.
What big piece of lab equipment it substitutes?	This device took the place of a storage oscilloscope and logic analyzer. Not any type of analyzer, it had to decode I2C protocol which most companies would sell to you separately.
How did you find about it?	I saw the big brother of the Analog Explorer being used at the university by my professor and started to investigate one for myself. I found the model the professor was using to be too expensive for my needs. I found its little brother the Analog Discovery which suited my needs.
How have been using it?	I used Analog Explorer to look at timing of code executed in my embedded system as well as troubleshooting I2C reads.
Price? Is it worth it?	Since I am also a student I could obtain this piece of equipment for $99.00. I would say it is well worth it when a comparable device would be $2,000.00 or more.
Would you recommend it to other students?	Being a teaching assistant in the embedded systems lab, I recommended this device to every student I could talk to. Students don't have much money to spend but I know they take their education seriously and this device would allow learning outside of the lab and help test ideas for those budding minds.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	This unit is definitely a substitute for the scope that is present in the lab but could only act as a complement for the logic analyzer since it doesn’t support as many bits as the lab equipment. The labs analyzer doesn't support analyzing protocols directly.
Cool things about it?	Most of the integrated instruments may be used simultaneously and have their own display that can be repositioned on the computers display. The 5 MHz Bode Plotter is a surprise because it's not mentioned in the advertisement on Digilent website. I'm sure you can't purchase a Bode Plotter at a price of $99.00.
Any other features not available at university's available equipment?	The University's lab doesn't have a Bode Plotter.
Do you use it for School/Personal/Both use?	I will use it for school and for my business startup.

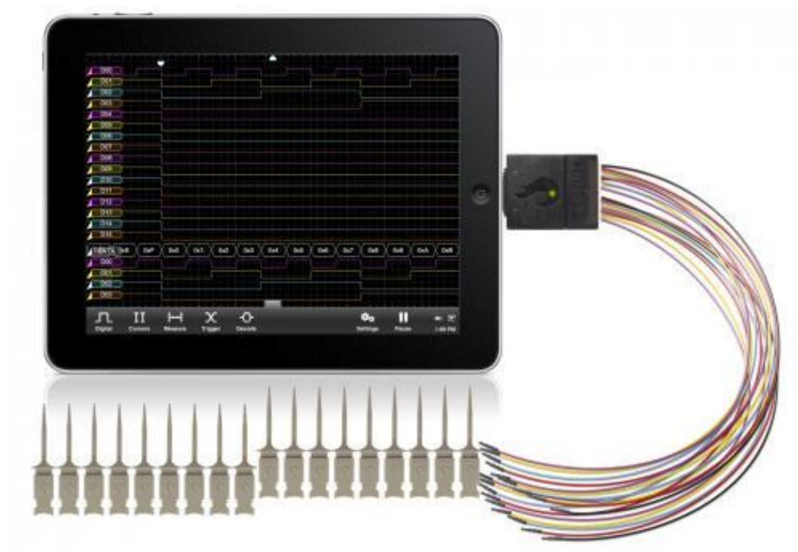
User	Computer Engineering Technology Student
Make and Model	Digilent - Analog Discovery
What were your original debugging requirements?	Needed a logic analyzer/protocol analyzer that was portable and capable of decoding I^2C
What big piece of lab equipment it substitutes?	This small, portable unit substitutes all of the basic laboratory equipment – power supply, oscilloscope, function generator, and logic analyzer.
How did you find about it?	I found out about this unit from my Embedded Systems Design Professor. He demonstrated analyzing I^2C protocol in class as a resource for us to troubleshoot our homework assignment. As soon as I saw this device, I knew I had to have something like it. I did some research and found the Saleae Logic16. I compared the two and found that the Digilent Analog Discovery does a lot more for only a third of the cost for students.
How have been using it?	I have used this unit to decode the I^2C bus in my current side project, a magnetic card swipe emulator.
Price? Is it worth it?	The price of the Analog Discovery is $99 for students or $199 for anyone. I think this unit is worth a lot more than $99, so it is a great deal for students. It functions as all of the basic laboratory equipment and is portable. All you need is a laptop to run the WaveForms software.
Would you recommend it to other students?	Yes, I would recommend this product to other students as it is a very useful tool in both analog and digital design/testing. The price of this portable unit is only a fraction of the cost of the laboratory equipment it substitutes and this unit is perfect for labs/side projects.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	I would recommend this unit as a portable substitute for a basic 5V power supply, oscilloscope, function generator, and logic analyzer.
Cool things about it?	• Portable • 5V power supply • 16 channels of discrete I/O • 2 channel oscilloscope • Can save screenshots for use in reports/documentation • Inexpensive
Any other features not available at university's available equipment?	All of the features are available on the university's available equipment; however, portability is a key advantage.
Do you use it for School/Personal/Both use?	I use this unit for both school and personal use.

