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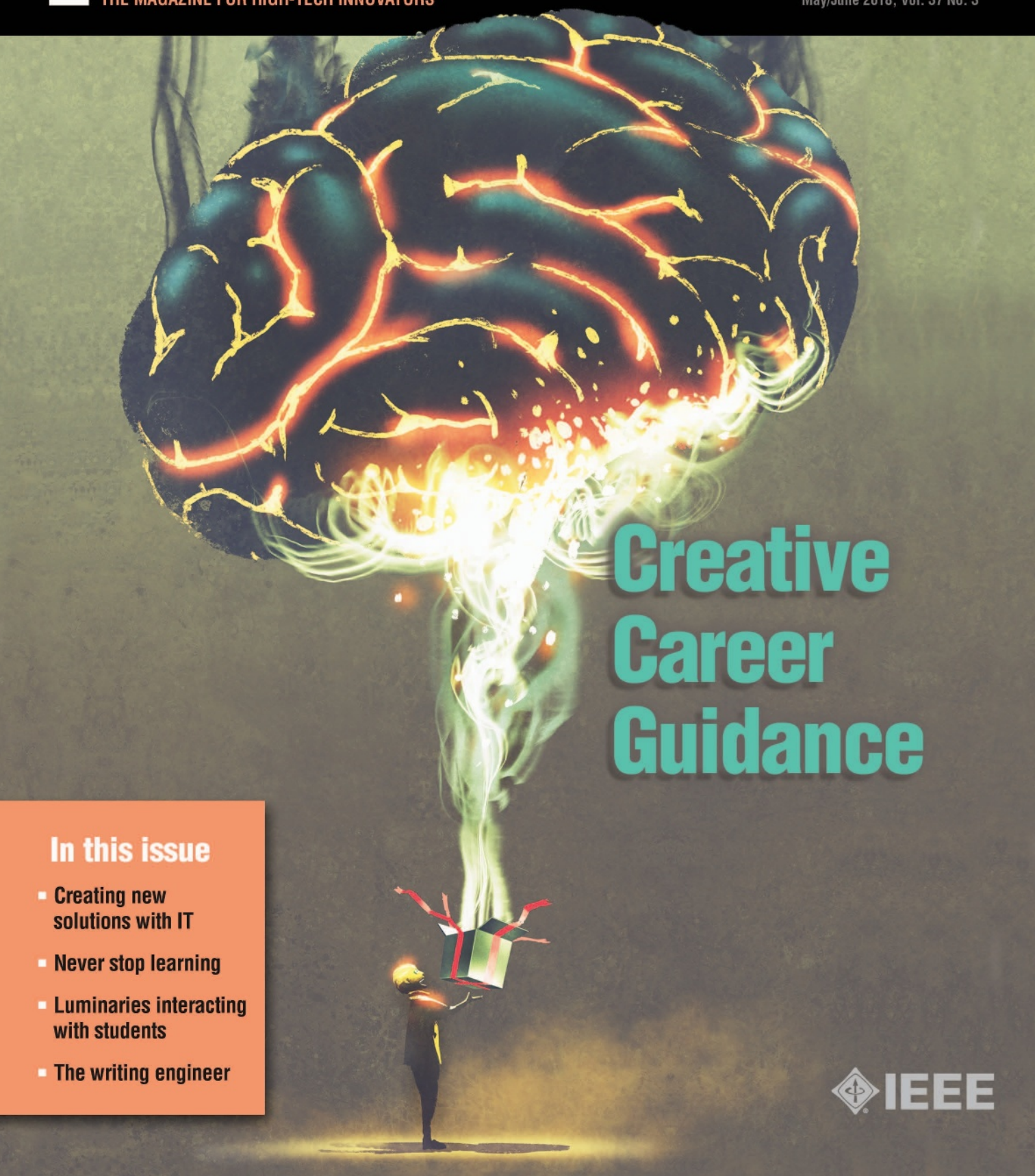

Creative Career Guidance

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THEME: CAREERS AND GRAD ED

ON THE COVER:
It's never too late to expand your knowledge base.

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DEPARTMENTS & COLUMNS

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An Education Revolution

by Cristian Quintero

Education is changing constantly, and it has evolved a lot in the last few years, but there is a big revolution that has just started. Universities as we have known them were founded around 400 years ago, with almost the same policies, rules, and teaching methods that were designed during those times.

For our generation, it is clear that the Internet has changed our lives forever; it has transformed the way we communicate, schedule a meeting, plan a trip, and, lately, the way we learn. I can't imagine how difficult it was to study engineering or any other career in the 1950s, having to spend almost the entire day at the library repeatedly reviewing the table of contents of books and flipping pages to find the relevant topic to read. And what if the book you needed was not in your library? Today, I can carry many books on my phone, find a keyword with a search tool, and if I don't understand something, I can just look to YouTube for a tutorial or explanation of the topic. We have truly come a long way!

I can't imagine how difficult it was to study engineering or any other career in the 1950s, having to spend almost the entire day at the library repeatedly reviewing the table of contents of books and flipping pages to find the relevant topic to read.

I have a question: In an era where information is in the palm of our hand and we can find and learn anything we want in a couple of minutes, in the future, will old teaching methods exist in physical places like the universities we currently know? Just think about it: Do we really need to attend classes? Do we need professors? Sometimes I ask myself these questions when I'm working on a project with my partners, and we don't know how to proceed. Our solution is to just Google what we need, and it's done! If I need to review something I previously learned (or improve a skill or my knowledge base), I don't take extra classes; I just look for a tutorial, and I'm ready for a test.

On the other hand, if I want to cook something delicious, I may review a tutorial to prepare the dish. But if I compared my meal with a similar one cooked by a chef, of course the chef's meal would be better since he or she knows many cooking techniques that were learned at school. So everything is not best accomplished via the Internet.

Every one of us is different, and that's why self-learning is, for me, the best way to learn. Self-learning allows us the opportunity to choose what we want to learn, when we want, and at our own pace. But a high-level self-learning has to be accompanied by a guide, who already knows deeply what the student is doing and has the power to correct what the pupil is doing wrong.

I'm sure that a lot of changes are coming, but what do you think? Will we experience a teaching/learning revolution in this century? Maybe in the future would we be able to be professionals without attending a university or taking magistral classes? I really want to hear your opinion, so please write and share your thoughts with me.

About the author

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Discover IEEE Collabratec

by J. Patrick Donohoe

IEEE Collabratec is an integrated online community that allows students, engineers, and technology professionals with similar interests to network and collaborate through online communities and groups. Online communities and groups provide the opportunity to ask and answer questions, post documents, and view relevant events. You can expand your professional network and stay connected with current contacts all in one place.

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Using Collabratec, exchanging great ideas with trusted colleagues and receiving their feedback is simple and easy, be it one-on-one or with members of a group.

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You can learn more about Collabratec from the student perspective by visiting https://www.ieee.org/membership_services/membership/students/index.html. Currently, the Collabratec directory lists over 450,000 users.

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by Athanasios Kakarountas

Solution #1: Losing Your Marbles

Pick a marble from the first pot. Since all the pots are incorrectly labeled, this pot cannot be the "black and red" pot. Thus, all the marbles in this pot must have the same color as the marble that was picked. Assume the marble is red. The first pot contains only red marbles. The second pot is labeled "black," so it can only contain both black and red marbles or just red marbles. But since we determined that the first pot contains red marbles, then the second pot must contain both black and red marbles. That means the third pot must contain only black marbles. Similar logic applies if the selected marble is black.

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Solution #2: Cup O' Joe

Mat is going to offer the coffee to you if you have indicated 6210001000 as the winning string. The first digit (6) indicates the six zeroes present, the second digit (2) reflects the ones present, and the third digit (1) indicates the two present, and eventually, even the 6 is counted once on the proper place, thus making the complete string required by the problem.

Solution #3: Weight and See

The best way for the two friends to solve the problem is to place three balls on one dish and the remaining three balls on the other dish, randomly chosen. If the scale is in equilibrium, the heaviest ball is one of the two not yet selected. So, with the following step, they will be able to immediately determine the heaviest ball. If the scale is not in equilibrium on the first try, the heaviest ball is one of the three on the heaviest dish. So, by weighing two out of three balls on the heaviest dish, they will be able to determine the heaviest ball. Eventually, with just two attempts, they will select the heaviest ball out of the initial group of eight.

Solution #4: A Helluva Card Game

The player to the left of the dealer—let's call him Larry—will lead. Two cards are known to Larry when he makes his bid: the card in his hand and the trump-suit-setting card—the "face-up card." Of the 50 other cards, at least 26 are inferior to the card in Larry's hand, those cards belonging to the other two suits. Therefore, in a two-player game, the probability that Larry will win the trick is at least 26 out of 50, which is greater than 50%. That is, Larry should bid to win one trick, regardless of the card he is dealt.

To continue, let's assume without loss of generality that the trump suit is hearts. If Larry was dealt a card that isn't hearts, let's assume, again without loss of generality, that it is clubs. If he is dealt 2♣, only 26 of the 50 unseen cards will lose to it. If he is dealt A♥, all 50 cards will lose to it. Therefore, it's possible to assign numbers from 26 to 50 to each of the cards 2♣,…,A♣; 2♥,…,A♥, from which sequence the face-up card has been removed. This number, k, is the number of unseen cards that will lose to Larry's card. It is the card's rank. The probability that the player to the left of Larry has a losing card is $k/50$. The probability that the player to the left of her also has a losing card is $(k-1)/49$. For an n-player game, then, the probability, p, that a card with rank k will win the trick for Larry is

$$p = \frac{k}{50} \times \frac{k-1}{49} \times \cdots \times \frac{k-n+2}{52-n} = \frac{k!(50-n+1)!}{50!(k-n+1)!}.$$

When $n = 2$, we already know that $k = 26$ is sufficient to make $p > 0.5$. By evaluating this function for different values of n and k, we discover that the optimal strategy for Larry is to bid to take one trick only when the card in his hand is at least as good as the card in Table 1.

TABLE 1. Is victory in the cards for Larry?

NUMBER OF PLAYERS, *N*	MINIMUM CARD RANK, *K*	NAME OF CARD
2	26	2♣
3	36	Q♣
4	40	3♥
5	43	6♥
6	44	7♥
7	45	8♥
8	46	9♥
9–11	47	10♥
12–15	48	J♥
16–26	49	Q♥
>26	50	K♥

Note that the name of the card in Table 1 must be increased by one if it would rank equal to or higher than the face-up card. P

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Selecting a development board for your capstone or course project

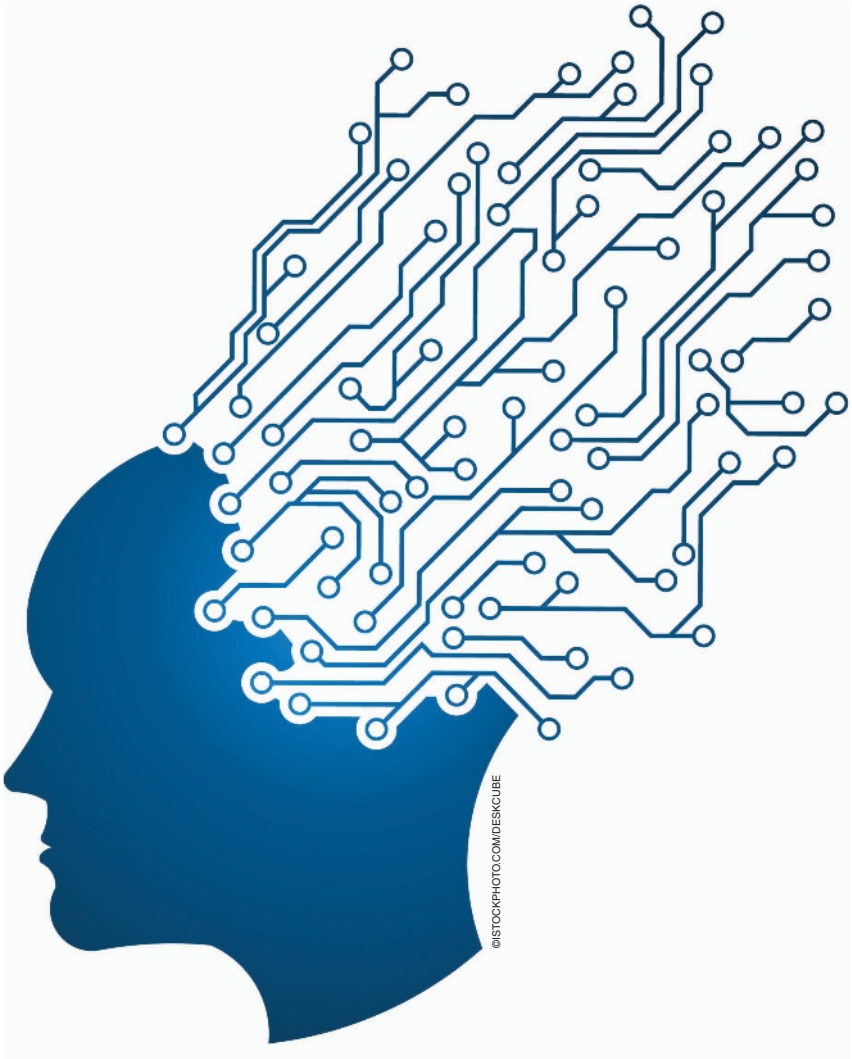
Rudy Lang, Michael Lescisin, and Qusay H. Mahmoud

It is apparent that development boards are an emerging area, given that the market size for microcontrollers has grown 11% from 2006 to 2013. As of 2013, over 700,000 official Arduino boards have been registered. Additionally, as of 2015, approximately 5 million Raspberry Pi products have been sold.

Development boards are a key component of this decade's Internet of Things (IoT) movement; they are designed to be efficient, connected, portable, and sensing. They complement the main idea of the IoT by interconnecting all types of devices—from consumer to industrial—and are useful tools for learning software and hardware design integration. They offer great features for both the student and veteran hobbyist.

Our objective in this article is to provide methods for selecting the correct development board given a particular project. This is geared toward students and instructors, but it may also prove useful for the general hobbyist. Nine of the latest and most popular boards on the market will be explored in-depth. The information in this article is intended to identify the boards' strengths and weaknesses and assist a developer with choosing a device. The following boards have been evaluated:

- Arduino Uno Rev 3
- Raspberry Pi 3 Model B
- BeagleBone Black Rev C
- Intel Galileo Gen 2
- LaunchPad MSP-EXP430FR5969
- NXP FRDM-KL25Z



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- pcDuino4 Nano
- ST-Nucleo L476RG
- C.H.I.P.

There are hundreds of different development boards on the market, many of which share a common goal of being compact, low-power, and versatile controllers. Given the diversity of these boards, presenting a criterion to categorize each one would not be practical. Rather, it is recommended that one follows the same thought process presented in this article. First, consider if the board contains the necessary components to run all of the features that you require. If not, does the board support expansions that can enable these features? Consider the supported programming languages and one's level of competence with those languages. The community and support for the board are arguably the most important factors. These could be the primary resources when designing a project. Moreover, it could be the main resource when fixing any issues that may arise. Finally, one must consider the cost versus the components of the board: Is it worth paying for? Figure 1 shows one of our evaluated development boards, the Raspberry Pi 3.

Defining a development board

A development board is a small, compact circuit board that contains either a microprocessor or microcontroller (or both) and supplies the necessary components—both hardware and software—to allow for bottom-up design and programming. The term *development board* is somewhat ambiguous; it is commonly interchanged with terms such as *microcontroller*, *embedded system*, and *single-board computer*. A microcontroller should not be confused with a microprocessor, which is simply a central processing unit (CPU) that communicates with external peripherals via data busses, as a microcontroller contains a CPU, RAM, ROM, and input/output (I/O) and is often designed for a specific purpose, such as data monitoring or control.

Identifying the project type and its needs

The first step in choosing the correct development board is to determine the project type. This article generalizes the various types of projects commonly created using development boards into the following categories.

- **Control** includes any component that asserts a physical force of some kind.
- **Sensing** comprises any component that provides any kind of input (mainly analog).
- **Visual** consists of any component that involves the manipulation of light.
- **Audio** includes any component that sends or receives sound.
- **Network** comprises any component that makes use of the Internet or some type of communication.
- **Software/Runtime Environment** refers to any feature that can be programmed on the board (the board will require an operating system).

Based on these six categories, a list of necessary components can be determined. The associated components are listed in Table 1. The information listed in this table is intended to be a guide only. The associated features are what developers in the community have typically used and are recommended by some manufacturers. There are often multiple ways to achieve a desired task.

A development board is a small, compact circuit board that contains either a microprocessor or microcontroller (or both) and supplies the necessary components—both hardware and software—to allow for bottom-up design and programming.

Programming the development board

The development environment affects how the developer interacts with the board. Support for multiple operating systems, languages, and integrated development environments (IDEs) create a richer programming environment and thus a more appealing development board.

Some development boards have custom IDEs associated with them, providing preconfigured device support and libraries, essentially offering an all-around more user-friendly workspace. More versatile IDEs (those not designed for specific development boards) allow users to explore alternative programming languages.

