Empowering Tomorrow's Engineers Using Active Learning Projects

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Abstract This paper presents a fundamental concept of the active learning system using the National Instruments (NI) myRIO architecture. Hardware and software platform that aims at giving engineering students the ability to design real systems quickly for automation, robotics, data logging or embedded systems are introduced. Then, a student design competition was organized for the students at national college students in Japan. Then, the assessment of active learning system is presented to understand its impact.

Key words myRIO, LabVIEW, embedded systems, real-time, FPGA, active learning, education

1. INTRODUCTION

Today's engineering students are being asked to not only master the fundamental elements of engineering, but to develop an appreciation for a complete system. To ensure that they graduate prepared to engage in modern engineering, students need to be immersed in real-world system design well in advance of graduation using the same technology they will see in their careers (Sheppard 2009). In addition to their analytic skills, which are well provided by the current education systems, companies want engineers with passion, lifelong learning skills, systems thinking, an ability to innovate, an ability to work in multicultural environments, an ability to understand the business context of engineering, interdisciplinary skills, communication skills, leadership skills, and an ability to change.

Education system needs to see and understands the relevance, reality, breadth, and authenticity of concepts both in the classroom and in the real world. One newer method that is proving to be effective in the classroom is project-based learning (PBL). PBL is a hands-on approach to learning where students are given a project to complete that incorporates a number of need-to-know concepts that they must learn, understand, and apply in order to complete the project. PBL also incorporates many concepts and subject areas including language arts, systems engineering, and team-work, rather

than just math or science concepts alone. This blend of concepts combined with a real-life type of project engages and encourages students to learn and want to learn and prepares them to be an effective member of the 21st century society.

While project-based learning can involve a wide range of concepts and application areas, NI LabVIEW is dramatically affecting traditional academic research and teaching. A laboratory based on LabVIEW makes researchers more productive and improves the way students learn. Rather than focusing on sometimes-tedious methods of gathering data, educators and students can focus on results and concepts. LabVIEW is a tool for the instructor to base projects around. It is flexible and customizable for every project, class, experience level, or instructor. Virtual Instruments (VI), LabVIEW programs, can be created by either student to research hypotheses or instructor to demonstrate specific application or concept area. Professors can also use LabVIEW in their research by integrating algorithm engineering within a single environment to decrease the design cycle length. By combining the theoretical models of the design using real-world signals, you can design, simulate, modify design parameters, and explore the algorithm implementation and thus remain on the same platform throughout their work. For students, VIs help visualize abstract concepts by using research-based instructional strategies. Marzano (1998) completed a meta-analysis of over 4,000 studies to determine which instructional techniques were most effective in positively impacting student achievement and Virtual Instruments play a part in 3 of the 7 techniques (computer simulation, graphical representation, and experimental inquiry).

At the university level, PBL has been incorporated into the curriculum with a variety of classes such as Senior Design as a capstone project to help transition students from theory to real-

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world projects by solving an open-ended problem and Introduction to Engineering courses to motivate and inspire students thus helping the retention rates of students in engineering. LabVIEW's flexibility and hardware interaction capabilities are ideal for senior design students that have a short amount of time to explore concepts and theories and put them into practice. Students can make hypotheses, simulate a system, collect and analyze data, and draw conclusions all from the LabVIEW environment. [Project-based learning] is flexible enough to allow the teacher to frame the project to intentionally draw out aspects of professional practice for instructional purposes. A professor can either spend just a few lectures teaching LabVIEW basic concepts or can direct students to either a free campus workshop or online training and students can then use it in nearly every project. Research also indicates that students believe that even a short exposure to graphical programming languages produced the same amount of increase in self-confidence as their longer-term use of traditional, text-based languages (Garrett 2008).