User	Electro-Mechanical Engineering Technology student
Make and Model	Saleae Logic 16
What were your original debugging requirements?	The original debugging requirements for the project were to determine how a UART library was creating a separate module to be non-responsive.
What big piece of lab equipment it substitutes?	The Saleae Logic 16, replaces both the oscilloscope, logic analyzer and protocol analyzer. The Logic 16 has the capability to sample at 50 MHz, and display waveforms in a graphical manner in order to analyze the result of certain hardware and software interaction. It is easier than an oscilloscope to setup, and far simpler than a logic analyzer.
How did you find about it?	I found the Saleae Logic 16, on Sparkfun electronics.
How have been using it?	I have been using it as both an oscilloscope, LA, and a protocol analyzer.
Price? Is it worth it?	$300, it has been worth every penny.
Would you recommend it to other students?	I would absolutely recommend it to other students who are working on complex electronics projects and need a single tool to do a variety of tasks.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	I would not use the Logic 16 to replace any equipment if I had it available. The Logic 16 has been perfect for owning only one piece of equipment.
Cool things about it?	Great interface that allows viewing 16 simultaneous channels of data for over 200 seconds of history.
Any other features not available at university's available equipment?	
Do you use it for School/Personal/Both use?	I use this for school and personal use.

User	Mechanical Engineering MSc student
Make and Model	Saleae Logic 16
What were your original debugging requirements?	During the initial stages of development problems were discovered on both an I2C bus as well as in a serial bus. Most requirements involved one or two serial communication buses with up to five additional digital logic lines.
What big piece of lab equipment it substitutes?	Logic analyzer with over 50 channels and giga-sample hold capabilities with a cost well over $10,000.
How did you find about it?	The device was discovered through suggestions found on Internet sites such as Spark Fun and Hack a Day. The final purchase was made from Spark Fun.
How have been using it?	Most of the use has been in industrial applications or in hardware development for graduate school.
Price? Is it worth it?	$400.00 Absolutely worth it!
Would you recommend it to other students?	After using this piece of equipment I would highly recommend it to any student or professional who performs development or debugging on embedded systems. This recommendation also applies to educational instructions as well.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	This device allows students to skip the 'degree in advanced triggering' needed to run equipment like the Logic Analyzer analyzes and allows them to focus on learning the actual course work. While this doesn't provide the 20+channel hardware and extremely high speed of larger devices; this is recommended for any one that doesn't have these specific requirements.
Cool things about it?	Fantastic user interface, simple to us with a rich feature set. Support for apple is a huge plus. Excellent sample and hold capability for the price range. Portable and durable!
Any other features not available at university's available equipment?	No additional features but this device includes only what is necessary, this makes the device far more useful than the larger bulkier lab versions.
Do you use it for School/Personal/Both use?	I have used it mainly for personal use, however I wish it were available to me when taking classes as a student.



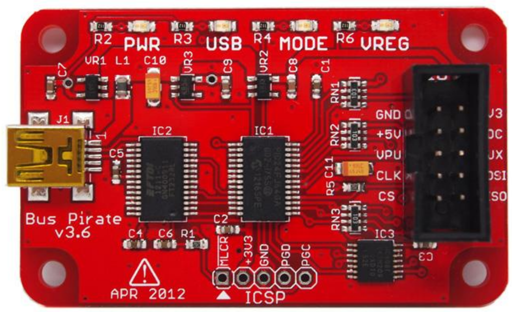
User	Computer Engineering Technology faculty
Make and Model	Oscium – iMSO-104
What were your original debugging requirements?	A portable oscilloscope with basic logic analysis.
What big piece of lab equipment it substitutes?	A portable digital oscilloscope.
How did you find about it?	Websites and embedded systems magazines.
How have been using it?	To prepare for lecture and/or labs, especially for pulse width modulation signals.
Price? Is it worth it?	The list price is $297.99. Yes, it is worth it, since it can be used with any generation iPhone and iPad, very convenient to carry around.
Would you recommend it to other students?	Yes, if they already have an iPhone or iPad and require portability (e.g. working a project in their car).
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	The bandwidth is quite limited but to work at home/projects or on the go is good.
Cool things about it?	Everything, it is a very neat and compact solution to debug applications in the field.
Any other features not available at university's available equipment?	It has an FFT capability which is extremely useful for filter design and to detect non desired frequencies in the analyzed signal.
Do you use it for School/Personal/Both use?	Both.