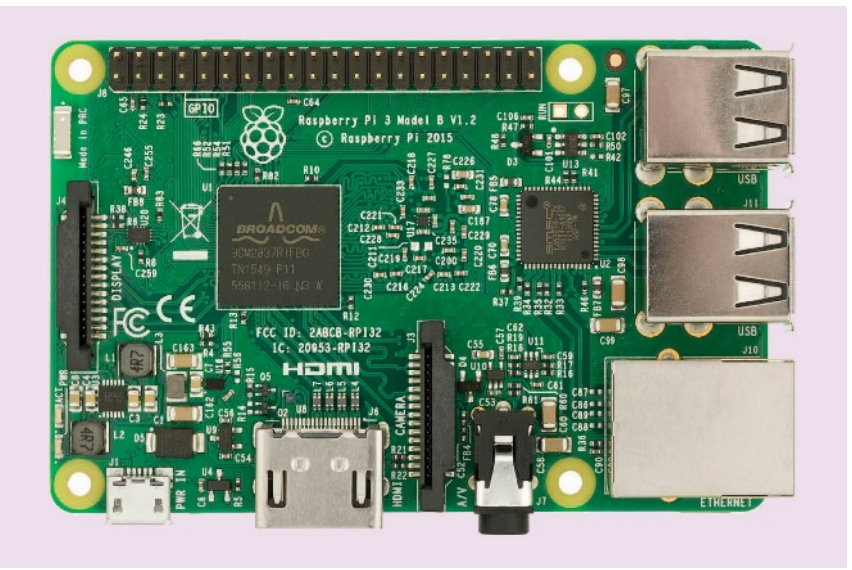

FIG1 The Raspberry Pi 3 was used in one of our projects.

TABLE 1. Associated components based on project features.

FEATURE	ASSOCIATED COMPONENT
Control	
Motor	Digital I/O, pulse-width modulation (PWM), analog-in, battery
Actuator	Digital I/O, PWM, battery
Pump	Digital I/O, PWM, battery
Solenoid	Digital I/O, PWM, battery
Sensing	
Photoresistor	Digital I/O, analog-in
Capacitive touch	Digital I/O
Gyroscope	Analog-In, inter-integrated circuit bus (I2C), serial peripheral interface (SPI) bus
Accelerometer	Analog-In, I2C, SPI
Hall effect	Digital I/O
Potentiometer	Analog-In
Pushbutton	Digital I/O
Thermocouple	Digital I/O
Tilt	Digital I/O
Infrared	Digital I/O
Visual	
LED	Digital I/O
LCD	Digital I/O, display serial interface (DSI)/high-definition multimedia interface (HDMI), SPI
Segment display	Digital I/O
Projector	HDMI, external power source
Laser	Digital I/O, battery
Audio	
Buzzer	Digital I/O
Speaker	Digital I/O, audio-out jack
Headphones	Audio-out jack
Synthesizer	Digital I/O, analog-in
Amplifier	Digital I/O, analog-in, battery
MIDI	Digital I/O, serial transmitter
Mic	Analog-in
Network	
Server	Ethernet, storage/SD
Media	Ethernet/Wi-Fi, storage/SD, USB
Radio	Ethernet/Wi-Fi, digital I/O
Bluetooth	Digital I/O, serial transmitter, serial receiver, USB
Wi-Fi	Digital I/O, serial transmitter, serial receiver, USB
Mesh network	Ethernet/Wi-Fi
Cloud	Ethernet/Wi-Fi
GPS	Ethernet/Wi-Fi, serial transmitter, serial receiver
Software	
Games	Operating system
Apps	Operating system
GUIs	Operating system
Hardware	
GPU	System-on-a-chip
RAM	SRAM, DRAM
Storage	EEPROM, FRAM, SD cards, USB

C is considered a universal language for microcontroller programming, with C++ following closely behind. Other programming languages may be used if they are compatible with the development board. The following sections provide a breakdown of nine popular development boards along with their commonly used software.

Arduino UNO REV 3

The Arduino Uno has its own cross-platform software development environment called Arduino Software IDE. Arduino programs are written in C or C++ and include the "Wiring" library, which simplifies the coding needed for basic I/O operations. Various third-party IDEs are compatible with the Arduino Uno.

Raspberry Pi 3 model B software

The Raspberry Pi's most popular operating system is Raspbian (based on Debian), but it is also capable of running Android and Microsoft's Windows 10 IoT operating system. Any language that can be used on ARMv8 may also be deployed on the Raspberry Pi. Such languages include Python, C, C++, Java, Scratch, and Ruby, with Python being the most popular. There are many expansion boards (shields) for the Raspberry Pi, including Sensorian (github.com/sensorian), which was designed and developed at the authors' university, the University of Ontario Institute of Technology.

BeagleBone Black REV C

The BeagleBone Black comes with the Debian Linux distribution preinstalled but is also compatible with the Android operating system. The board supports any programming language that can be used with those operating systems.

Intel Galileo Gen 2

The Intel Galileo Gen 2 board runs on a basic Linux operating system and has a cross-platform IDE similar to that of the Arduino. Additionally, it is compatible with the Arduino software development environment.

TI Launchpad MSP-EXP430FR5969

Texas Instruments (TI) offers free software development tools for the Launchpad, such as the Code Composer Studio IDE and Energia. Energia is a rapid prototyping platform based on the Arduino IDE. TI offers free (limited size) cloud-based development tools for quick use. All these tools accept C/C++ code for programming the LaunchPad. Other C/C++ compilers may also be used.

NXP FRDM-KL25Z

The FRDM-KL25Z runs on the mbed operating system, which provides a framework that reduces low-level work, thus facilitating program development. The FRDM-KL25Z is supported by the mbed software development kit, which is a C/C++ microcontroller software platform. It is built on the ARM Cortex Microcontroller Software Interface Standard application programming interfaces, making deep hardware coding possible. A benefit of being an mbed-enabled device is that there are online compilers and tools available from the ARMmbed website, which run cross-platform.

pcDuino4 Nano

Similar to the Raspberry Pi 3, BeagleBone Black, and C.H.I.P., the pcDuino4 Nano is capable of running Linux distributions (such as Debian) and can, therefore, use any programming language or tool chain supported by Linux.

ST-Nucleo L476RG

The ST-Nucleo is versatile in that it is compatible with most IDEs that can compile C/C++ or Assembly. Some examples would be Visual Studio, mbed (online compiler), IAR Embedded Workbench, or ST's compiler—STM32CubeMx. Programming the ST-Nucleo can be much more challenging than more popular boards, such as the Arduino, given that it requires a lower-level understanding of the processor. It is recommended for individuals who have a better understanding of microprocessor architecture and development, as well as those who seek more fine-grained control over a project.

Many development boards are manufactured with an open-source design, which encourages creative upgrades, customization, and bottom-up programming, and are not limited to the preconfigured components.

C.H.I.P.

Next Thing Co., the makers of C.H.I.P., ship the board with a customized Linux distribution known as the CHIP operating system. Being a Linux-based device, it can use any programming language or tool chain that is supported by Linux.

Development board community and support

A community based around a development board will aid in its development (growth), implementation, and ease of use. The resources that come with a community can make a significant impact on a user's choice. Resources include schematics, source code, tutorials, parts and expansions, and solutions to issues.

Many development boards are manufactured with an open-source design, which encourages creative upgrades, customization, and bottom-up programming, and are not limited to the preconfigured components. Communities and third parties often design and build expansions for the boards that greatly increase their versatility and functionality.

Arduino UNO REV 3

The community based around the Arduino Uno development board is very large. The official forums have more than 280,000 registered members. The official website supplies developers with documentation for Arduino's functions and libraries and houses a "Playground" in which users (the community) can share their projects and research for the benefit of others.

Raspberry Pi 3 model B

The community focused on the Raspberry Pi is very large. The official forums have more than 190,000 registered members. The official website features a number of unique projects and resources that teach the basics of the device. Third-party sites exist that provide tutorials for more advanced projects.

BeagleBone Black REV C

The BeagleBone development board community is relatively small compared to Arduino and Raspberry Pi communities. The official forums have approximately 10,000 registered members. The community is active in developing *capes* (plug-ins), some of which are sold as products by third parties.

Intel Galileo GEN 2

Intel hosts a small but growing support community for the Galileo board at https://communities.intel.com/community/tech/galileo/content. The Galileo Gen 2 supports some Arduino libraries thus giving projects designed with the Galileo board the advantage of being supported by the much larger Arduino community.

TI LaunchPad MSP-EXP430FR5969

The LaunchPad has a small, yet active, community. There is a notable social media presence, given that TI microcontrollers are popular in the maker community. The Facebook group, facebook.com/timicrocontrollers, alone has over 27,000 subscribers. TI hosts a well-organized webpage with information on the LaunchPad series, such as specifications, applications, software, tutorials, projects, and expansions.

NXP FRDM-KL25Z

The community for the Freescale FRDM-KL25Z is significantly smaller compared to the other the communities for development boards we

TABLE 2. Power, I/O, and cost of the discussed boards.

BOARD	OUTPUT VOLTAGE	POWER CONSUMPTION[1]	GPIO PINS	ANALOG IN	COST [US$][2]
Raspberry Pi 3 Model B	3.3 V	300 mA–1.34 A	17	No	35.00
BeagleBone Black Rev C	3.3–5 V	210 mA–460 mA	66	Yes	55.00
Arduino Uno Rev 3	3.3–5 V	23 μA–45 mA	22	Yes	24.95
Intel Galileo Gen 2	3.3–5 V	379 mA–430 mA	20	Yes	45.00
LaunchPad MSP-EXP430FR5969	5 V	0.02 μA–100 μA	20	Yes	15.99
NXP FRDM KL25Z	3.3 V	2 μA–20 mA	64	Yes	15.00
pcDuino4 Nano	5 V	Unknown	18	Yes	25.00
ST NUCLEO-L476RG	3.3–5 V	300 mA	64	Yes	13.72
C.H.I.P.	3.3 V	80 mA–500 mA	80	Yes	9.00

[1]Power consumption varies widely depending on operation mode and load demand.
[2]Lowest listed prices, excluding taxes.

have discussed. Freescale hosts a small community portal and forum specifically for its Kinetis Microcontroller line (under which the FRDM-KL25Z falls). There exists an online database called "Cookbook" (available at developer.mbed.org/cookbook/Homepage), which features hundreds of peripherals and module libraries designed for mbed-enabled devices.

PcDuino4 Nano

LinkSprite, the producer of the pcDuino4 Nano, hosts a community forum at linksprite.invisionzone.com for discussion and development of the board; however, its member base is relatively small at just over 3,000 people. The company hosts a learning center webpage and links to a number of blogs and websites that provide tutorials and projects for the board.

ST Nucleo L476RG

The mbed initiative provides numerous resources for ARM development and specific support for the ST Nucleo boards. Such resources include modules, components, and cloud services. ST provides a message board from which users can find support for the ST Nucleo.

C.H.I.P

The C.H.I.P. microcomputer is relatively new to the market, having first launched in early 2016. Next Thing Co. hosts expansive documentation on the microcomputer, covering its setup and configuration. The company's official forum, bbs.nextthing.co, has just under 8,000 registered users and is populated daily.

Development board specifications

This section explains the significance of each development board parameter, while Tables 2–5 compare each board in terms of the areas of focus described in the "Identifying the Project Type and its Needs" section.

CPU and clock speed

This variable affects the overall performance of the board: how fast it can run computations. It should be noted that comparing clock speed between unrelated CPU families may not provide a meaningful comparison; other factors, such as instruction cycles, instruction sets, and pipeline depth, also affect microcontroller performance.

RAM

This variable affects the number of tasks that can be run simultaneously. It also impacts how fast data can be processed, as swapping data from RAM to nonvolatile storage incurs large performance overheads.

The graphical processing unit

A graphical processing unit (GPU) will allow a development board to run video output (e.g., VGA/HDMI). A high-performance GPU is most needed when processing video/images with the development board.

Storage

Storage affects the size of programs, operating systems, and generated/downloaded data that can be stored on a development board.

TABLE 3. The audio/visual details of the discussed boards.

BOARD	VIDEO OUT	DSI	CSI	AUDIO OUT
Raspberry Pi 3 Model B	HDMI	Yes	Yes	HDMI/audio jack
Beagle Bone Black Rev C	MicroHDMI	No	No	MicroHDMI
Arduino Uno Rev 3	No	No	No	No
Intel Galileo Gen 2	No	No	No	No
LaunchPad MSP-EXP-430FR5969	No	No	No	No
NXP FRDM KL25Z	No	No	No	No
pcDuino4 Nano	HDMI, CVBS	No	Yes	3.55-mm audio jack
ST NUCLEO-L476RG	LCD driver	No	No	No
C.H.I.P.	Yes, TRRS	No	Yes	Yes, TRRS

The number of general-purpose I/O pins

General-purpose I/O (GPIO) pins are used to connect components to the development board; thus, more pins typically means more simultaneously connected components. GPIO pins are usually assigned specific functionalities by the manufacturer, such as interintegrated circuit (I^2C), serial peripheral interface (SPI), and universal asynchronous receiver/transmitter (UART). These standards facilitate interoperability with third-party devices such as displays or sensors.

The analog-in

Analog-in pins are necessary for any data acquisition (sensors) and are parameterized by their resolution and sampling rate. *Resolution* refers to the number of discrete levels to which the input signal is quantized, while *sampling rate* is the number of data points that can be obtained in a fixed time interval. High resolution is required for precise measurements, while high sampling rates are required for fast changing signals.

Pulse width modulation

Pulse width modulation (PWM) is a type of digital signal that is ideal for mimicking analog signals. PWM works by varying the duty cycle of a square wave pulse in proportion to the desired value of the analog output. Similar to analog inputs, PWM outputs are parameterized by resolution and sampling rate.

Significance of being open-source

The Open Source Hardware Association defines open-source hardware as having a design that anyone can make, modify, distribute, and use. The software associated with the hardware must be sufficiently documented to write open source software or fall under an Open-Source-Initiative-approve license. A development board will be labeled "partially open-source" if it falls under only the hardware definition or the software definition.

Power consumption

Power consumption can play a major role in design choices. For portable projects, one must consider the runtime requirements and power demand of the board/associated components when selecting an energy source. For example, a development

TABLE 4. Networking/storage of the discussed boards.

BOARD	ETHERNET	WI-FI	BLUETOOTH	EXTERNAL STORAGE	INTERNAL STORAGE
Raspberry Pi 3 Model B	Yes	Yes	Yes	microSD	No
Beagle Bone Black Rev C	Yes	No[1]	No[1]	microSD	4 GB
Arduino Uno Rev 3	No	No[1]	No[1]	No	32 KB
Intel Galileo Gen 2	Yes	No[1]	No[1]	SD	8 MB
LaunchPad MSP-EXP430FR5969	No	No[1]	No[1]	No	64 KB
NXP FRDM KL25Z	No	No[1]	No[1]	No	128 KB
pcDuino4 Nano	Yes	No[1]	No[1]	microSD	No
ST NUCLEO-L476RG	No	No[1]	No[1]	No[1]	1 MB
C.H.I.P.	No	Yes	Yes	No[1]	4 GB

[1]The board is capable of using the technology with the help of peripherals.

TABLE 5. Chip set/software of the discussed boards.

BOARD	CPU	GPU	RAM	OPERATING SYSTEM	OPEN SOURCE
Raspberry Pi 3 Model B	ARM Cortex-A53 (1.2 GHz, four cores)	Broadcom VideoCore IV	1 GB	Linux, Windows 10	Partially
BeagleBone Black Rev C	ARM Cortex-A8 (1 GHz, one core)	PowerVR SGX530	512 MB	Linux, Android	Partially
Arduino Uno Rev 3	Atmel AT-mega328P (16 MHz, one core)	No	2 KB	No	Yes
Intel Galileo Gen 2	Intel Quark X1000 (400 MHz, one core)	No	256 MB	Linux	Partially
LaunchPad MSP-EXP-430FR5969	MSP-430FR5969 16-bit (16 MHz, one core)	No	2 KB	No	Yes
NXP FRDM KL25Z	MKL25Z128V-LK4 (48 MHz, one core)	No	16 KB	mbed	Yes
pcDuino4 Nano	ARM Cortex-A7 (1.2 GHz, four cores)	Mali-400MP2	1 GB	Linux, Android	Yes
ST NUCLEO-L476RG	STM32 (80 MHz, one core)	No	128 KB	mbed	Yes
C.H.I.P.	ARM Cortex-A8 (1 GHz, one core)	Mali 400	512 MB	CHIP OS (Linux)	Yes

General-purpose I/O (GPIO) pins are used to connect components to the development board, thus more pins typically means more simultaneously connected components.

board serving as a data logger in a remote location must run uninterrupted for months, while one working as a mobile personal computer only needs to run for several hours before recharging. Power consumption can be difficult to quantify as many boards have varying modes of operation—some can enter a very low power-consumption mode when idle. When considering power consumption, the designer should contemplate the following factors: required computational power (can the code be made more efficient and run on a development board with lower power consumption?), maximum run time without recharging, and the cost/size of the energy source.

Board recommendations

In this section, we provide recommendations of boards for given classes of projects.