Dr. Doug Williams has explored utilizing LabVIEW in conjunction with embedded hardware in a typically lecture-only DSP course. The primary goal of these initiatives is to fill the gap between the theory and the hands-on experience. Students are able to interact with this external hardware and play with the captured data through GUIs, thus putting theories to the test. Dr. Williams describes why LabVIEW was beneficial for his course in 4 ways: "First of all, use of a graphical programming language like LabVIEW can ease the implementation of relatively harder DSP concepts. Second, the modules can be extended easily for the implementation of other more advanced concepts. Third, the modules may be easily incorporated into classes that are taught online as well; for instance, the hardware can be sent to students at remote locations while the pre-compiled or wholly/partially implemented modules can be downloaded from the web. Lastly, the associated cost of having the external boards or brick is small, being only on the order of several hundred dollars. Thus, a combined use of external hardware platforms and graphical programming languages can facilitate the need of both educators and students in teaching and learning fundamental digital signal processing concepts in the undergraduate curriculum, which can be relatively difficult topics for students to grasp" (Williams 2008). This allows for greater student understanding and learning with little changes to curriculum as well as little cost.

2. ENGINEERING AND ACTIVE LEARNING

At National Instruments, we believe that active learning is what solidifies theoretical concepts and prepares students for industry or advanced research. Skills learned in the classroom paired with platforms that scale to industry prepare students to solve the grand challenges of tomorrow; at NI, we put this into practice by

packaging industry-standard technology into education form factors and working with partners to develop courseware. Learn how the same industry-leading NI hardware and software technology used by more than 35,000 companies also improves education in more than 6,000 universities around the world.

The foundation of any successful career path or life decision is inspiration. Engagement and preparation are what take that inspiration and turn it into something applicable. And realization is achieving something great, something equal or better to the very thing that inspired you in the first place—in fact, the realization of your goals just might be the inspiration for someone else who is just getting started. Our society depends on this cycle to continue the success of the human race. We need the children of tomorrow to be inspired to pursue greatness, our elders and educators to facilitate this preparation, and our economy and market to help people realize their goals and vision. So is it safe to assume that this cycle is in place for all careers and professions?

It is safe to say that there is a surplus of inspiration for our children to grow up to be professional athletes, just turn on the television or go to a professional sporting event and you will be inspired. The same is true for musicians—just turn on the radio or go to the orchestra. And science and engineering is full of inspiration from renewable energy to electronic gadgets, and even rockets launched into space. So then why is there such a shortage of scientists and engineers around the world? The problem is in the preparation. The preparation for future scientists and engineers has turned into a hands-off barrage of theory and equations that extinguishes even the brightest of flames. This gauntlet of mathematics and computer simulation prevents students from actually experiencing the physical phenomena that keeps them engaged. They never actually get to "do engineering."

But it doesn't have to be this way. Let's take a lesson from learning a musical instrument. When a child goes to the Sydney Opera House and hears the xylophone for the first time, she becomes inspired to play it. So what do her parents do for her? Buy her reams of sheet music and force her to first learn how to read musical notes before she ever gets to actually play the xylophone? No, they do not. They buy her a bright, multicolored xylophone that fits her perfectly at her age. She can chew on it, drop it, play it, and not worry about breaking it. She learns a few basic things about making noise, and then progresses nicely throughout her childhood learning on this platform of a mallet and planks to make music until she majors in music at the university level. When she eventually tries out for the Sydney Opera House orchestra, she has all the skills that she needs to land the first chair.

If we want to keep students inspired throughout their engineering education and prepare them for the jobs of tomorrow that don't exist today, we have to provide hands-on tools and applicable, real-world experiences along the way that motivate them to continue. At NI, we have created an educational continuum that parallels

the progression of learning to play an instrument or ride a bicycle. This continuum consists of NI LabVIEW graphical system design software combined with scalable hardware platforms for each stage of engineering education, from kindergarten to rocket science (Wilson 2013).

We know that textbooks, theory, and simulation are important for science and engineering education, but they do not have to be the only experience. Students can learn fundamental concepts and build up to more complex systems, with hands-on project work throughout that helps to solidify the textbook theory.