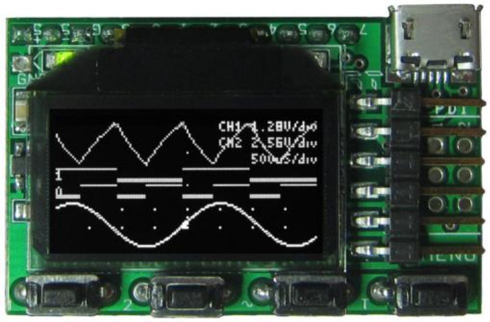
User	Computer Engineering Technology professor
Make and Model	Oscium - Logiscope
What were your original debugging requirements?	A logic analyzer with serial protocol decoding, especially UART, I2C and SPI.
What big piece of lab equipment it substitutes?	A logic analyzer.
How did you find about it?	Websites and embedded systems magazines.
How have been using it?	To prepare lectures and laboratories both at my office and at home, for projects where it is difficult to bring a big piece of equipment.
Price? Is it worth it?	List price $389.99. If you already have an iPhone and/or iPad and require quick access to data analysis or serial protocol decoding, yes it is worth it. If you are traveling or consulting is ideal.
Would you recommend it to other students?	Yes, it is a nice piece of equipment with many capabilities.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	Not for a full equipped lab, but in our case we do not have serial decoding capabilities and could be very useful.
Cool things about it?	Size, convenience, resolution, triggering capabilities.
Any other features not available at university's available equipment?	The serial protocol decoding is a feature we currently do not have. An equivalent MSO will be no less than $3K to bring these capabilities to the lab.
Do you use it for School/Personal/Both use?	Both.

User	Computer Engineering Technology student
Make and Model	Seeed Studio - DSO Quad
What were your original debugging requirements?	Needed a portable oscilloscope for class and side projects for when access to the lab wasn't available.
What big piece of lab equipment it substitutes?	This small handheld unit substitutes an oscilloscope, function generator, and has basic logic analyzer functionality with an installed app.
How did you find about it?	One day I was researching online for a side project and saw someone using the Seeed Studio DSO Nano V2 in a photograph. At the time, I didn't even know they made portable oscilloscopes, inexpensive ones at least. I didn't know the model when I saw the photograph, but I immediately began searching the web until I found it. When I made it to the Seeed Studio website, I found the DSO Quad which is a four channel, updated version.
How have been using it?	I have used this portable unit for many different purposes. The main functionality of the unit, with its base firmware, is an oscilloscope and function generator. However, additional apps can be installed on the unit. I have installed a simple logic analyzer app and a frequency response app. I have used the logic analyzer app for simple I^2C debugging.
Price? Is it worth it?	The price of the DSO Quad (4 channel) is $199, or $219 for the aluminum alloy version. The DSO Nano V2, a two channel version, is also available for $89. I definitely think both of these units are worth the price, depending on your requirements.
Would you recommend it to other students?	Yes, I would recommend this product to other students as it is a very useful tool in both analog and digital design/testing. The price of this portable unit is only a fraction of the cost of a regular desktop oscilloscope and this unit is perfect for labs/side projects.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	I would recommend this unit as a portable substitute for a basic oscilloscope, function generator, and simple logic analyzer or frequency response curve generator.
Cool things about it?	• Portable • Rechargeable batteries via USB • Completely open source • Can install user applications

	• Can save screenshots for use in reports/documentation • Inexpensive
Any other features not available at university's available equipment?	All of the features are available on the university's available equipment; however, portability is a key advantage.
Do you use it for School/Personal/Both use?	I use this unit for both school and personal use.



User	Computer Engineering Technology professor
Make and Model	Dangerous Prototypes – Bus Pirate
What were your original debugging requirements?	Decode and reverse engineer serial transmissions.
What big piece of lab equipment it substitutes?	Mixed Signal Oscilloscope with serial protocol decoder or logic analyzer with serial decoding.
How did you find about it?	Through students word of mouth.
How have been using it?	We have been using to decode UART, I2C and SPI signals.
Price? Is it worth it?	$27.15. Yes it is a great inexpensive tool.
Would you recommend it to other students?	Yes, for the price, every student could afford one for their toolbox for the price of one dinner.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	Not as replacement but as complement to the oscilloscope/logic-analyzer.
Cool things about it?	Low bandwidth logic analyzer, USB to serial, serial protocol decoder and scriptable in perl or python.
Any other features not available at university's available equipment?	Serial protocol decoder
Do you use it for School/Personal/Both use?	For Both.