Arduino UNO REV 3

The Arduino Uno is an open-source, low-cost, and versatile development board. It supports many expansions, making it compatible with almost every feature listed in the "Identifying the Project Type and its Needs" section. This board requires minimal setup and offers a user-friendly development environment. The Arduino Uno is limited by its small RAM, making it useful only for simple, lightweight programs. Some examples of its use include temperature recording, liquid-crystal display control, motor control, musical instrument digital interface control, security systems, and remote control (Bluetooth/Wi-Fi).

Raspberry Pi 3 model B

The Raspberry Pi 3 is a partially open-source, low-cost, credit-card-sized computer which, like the Arduino Uno, supports many expansions. The Raspberry Pi 3's GPU and RAM make it a relatively powerful development board, capable of many tasks. It can run Linux, Windows 10 IoT, and Android. Its HDMI, Wi-Fi, and ethernet interfaces make it ideal for media applications. The Raspberry Pi lacks native analog-inputs and has fewer GPIO pins compared to similarly priced boards. Some examples of its use include security cameras, media servers, spectrum analyzers, remote controls, and quadcopters.

BeagleBone Black REV C

The BeagleBone Black is a partially open-source, moderately priced, and fairly versatile Linux-based development board. The setup for this device is incredibly simple, as it has Linux preinstalled and requires just a USB cable to get started. Its embedded multimedia card offers a performance improvement over booting from an SD card. The BeagleBone Black holds 66 GPIO pins, allowing it to run many components simultaneously. The BeagleBoard.org community has designed over 80 expansions (called *capes*) for the BeagleBone Black. One of its drawbacks is its price, costing, on average, US$20 more than Raspberry Pi and US$30 more than the Arduino Uno. Some examples of its uses include embedded cloud computing, hexapod robots, automotive controller area network (CAN) bus, and global positioning system trackers.

Intel Galileo GEN 2

The Intel Galileo Gen 2 is an open-source development board featuring a genuine Intel processor. The Intel Galileo is pin-compatible with shields (expansions) available for the Arduino Uno. It features a real-time clock, allowing it to track time even when powered off and is the only board in this group to support mini-PCIe. The Intel Galileo Gen 2 is limited by its price, costing three times more than an Arduino Uno and twice as much as a Raspberry Pi 3. It has no GPU and, therefore, lacks native video output. It is notably larger than the other boards, which may be unappealing for wearable applications. Some examples of its uses include autonomous navigation rovers, health-monitoring devices, smart water meters, and social media communication and interaction.

TI LaunchPad MSP-EXP430FR5969

The LaunchPad MSP-EXP430FR5969 is a very low-cost, low-powered, simplistic development board. This board comes with ferroelectric RAM, which is nonvolatile, high endurance, and high speed. It features an onboard supercapacitor, allowing some applications to run without external power. The LaunchPad MSP-EXP430FR5969 makes for a competitive alternative when compared to the Arduino Uno, beating it out in areas such as RAM size, GPIO pin count, and cost. The community and project support for this device is relatively sparse compared to the other boards. TI does, however, offer its BoosterPack plug-in technologies to expand the capabilities of the board. Some examples of its uses include smart lighting control, multisensor data logger, and wearable electronics.

NXP FRDM-KL25Z

The FRDM-KL25Z is somewhat unique compared to the other devices we have discussed. It is the only board that uses the mbed operating system and features a three-axis accelerometer, a tri-color LED, a capacitive touch "slider," and 64 GPIO pins. Despite its low-cost and open-source platform, the FRDM-KL25Z has a very small community and has yet to generate many projects. Some examples of its uses include USB human interface input devices and robotic arms.

pcDuino4 nano

The pcDuino4 Nano is the smallest microcomputer featured in this article—two-thirds the size of the Raspberry Pi 3. The board is equipped with an HDMI port, an ethernet port, three USB host ports, and 40 GPIO pins. There is also a USB-on-the-go port allowing the board to behave as either a host or a peripheral. It is the only board to have a built-in microphone and infrared receiver. Some examples of its uses include the Android Smart TV box, home automation systems, and video surveillance robots.

ST Nucleo L476RG

The ST Nucleo is similar in terms of components to the Freescale and Launchpad devices. One main differentiating feature is that the Nucleo supports CANs, which means it can communicate with other CAN-enabled devices without a mediator. The ST Nucleo is compatible with some Arduino-based shields, giving it more functionality. Some examples include dc motor control and GPS vehicle tracking.

C.H.I.P

The C.H.I.P. microcomputer houses 80 GPIO pins, a USB connector, a battery connector, and built-in Bluetooth and Wi-Fi. Some of the GPIO pins feature UART serial, I^2C, and complementary metal–oxide–semiconductor serial interface functionality. The company provides both VGA and HDMI adapter shields for additional connectivity. A single 3.7-V lithium-polymer battery can power the device, making it easily portable. Some examples of its uses include portable gaming devices, spectrum analyzers, home Wi-Fi security, and Wi-Fi routers.

Development board decision examples

This section focuses on our thoughts regarding the selection of a development board for each of our capstone projects.

Project A

This engineering capstone project involves processing real-time video from vehicle-mounted cameras and issuing alerts to the driver about the roadside dangers detected by computer-vision algorithms. Due to the video processing nature of this project, low-power microcontroller boards can be ruled out, as they are incapable of processing the video data in real time as required for generating real-time alerts.

Several of the computer-vision algorithms are parallelizable and could thus benefit from a multicore processor. Of the reviewed boards, only the Raspberry Pi 3 Model B and the pcDuino4 Nano have multicore processors. These two boards are quite similar in specification—they both have CSI camera connectors, 1-GB RAM, and run Linux from a micro SD card. Even though the pcDuino4 Nano sells for less than the Raspberry Pi 3 Model B (US$25 compared to US$35), author Michael Lescisin's capstone team opted for the Raspberry Pi 3 Model B due to the much larger maker community. OpenCV has been used and is well documented on the Raspberry Pi 3 Model B (Fig. 1), but the same level of support cannot be found for the pcDuino4 Nano.

Project B

This engineering capstone project involves collecting sensor data (such as temperature, humidity, and ultraviolet intensity) from a wireless, solar-powered node and transmitting it to a personal device for visualization and storage. The key requirement for this project is the node's power consumption. The node must sustain itself for long periods—upward of 200 days. As a result, it was essential to choose the lowest-powered microcontroller unit (MCU) with the appropriate number of GPIO pins. The use of an operating system or any visual/audio peripherals was not needed, so boards such as the Raspberry Pi, BeagleBone, Galileo, and pcDuino were not considered.

For the design to be wireless, the MCU needed to support connectivity technologies such as Bluetooth, Wi-Fi, or radio frequency (RF). Another important consideration was the need for the board to be open source, as the actual node itself is a custom-printed circuit board that incorporates the MCU of the development board, along with all its dependent components. This limits the options to the TI, NXP, and ST products. To keep the complexity of the design low, the MSP-EXP430FR5969 (Fig. 2) was chosen.

This MCU proved to be a good option for a wireless node. It's low power consumption allowed it to run continuously—transmit data over

For portable projects, one must consider the run-time requirements and power demand of the board/associated components when selecting an energy source.

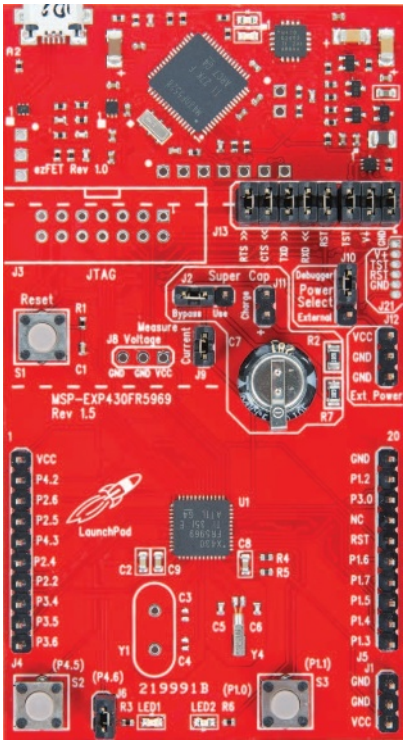

FIG2 The MSP-EXP430FR5969 LaunchPad was used in one of our projects.

Given the large number of development boards on the market, selecting one for a project may be challenging.

RF—given a 490-mV input voltage. It contained enough GPIO pins to dedicate 14 3.0-V, I2C-enabled breakout headers for peripheral sensors. It's 64-kB internal storage also provided enough space to briefly store sensor data until transmitted.

Conclusion

Given the large number of development boards on the market, selecting one for a project may be challenging. In this article, we provided a framework for selecting an appropriate development board for a given project by a means of filtering through categories of project type, programming methods, community and support, hardware/software specifications, and common use cases for various boards. By following the framework described in this article, a project designer should be able narrow down the set of candidate development boards for his or her project.

As new development boards are created and begin to appear in the marketplace, the boards discussed in this article will become decreasingly relevant. However, the classes of boards that they represent, such as 8-b microcontroller or single-board Linux computer, will still be relevant for the foreseeable future. By following the thought process we have described, project makers will currently be able to select one of the nine discussed development boards. In the future, this article will serve as a guide to which class of development board would best suit their project.

Disclaimer: The primary intent of the article is to act as a guide for students and instructors. Our goal was to provide the reader with a convenient and detailed source of reference for a wide range of development board options. The opinions stated within this article are our own. For more information on products contained in the article, please visit the manufacturers' websites.

Read more about it

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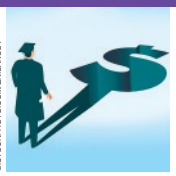

CreativITy: Using IT to create radical new solutions

Kai A. Olsen

A painter standing before a white canvas with brushes and a palette has the freedom to express anything—a landscape, a bowl of fruit, or a portrait. For creative painters, such as Leonardo da Vinci, Michelangelo, Rembrandt, Picasso, and Munch, it seemed that the canvas offered no limitations as to what could be expressed.

As information technology (IT) consultants, programmers, or system developers, we are in a different league. However, our tools offer us some of the same freedom as painters. Instead of replicating the solutions of yesterday, we have the option of introducing more disruptive systems. Rather than improving efficiency by a few percentage points, we can offer radical new processes—perhaps solutions—that can cut costs in half or more, handle greater complexity, or offer new products.

To achieve these results, one needs to listen to customers and work hard to understand their real problems. This is difficult. Customers are often strongly entrenched in their existing processes. Furthermore, they may suggest solutions based on their limited understanding of what is possible to achieve with IT, in many cases influenced by the systems that they

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employ today or that their competition use.

In his famous paper, "IT Doesn't Matter," Nicolas Carr calls IT a "commodity." He shows that companies use the same tools and consultants. Thus, IT is as electricity, says Carr, something that one needs but that does not offer any competitive advantage. If we offer a standard solution to our customers, using off-the-shelf software products, Carr is right. However, if we are able to think creatively, we may offer something else, that is, use IT to offer radical new solutions.

Clearly this is not always easy. There may be constraints that limit the freedom we have as consultants or developers. But there are many situations where we are allowed to think creatively. If we use these opportunities, we don't only provide value to the customers, but the development job becomes really interesting, perhaps to the degree where we feel as creative as (other) artists.

The opportunity to offer smart solutions may come in any type of application, as long as the following conditions are present:

- a good understanding of the customer's real problems
- proficiency with the methods and tools of the IT profession
- a willingness to think in new ways.

A set of cases will show that these opportunities can offer themselves in many types of situations. Note that all of these projects are of the type that we can expect to meet as consultants and developers. In our cases, the customers are quite ordinary companies, and the developers have been hired to offer traditional solutions. Still, when we see the opportunity to offer new and more radical alternatives, the customers have expressed no problems in recognizing the advantages and given us the go-ahead to proceed. The possibility of getting a leg-up on the competition is always attractive.

Handling variants in a furniture company

The customer is a company that produces furniture for ships. As space aboard a ship is limited and expensive, the idea is to adjust the furniture to the cabin. For example, if the bunk (bed) is in a corner next to the bulkhead, no end piece may be needed. If there is no space for a 200-cm bed, a shorter bed is produced for this cabin. If a table is connected to the bed, no legs are needed at one end (and not on the other end either, if it is next to a wardrobe). All pieces have edging, except on edges that are not seen (e.g., because the edge is connected to a wall). Furthermore, the customer is controls the color, length, width, and types of drawers.

The problem with handling this flexibility is that it requires many variants of each piece of furniture. A bed, a table, or any piece of furniture may exist in a large number of variants. In the previous system, the company operated with 40,000 furniture descriptions, each detailing which components went into this variant. The sheer number of descriptions made it difficult to get an overview. In many cases, it was easier to develop a new description than to find the one that was needed. Understandably, a lot of effort went into describing furniture variants.

TABLE 1. An example of a "goes into" relationship.

PARENT	NO.	CHILD
Bunk	1	Bottom part
Bunk	1	Top part
Bottom part	1	Frame
Bottom part	2	Drawers

With this number of descriptions, it became nearly impossible to make general changes. For example, assembly may become easier if a person cut a half millimeter of traverse board. But just to find the affected descriptions and perform the change would be a major effort.

A better solution would be to specify more generic or general descriptions. We do this all the time when we program. For example, a procedure for sorting will take the list to be sorted, as well as information on how the procedure should perform the sort (e.g., ascending), as parameters. In this way, the procedure can be used for any type of sorting. For programming, this idea has been extended to offer generic modules or classes with an interface of parameters and a body part that describes the execution.

However, this is not easy to achieve for product structures. These are usually described by specifying the "goes into" relationships through data tables (e.g., stating that a bunk consists of a bottom part and a top part, that the bottom part consists of a frame and two drawers, that the bunk has an end piece at either end, etc.)—as shown in Table 1. This simple structure may be augmented by if-statements, saying that the "goes into" relationship should be considered only if the statement is true (e.g., that the drawers should be included only if the customer has selected this option). But this method does not give enough freedom to express all variants.

We need a much more flexible approach. Based on previous research, we were able to offer a new solution to the customer: to describe products as programs by applying the idea of generic classes. That is, every piece of furniture has a list of attributes that describe the variants as well as a program part that can be executed to present the parts that are needed for the particular variant.

As an example, the attributes for a bunk are presented in Fig. 1. Each attribute may have a set of allowed values. When specifying a piece of furniture for a customer order, each attribute must be given a value. This process is simplified by using default values. Some of these can be offered as parameters (e.g., $colorPartOver will be a value that is offered for a cabin, a deck, or the whole ship).

A part of the program for this piece of furniture is presented in Fig. 2. This is written in a special-purpose programming language designed for the application. It offers everything that is needed to describe furniture and most of the statements that we will find in a traditional programming language, such as if-statements, loops, arithmetic and logical expressions, and procedure calls (here expressed as include-statements).

When a customer orders a piece of furniture, the value for each attribute is given based on what the customer wants. With the attribute values, the system can execute the program to produce the component lists that are needed to build this piece of furniture. We see that the program approach offers full flexibility.

With this generic system, we are able to reduce the number of furniture descriptions from 40,000 to 40. Still, with the 40, we can produce an unlimited number of variants. That is, nearly all customer specifications can be handled with the existing descriptions. Or, in other words, one has the ability to allow the customer full freedom when specifying furniture. The advantage is also a much better overview and significant reduction in the time used to create and modify furniture descriptions. With only one description for each type of furniture, it is easy to tweak the descriptions (to perform small changes over time that offer a better product) as one gets more experience. This allows for significant savings in production.

In addition to the advantages that come from a very limited set of descriptions, the programming approach makes it easy to compute the need for materials, costs, weight, and number of packages. That is, the programming approach defines a foundation where it is easy to add new functionality. The system has been running for two years and is used for the whole process, both for administration and production.

We see that when programmers have a deep understanding of the processes that their customers perform, new possibilities emerge.

The main idea here was to see that the number of variants was the problem and find a method that could handle these issues. With this in mind and some experience from programming languages, the solution, describing products as programs, was not far off.

Ship propellers

For several years, I have worked with a foundry that produces propeller blades for ships. Each propeller is made out of three or more blades, where each blade may have a height of several meters and weigh many tons.

The process starts by making a model of the propeller in wood using a five-axis milling machine. The model is then set in a sand fixture to get a mold. The mold is filled with nickel aluminum (bronze) at 1,200° C. The problem is that the cast will shrink as the metal cools off. Therefore, the model is inflated with a given percentage (e.g., made 5% larger). The finished cast is checked to ensure that it fulfills the requirements set by an international standard for propeller blades. If the measurements are outside the allowable limits, material must be grinded off.