Do engineering concept combine the essential elements of engineering to build real-world systems. The graphical system design approach enables students to beyond theory and simulation. Today, students around the world create amazing innovative projects using myRIO (https://youtu.be/sKbvbNz_JdY) and LabVIEW. From inexpensive medical devices to complex underwater autonomous vehicles, do engineering possibilities are endless. Please refer to following website to see the winning student design applications around the globe. (https://decibel.ni.com/content/community/academic/student_competitions)

3. MYRIO EMBEDDED DEVICE

National Instruments has been working on a device called NI myRIO, a hardware & software platform that aims at giving engineering students the ability to design real systems quickly for automation, robotics, data logging or embedded systems. The hardware is based on Xilinx Zynq-7010 with a dual-core ARM Cortex-A9 processor and an FPGA with 28,000 programmable logic cells, and features 10 analog inputs, 6 analog outputs, audio I/O channels, and up to 40 lines of digital input/output (DIO).

The NI myRIO embedded student design device was created for students to “do real-world engineering” in one semester. It features a 667 MHz dual-core ARM Cortex-A9 programmable processor and a customizable Xilinx field-programmable gate array (FPGA) that students can use to start developing systems and solve complicated design problems faster—all in a sleek and simple enclosure with a compact form factor. The NI myRIO device features the Zynq-7010 All Programmable system on a chip (SoC) to unleash the power of NI LabVIEW system design software both in a real-time (RT) application and on the FPGA level. Rather than spending copious amounts of time debugging code syntax or developing user interfaces, students can use the LabVIEW graphical programming paradigm to focus on constructing their systems and solving their design problems without the added pressure of a burdensome tool.

NI myRIO is a reconfigurable and reusable teaching tool that helps students learn a wide variety of engineering concepts as well as complete design projects. The RT and FPGA capabilities along with onboard memory and built-in Wi-Fi allow students to deploy applications remotely and run them without a remote computer

connection. Three connectors (two NI myRIO expansion ports [MXP] and one NI miniSystems port [MSP] that is identical to the NI myDAQ connector) send and receive signals from sensors and circuitry that students need in their systems. Forty digital I/O lines overall with support for SPI, PWM out, quadrature encoder input, UART, and I2C; eight single-ended analog inputs; two differential analog inputs; four single-ended analog outputs; and two ground-referenced analog outputs allow for connectivity to countless sensors and devices and programmatic control of systems. All of this functionality is built in and preconfigured in the default FPGA functionality, which eliminates the need for expansion boards or “shields” to add utility. Ultimately, these features allow students to do real-world engineering right now—from radio-controlling vehicles to creating stand-alone medical devices.

Student-friendly and fully-capable out of the box, the NI myRIO device is simple to set up, and students can easily determine its operational status. A fully configured FPGA personality is deployed on the device from the factory, so beginners can start with a functional foundation without having to program an FPGA to get their systems working. However, the power of reconfigurable I/O (RIO) becomes apparent when students start defining the FPGA personality and molding the behavior of the device to the application. With the device’s scalability, students can use it from introductory embedded systems classes through final-year design courses.

3.1 Hardware Configuration

The NI myRIO-1900 provides analog input (AI), analog output (AO), digital input and output (DIO), audio, and power output in a compact embedded device. The NI myRIO-1900 connects to a host computer over USB and wireless 802.11b.g.n.

NI myRIO hardware specifications are given below.