User	Electrical Engineering MSc student and GRA
Make and Model	XMEGA Xprotolab
What were your original debugging requirements?	A robust tool for debugging I2C.
What big piece of lab equipment it substitutes?	The Logic Analyzer or an expensive Mixed signal oscilloscope.
How did you find about it?	At the gabotronics stall at The World Makerfaire NYC.
How have been using it?	I have used it with the raspberry PI and Arduino, while interfacing with PMOD TEMP2, I2C temperature sensor from Digilent, I2C controlled RGB led from MBLINK and to interface ADJD-S311-CR999 based color sensor from Sparkfun.
Price? Is it worth it?	For $50 I think it is worth, compared to other alternatives sold at $100 to $200 .
Would you recommend it to other students?	Yes, I would definitely recommend it to anyone looking for a really cost efficient oscilloscope and logic analyzer.
Would you recommend it as a substitute/complement for (a) particular lab piece(s) of equipment?	The accuracy and scope of use, is quite limited compared to lab equipment, with a limited 3.3 volt voltage input limit on the digital lines, to slow sampling rates like 2 MSPS and a 1" screen, it can never replace the lab equipment but can be used by students and hobbyist, running on a low budget.
Cool things about it?	The Xprotolab decodes the various protocol messages and prints out the hex values on its tiny screen. The Xprotolab logic analyzer has two modes, The waveform mode, that shows you the waveforms, that helps to confirm the proper hardware functioning of the device, and the data view that gets rid of all the wave forms and prints the data in the order it is received. This helped me to see if the device is receiving the right data and analyses the various responses the device is sending. The protocol sniffer in the Xprotolab supports UART, SPI and I2C with a buffer size of 256bytes working at 2MSPS. The logic analyzer supports up to 8 digital channels. The Xprotolab runs on an ATMEL XMEGA32A3, with a tiny 1", 128x64 pixel display with 4 tactile switches and USB connectivity with Windows and Android. The Oscilloscope has a much higher voltage range of -14V to +20V with an analog Bandwidth of 200kHz, taking up to 2 mega samples per second.Another Handy feature of the Xprotolab is the AWG, this is very useful since the Xprotolab fits on any bread board, it can be used as a signal generator, or a variable voltage source. With an Analog Bandwidth

	of 44.1kHZ with a conversion rate of 1MSPS (8 bit resolution). This Xprotolab comes with and FFT tool that can display the FFT of your input at the analog channels.It also comes with a free open-source PC/Android software that can be used to connect the Xprotolab with a PC and/or Android phone. This software can be used to change modes make measurements and capture waveforms.
Any other features not available at university's available equipment?	The data view mode of the Xprotolab is not something I have seen on any logic analyzer, in most logic scopes it becomes hard to scroll through the waveforms and read data, a simple text console displaying I2C data in the order it is received is a very handy feature.
Do you use it for School/Personal/Both use?	I use it for school and Personal projects.

Conclusions

While this is by far an extensive list of *embedded tools you wish you had while growing up*, this is just a small sample of the boards that both students and faculty have been using to either complement or substitute equipment in the lab as well as to work at home and projects outside school. When the faculty author was growing and working in industry, the devices used to debug embedded systems were in the range of tens of thousands of dollars and only by working in a big to medium size company, you had access to these tools. For working on independent projects or consulting, it was impossible to have the same level of tools students have available these days. Five years ago we were still programming devices and letting them run until they crashed and then we had to scratch our heads and figure out what was the reason for failure unless you had access to high end equipment in the lab.

So what is the take on this paper, we need to listen to our students and be close to them. They will find the right tool for the right task at the right price. Especially those motivated students that take the initiative to solve problems without relying on a university or faculty to solve these for them. Students could think in applications that faculty and university cannot plan ahead since they do not exist yet. While students should follow a curriculum to be able to be trained to join industry, the curriculum should as well adapt to students and the needs of the market . Which one is the best embedded tool? The answer is: "it depends what you want to use it for, what equipment you do not have available, where do you want to work and what your budget is.

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