The first task was to develop a program that could measure the cast and then help an experienced

Attribute	Show to customer	Allowed values (e.g., 40;60;100)	Default value
length	☑		2000
width	☑		800
colorPartOver	☑	1040;1040AR+;1079;1614;1834;2001;2253;2731;3210;	$colorPartOver
colorPartUnder	☑	1040;1040AR+;1079;1614;1834;2001;2253;2731;3210;	$colorPartUnder
colorDrawer	☑	1040;1040AR+;1079;1614;1834;2001;2253;2731;3210;	$colorPartOver
noOfDrawers	☑		2
drawerSide	☑	left; right	
frontguard	☑	without;free;bulkhead;adjustable	free
frontguardUpper	☑	without;free;bulkhead;adjustable	free
bedendleft	☑	with;without;free;bulkhead;high	without
bedendright	☑	with;without;free;bulkhead;high	without
bunkendleft	☑	with;without;free;bulkhead;high	without
bunkendright	☑	with;without;free;bulkhead;high	without
noOfKeylocks	☑		0
fireRetardent	☑	true;false	false

FIG1 The attributes for a bunk.

```
!UPPER PART
include mountingProfile(length-3;0) as mounting
if frontguardUpper = 'adjustable' then
   include bedguardAdjustable(colorPartOver;fireRetardent) as bedguardadjustable
elseif frontguard <> 'without' then
   include bedGuard(colorPartOver;frontguardUpper;fireRetardent) as upperguard
end if
include BedPart(length;width;colorPartOver;fireRetardent) as upperbedpart
if (bunkendleft = 'free') | (bunkendleft = 'bulkhead') then
  include bedGuardEnd(colorPartOver;bunkendleft;fireRetardent) as endguardleft
end if
```

FIG2 Part of the program describing a bunk.

You can see that one doesn't have to operate a multibillion dollar company to showcase creativity.

operator find the amounts of material that had to be removed. This could be as simple as grinding of a millimeter at one position on the blade and, perhaps, a couple of millimeters at another position. Often this operator would use a large part of a working day to find the right combinations of grinding (i.e., those that would offer a blade that fulfilled all of the requirements). While an earlier spreadsheet solution checked only a part of the control variables, the task was to include the full set.

We then found that with all control variables, in practice, finding the right amount of material to remove at a tentative 35 positions on the blade would be a nearly impossible task to perform manually, even for an experienced operator. Brute force was the answer. Instead of asking the user to find the grinding spots, the program ran through all of the possible combinations. In a couple of seconds, we not only had a solution but were also able to present the answer that required a minimum amount of grinding. With this simple approach, the customer got a full system for US$10,000. After three weeks of use, its development costs had been covered. This was 20 years ago, and, since then, the system has produced the same amount of savings every three weeks. In addition, the company has been able to handle more complex orders.

It is important to notice that the customer had no idea that this was possible; they had never heard about brute force algorithms. This is the part where the experienced programmer sees which tools can be used to solve the customer's real problems. In this case, brute force (i.e., the approach where we use the power of the computer to run through all options) was the answer. Brute force algorithms are simple to implement and are also very robust. For example, our algorithm can work on any type of propeller blade.

After working with this company for several years, we (the company personnel involved in the system development and myself) saw many new possibilities for applying novel solutions. An important project included reducing the amount of grinding that was needed on each blade. The traditional process of making a too-large model and then expending a lot of effort to grind off the additional material from the cast clearly offered an opportunity for improvement. The idea was to develop a model that was much larger, where the shrinkage was the greatest (e.g., around the edges) and only slightly larger where the shrinkage was less (e.g., in the middle of the blade). Working together with experienced personnel from the company, I was able to determine slim "shrink-to-fit" models (those that produced casts that were close to the requirements and only needed a minimum amount of grinding). The allegory to blue jeans is not accidental.

The problem is that this, in contrast to just inflating the geometry by 5%, creates quite a new geometry for the blade. For example, the spline curves that defined the geometry had an inclination to go wild when we made small adjustments to the controlling points. We had to develop new techniques to describe the geometry and add routines that smoothed the curves. Developing the program was a major effort, but, in the end, we were able to produce casts where the grinding effort was reduced by 50%. In addition, the system required less material for each blade and, therefore, also less energy to heat the metal.

Again, we see that when programmers have a deep understanding of the processes that their customers perform, new possibilities emerge. A 50% saving in one of the most labor-intensive tasks for this company offered a huge benefit, profit in good times, and a way of survival in rough times.

An app for plumbers

At one time, there was a possibility for those that did not excel in school to get a practical occupation, away from having to write or perform complex calculations. Not so today. We work for a chain of plumbers. While plumbers perform a practical job, they are required to follow strict health, safety, and environment procedures. In addition, many customers require extensive documentation. These regulations also affect managers, who have to follow such guidelines for organizing work, sick leave, and yearly employee conversations, providing plumbers with the necessary certificates, and much more. Just to get an understanding of the requirements is a huge task, both for the plumber and the manager.

While an abundance of checklist and field service systems exist, our idea, developed in close cooperation with the customer, was to implement the concept of a process list. A process list should lead the user through a complex task, ensuring that all regulations are followed. It would be available on any mobile unit (e.g., smartphone) and work both online and offline. Input should be limited to a minimum: to hit buttons, choose from predetermined answers, or take a picture.

The process lists are developed by the chain office for each different job type. The plumber or manager who follows the list is guaranteed that all regulations are followed. Any change in regulations would immediately be handled in a new version of the affected process list. That is, neither plumbers nor managers would need to read all the information they receive from authorities. All processes are broken down to answering a question and then hitting the next button.

The process list also handles all communication with the customer, head office, or authorities. When the plumber starts working at a residential home, the customer, if not present, will receive an automatic text message. A similar message will be generated when the plumber leaves the premises. Applications

and notifications to the authorities can be forwarded automatically. The head office will be informed of the progress directly by the status of the process list.

In the office, the manager will follow the process list for sick leave, knowing that the correct procedure is followed. The system automatically warns when an employee requires a follow up and also takes the manager through the required steps. Even if this is the first time a procedure is performed, the manager will know that everything is handled correctly. If the authorities ask, a button click will provide the necessary documentation.

The user-interface part—the app and the communication protocols that are used—is nothing new. The important aspect is how the central office can turn regulations into process lists. Instead of requiring every plumber and manager to turn regulations into practice, this is done only one time—at the chain office. It is not an easy task; a lot of effort goes into developing process lists and testing them in practice.

Managers and plumbers can also create their own process list. This may be necessary for companies that perform special jobs. To simplify the creation of process lists, we offer a visual system where items can be created and placed in the list by a drag-and-drop system. Process lists created by chain members can later be offered to the whole chain.

The main idea here has been to remove bureaucracy by recording everything and leading the plumber through the best way of performing a job, including all of the necessary steps. Since input requires a simple button click or taking a photo, the time used by the plumber is negligible. He or she can now concentrate on the practical tasks. The system is currently installed at 30 member companies. The idea is to cover the whole chain in the next 12 months. Feedback, so far, is very promising. The new plumber sees the advantage of getting the best practice approach to a job by following the list, while the more experienced workers recognize the value of leaving the bureaucracy to the system. In addition, all the bureaucratic requirements are handled by the system without any extra burden on the user.

As IT consultants, programmers, and system developers, we can ensure that our customers get the most out of IT.

The inspiration for the process lists is the wizards that are present in many computer systems for performing complex tasks. The creative point in this application is seeing that the wizard idea can offer a solution to the ever-increasing requirements that have to be handled by plumbers and their managers. Instead of reducing bureaucracy by trying to limit the input, we instead register everything that is needed for a job—but ensure that the input phase itself can be performed without additional costs. This has become a very useful and important tool for the plumber—"don't leave home without it" has become the slogan.

The chain has the advantage of being able to offer a useful system to its members, a system that is not available to the competition. The next step will be to add additional functions to the app, making this an important tool for communication between the head office and the member companies and their employees.

A hiking guide

Many people enjoy taking advantage of the great outdoors, and hiking is just one of many popular options to do so. Hikers have an abundance of guides, for every part of the world, available to them. While most guides offer pictures, the actual directions are based on text. An example may be the following:

> From the parking lot, we take the path to the right. This will take us up through the woods. The trail splits after we get out of the woods. Here, we will follow the branch to the left. The last part is steep and exposed. Some simple climbing is needed to pass a difficult point.

The problem for the reader is visualizing the text. There may be several paths leaving from the parking lot: at which point are we leaving the woods (when the trees become more sparse or when we have passed the last tree?), how exposed is the trail (are we taking about walking on the top of a huge cliff or is it just a few meters drop?); what kind of climbing equipment is needed, and is this on an exposed part where there is a risk of falling off a cliff? The problem is that a trail is less formalized than a road. On a road, our directions are supported by our expectations of what a road is, road numbers, and signs. This is not the case on many trails.

The solution is to replace text by pictures, show an image of every point where we have a choice, and use arrows to indicate in which direction to go. Two examples are offered in Fig. 3. This method offers much more precise direction. The method is not new; in 1907, Gardner S. Chapin and Arthur Schumacher had pictures with arrows for directions in their book, *Photo Auto Maps*. It showed "photographs of every turn" from New York to Albany, a total of 58 images.

Today, digital cameras and typesetting systems should make the method more practical. However, a guide may have as much as 1,500 photographs, each with arrows, text boxes, and picture numbers. Few typesetting systems are able to handle this complexity without requiring much effort on behalf of the authors. As a result, most guides are still based on text.

Our solution was to add special purpose macros to Microsoft Word. In our case, we developed macros that can adjust pictures on a page, which insert arrows and picture numbers automatically and keep track of text boxes, etc. The code also

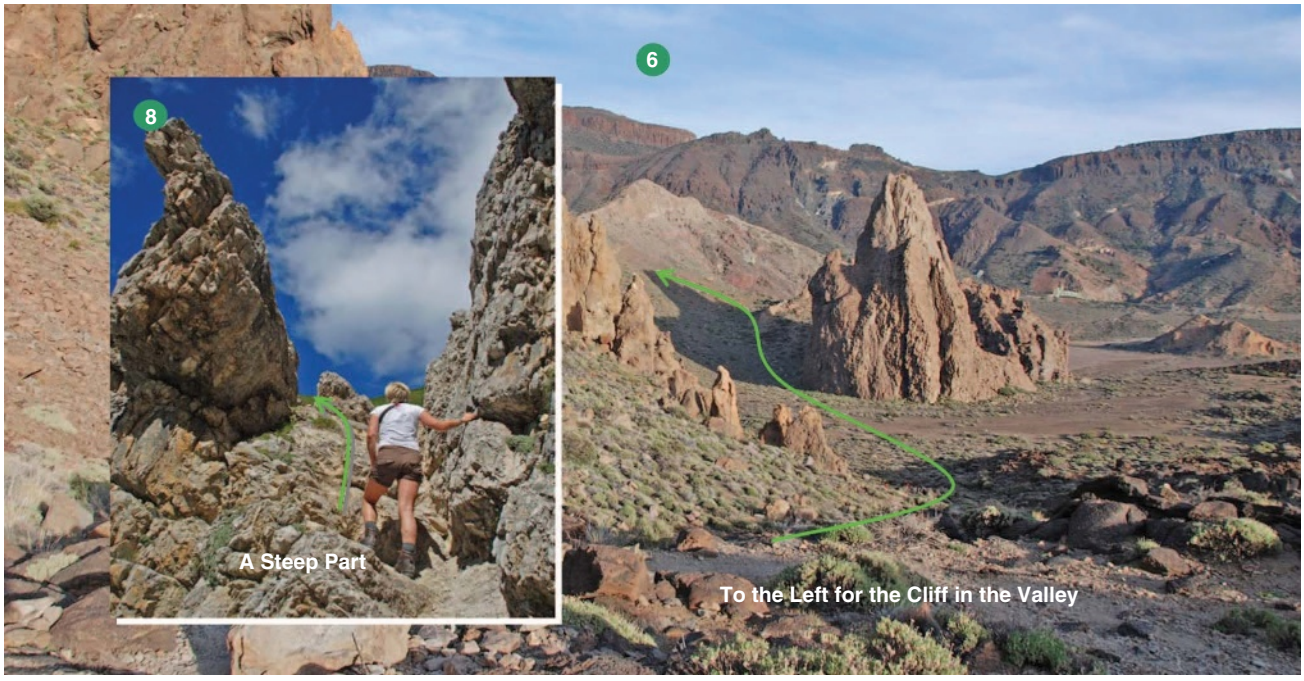

FIG3 A visual hiking guide.

checks consistency, both the tour description and the accompanying maps, ensuring that all pieces are included. With approximately 70 macros, each available as a button on the user interface, and 3,500 lines of macro code embedded in Word, we offer authors a simple way of producing visual tour guides.

In contrast to the other aforementioned cases, the central idea here is to understand that digital cameras and modern IT offer a "disruptive" solution to making hiking guides. The software needed is quite simple, especially as we often rely on a common word processor. Turning a standard typesetting system such as Word into a special-purpose typesetting system for visual tour guides is fairly straightforward. However, the developers must be able to see that the macro option is the solution in this case. Our customers report that the time used to create a hiking description is dramatically reduced. In addition, it is possible to do it right the first time, as the system aids with proofreading.

Conclusion

A set of cases has been offered to show the importance of seeing new opportunities and solutions that can be addressed by IT. Variants—different versions of a product—are handled by describing products as programs. Manual processes are automated, with IT smarter solutions offering great savings. Instead of complaining about bureaucracy, we can implement solutions where regulations are handled behind the scenes without any burden on the users; and, with IT, it becomes practical to tell a story using pictures rather than words.

Today's system developers have a large choice of tools available. In the systems I have presented, standard programming languages, development kits, and open software available on the Internet have all been employed. Some of the systems run on client-server systems while others are in the cloud. This vast range of tools and hardware makes it possible to offer creative solutions with limited costs.

Clearly our cases are modest compared to the creativity shown by Microsoft, IBM, Google, Facebook, WhatsApp, Instagram, Snapchat, and many others. But you can see that one doesn't have to operate a multibillion dollar company to showcase creativity. As IT consultants, programmers, and system developers, we can ensure that our customers get the most out of IT. At the same time, we may enjoy the thrill of finding and implementing radical new solutions.

Read more about it

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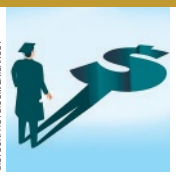

Never stop learning

Raymond E. Floyd

You may have asked yourself, "When does someone stop learning?" Some believe that it occurs following the completion of high school. What else might someone want to know? You have completed several years of English, read several works of literature, perhaps written a paper or two, and probably taken mathematics through geometry, algebra, and even trigonometry (if you were unlucky). Throw in the odd civics class, geography, state history, biology, and physical education, and what else is there to know?

The unfortunate truth is that when such a person goes to seek a career, he or she finds that his or her vast wealth of knowledge may, at best, result in an "award" of an opportunity at a minimum-wage job at a local restuarant or some similar occupation. While they may follow this route, the old-fashioned "school of hard knocks" may make this less than an enjoyable journey. All those who decide they have all the knowledge they need for life may not be forced into low-paying jobs. Some may be atypical individuals who understand the needs of others and perform above the norm without further training. Such individuals are rare.

When a person leaves high school he or she typically has four choices: 1) work, 2) marriage, 3) military service, or 4) college. It could be argued that there is a fifth choice for the new graduate—simply do nothing. You may be fortunate enough to take the fifth choice due to family fortune, but it is seldom going to be a long-term decision. In some cases, the choices may be combined, such as marriage and work, military and marriage, and other similar mixes that may be appropriate to your particular situation. One could argue that other choices also are possible, such as being a life-long volunteer or spending one's life in service to others, and that is a wonderful goal. Likewise, entry into religious service may be a choice. As evidenced by many today, one could also decide to become a politician, vying from appointment on the local

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If nothing else, I have found that learning never really stops, there are always fresh paths to follow with new needs of understanding.

school board to the lofty goal of becoming president of the United States. Since this article is more aligned with learning, it is choices three and four that will be looked at in greater detail.

For many, the choice of military service can be a great help in determining the direction they wish to pursue for the remainder of their lives. Beyond discipline and maturity, the military offers many fields of training that help build the foundation of the career when the individual leaves military service. In many cases, an individual coming out of high school may not have a firm grasp on what it is he or she wishes to do with the remainder of his or her life, and the military can provide that direction. Military service is one of life's learning experiences for all who participate. From my experience, I changed from planning on being a chemical engineer to working toward a career as an electrical engineer. The foundation for this change in career paths was the training I received in missile guidance systems and radar—both in electronics.

That leaves the fourth choice—college. When this choice is the one taken, many students are in for a rude awakening; they are no longer in high school! Many professors have little time or patience for students. The expectations are that the student has the basic background required for the course, they should understand and research solutions for complex topics, and can express their findings in a concise and complete manner.

According to the National Center for Education Statistics, regardless of the field being pursued, about one in five students will not be prepared for college studies coming out of high school and require remedial classes to prepare them for the college-level classes required of the degree being pursued. While students may believe they were taught everything in high school, they find that there is much more to learn, explore, and understand as they go through college. English will be more than the parts of speech, as they learn to write in a range of styles from short stories, poetry, news articles, and technical reports. Literature classes require more than simply reading a book. In many cases, the assignments entail the student providing his or her opinion of what message the author was trying to impart. And when it comes to technical matters, the added depths of calculus, differential equations, and other advanced mathematic subjects can seem quite daunting.

There is so much more to learn. Whether the student is satisfied with a bachelor's degree or decides to pursue his or her newly learned subject matter to greater depths and specialties through a master's degree or a doctorate, he or she will learn new material along the way; it isn't simply a repeat of all he or she knew when high school was complete.