SoC: Xilinx Zynq-7010 with a dual core Cortex A9 processor and FPGA with 28,000 cells

Connectivity: Wi-Fi

USB: 1x USB host port, 1x USB device port for connection to PC

Audio: Audio In, Audio Out

Power: 6-16V Input, or battery

Miscellaneous: User and reset buttons, power, status and Wi-Fi LEDs, 4 user-defined LEDs, on-board accelerometer

Fig. 1. NI myRIO hardware; front (left) and back(right) view

Expansion Ports:

- i) myRIO Expansion Ports (MXP) (Fig. 2) – Two identical ports (MXP A and MXP B) with 4 analog inputs, 6 digital inputs/outputs, 2 analog outputs, 1 quad encoder, 3 PWMs, 1 UART, 1 I2C and 1 SPI by default. Ports configuration is customizable with LabVIEW FPGA.
- ii) miniSystems Port (MSP) – Power, 2 analog outputs, 4 analog inputs, and 8 digital inputs/outputs by default.

Ports configuration is customizable with LabVIEW FPGA.

Fig. 3 shows the block diagram of NI myRIO-1900. Fig. 4 shows the signals on Mini System Port (MSP) connector C. Note that some pins carry secondary functions as well as primary functions.

NI myRIO-1900 Expansion Port (MXP) connectors A and B carry identical sets of signals. The signals are distinguished in software by the connector name, as in Connector A/DIO1 and Connector B/DIO1. Fig. 5 shows the signals on MXP connectors A and B.

Fig. 2. myRIO default I/O configuration

Fig. 3. myRIO hardware architecture

Fig. 4. Primary/Secondary Signals on MSP Connector C

Fig. 5. Primary/Secondary Signals on MXP Connectors A and B

3.2 Software API

NI myRIO runs Linux, and is programmable with C/C++, or LabVIEW. When designing NI myRIO, our aim was to give students access to the same industry-grade technology they would see upon graduation; however, we know that students approach this technology with various knowledge levels and may not be ready for the advanced programming required of a professional engineer. Using the LabVIEW RIO architecture approach, we can take advantage of LabVIEW system design software to offer NI myRIO users a spectrum of programming complexity. Depending on programming knowledge, students can begin with configuration-

Fig. 6. LabVIEW block diagram and myRIO APIs

based Express VIs and move to advanced modes of programming as they feel ready.

At the simplest level, students can gain quick access to a predefined shipping FPGA bit file using Express VIs specifically created for NI myRIO. Express VIs are configuration-based functions that minimize programming and can be found on the NI myRIO palette in LabVIEW.

As students gain programming knowledge, they can graduate to more advanced programming using the NI myRIO Advanced I/O API. To help students transition from Express VIs to traditional LabVIEW programming, each Express VI includes a “View Code” button that gives students the ability to see the detailed underlying code.

Students can copy and paste this code to a LabVIEW block diagram or can program from scratch with lower level peripherals using the Advanced I/O subpalette.

At the most fundamental level, students can investigate and implement the same LabVIEW programming techniques used by professional engineers. By double-clicking on any Advanced I/O VI, students can see the low-level handshake between processor code and the FPGA bit file.

Students programming on this level can completely customize both processor and FPGA code using the same low-level LabVIEW peripherals used by professional engineers working with products like NI CompactRIO and NI Single-Board RIO.

Although LabVIEW provides engineers the tool for total system design, engineers may choose to execute some tasks in a programming language such as C or C++. Because the dual-core ARM Cortex-A9 processor on NI myRIO runs the NI Linux Real-Time OS, users can choose to program the processor in C or C++ using the Eclipse IDE. This gives students the ability to choose the

programming language that is best for the task at hand. This same option is offered to professional engineers with the new NI cRIO-9068, which uses the same Zynq chip technology found in NI myRIO.

As crucial as the approachability of the programming experience was to the design of NI myRIO, the algorithms that students develop need to be backed by powerful hardware that delivers the performance required to give students the ability to design complex, real-world systems. NI myRIO features the Xilinx Zynq-7010 all-programmable system on a chip, which includes a dual-core ARM Cortex-A9 processor and an Artix-7 FPGA. This industry proven hardware empowers students to imagine an idea and then create it, innovating with the confidence of powerful technology.