Workforce lessons

When a student has finished the degree program that he or she decided upon, it is time to pursue a career. It may take a turn into industry or the academic world (grade school, high school, or college). In industry, new hires must learn company jargon as well as new technologies, people, and rules. In short, there are a host of new subjects that will have an effect on their future career choices. If they move from one company to another, they will find a different set of circumstances and procedures and must continue to learn and expand their knowledge base.

In academia, the student that becomes a teacher discovers that all students don't have the same learning rate or background knowledge. Each student's needs must be understood and accommodated. As the years go by, new discoveries will change curriculums, and teachers learn and adjust their material to accommodate such changes.

In my experience, I found the military to be a good choice and completed my service obligation with a strong desire to pursue electronics as a career field, with an emphasis on computer systems. While my career and family slowed my pursuit of a degree for a few years, I did earn my B.S.E.E. degree when I was 33 years old, followed by my M.S.E.E. at the age of 40. I was still learning. After a successful career in electronics, I found that I still wanted to continue my life's learning experiences, so I pursued a Ph.D. degree in management, which I completed at the age of 72.

Now I know I knew all I needed to—I could finally stop learning, right? Fat chance! Life has a funny way of redirecting one's plans. I was given the opportunity to take my experiences and impart them to freshman college students, I became a teacher. While I thought I had the knowledge I needed, I found that I still have a few things to learn. If nothing else, I have found that learning never really stops as there are always fresh paths to follow with new needs of understanding.

But college is not the only avenue for learning. A person may decide to become an artisan, where most of his or her training is in the form of apprenticeships—time spent in the company of the artist learning the process, procedure, the art of the field. In other instances, the knowledge gained may come from professional organization participation—both as a contributor and receiver of new knowledge from conferences, web presentations, and adult education programs. Another avenue for continued learning is through serving as a volunteer in a community or professional organization. There are many such opportunities available for those wishing to participate, and

each offers a learning experience for the participant.

In today's environment, the massive open online course (MOOC) offerings have become a path to gain new insight into a particular subject. MOOCs were first organized in 2008 and have rapidly expanded to include many universities offering thousands of courses through a number of online support networks. The whole topic of distance education is gaining momentum. The opportunities are there to learn about countless subjects. In many cases, universities offer complete degree programs via online course offerings.

If you wish to pursue such an opportunity, there are a couple of caveats of which you should be aware. First, not all online degree programs are accredited by ABET. (ABET accredits college and university programs in the disciplines of applied and natural science, computing, engineering, and engineering technology at the associate's, bachelor's, and master's degree levels.) Currently, there are only about a dozen programs accredited by ABET that are 100% online programs, with the majority being B.S.-level degrees. Second, advertising stating that a university is ABET accredited is misleading. ABET does not accredit universities, only specific programs within the various colleges making up the university (i.e., a B.S. degree in electrical engineering, B.S. degree in computer engineering, B.S. degree in mechanical engineering, etc.).

Beyond pursuing a degree online through the MOOCs, vast offerings provide credit for professional development hours required to maintain licensure. There are many professional career fields that require an ongoing effort to improve an individual's knowledge base. In this case, the individual is required to have some number of continuing education hours each year to maintain his or her license. The hours may be formal training programs, conference attendance, webinars, or similar activities, with each opportunity providing new knowledge to the attendee. The person attempting to gain such credit must check with the licensing authority to ensure that such online training meets the board's requirements for ongoing development.

The choice is not really important, the point is to continue to learn, expanding that knowledge base that you can enjoy throughout your lifetime.

MOOCs are opening another door for people to continue their learning. There does not have to be a specific target or goal for the learning, simply the desire to find out more about a particular subject. If one does a web search on lifelong learning, there are thousands of returns. A large number will be from universities that offer adult educational classes on a variety of subjects and are not concerned with degree requirements. The course offerings more reflect an opportunity to gain knowledge on other subjects like estate planning, computers, real estate, and photography, to name just a few. The intent is to provide an opportunity for people to gain knowledge outside of their current base. It has been said the more that people can continue to maintain mental health, the more likely they are to maintain physical health as well.

Learning lasts

Here's one final thought about the continuation of the learning process. At some point, you can move from the learning side to the teaching side, thus bringing the years of knowledge of real-life systems to the classroom. Such effort provides a great learning platform for the budding engineer—taught by someone who has been there and done that. You may even find that as you provide that learning experience, you will gain new knowledge in relating to students, advising subject selection to support their long-term goals, and becoming part of the ongoing learning experience.

We never stop learning. As you grow older, there are many things to pursue in the quest for new knowledge. It could be learning the ins-and-outs of photography, computers, music, or any number of subjects you didn't have time to pursue earlier in life. The choice is not really important, the point is to continue to learn, expanding that knowledge base that you can enjoy throughout your lifetime.

Read more about it

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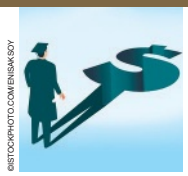

Managing your career in a dynamic environment

Seppo J. Ovaska

Right after signing on the dotted line for your first full-time engineering job, you might have a mixture of diverse feelings, including enthusiasm, happiness, pride, humility, and/or anxiety. You have just graduated and worked hard for years to prepare yourself for the next stage of your life, and you are now a professional engineer—congratulations!

Occasionally, such issues as job retention and advancement may weigh heavy on your mind. In this article, I will first describe the *dynamic work environment* as well as its opportunities and challenges. This is followed by a discussion of job retention and career advancement. The following commentary reflects my 38-year career as an electrical engineer, first in industrial research and development (R&D) and later in academia.

Dynamic work environment

The work environment of engineers is increasingly dynamic with various uncertainties. These dynamics are related to the following factors.

1) Novel innovations and associated product or service concepts may create foundations for new technical disciplines with high demand, such as cybersecurity that will have a critical role with the success of the Internet of Everything (IoE).
2) Major segments of high-tech industry may disappear unexpectedly. For example, the technological evolution had dramatic consequences for Nokia Corporation, the leading manufacturer of cell phones prior to the touch-screen smartphone era; their layoffs left thousands of engineers unemployed.
3) Globalization has speeded up the founding of new—and the expansion of existing—international

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corporations, which often results in company acquisitions, the merging of operations, downsizing of redundant workforce, as well as an increasingly international and exciting work environment.

The first factor is an opportunity for new graduates. On the other hand, a more established engineer, who is supposedly committed to lifelong learning, could either upgrade his/her qualifications by enrolling to a master's program that is taught in the evenings or on weekends or take complementary classes on focused topics. As an example, an M.S. degree program in cybersecurity is available at the New York University (NYU) Tandon School of Engineering, which is one of the National Centers of Academic Excellence in Cyber Operations. Be sure to remain proactive in keeping your knowledge and expertise up to date.

If a segment of industry is vanishing, such as traditional cell phones, it is devastating, especially to those loyal engineers who have spent their entire career in the same field and possibly even with the same company. Their expertise as R&D engineers may be deep but narrowly focused, and there might not exist job opportunities within that exact field anymore. In such a situation, a continuing education program that would complement one's existing knowledge capital would be a wise choice. In the example of past Nokia engineers, the IoE could be a potential "new beginning" that would be supported by their core expertise in mobile communications and handsets. So, do not throw away what you have already mastered, but try to enrich it with some new discipline or technology.

Although the first and second factor are both related to the notion that the high-tech industry has a rapidly changing knowledge base, they are discussed separately because the first is an opportunity to be observed or even predicted, while the second is a type of emergency condition.

Globalization is sometimes seen as a threat for lifelong employment; and it seems to be a current trend that corporations are becoming more globally affiliated. This calls for a positive attitude and adaptability to the evident consequences. In the short term, such consequences may seem merely negative, but, in many cases, the long-term opportunities for individual engineers are positive and desirable. In my case, I once received an opportunity to work for a period of 15 months in a newly acquired American subsidiary company of the corporation for which I was working. This temporary transfer clearly shaped my career and personal life. The key is the ability to be flexible in this globalized work environment.

Manifold uncertainties, including evolving immigration policies, financial recession cycles, global security threats, and even climate change, make for an ever-changing employment environment.

In addition to the aforementioned employment dynamics, manifold uncertainties, including evolving immigration policies, financial recession cycles, global security threats, and even climate change, make for an ever-changing employment environment. Coping with this enviroment requires one to brainstorm back-up career paths every now and then.

Job retention

When organizations are downsizing and laying off some engineers (not masses), it is not only your present knowledge capital that maximizes the chances to retain your job. In addition, you are expected to be a team player, at least a moderate communicator, and it helps if you are a committed and hard-working employee.

I have seen a couple of cases where the company was downsizing due to a minor financial crisis, and, in addition to the well-justified layoffs, also a few additional people with "difficult" personalities were laid off. In one case, the vice president bluntly described the action as "cleaning the corners."

Fortunately, teamwork and communication skills can be practiced and learned, either individually or in classes and seminars. The issue of teamwork in an engineering sense was defined by Bloomfield, and Choren provides an introduction to communication skills for engineers in the May/June 2015 *IEEE Potentials* article, "The Importance of Communication in the Workplace."

But what if you are not so committed, somewhat lazy, or have a difficult personality? Well, the first thing is to be honest with yourself and try to evaluate objectively—maybe with the help of a friend or colleague—whether or not these undesired qualities describe you. It should be noted that, in some cases, the lack of commitment and occasional laziness might be symptoms of job dissatisfaction. If that is the case, you should plan to "Move on!" as suggested by Ray Floyd in a recent *IEEE Potentials* article. On the other hand, if others see you as a difficult person, identify your harshest characteristics and aim to attenuate them gradually instead of letting emotions distort your professional image. Finally, job retention can be summarized by the followng piece of advice: Learn to know yourself and maintain yourself as a decent and agile company citizen.

Career advancement

A few years after getting their first job, engineers typically begin to consider their long-term future and advancement opportunities. Career advancement could be either a promotion in the present organization or a switch to another company with higher-level responsibilities. The relevance of the "Stay or switch?" question often comes to the forefront after several years with the same employer and without a promotion.

It's a good idea to explore two or three organizations and overlapping

It's a good idea to explore two or three organizations and overlapping fields of interest within the first ten years after graduation.

fields of interest within the first ten years after graduation. Experience with diverse organizations—small and large, domestic and international, or private and government—as well as with a sample of application segments creates a fruitful soil for the rest of one's career and lifelong employability. After such an educative term, one's adaptability to changes and different organizational conditions is better than after ten years in just a single company and in the same position. There is much appreciation for such flexibility within the fast-changing job market, particularly in start-ups.

Large organizations often have two ladders of advancement: specialist and management. But in smaller firms, the specialist ladder may have only a couple of steps. Which one of these ladders should you pursue? It depends. Many engineers make a transition to management smoothly and successfully, but others may fail because they "...made the choice for wrong reasons and to satisfy the wrong needs," as discussed by Badawy. Technical management is about getting things done through the team or department that works for you. As a result, you must be able to feel true satisfaction about the efforts and accomplishments of others. This is a vital issue to remember when considering the management ladder.

After some time in industry or government, you might feel that such an environment is not optimal for your needs and expectations. There is another option: getting a Ph.D. degree and making a move to the academic world. This might be a valid track after a few years as a practicing engineer; I made such a transition after 12 years in industrial R&D. However, academia has its unique structures and practices, and it takes time to learn and understand how one eventually becomes a professor. To begin, the book *Tomorrow's Professor: Preparing for Academic Careers in Science and Engineering* gives a pragmatic discussion on preparing for academic careers in engineering. It is a valuable resource for launching one's journey toward academia.

Career management is a multidimensional endeavor that needs explicit attention and alertness. Remember, you are continuously responsible for your career.

Read more about it

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When scientific luminaries interact with students

Sharad Sinha

One of the most effective methods for exposing young minds to scientific pursuits is providing them a platform to interact with scientific luminaries. We can hold hackathons, competitions, field trips, seminars, and symposiums, but nothing is more illuminating than close personal interactions with people whose works have contributed enormously to the advancement of knowledge. The triumphs and the tribulations of these scientists can provide immensely valuable perspectives to participants.

The Heidelberg Laureate Forum (HLF) is one such event where young researchers, mostly doctoral and postdoctoral candidates, from all over the world get the opportunity to experience close interaction with the winners of the Association of Computing Machinery (ACM) Turing Award, ACM Prize in Computing, Fields Medal, and Nevanlinna Prize. (The last two awards are in the field of mathematics.) HLF refers to these outstanding contributors as *laureates*. I had the opportunity to attend

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At HLF 2017, Sir Michael Atiyah, Fields Medalist, gave a fabulous talk, "The Discrete and the Continuous from James Clerk Maxwell to Alan Turing," where he related Maxwell's work on electromagnetism with Alan Turing's work on computation.

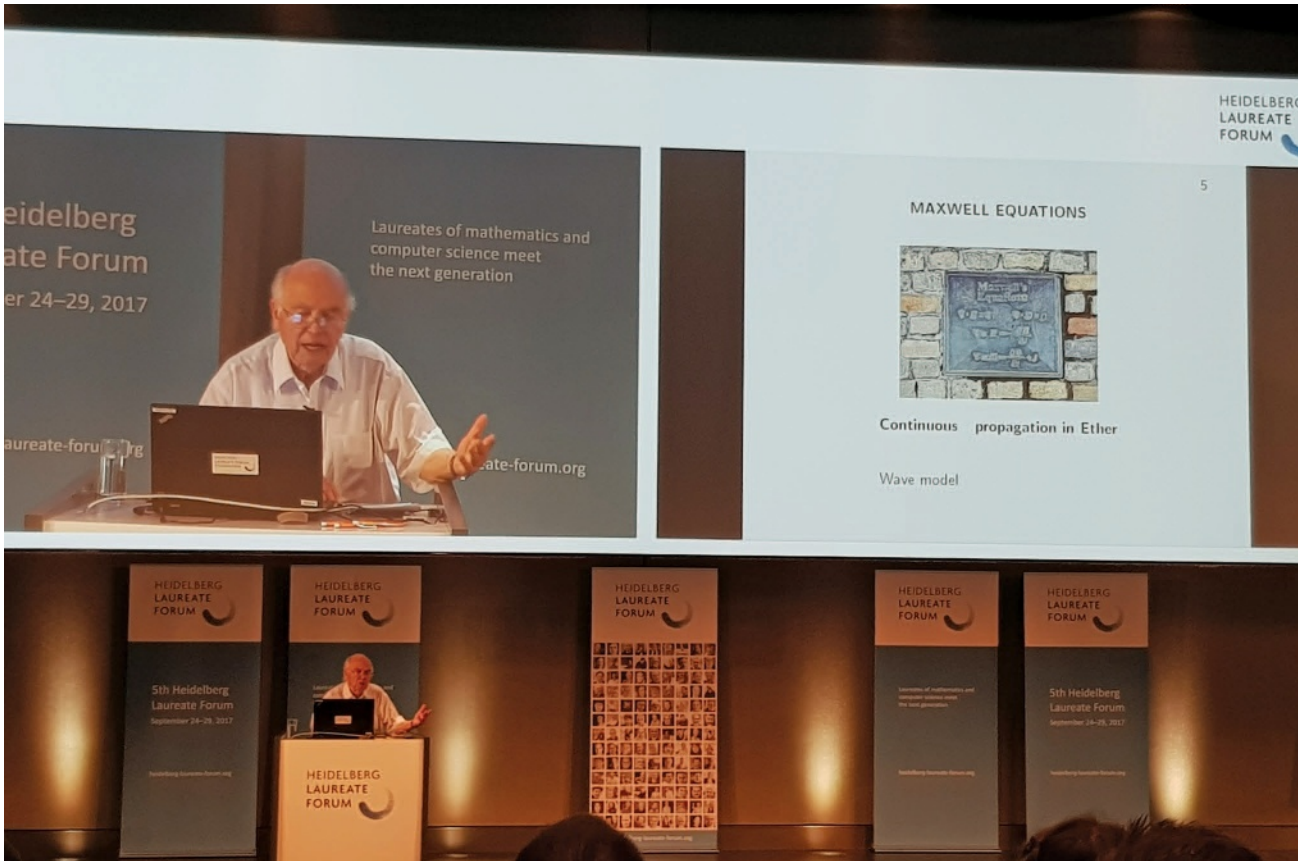
HLF 2017 as a press delegate, and in this article, I would like to share the importance of such events in scientific advancement.

HLF is the brainchild of Klaus Tschira, physicist and cofounder of German software giant SAP, and it is supported by a number of partners. This is also one reason why HLF includes a visit to a SAP office. Additionally, the trip helps young researchers get a taste of industrial research problems and allows for an opportunity to interact with senior management to learn more about industrial job opportunities for holders of advanced degrees (such as a Ph.D.). These interactions help students visualize the relationship between basic research and its applications.

However, the main thrust of the event is the talks delivered by the laureates and the interaction between them and the young researchers. Attendees can approach any laureate during the weeklong event and discuss their ideas. The average age of the laureates at HLF 2017 was in the range of 60–70 years, and they were all excited to talk to the young researchers. This type of interest shown by the laureates inspires the next generation of researchers to scale new heights. Many attendees were extremely happy to have such unfettered discussions. I believe that this encourages newcomers in a scientific field to pursue their wild and crazy ideas and not give up on them easily.

Events like HLF help participants interact with people outside of their own areas of expertise. It is an opportunity for graduate students and postdoctoral fellows to break from their laboratory routine and expand their horizon of thinking. It is also a chance to attend workshops in areas that may be orthogonal or tangential to their own expertise. Sometimes the laureates would present their work from a historical perspective. Such presentations enrich a researcher's learning of the evolution of a field. Insufficient knowledge of the history of a particular field in science and technology can lead to duplication of efforts. With this knowledge, researchers are in a better position to decide which paths of research to follow.

Sometimes, one gets to see amazing new relations between ideas. At HLF 2017, Sir Michael Atiyah, Fields



Sir Michael Atiyah giving his talk, "The Discrete and the Continuous from James Clerk Maxwell to Alan Turing."

(From left) *IEEE Potentials* Associate Editor Sharad Sinha with Guillermo Curbera (International Mathematical Union), Jen Gallenbacher (TU Darmstadt), Natalia Diaz Rodriguez (postdoc participant), and Dirk Huylebrouck (Belgium).

Medalist (1966), gave a fabulous talk, "The Discrete and the Continuous from James Clerk Maxwell to Alan Turing," where he related Maxwell's work on electromagnetism with Alan Turing's work on computation. On another occasion, Vinton G. Cerf, the founder of the Internet, was answering a variety of questions during an event for the press delegates. For instance, he shared his views on building a "safer Internet" with respect to Internet crime (like malicious hacking) and the existence of the "dark web," which is often regarded as a dark underground for many criminal activities. Cerf holds the view that Internet security is a shared responsibility. Programmers alone cannot build a secure Internet, although they have a role to play. Some degree of legislation and training of the users of the Internet is also required. Cerf considers it partly a societal problem and a nontrivial issue that needs a holistic approach considering how technology is designed, used, and legislated.

A unique facet of HLF is its coverage by science and technology writers and editors. At HLF 2017, more than 15 press delegates were present from all over the world: Asia, Australia, Europe, North and South America, and Africa. Some were science writers associated with the mainstream press, a few were freelancers, and some (like myself) were from academic backgrounds. I believe that a properly coordinated press program helps in the promotion of the event and consequently in raising awareness among researchers about such avenues. Science is not as well represented in the mainstream media as politics and economics. Therefore, press programs are necessary for creating public awareness—those who are generally not directly associated with the practice of science or the formulation of science policies.

The sixth edition of HLF is just around the corner, in September 2018. I encourage you to apply to be a participant and learn from the unique experiences that HLF offers.

Read more about it

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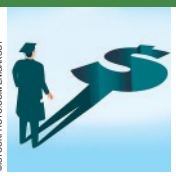

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The writing engineer: Combining words and technical expertise to further the field of engineering

Erin Winick

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A science, technology, engineering, and mathematics (STEM) degree can be the perfect start to a career not as a university researcher or industry engineer, but as a writer. While it might be a stereotype that engineers tend to be bad writers, I was determined to break this mold. Throughout college, while studying for my mechanical engineering degree, I found many people who did fit this mold. Lab mates happily passed writing duties off to me for lab reports, and I had to twist the arms of friends to write award applications.

I was happy to take on these tasks, but it also showed me a gap that currently exists in much of the engineering field. There is a lack of public awareness of what the job of

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an engineer entails and the diversity of the field. This resistance to writing and communication with the public, in general, is a major contributing factor to this gap in understanding.

I decided that I wanted to dedicate my career to changing the conversation about engineering.

Making a change

I saw an opportunity to help fill this void in understanding that exists between the public and the work of engineers and scientists. While in college, I began freelancing, writing for everything from start-ups and kid science magazines to technical publications. I loved leveraging what I was learning as an engineer for this nontraditional career. I decided that I wanted to dedicate my career to changing the conversation about engineering.

Upon graduation, instead of entering an entry-level engineering job at one of the companies at which I had an internship in college, I started my own company and began work full time as a freelance science writer and communicator. As any of you who freelance out there know, the industry provides varied work but is inconsistent. You can spend one entire week pitching articles or struggling to find work and the next bogged down with work late into the night. Despite having an engineering degree and some good bylines to my name, I knew I needed a bigger publication to help launch me forward and get the chance to learn from those more experienced.

Launch pad

That's where *The Economist* came in. The renowned international publication is notoriously hard to break in to, save for a few internship positions they offer each year, one of which is in the science and technology section: The Richard Casement Internship. In the midst of applying to a slew of science communication internships and fellowships, I sent in my application, not expecting to hear anything back. But then I did. And I was off to another country to spend three months in London writing about science for *The Economist*.

Let me tell you, it was a wild three months spent absorbing everything I could from the people around me. I was working in the midst of Ph.D.s and experts in business. I got to meet a group of people who had the passion—as I did—for covering and telling the stories of science and technology.

I did not feel like an intern during my summer there; I felt like a full-time employee. The publication treats its interns like every other writer on staff. I covered a wide variety of topics ranging from virtual reality on roller coasters to new manufacturing techniques for creating apparel.

I was truly given the freedom to explore and try out whatever I wanted. I appeared on *The Economist*'s science podcast, Babbage. I traveled to France for an interview and wrote for the publication's blog. I helped write the script for a video and also participated in weekly discussions between editors about content for next week's issue.

Some of the highlights of the experience were writing the lead story

Winick outside *The Economist* offices in London, United Kingdom.

Winick with an article she authored in a print issue of *The Economist*.

Clocking In

A daily look at the workplace of the future

The logo for *Clocking In*, Winick's newsletter for *MIT Technology Review,* which is focused on the future of work.

My biggest project in my new role is owning and creating *Clocking In*, an e-mail newsletter I have launched that is focused on the future of work.

for the science section for two different weeks and having one of my articles shared by Eric Schmidt, former head of Alphabet, on Twitter. It was amazing to know that people with such huge influence were reading what I wrote. It was a baptism by fire in refining my writing and learning the ways of a publication like *The Economist*.

Going pro

While the experience was spectacular, it was only three months. It was the training ground for something more. Toward the end of my internship, I was in full job-search mode, looking for the next step in my career. I was seeking a job in which I could apply my entrepreneurial interest, engineering experience and knowledge, and writing passion. During my last week at *The Economist*, I received the call I had been waiting for, and I accepted a job as associate editor of the Future of Work for *MIT Technology Review*. I get to write about the latest and greatest in engineering, artificial intelligence, manufacturing, tech entrepreneurship, and more. This has been my job since October 2017.

My biggest project in my new role is owning and creating *Clocking In*, an e-mail newsletter I have launched that is focused on the future of work. I get to show my own personality and voice in writing the newsletter and develop a product from square one. I am profiling people working in jobs of the future, featuring question and answer interviews with experts, making stat info graphics, and covering daily news on the workplace of the future.

It has felt amazing to have access to the MIT community, move to Boston, and take another step forward in furthering coverage of the engineering fields. The lessons I learned in both my engineering and *The Economist* internships come into play every day in my new job.

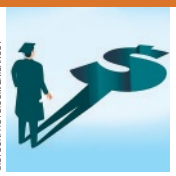
A call to action

To anyone who has a love of both STEM and writing, I would encourage you to give science and engineering communication a try. While I have met a decent amount of science communicators, the number of engineering communicators is much smaller. It doesn't have to be your full-time gig. Sharing your work on Instagram and Twitter, engaging with people outside your field, or writing a blog are all amazing starts.

The more everyone understands that engineers are not just designing bridges and making your cell phones, the more support engineers will receive for their work. And it may just have the added bonus of inspiring a few young makers and creators out there as well.

About the author

Erin Winick (erin.winick@gmail.com) is the founder and CEO of Sci Chic and works as the associate editor of the Future of Work for *MIT Technology Review*. She graduated from the University of Florida with a B.S. degree in mechanical engineering in December 2016. You can find her online at erinwinick.com and on Twitter @erinwinick. Those interested in signing up for her daily future of work newsletter, *Clocking In*, may do so at technologyreview.com/newsletters/clocking-in/.



Learning 101: The untaught basics

Junaid Qadir and Muhammad Ali Imran

Despite the accessibility of a wealth of information in the current era—books, universities, and online massive open online courses (MOOCs)—well-intentioned and hard-working students often fail to learn effectively due to deficient learning techniques or improper mind-sets. Two things, in particular, hinder students from achieving their potential. First, the students' intuition regarding how learning works is often flawed and counterproductive; second, despite significant progress in the research discipline of "learning sciences," these hard-earned scientific insights have not yet filtered their way through the research community to the students who stand to benefit most from this knowledge.

In this article, we aim to popularize the important insights from learning-science researchers by making it accessible to students, who continue to largely use suboptimal intuitive learning techniques (not knowing any better). The benefits of becoming wise to these insights are immediate and substantial: we can use this knowledge to understand and calibrate our learning, and it can also facilitate efficient learning.

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Common learning impediments

To learn optimally, we need to discover how to learn effectively and also to identify and avoid common learning impediments. In our previous work, we identified seven common learning impediments (shown in Table 1). These impediments emerge from deficient mind-set (numbers 1 and 4), focus (2 and 3), support (5 and 6), and metacognition (7). These issues are not insurmountable; three potential remedies for each learning impediment are identified in our previous work as shown in Table 1. A major impediment—arguably the mother impediment of all the listed impediments, if considered broadly—is number 7, "Not learning how to learn." The overarching remedy for this problem is to spend time developing better metacognitive skills. Our aim is to succinctly present the relevant research findings in an accessible manner so that you can use this knowledge to improve your metacognitive skills and learning strategies.

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101—©ISTOCKPHOTO.COM/OLIVIER LE MOAL

Learning how to learn

The most useful piece of learning for the uses of life is to unlearn what is untrue.

—Antisthenes

Despite our intimacy with the task of learning (through the trials and errors of everyday living), research has shown that our metacognitive judgment about learning (i.e., our intuitive understanding of how we learn) is flawed, and many of our well-established and commonly accepted intuitive notions are not only incognizant of scientific findings about learning but oppose the optimal course of action. Unfortunately, the common societal attitude, and the general assumption in colleges and universities, is that students can automatically figure out the art and science of learning by themselves. This is reflected in the way we emphasize the teaching of content and subjects in educational institutions but not the dissemination of information regarding an optimal learning strategy.

There is a Taoist saying that states, "To gain knowledge, one should add something every day, but to gain wisdom, one should subtract something every day." We propose that students should supplant the erroneous intuitive learning model with an improved metacognitive model of how learning

To learn optimally, we need not only discover how to learn effectively but also to identify and avoid common learning impediments.

actually works. This exercise is especially timely keeping in mind the abundant learning opportunities in the modern world (e.g., in the form of free open educational resources, such as MOOCs) that present unprecedented opportunities for life-long learning. We feel that these abundant resources will only lead to learning advances when the students are equipped with effective learning skills—skills they can acquire by mastering the contents of the oft-untaught "Learning 101" course.

To learn, we must first unlearn: Why learning can be paradoxical

> *True wisdom comes to each of us when we realize how little we understand about life, ourselves, and the world around us.*
>
> —Socrates

Our intuition about learning is usually centered on a short-term vision of fluency, which may not translate and generalize to other settings and which is transient and fleeting. The "paradoxes of learning" arise due to the apparent dissonance between how learning actually works (particularly in the long term) and how we think it works. In many cases, our minds are fixated over some ideals that are not desirable from the point of view of learning: we call these *undesirable fixations*. On the other hand, many seemingly undesirable difficulties can have desirable consequences: we call these *desirable difficulties*. To become sophisticated learners, we must lose our undesirable fixations and embrace desirable difficulties.

TABLE 1. Common learning impediments and remedies (reproduced from Qadir).

Impediment 1) Having a fixed mind-set Solution: Conquer your mind to realize your potential. Remedy I: Have a growth mind set. Remedy II: Aim for mastery. Remedy III Use intrinsic motivation.
Impediment 2) The failure to engage "yourself" in learning Solution: Knowledge will not give you its part until you give to it all of yourself. Remedy I: Ask questions. Remedy II: Study more actively. Remedy III: Make an effort to enjoy the subject.
Impediment 3) The failure to manage time Solution: Until we can manage time, we can manage nothing else. Remedy I: Form good habits. Remedy II: Learn mindfulness and the art of focusing. Remedy III: Practice prioritization and discipline.
Impediment 4) Failing to realize that failing is key Solution: Err unabashedly and learn—like a child does. Remedy I: Embrace failure and impediments. Remedy II: Make peace with confusion. Remedy III: Value effort over intelligence, and the process over extrinsic reward.
Impediment 5) Failing to realize that learning is social Solution: No one can do it for you, but you can't do it alone. Remedy I: Have a mentor. Remedy II: Seek feedback. Remedy III: To learn, teach.
Impediment 6) Existing in a learning monoculture Solution: Encourage learning multiculturalism. Remedy I: Avoid the illusions of learning. Remedy II: Seek diverse knowledge sources. Remedy III: Adopt diversity in study techniques.
Impediment 7) Not learning how to learn Solution: Don't be a highly qualified grade-A sheep. Remedy I: Develop metacognitive skills. Remedy II: Learn critical thinking. Remedy III: Become a life-long learner.

Desirable difficulties

While we intuitively dislike difficulties and try to avoid them, many (but not all) difficulties have a positive effect on learning. The well-known cognitive psychologist Bob Bjork coined the term *desirable difficulties* to describe difficulties that have a positive effect on learning.

1) Effortful learning is better learning

> *Practice that's spaced out, interleaved with other learning, and varied produces better mastery, longer retention, and more versatility. But these benefits come at a price: when practice is spaced, interleaved, and varied, it requires more effort.*
>
> —Brown, Roediger, and McDaniel

- A famous aphorism advises, "No pain, no gain." While we admire effortless learning, research shows that it is mostly transitory. Learning—i.e., actual learning that requires the ability to remember and transfer concepts in the long term—requires effort and reaching out. Independent and active learning also appears to be difficult, but it also leads to better, long-lasting learning. Unfortunately, many students back off at the slightest hint of discomfort or prematurely conclude their lack of feel for the subject.

- Most effective learning techniques take effort: research literature in the learning sciences has documented the efficacy of a number of effective learning techniques—e.g., retrieval practice and the use of spacing and interleaving—most of which require effort. Retrieval practice—recalling facts or concepts or events from memory—is a particularly effective learning strategy. One of the most striking research findings of the learning sciences is the efficiency of testing and retrieval practice—and the more effort put into the retrieval, the stronger the benefit. Another powerful technique is spaced learning (to space out the learning process and avoid cramming material without practicing it) and interleaving (not studying something in isolation but mixing the subject and task being studied with other things). Research has shown that, while retrieval is harder with spaced learning and interleaving, resulting in the feeling that learning is less accomplished, the ensuing education is actually deeper and will lead to easier retrieval in the future.

2) To learn, you must forget, then interrupt forgetting

It is only what breaks that grows.

—Unknown

- The futility of cramming: while cramming can result in short-term learning benefits (e.g., good results for students who study just before an exam), the knowledge achieved is fleeting and drifts away as quickly as it was gained. Learning is a natural system that evolves at a natural rate—just like agricultural systems have their natural cycles of harvest—and you cannot cram in your sowing and expect an amplified harvest. Learning also happens naturally in a slow and steady fashion. Students often assume that mass reading and overlearning in one sitting is a good learning technique due to the resulting fluency. This fluency illusion—and not anxiety, poor luck, unfairness, or uneven stupidity—is most often the culprit behind poor learning and unexpectedly poor test performances. Just like a bodybuilder knows not to get fooled by the temporary muscle pump after an intensive exercise, a student would do well not to get duped by the evanescent feeling of fluency.
- Using forgetting and learning symbiotically: it is often thought that the central challenge to improving the way we learn is to eliminate or overpower the process of forgetting. It is true that periodic practice is necessary since it arrests forgetting and strengthens retrieval routes. But while we stigmatize forgetting, we must remember that forgetting is a necessary corollary to learning, and forgetting and learning work together symbiotically and together form the part and parcel of learning. Recent research is establishing a friendly, rather than an adversarial, role of forgetting. In particular, practice before forgetting is wasteful, while practice after forgetting leads to longer-lasting learning.

3) Disfluency/discomfort can be good for learning

That which does not kill us makes us stronger.

—Nietzsche

- The benefits of slowing down learning: in the modern world of abundant, open, high-quality resources such as MOOCs, the combination of the propensity for immediate gratification, the loss of the ability to focus, and the illusive power of fluency masquerading as learning has become toxic for deep learning, and it will help here to recognize that "slower can be better especially for long-term learning." Many celebrated geniuses (e.g., Einstein, Edison, Darwin) were actually considered slow learners in school. Cognitive research has shown that slowing down learning or making it harder—e.g., by omitting letters from words in a text—can actually improve retention of material. This is because it forces the student to be more active (by working harder in supplying the missing letters). In the pithy formulation of Daniel Willingham, "Memory is the residue of thought." Active learning can also be engaged profitably by asking a student to solve a problem before being taught, even if errors are made in the attempt (as long as the correct solution is provided). This happens because the student's attempt to answer the question activates a search for relevant prior information and patterns in a way that helps the student retain the knowledge much more than simply reading would have accomplished.
- The upside of confusion and perplexity: John Dewey noted that the origin of thinking is some perplexity, confusion, or doubt—since we reflect when such an event arises and not when everything goes smoothly. Although we dislike effortful grappling with confusions, these activities serve as the stepping stone toward mastery. Becoming smart entails the feeling of being dumb during learning.