4. BUILDING APPLICATIONS USING MYRIO

NI myRIO is used for a variety of teaching applications to improve student learning in engineering education. Whether used alone or paired with add-ons, NI miniSystems, or third-party sensors, NI myRIO can help students learn multiple engineering concepts on one device.

In this section, we introduce how to implement an accelerometer with a myRIO that measures X, Y, and Z acceleration. Accelerometers measure both static acceleration for leveling, tilt, and drop sensor applications as well as dynamic acceleration for shock and vibration data acquisition. Accelerometers have a wide range of applications from motor vehicle control systems to Smartphone user interfaces.

An accelerometer measures the position of an on-chip suspended proof mass and reports motion of the proof mass as acceleration in “gees”. Accelerometers measure both static acceleration for leveling, tilt, and drop sensor applications as well as dynamic acceleration for shock and vibration data acquisition. NI myRIO Mechatronics Kit accelerometer based on the Analog Devices ADXL345 triple-axis digital accelerometer with I2C-bus serial communications.

The ADXL345 provides a high degree of flexibility and includes on-chip event detection including single-tap and double-tap, activity, and free-fall.

Fig. 7. Configuring myRIO

Fig. 8. LabVIEW APIs

Creating the accelerometer demo:

Step 1: Connect the accelerometer as indicated in the circuit diagram in Fig. 9.

Step 2: Open the Accelerometer demo folder and project (Accelerometer demo.lvproj). Open the VI titled “Main.vi”. The front panel of the VI should look like the picture shown in Fig. 10.

Step 3: Run the VI and observe the front-panel display as you shake the accelerometer. Try shaking the accelerometer along a particular axis and then correlate this motion with what you see on the front

Fig. 9. Demonstration setup for accelerometer connected to NI myRIO MXP Connector A

Fig. 10. LabVIEW accelerometer demo front panel

panel. Try tapping the edge of the board on the table or tap the edge with your finger. The NI myRIO onboard LED0 will flash to indicate that a single-tap event was detected by the accelerometer. Single-tap detection is only enabled along the X-axis. Try tapping on the three different axes as you observe the LED.

The demo VI displays the triple-axis accelerometer values in three formats: as the six bytes retrieved from the accelerometer "DATA" registers, as three signed integers formed by combining the two bytes retrieved per axis, and as a waveform chart. You will soon learn how to convert these values to "gees." The VI also displays the contents of the "INTERRUPT_SOURCE" register. Before running the main loop the VI configures the accelerometer registers for data rate, resolution, range, and single-tap detection on the X-axis.

For more detailed explanation of how the main VI works, please watch the video: https://youtu.be/-_GWEsrfxU4

More examples can be found on the "NI myRIO Project Essential Guides" (Doering). NI myRIO encourages students to let their ideas run wild and provides them with the hardware and software to get the job done. Based on NI's industry recognized RIO hardware, the latest gadget for young engineers is anything but a toy.

5. MYRIO STUDENT DESIGN CONTEST

Last several years, National Instruments Japan organized a student design contest with collaboration of National Institute of Technology (Kosen Kiko, <http://www.kosen-k.go.jp/english/index.html>) in order to initiate an active learning system for technical college students. myRIO is a recommended embedded platform

because of their powerful architecture. Students are free to design any kind of embedded projects to increase their motivation and accelerate the active learning cycle. Around 15-20 teams participated to myRIO student design contest in every year.

Student teams include 2 to 5 students from each schools and professors become an advisor during the development phase. However, every team decide the project outline and divide the responsibilities to complete the project. NI launched a community website to share some materials and posting the students' questions to create an active learning environment. Student almost had 4 months of development time everything from the scratch.

Various design projects have been developed from autonomous robots to drones, from smart houses to alarm system including both image and sensor data analysis and recognition. Fig. 11 and Fig. 12 show the 2016 winner team project from Kurume Technical College (<https://youtu.be/8BhxTDWCmUI>) and 2015 winner team project from Kagoshima Technical College (https://www.youtube.com/watch?v=GzxK0f_Nj_M).