While cramming can result in short-term learning benefits, the knowledge achieved is fleeting and drifts away as quickly as it was gained.

Undesirable fixations

Due to our flawed intuitive model of how learning works, most learners are unduly and counter-productively fixated on perfection, fluency, and discipline as learning ideals. We discuss next why these fixations are undesirable.

For optimal learning, one must understand a subject, encode it in storage memory elaborately and memorably, and then practice it in a variety of settings.

1) Fixating on perfection: Why mistakes are required

An expert is a man who has made all the mistakes which can be made, in a narrow field.

—Niels Bohr

- Understand the importance of errors and mistakes: in general, students view errors and mistakes as something to avoid (since mistakes are often interpreted as being inadequate). Mistakes, however, serve as the necessary stepping stones to mastery and advanced learning. Any educational activity that aims to eliminate all errors can lead to superficial and fragile learning. By becoming open to mistakes, students will be more amenable to embrace learning practices laced with desirable difficulties that lead to better, long-lasting outcomes.
- The mirage and futility of chasing perfection: learning without mistakes is fragile and dangerous, since it is typically the result of fluency rather than mastery. It's important to allow for mistakes to happen through extensive exploration of the subject, other viewpoints, spaced learning, and interleaving, among others. Fixating on perfection also engenders a psychological mind-set—called a *fixed-mind-set*—that is not conducive to learning. Students with a fixed mind-set see events and circumstances as a direct measure of competence and worth. Students with fixed mind-sets obsess over documenting their intelligence instead of focusing on developing their intelligence.

2) Fixating on fluency: Why fluency is not sufficient

Rising familiarity with a text and fluency in reading it can create an illusion of mastery.

—Brown, Roediger, and McDaniel

- The fluency illusion: the fluency illusion underlies the widespread adoption of suboptimal learning techniques such as rereading and massed practice that engender fluency but are inefficient compared to other techniques. The fluency illusion is arguably the biggest cause of our flawed learning intuitions. One reason for its significant role in messing up our intuition is that fluency feels good. To further complicate matters, techniques conducive to long-term learning (such as spaced learning, retrieval practice, and interleaving) initially manifest disfluency. Such techniques do not appeal to students since learning appears slower and devoid of the rapid improvements that massed practice can demonstrate. But fluency—when not strengthened by repetition and retrieval exercises—is deceptively transient. Although commonly conflated, it is important for all students to remember that fluency and mastery are two very different things.
- Massed practice (and rereading) is suboptimal: the strategy of rereading text and massed practice (contiguous practice that is not spaced out) is the technique of choice for many students since it aligns well with the intuition honed on a mind-set that emphasized learning in the short term and equates fluency with learning. As noted by Brown et al., rereading as a learning technique suffers from three problems: 1) it is more consuming; 2) it does not result in durable memory, since the forgetting process has not yet set in; and 3) it unwittingly involves a deceptive feeling of faux mastery that comes with growing familiarity with the text.

3) Fixating on discipline: The upside of variety

You don't understand anything until you learn it more than one way.

—Marvin Minsky

- Idolization of focus and the Einstellung effect: discipline and focus are celebrated—not without reason—as virtuous facilitators of success. But too great a focus on discipline can prove to be an overkill for the purpose of learning, and a pluralistic and varied approach that allows for some serendipity may be better suited. For example, while we do need to focus intently for problem solving, too much focus can block us from accessing fresh ideas. The more we are focused on producing creative solutions quickly, the less likely we are to be successful. This phenomenon is called *Einstellung* and has been empirically demonstrated in numerous experiments. Focusing intensely on a creative task in a single setting, especially when one is stuck, may be the worst possible strategy; sometimes all you need is a break to freshen up your thinking. Even though we stigmatize procrastinating, it may be good in certain learning situations, especially when we want to arrive at creative solutions.
- Variety is the spice of learning: a variety of environmental stimuli and input modality is also very important for learning. There is no formula for the complex process of learning, but if we had to come up with a simple one, Mastery = Understanding + Repetition (in varied settings) would be a good candidate. The learning potency of variety is also demonstrated in the empirical efficacy of interleaving (i.e., interspersing various topics together), and the positive interleaving effect can be explained on the basis that it

allows for the encoding and embedding of new knowledge in existing networks of prior perceptions, facts, and thoughts.

For efficient learning, use optimal learning techniques

Rereading text and massed practice of a skill or new knowledge are by far the preferred study strategies of learners of all stripes, but they're also among the least productive.

—Brown, Roediger, and McDaniel

A) Testing/retrieval practice as a learning tool

In virtually all areas of learning, you build better mastery when you use testing as a tool to identify and bring up your areas of weakness.

—Brown, Roediger, and McDaniel

Despite getting a bad rap, testing—or retrieval practice, as it is customarily called in the learning sciences—is a very powerful, but underestimated, learning technique. Retrieval practice or testing methods include inter alia, quizzes, and exams in formal assessment settings; self-test (e.g., through flashcards); and oral examination. In our context, testing simply implies the action of forcing students to recall the learned information from memory. It has been shown that a single simple quiz can help produce improved learning compared to techniques that are most popular with students (rereading text and reviewing notes). The potency of testing or retrieving information from human memory arises from the fact that retrieval is a "memory modifier" rather than simply some inert playback—in particular, retrieved information, rather than being left in the same state, becomes more recallable in the future. Testing can help students achieve three crucial aims: 1) by supporting recall, the retention of knowledge is enhanced; 2) by enhancing self-awareness, students become more aware of their mental processes and can better understand what they do and do not know; 3) by putting students in controlled adversity situation, important noncognitive skills, such as resilience and grit, can be developed.

The fluency illusion underlies the widespread adoption of suboptimal learning techniques such as rereading and massed practice that engender fluency but are inefficient compared to other techniques.

B) Spaced learning and interleaving

The truth is, nothing in learning science comes close [to spaced learning] in terms of immediate, significant, and reliable improvements to learning.

—Benedict Carey

A substantial body of research has demonstrated the power of spaced learning. Although the brain is not like a muscle in any straightforward sense and is much more eccentric, it is instructive to note that massed learning can provide temporary fluency, just like a body builder can pump muscles temporarily by cramming in exercises. However, growth occurs only with a spaced exercise routine (in which exercise and rest follow each other cyclically). Similarly, long-term learning also requires spaced practice and does not result from cramming. There are two main benefits to spaced learning: first, it requires the exercise of retrieving from long-term memory; second, the time between the spaced learning sessions allows our minds to better organize and interconnect new and prior knowledge.

The related technique of interleaving encourages the incorporation of variety by suggesting that the practice of different knowledge or skills should be performed together. Such a practice allows for better recognition of the context of the knowledge or skill being learned. This allows for better discrimination and problem-solving skills as the students begin to get a grip on the techniques to use in various situations. Although retrieval will feel more difficult with interleaving, the effort produces longer-lasting learning and a more versatile ability to generalize and apply the knowledge correctly as per the context.

C) Aiming for mastery

To be a sophisticated learner requires understanding that creating durable and flexible access to to-be-learned information is partly a matter of achieving a meaningful encoding of that information and partly a matter of exercising the retrieval process.

—Bjork, Dunlosky, and Kornell

Transforming into an effective learner is much more than becoming fluent. For optimal learning—i.e., learning with efficiency (learning the most in a given time), flexibility (the ability to generalize to new situations), and longevity (the ability to remember the knowledge for a long time)—one must understand a subject, encode it in storage memory elaborately and memorably, and then practice it in a variety of settings. As noted by Bjork et al., becoming a sophisticated learner entails a meaningful encoding of learned information (into the storage memory) as well as the exercising of the retrieval process (through retrieval memory). This requires familiarization with activities and techniques that can enhance storage and the subsequent retrieval of the content and procedure to be learned. In addition, one must become aware of certain illusions and biases that can impede learning.

Previous research has demonstrated that one important difference between the knowledge of experts and novices is that the former have much more dense connections between the various concepts, facts,

An attempt to connect new knowledge with prior knowledge will pay dividends, as the new knowledge becomes well entrenched.

and skills that they possess. The strength of encoding in memory (to be specific, the storage memory) depends on how connected the knowledge being learned is to other previously acquired knowledge. An attempt to connect new knowledge with prior knowledge will pay dividends, as the new knowledge becomes well entrenched. In this regard, researchers have shown the power of the unconscious and the role of sleep and rest in learning. In the words of the cognitive psychologist Richard Nisbett, one should never fail to take advantage of the free labor of the unconscious mind.

Conclusion

To learn, you must work with zest, invest effort into learning, and recognize and resist the illusions of learning (such as confusing fluency with mastery). To benefit from optimal learning techniques shown in the literature, the following recommendations are provided.

1) Space out, rather than concentrate, your learning sessions.
2) Interleave, rather than block, study/practice sessions on separate to-be-learned topics.
3) Test yourself on the learnt knowledge, and resist the urge of looking things up and rereading.
4) Vary the conditions of your learning—even the environmental context of studying—and avoid learning in the same modality and environment.

Although the aforementioned techniques are efficient in terms of long-term learning, the caveat is that using them may result in more effort and even uncomfortable experiences.

So how can you ensure that these efficient but effortful techniques are adopted? One way is to develop a growth mind-set, through which you recognize that intelligence is not a fixed trait but is something that can grow with effort, dedication, and hard work. Mistakes, forgetfulness, and effort must not be construed as a sign of lack of learning competence but as a necessary stepping stone to substantial learning. Armed with these new Learning 101 insights, we hope that students will adopt more-efficient learning techniques and become independent, self-regulated, and sophisticated learners.

Read more about it

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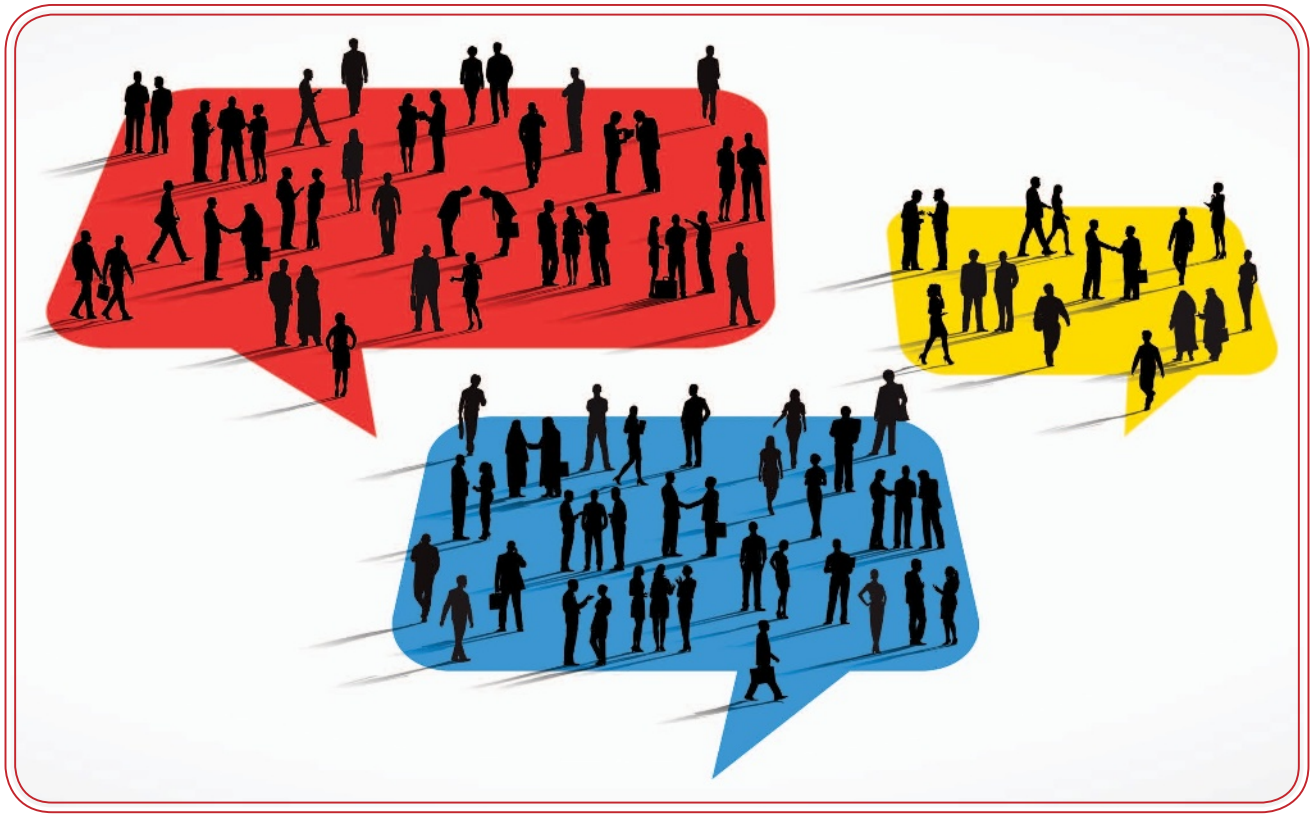
Lessons from the conference banquet: The art of small talk

Y.H. Tan



Of all the unknowns facing young graduate students at their first conference, perhaps the most social anxiety inducing would be the question of how much they should network as well as all the unspoken, but expected, social exchanges that come with that effort. Although most career counselors would suggest that conferences are prime opportunities for you to network and form new alliances, it's difficult to avoid the almost-instinctual excuses of "I'm just a student" and "That's just for the experienced faculty members."

Personally, I have never enjoyed the networking process. Sure, it's nice to find a new collaborator who shares your vision, but, more often than not, it's a lot of small talk with people you might never see again (save for that courtesy postmeeting e-mail, if you happen to exchange contact information). Small talk is, by definition, not particularly meaningful, and networking is, at best, a necessary chore for many.

While it's easy to disappear into the mass of people during technical sessions, the social events seem designed to force you to engage with the other attendees. This is where

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While it's easy to disappear into the mass of people during technical sessions, the social events seem designed to force you to engage with the other attendees.

the lonely student, who doesn't know anyone at the conference, has to either fiddle with his or her phone for the entire evening or pluck up the courage to strike a conversation with someone. Depending on the individual, this can range from being a breeze to a complete nightmare.

The one conference social event where it's almost impossible to escape small talk (even if you're not actively trying to network) is the conference banquet—the highlight of the social program and the official ticket to relax and have a great meal. Pondering whether it's worth forgoing the most lavish meal of the week to escape a potentially awkward evening is something that has happened to every introverted attendee. Eventually, you go; it just doesn't make sense to miss a meal that's already paid for anyway. Taking your seat at a table full of strangers, you may question whether that was a wise decision. Hopefully someone will take the initiative and talk to you first.

I found myself in that uncomfortable situation a few months ago at my first major conference as a graduate student. Not knowing what to expect, nor planning to form any future working relationships, I sat down at a half-empty table hoping for an uneventful evening. Having been either a bystander or directly involved in too many half-attempts of people trying to start a conversation with strangers in the past two days, I was not looking forward to any more of that situation.

Then, a sprightly middle-aged man grabbed the chair next to me. He introduced himself as "Jonathan" by enthusiastically grabbing his conference badge. I replied by doing the same because it's a fantastic way to introduce yourself at a conference. I wondered if I should address him as "Prof. Jonathan" (because he was one) but eventually decided against it since he approached me on a first-name basis. He began the chat with the usual basics, and I responded accordingly. I can handle the basics—where you're from, your projects and papers, etc.

Dinner soon started with a stage performance that captured the attention of very few. Surprisingly, I found myself engaged with Jonathan's stories about his work and experiences. It helped that he was a natural storyteller, with anecdotes flowing naturally and informally, unafraid of exposing embarrassing mistakes in the past, which might seem amateurish for a professor of his stature but, at the same time, were incredibly relatable and accessible for a young graduate student like myself. The discussion was kept marginally technical, which felt apt, yet comfortable. I was encouraged to share my own experiences, even if they were less by virtue of me just having not been alive as long as he. It didn't matter, Jonathan could bounce off anything with an insightful comment or, at least, a humble opinion.

The conversation quickly drifted from our work to other interests, family, the jazz band playing on stage, and the fascinating story of how he became a vegetarian. What surprised me most was how easily the conversation carried itself, with me at ease in a situation where I would typically be awkward and lost for the next appropriate thing to say. Above all, it was actually rather enjoyable.

What made this particular interaction different from all of the other uncomfortable attempts at small talk was, upon reflection, the sincerity of the replies. Being genuinely interested changes the tone of the conversation from a social obligation to an enjoyable time, and nothing encourages further discussion more than having a good time. No one likes to talk to people who make everything about themselves, which is a trap that we can all fall into unknowingly. It was such a great reminder that everyone has something to give and so much more to learn.

Before I realized it, three hours had passed since the banquet started. (I had planned on staying for, at most, two.) Dessert had been served, and the stage program was coming to a close. It was time to leave, and I ended our conversation with "Hope to talk to you again!"—a rare occurrence where I actually meant it.

It would be nice if I ever have the good fortune to work with Prof. Jonathan in the future, but even if our paths never crossed again, at the very least, he taught me something that I never expected to learn that evening. Small talk doesn't have to be particularly meaningful, but it can, and should, at least be enjoyable.

About the Author

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If I were a student again: My next choice

Seppo J. Ovaska

At the beginning of my career, a senior colleague advised me that a carefully thought-out and up-to-date plan of one's career path is necessary for successful lifelong employment from graduation to retirement. Maybe this was a generalizable fact, maybe not, because the changing world as well as evolving employment opportunities and other conditions do create obvious uncertainties to any plan. Nevertheless, it is certainly useful to brainstorm, analyze, and prioritize potential career steps—or even career leaps—every now and then.

Before you get that far, you have to decide the beginning of your pathway. In this article, I assume you have chosen either electrical engineering (EE) or computer engineering (CPE) as your preferred program. What is the state of EE and CPE, what are the employment opportunities, and what kind of knowledge has the biggest demand in 2050? Nobody knows, but do not worry; engineers have faced these uncertainties since the beginning of the profession. Fortunately, lifelong learning opportunities make it possible to complement and upgrade one's knowledge capital during his or her entire career.

Looking back

Forty years ago, I was thinking about the critical question: How should I focus my studies? I was in an EE program and had chosen the "electronics" option. But what was electronics at that time?

- The main stream of study was called *applied electronics*, which was actually analog electronics.
- Digital electronics and computer engineering was a rising field, but there were not many industrial jobs for such specialists in my home country of Finland.

As we know, analog electronics is now largely dead except in measurement and radio-frequency applications. Luckily, my intuitive choice was digital electronics and computer engineering.

The reason for my decision was the emerging technology of microprocessors, which I considered both fascinating and promising—everyone could build a compact micrcomputer for automation, control, or other applications. This has literally played out with an accelerating pace over the past decades, and it is continuing vigorously. The initial skepticism gradually turned to enthusiasm, which has led, among various

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developments, to the ongoing boom of the Internet of Things (IoT) and the Internet of Everything (IoE).

As a new graduate, I started with microcomputer research and development (R&D). Later, it was called *embedded systems development*, when the volume of software development had exceeded the need for hardware development in industry. During those years, I developed control systems for high-rise elevators, until I made a career switch to academia. Currently, I teach courses on embedded systems for first-year master's degree students. Hence, the rather subjective choice of digital electronics and computer engineering—focusing on microprocessors—has carried me throughout my career.

Current options

Today's EE/CPE students have several attractive focus areas and associated courses from which to choose. These include the following examples:

- artificial intelligence (or computational intelligence)
- embedded systems in biomedical applications
- the IoT (or the IoE)
- fifth-generation wireless systems
- network and computer security (or cybersecurity)
- power electronics for renewable energy solutions
- robotics (or flying drones and personal robots)
- smart grid.

These examples have a significant relationship to information and communications technology (ICT). ICT is no longer a special topic that belongs only to engineers with a CPE background or to computer science people. Its role on the more traditional EE side is expanding continually. New EE/CPE graduates with specialization in the aforementioned areas have numerous employment opportunities globally.

My next choice

But which one(s) of those focus areas could carry me best over the next 40 years? I can see that there is an analogy between the mounting demand of microprocessors in 1977 and network and computer security in 2017. The use of wireless communications is currently expanding like a revolution, while, in the past, development was more evolutionary. It has been forecasted that in 2020 there will be 30–50 billion IoT devices connected to the Internet, and most of the connections will be wireless. This trend is going to continue to the foreseeable future. What an opportunity for hackers and network terrorists!

Therefore, my choice of study focus would be network and computer security or, more broadly, cybersecurity. Currently, too many companies developing automation and control systems act like the issue of cybersecurity is a network issue only and does not have direct connections to the applications core of their products. Furthermore, the "network issue" is supposed to be handled by communications people and network operators as well as by providers of system software. As a result of this naive attitude, we have seen news reports about hackers who killed an automobile remotely on a highway and made a destructive cyberattack on a steel mill. In addition, many such attacks remain unpublished because the corporations involved feel the need to protect their public image.

Would you show your driver's license to a police officer if he asked? You should. Would you jump from the top of a high-rise building to the ground if the same police officer asked you to do so? Absolutely not! We human beings have a built-in feature called "self-preservation," while a similar feature is largely missing from "the Things" that are connected to the Internet.

As a result, there is a lot of security-related R&D work for EE/CPE people. This work is focusd on network issues as well as the applications side, and it should be tolerant against intrusions and irrational commands coming from remote sites. And this tolerance could be implemented using advanced artificial intelligence complemented with biometric authentication technologies. Furthermore, because hackers and network terrorists evolve their techniques swiftly and continuously, there is a huge amount of work ahead to keep the multibillions of IoT/IoE devices in order.

Conclusion

By focusing on network and computer security issues—particularly on the applications side—I believe I could finish my "second career" as a *security specialist for embedded IoT/IoE systems* with another four decades of industrial/academic experience. My secondary choice would be robotics, because there is a huge amount of eagerness and novel business opportunities behind the diverse robotics dimensions, such as:

- flying drones
- personal robots
- swarms of service robots
- micro/nano robotics.

Finally, it is fair to admit that my embedded systems background may bias the primary choice toward cybersecurity.

Read more about it

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A team sport

by John Treichler

I grew up in small town on the Gulf Coast of Texas, and it was the bedroom community for a big Dow Chemical plant. Although the population was only about 7,000, it was rich in an important asset—engineers. As a kid, it seemed to me that half of all the adult males who lived there were engineers—mostly chemical, but a lot of mechanical and electrical engineers as well. Not knowing any better, I assumed that all towns were like that, and the type and manner of thinking that engineers do was, well, normal.

Treichler believes that communication, both verbal and written, is crucial to professional success.

I also thought that I knew what happened to engineers right out of school when they came to work at Dow for their first job. They show up on the appointed day, dressed in a jacket and tie, and armed with an expectant, but perhaps slightly uncertain, smile. They would be immediately counseled to get rid of the jacket and tie ("It's too darned hot here in Texas for that!") and then sent out into the plant with someone slightly more experienced to learn their way around and "get their hands dirty." The new hire would be assigned to one of the products (vinyl chloride, say) and spend a couple of years learning absolutely everything about it and the plant that produced it. Without realizing it, they would become the local expert and, a bit to their surprise, within a few years find themselves leading even younger engineers and then moving into management and leadership roles. So, when I went off to college to get an electrical engineering degree, I thought I would have a similar experience when (and if) I graduated, and I was looking forward to it.

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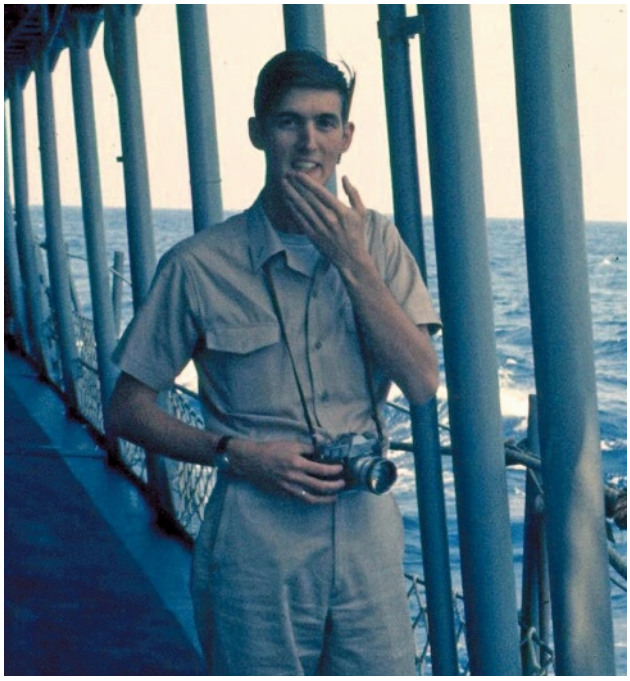
In fact, it didn't work that way at all. My first post-college job wasn't with a company, but with the U.S. Navy. How did this happen, you might ask? I would love to tell you that military service was a long family tradition or that I signed up in a flash of patriotic fervor. In fact, a key consideration was that the Navy Reserve Officers' Training Corps program was willing to provide financial support for my college education. In trade for this support, I would take extra classes in college (for example, celestial navigation), spend three summers out in the fleet, and then put in four years of active duty on a ship. I was quite conflicted by the choice I'd made. While very practical in terms of paying for a chunk of my undergraduate education, spending four years in the Navy hadn't been a part of the plan for my life. What I really wanted to do was be an engineer—to go design and build things—to bend technology to the needs of humanity. I thought at the time that the Navy and engineering had nothing in common. I was wrong, and it turned out that my engineering education couldn't have been a better way to prepare me for the Navy (and, later, vice versa).

I entered the Navy as the lowest of officers—an ensign—and was assigned to a ship older than I was as what's called a division officer. As a division officer, I had three almost-orthogonal sets of responsibilities. While underway (which seemed to me to be constantly), I stood watches on the bridge four of every 16 h, rotating day in and day out. I also had a full-time administrative duty—the first one being the responsibility for the repair of most of the ship's electronic gear. On top of all that, I was the leader of a division of ten enlisted men. Thus, I had operational, administrative, and leadership duties all at the young age of 22. By the time I left the Navy four years later, I had qualified as a fleet officer of the deck, moved up two steps



Treichler, as a young naval officer in 1972, taking pictures of the Soviet Mediterranean Squadron.

in rank, deployed overseas four times, commissioned a new ship, taken my ships through four shipyards, and ended up leading 75 officers and enlisted men. All this before I was 27 years old. I wasn't unique, of course. This is what the Navy expects of its junior officers.

Preparation and process

What did my engineering education do to prepare me for this? As a review, let's think about the engineering process—clearly stating the problem to be solved, analyzing the problem and the degrees of freedom available to solve it, designing a solution, implementing the solution, testing the result, training all involved to use the solution, and—all along the way—communicating with everyone involved about the plan to reach the desired outcome. (And if money and schedule are important, doing the job within those constraints.) Of course, when I was an undergraduate student at Rice University, I thought in terms of solving problems with transistors and z-transforms. What I didn't realize until about halfway through my time in the Navy was that I was using the engineering design process all the time—but I was using it to solve problems related to personnel, equipment management and maintenance, and even real-time ship maneuvering. The process that engineers learn about in engineering school seemed to be almost universally useful. It certainly was in the Navy, and my experience since age 27 continues to prove that. Engineers are trained problem solvers. Sometimes the tools needed to solve the problem at hand are semiconductors and software, but the methods work on a far larger management and leadership scale as well.

This isn't intended to be an advertisement for the U.S. Navy nor any of the armed services. My story is an example that a good engineering education, and the thought processes that engineers are taught to use, turn out to be valuable for many jobs. It is little wonder to me that engineers are so successful, on average, in fields that don't, at first blush, seem to need engineering skills—medicine, law, business, and even government leadership come to mind. It's just the same as the Navy. Engineers are problem solvers, and the world needs those skills in many places.

Words of wisdom

I would like to provide you with a few pieces of advice that I learned from my time in the Navy. I hope these are useful to you if it turns out that your first job, like mine, isn't exactly what you expected it to be.

- You don't have to like what you are doing to do a good job. No job is purely fun, and some are very little fun (riding out storms in the Aegean comes to mind), but your execution of your job to your personal high standard is important. You will notice, even if no one else does.
- You don't have to like your boss. My first boss (my first captain) seemed to be aloof and unfriendly. In retrospect, he had a powerful positive force on my life. He was thoroughly competent, which made him brave enough to let 23-year-olds like me drive his ship. In the process, he gave me the confidence to take on even bigger challenges in my future life.
- Even if your boss doesn't like you when you first meet, your good work and loyalty to the common objective can turn him or her around, and, in fact, make him/her a lifelong friend.

Conversely, did my first job teach me things that helped me in the engineering career that followed my tour in the Navy? You bet. While another column could be written about each one, I'll list just a few.

- Virtually no engineering problem can be solved by one person alone. As a result, engineering is a team sport. Teams need leadership, and you definitely learn about leadership (many good examples but some bad) in the Navy.
- Engineering solutions are rarely operated in the field by engineers. As an "operator" in the Navy, I learned that engineering solutions must be designed to be used by sailors—and that sailors, on average, don't know calculus, nor do they love buttons, knobs, and lights added seemingly for their own sake. Equipment built for engineers by engineers is almost always useless in operational practice.
- The ability to communicate upward, downward, and to your peers, in writing and verbally, tersely and in detail, is crucial to professional success. It was true in the Navy and is equally true outside of the service. The good news is that the Navy taught me the value of it. At this point in my career, I spend approximately 98% of my time communicating. You have to learn somewhere how to do this. If you haven't already, you should start.

- The Navy taught me how to operate in high-stress environments. Almost getting run over by an aircraft carrier isn't the same as recognizing that your project is getting completely out of financial control, but the skill to remain calm, quickly analyze the situation, and then act constructively to solve the problem is needed in both situations (albeit a little quicker in the case of the aircraft carrier).

I should add that I have had several "first jobs" since my time in the Navy. Not first chronologically, perhaps, but first in the sense that they were different enough that they forced me out of my comfort zone and into learning new things. While waiting for my wife to finish graduate school, I took what I thought would be a one-year temporary job with a small company in Palo Alto, California. They wouldn't tell me what they did or who they did it for. My mentor merely said, "Trust me. You'll love it." I did, and that temporary job effectively sent me down the career path that I'm still on. I worked at that first job for six years and then went to a very different first job, teaching electrical engineering at Cornell University. From there, it was off to a startup in Silicon Valley, which is where I remain even after 34 years.

My newest first job is as the president of the IEEE Foundation, the IEEE's partner in performing philanthropic work in the world—as the IEEE logo says, applying "technology for the benefit of humanity." This job is also forcing me to learn about new things, meet new people, and solve yet a new set of problems.

A final thought: Life is all about solving problems, and engineers are trained to do exactly that. In fact, I claim that they do it better than almost everyone else. So, take that thought into your first job and use those skills. They will serve you well over your whole career—whether that career is in engineering, in another field, or even the U.S. Navy.

About the author

John Treichler (John.R.Treichler@raytheon.com) earned his undergraduate degrees from Rice University in 1970 and his Ph.D. degree in electrical engineering from Stanford University in 1977. He served as a line officer aboard destroyers in the U.S. Navy from 1970 to 1974. Since 1977, he has worked for ARGO Systems, taught at Stanford and Cornell University, and helped found Applied Signal Technology, Inc. in 1984 as its chief technical officer. He joined the IEEE in 1970 and is a Life Fellow. He is a member of the National Academy of Engineering and is currently the president of the IEEE Foundation, the IEEE's philanthropic partner in investment in the IEEE's mission.

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by Athanasios Kakarountas

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Problem #1: Losing Your Marbles

This problem was submitted by Edwin Torres, George Washington University.

There are three opaque pots on a table. You cannot see inside the pots, but you know that one pot contains black marbles, one pot contains red marbles, and one pot contains both black and red marbles. Each pot is incorrectly labeled. The first pot says "black and red," the second pot is labeled "black," and the third pot reads "red." How can you determine what is inside each pot by only picking and viewing one marble from one of the pots?

Problem #2: Cup O' Joe

This problem was submitted by Enrico Massoni, University of Pavia.

Mat and four friends go for coffee. Mat says, "I will buy a coffee for the person who can solve a question in the shortest time. The question is: What is the only number formed by ten digits in which the first digit indicates the number of zeroes present in the string, the second digit indicates the number of ones, the third digit indicates the number of two, … and so on until the last digit?" Are you able to earn the coffee?

Problem #3: Weight and See

This problem was submitted by Enrico Massoni, University of Pavia.

Two friends are playing with an old scale. They have eight balls, seven of the same weight and only one that is 1 lb heavier than the others. The friends are allowed to use only the old scale with two main dishes and can perform the measurement only twice. How can they find the heaviest ball?

Problem #4: A Helluva Card Game

Oh Hell! is a popular trick-taking card game with trumps and contracts, played using a standard 52-card deck. Any number of people can play. An interesting feature of Oh Hell! is that the number of cards dealt into each hand varies from one round to the next. This problem focuses on what happens in the first round of an Oh Hell! game.

In the first round, each player is dealt just one, face down. The dealer then turns the next card face-up in the deck. That card determines the trump suit. In a clockwise direction around the table, starting from the left of the dealer, each player states how many tricks he/she will contract to win. In the first round, this must be either zero or one. Once each player has made a bid, the player to the left of the dealer reveals his/her card (i.e., he/she leads). Again, in a clockwise direction, each other player plays his/her card too. Being a single-trick round, players have no choice about which card to play. They must reveal the card they have been dealt. The highest card in the led suit wins the trick, unless a trump is played, in which case the highest trump wins. The highest ranking card in any suit is the ace, followed by the king, queen, etc.

The scoring system is such that players are rewarded if they win exactly the number of tricks they contract to take, and, conversely, they are penalized if they win either too few tricks or too many.

For the player to the left of the dealer, what is the strategy for making a bid in the first round that will give the highest probability of fulfilling his contract (the "optimal strategy")? P

If you have a problem for the Gamesman, please submit it along with the solution to potentials@ieee.org.
Solutions are on page 5.

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