Students built hardware configuration of the system and implemented the actual programming using LabVIEW. They mainly affiliated to electrical, mechanical and information processing departments between grade 3 to 5. In Japan, students who have completed colleges of technology are granted the title of associate (Jun-gakushi) and may apply for admission to the upper division of university. Colleges of Technology are also allowed to offer a two-years advanced courses, which follow the five-year program in order to provide a higher level of technical education.

Most of the students did not have previous experience on LabVIEW and myRIO but only fundamental programming experience on Basic or C languages.

Fig. 11. Winner projects of myRIO design contest; pet robot

Fig. 12. Autonomous solar charger (right)

Fig. 13. Skill assessment before and after the myRIO contest

We have conducted a skill test assessment for each student before and after the contest. Fig. 13 shows the assessment results of 20 students participated to myRIO contest final stage in 2016. As shown, all pre-identified skills are significantly improved after the contest based on the survey results. The following 8 skills (independence, responsibility, thinking power, discovery, teamwork, leadership, communication and consensus building) identified by National Institute of Technology (Kosen) to measure the actual impact of active learning.

We also measured how myRIO student design contest helped student motivation as a part of active learning. For this purpose, we asked questions and students rated their satisfaction level in which 1 is extremely disagree, 4 is neither agree or disagree, 7 is extremely agree. As shown in on Table 1, students found myRIO design contest somehow motivating and wanted to have a similar active learning projects in other classes based on the weighted average results.

Similar to previous case study, many students are already taking advantage of active learning by building complex projects such as a myRIO controlled Segway, and are posting their work to YouTube our myRIO Community website. Today, myRIO is used for a variety of student design projects such as NI ARC in Australia (<https://youtu.be/Vf7MyJQSTn8>).

Below more examples can be found on how myRIO is actually used:

Table 1. Student assessment results of myRIO contest

Assessment Score	Did you have a fun (higher motivation) in this project?	Do you want to have similar projects in other classes?
1	0	0
2	0	1
3	1	1
4	4	1
5	2	6
6	5	4
7	7	7
Weighted average	5.4	5.6

- 1) NI myRIO Project an LED Light Show (<https://youtu.be/d63cq6Waj0Y>)
- 2) University of Leeds Controls Electric Guitar with NI myRIO (<https://youtu.be/ZpsrZv2wUF4>)
- 3) GDP45 Autonomous Quadrotor using the NI myRIO (<https://youtu.be/Qax5CZTzE5U>)
- 4) Paintball Picasso | Waterloo Labs | Episode 09 (<https://youtu.be/9VCLxXFE3OA>)
- 5) SquidFIN - Robotic fish fin propulsion system (<https://youtu.be/RJECIb1ARTQ>)

6. CONCLUSION

Educators around the world are using various tools to foster the next generation of innovators by creating a hands-on, active learning environment. NI is committed to enhancing engineering education worldwide by providing graphical programming software and modular hardware to bring together theoretical concepts and real-world applications. There is widespread consensus that our current education system fails to prepare all students with the essential 21st century skills necessary for success in a global economy. The incorporation of active learning into curriculum has proven to be an excellent way to address this issue. "By building off and further developing skills used in other environments, LabVIEW use promotes deep understanding of transferable knowledge and its use is thus supported by constructivism and other learning theories." (Garrett 2008) LabVIEW's versatility, ease-of-use, and graphical nature can be a platform that can be used by student and instructor alike to design, prototype, and test hypotheses, theories, and concepts no matter the concept area.

Today, a globally adopted industry proven hardware/software design approach is in the hands of students. With a gradual approach to learning advanced concepts in embedded and FPGA programming, students can begin learning this technology at a level appropriate for them while educators gain the confidence that this tool can accompany students from introductory to advanced courses. myRIO student design contest proved that students are able to complete meaningful projects in a single semester while being assured that they are learning on a tool that prepares them for their careers as professional engineers.

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